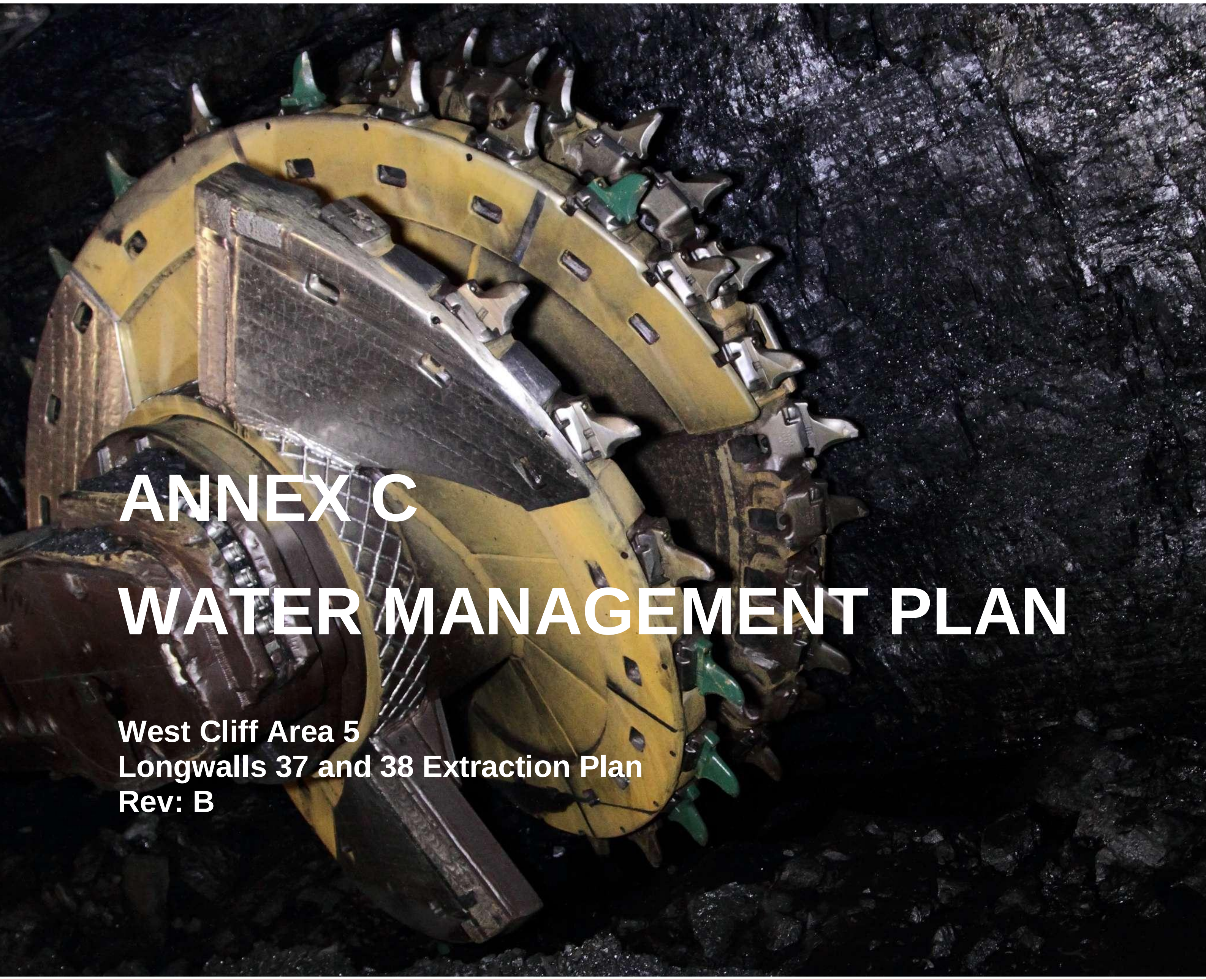
Illawarra Coal



ANNEX C

WATER MANAGEMENT PLAN

West Cliff Area 5
Longwalls 37 and 38 Extraction Plan
Rev: B

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Review History

Revision	Description of Changes	Date	Approved
P0	New Document	31 July 2012	GB
P1	Revisions to include amended G/W and S/W assessments	January 2013	GB
P2	Finalised Draft following BHPBIC comments	March/April 2013	GB
A	Draft for Agency Comment	June 2013	GB
A	Final (no further comments)	August 2013	GB
B	Revisions to address feedback from DP&I	March 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 the BSO project (MP08_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 Longwalls 37 and 38 Extraction Plan for West Cliff Area 5. 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 by Cardno on behalf of BHPBIC 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 Office of Environment and Heritage (OEH), Sydney Catchment Authority (SCA) and New South Wales Office of Water (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 is defined in accordance with Mine Subsidence Engineering Consultants (MSEC, 2013), as the surface area predicted to be affected by the proposed mining of Longwalls 37 and 38 and encompasses the area bounded by, whichever is the greater of the following limits:

- 35^o Angle of Draw for the maximum depth of cover, which equates to a horizontal distance of between 320m and 380m outside the limit of the proposed extraction area); and
- The 20mm predicted limit of vertical subsidence, which is generally within the 35^o Angle of Draw.

Additionally, features sensitive to far-field movements, which includes horizontal, valley closure and valley upsidence movements, which may be outside the 20 mm subsidence zone or 35^o Angle of Draw have been assessed including:

- Watercourses (including the Georges River); and
- Groundwater bores.

The Longwall 37 Study Area is located primarily to the west of the Georges River; and the Longwall 38 Study Area is located primarily to the east of the Georges River. The Study Area locations are illustrated by **Figure 1** (MSEC, 2013). It is noted that while the Study Areas include the Georges River, neither of the proposed longwalls mine under the River.

1.3 OBJECTIVES

The objectives of this WMP are to identify sensitive surface water and groundwater features and characteristics within the Study Areas of Longwalls 37 and 38; and to manage the potential impacts and/or environmental consequences of the proposed workings on watercourses and aquifers, to ensure compliance with the BSO Approval Conditions, including the Performance Measures for natural (*Condition 1, Schedule 3*) and built features (*Condition 3, Schedule 3*). Specific focus will be on the Georges River, smaller watercourses and groundwater resources as shown in **Figure 1** and **Figure 2** (MSEC, 2013, Drawing 533-07).

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 Infrastructure (DP&I)
- Trade and Investment - Division of Resources and Energy (DRE)
- OEH
- NoW

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

2 STATUTORY REQUIREMENTS

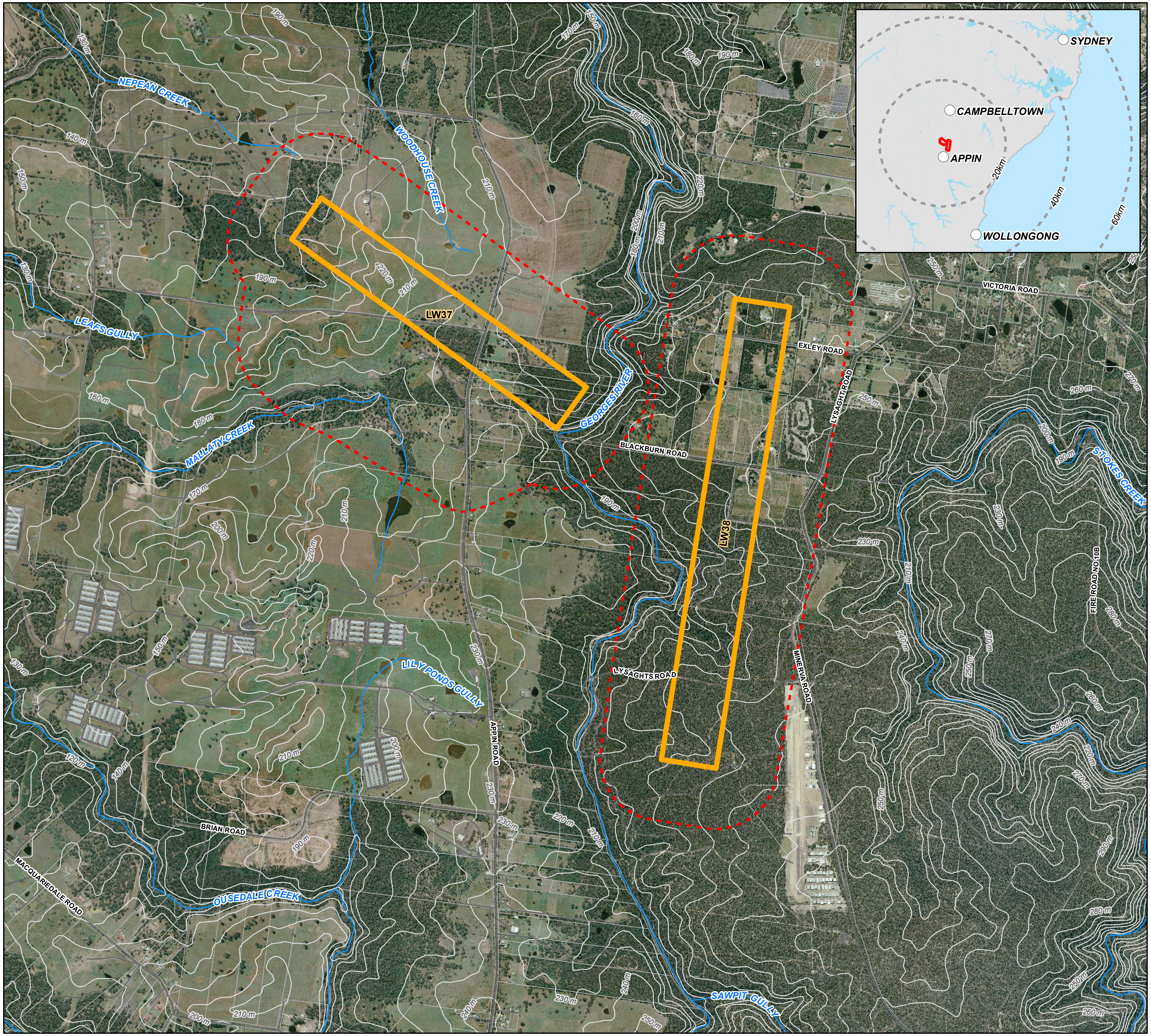
Extraction of coal from Longwalls 37 and 38 will be in accordance with the conditions set out in the BSO Approval, applicable legislation as detailed in **Section 2.2** and the requirements of relevant licences and permits, including the relevant conditions attached to mining leases.

As the waters of the Georges River were previously classified as *Class C* under Part 3 of the *Clean Waters Act 1970* (State Pollution Control Commission, 1980) it is categorized as an area of environmental sensitivity for the purposes of the WMP.

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 workings on groundwater and surface water features in the Study Area (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**.



bhpbilliton
ILLAWARRA COAL

West Cliff Area 5 Study Areas (LW37 and 38)

Legend

- Study Area
- Local Roads (LPI)
- 10m Contours (LPI)
- Watercourses (LPI)
- Cadastre (LPI)
- West Cliff LW 37 and 38 (BHPBIC 2013)

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 NSW/ACT Pty Ltd (WOL)
Date: 14/03/2013
Coordinate System: GDA 1994 MGA Zone 56
Project: 112054-01
Map: G1002_WCA5_ExtractionPlan.mxd 03

Aerial imagery supplied by BHPBIC (2007 and 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;	Section 4
(b) a detailed description of the measures that would be implemented to remediate predicted impacts.	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:	
– the relevant statutory requirements (including any relevant approval, licence or lease conditions);	Section 2
– any relevant limits or performance measures/criteria;	Section 5
– 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;	Sections 5 to 8
(d) a program to monitor and report on the:	
– impacts and environmental performance of the project;	Section 6
– effectiveness of any management measures (see c above);	
(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;	Section 8
(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	
(h) a protocol for periodic review of the plan.	Section 10

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 conforms to the requirements of relevant legislation and 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).
- 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).

2.3 RELEVANT LEASES AND LICENCES

The following licences or permits apply to BHPBIC's operations in West Cliff Area 5:

- 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.environment.nsw.gov.au/poeo.
- Bulli Seam Mining Operations Plan (MOP) November 2012 to September 2019.
- All relevant OH&S and HSEC approvals.
- Any additional leases, licences or approvals resulting from the BSO Approval.

Table 2.2 – West Cliff Leases and Licences

Mining Lease - Document Number	Issue Date	Expiry Date/ Anniversary Date
CCL 724	4 July 1991	26 October 2011 (renewal pending)
Part CCL 767	29 October 1991	8 July 2031
CCL 381	24 October 1991	23 October 2012 (renewal pending)
ML 1678	27 September 2012	26 September 2033
MPL 200	13 January 1982	13 January 2024
MPL 201	13 January 1982	13 January 2024

3 BASELINE ASSESSMENT

Baseline water quality monitoring has been undertaken in the Georges River, upriver, adjacent to and down river of the proposed longwalls from 2004, with baseline water quality monitoring undertaken in Mallaty Creek (MC) and Nepean Creek (NC) from 2008. Ecoengineers have undertaken an *Assessment of Water Quality Effects and Water Quality Monitoring Plan – West Cliff Colliery Longwalls 37 and 38 Extraction Plan,* (Ecoengineers, 2013) included as **Attachment B.** Monitoring has continued and further sites have been installed since this assessment to provide a comprehensive dataset prior to mining.

A baseline Hydrogeological Assessment (Heritage Computing, 2010) was undertaken in support of the BSO Environmental Assessment (EA). The Study Area for this assessment included the area encompassing West Cliff Longwalls 37 and 38. A groundwater assessment has been undertaken by Geoterra, *West Cliff Ground Water Assessment Longwalls 37 and 38*, to further study groundwater impacts as a result of the proposed extraction (Geoterra, 2013) included as **Attachment A**.

Baseline aquatic ecology investigations of waterways within the area have been undertaken since 2003. Specific investigations in the Georges River have been undertaken by The Ecology Lab (Cardno Ecology Lab) annually since 2005. Further detailed Aquatic Ecology information is contained within the Biodiversity Management Plan, attached as **Annex D** to the Extraction Plan and in *West Cliff Longwalls 33-38 Aquatic Ecology Monitoring 2002-2013* (Cardno Ecology Lab, 2014) included as **Attachment C**.

3.1 SURFACE WATER FLOW

The land in the eastern part of the Longwall 37 Study Area generally drains to the Georges River, with the central and western areas draining to Nepean, Mallaty or Woodhouse Creeks, as well as a number of minor tributaries to the Nepean River. The Study Area associated with Longwall 38 drains west to the Georges River via several tributaries.

The creeks draining to the Nepean River from the Longwall 37 Study Area have the following characteristics:

- Nepean Creek: within the Study Area is a First Order stream with sparse riparian vegetation which flows northwest;
- Mallaty Creek: within the Study Area is a First Order stream which flows in a westerly direction until it joins Ousedale Creek; and
- Woodhouse Creek: within the Study Area is a First Order stream with no riparian vegetation which flows north to the Nepean River.

The creeks have an approximate gradient of between 15 and 40mm/m. The upper catchments of these streams are characterised by outcropping Wianamatta Shale, with the landscape types classified as Cumberland Plains Lowlands and Hawkesbury-Nepean River Valley (Ecoengineers, 2013).

The Georges River receives water from the following sources:

- Inputs from Appin Village, including storm water and waste water overflows and seepage;
- Flows sourced from the catchment; and
- Flows sourced from the EPA Licensed Discharges at Appin and West Cliff Collieries.

Water flows in the Georges River, upstream of the licensed discharges have been measured since 2002, with the results summarised in **Table 3.1**.

Table 3.1 – Summary of Flow Rates recorded at Georges River Upper Flow Station

Period of Data	16 October 2002 to 8 November 2011
Total No. of Recordings	136 recordings
Minimum Flow	0.00 ML/day
Maximum Flow	4.00 ML/day
Mean Flow Rate	0.35 ML/day
Median Flow Rate	0.10 ML/day

The data indicates that there are relatively low flow rates upstream of the licensed discharges. Since the implementation of controlled releases from West Cliff Colliery in August 2004 water flows have been substantially continuous (Ecoengineers, 2013).

Table 3.2 illustrates the water flows from the EPA licensed discharges, indicating that the primary median flows are from the West Cliff Colliery discharge point. Consequently, the current water flows within the Georges River are primarily sourced from the upriver catchment and from the EPA licensed discharges at West Cliff Colliery, as illustrated in **Table 3.3**, which excludes sporadic releases from Appin Colliery prior to 21 October 2005.

Table 3.2 – Summary of Licensed Discharges from Appin and West Cliff Collieries (2 August 2004 – 24 May 2009)

	Appin Discharge	West Cliff Colliery Licensed Discharge Point 10	Brennans Creek Dam Overflows (Licensed Discharge Point 1)	Combined Discharge & Overflows
Period of Data	1 January 2004 to 27 November 2012	2 August 2004 to 22 November 2012		
Total No. of Recordings	3127 days	1014 days	2974 days	1014 days
Total No. of Days of Zero Flow	2233 days	40 Days	1201 days	37 days
Estimated Minimum Flow	0.0 ML/day	0.0 ML/day	0.00 ML/day	0.0 ML/day
Estimated Maximum Instantaneous Flow Rate [1]	1.9 ML/day	8.3 ML/day	360.8 ML/day	370 ML/day [2]
Estimated Mean Flow Rate	0.1 ML/day	1.7 ML/day	2.2 ML/day	4.0 ML/day
Estimated Median Flow Rate	0.0 ML/day	1.1 ML/day	0.0 ML/day	1.1 ML/day

[1] Instantaneous Flow Rate measured at a single point in time. This measurement does not imply the flow rate was sustained for an entire day.

[2] Brennans Creek was flooded and no measurement from Point 10 was possible.

Table 3.3 – Estimated Percentiles of Total Recorded Discharge from West Cliff Colliery for the Period 2 August 2004 to 22 November 2011 (N = 1210 Measurements)

FLOW RATE (ML/day)	PERCENTILE
0.42	10.0
0.57	15.0
0.68	20.0
0.75	25.0
0.83	30.0
0.90	40.0
1.07	50.0
1.31	60.0
1.81	70.0
2.16	75.0
2.44	80.0
3.06	85.0
4.60	90.0
7.80	95.0
30.24	99.0

West Cliff Colliery releases water on an almost continual basis to the Georges River via Brennans Creek from Brennans Creek Dam (BCD). This controlled discharge aims to:

- Restrict discharges from License Point 10 to a maximum pH of 9.0;
- Steadily reduce salinity levels over time;
- Provide a stable environmental flow in the Georges River.

The discharge regime has been successful, contributing the major flow component of the Georges River since inception, with salinity of water discharged from West Cliff Colliery being reduced from an average value around 4000µS/cm (2004) to an average value of around 2000µS/cm (2011/2012), despite drought conditions in the three years leading up to 2006.

The Georges River may generally be described as a 'losing' system for most of the time, where the predominant flow direction is from surface to groundwater storage during dry conditions. The river may reasonably be expected to become a gaining system during extended periods of higher than average rainfall. Upstream of the Study Areas dry weather flows averaged close to 1.0 ML/day (Ecoengineers, 2013).

3.2 SURFACE WATER QUALITY

Baseline water quality monitoring has been undertaken; with the characteristics of water quality at selected sites between August 2004 and February 2010 illustrated in **Table 3.5**. **Figure 2** shows the location of existing water quality monitoring sites. **Table 3.4** illustrates the characteristics of baseline water quality in Mallaty (MC105) and Nepean (NC10) Creeks. It is noted that comprehensive baseline data was not available at the time of the assessment but the recommended additional monitoring (Ecoengineers, 2013) has been implemented and a comprehensive baseline record is now available prior to mining.

Table 3.5 illustrates that there is very little difference between mean Georges River baseline water quality immediately up river, adjacent to and immediately down river of the Study Areas (Ecoengineers, 2013).

Table 3.4 – Average Baseline Water Qualities in Mallaty (14 September 2011 – 11 September 2012) and Nepean Creeks (13 August 2009 – 5 August 2012)

Site	N	Ca mg/L	Mg mg/L	Na mg/L	T. Alk. mg/L as $CaCO_3$	SO_4 mg/L	Cl mg/L	Tot. Fe mg/L	Tot. Mn mg/L	Filt. Ni mg/L	Filt. Zn mg/L
MC105	2	19 ±15	44 ±45	197 ±203	113 ±88	31 ±4	363 ±360	2.84 ±2.68	0.444 ±0.455	0.002 ±0.000	0.028 ±0.026
NC10	15	20 ±7	90 ±41	467 ±222	149 ±60	26 ±18	898 ±436	1.95 ±2.08	0.445 ±0.504	0.001 ±0.001	0.017 ±0.009

3.3 GROUNDWATER

The Georges River is a system that is generally "losing" during dry periods, along with groundwater flows from the plateau under a regional hydraulic gradient to the river during and following significant rainfall recharge events. 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, or along the Hawkesbury Sandstone / Wianamatta Shale interface (Geoterra, 2013).

Recharge of the regional groundwater system occurs with an extended delay, after rainfall infiltrates into the plateau soil, as well as the underlying Wianamatta Shale and/or Hawkesbury Sandstone.

Some water may discharge from temporary seeps in 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 (Geoterra, 2013).

Within the Study Area, Geoterra 2013, states that 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.

Four NoW registered bores are located within or adjacent to the Longwall 37 and 38 Study Area, with only one bore (GW 72454), which is above the northern end of Longwall 38, contained within the Study Area. **Figure 2** shows the location of the existing groundwater monitoring sites and general location of recently installed sites.

All private bores were drilled between 152 – 279m below surface, with water obtained primarily from dual porosity sandstone aquifers. Yields of up to 0.3L/sec were obtained from inflow zones in the sandstone which range from 29.8 – 163m below the surface.

GeoTerra (2013) observed that 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 NoW data, the majority of aquifer intersections over the proposed mining area lie below the elevation of the Georges and Nepean Rivers.

A number of piezometers have been installed by BHPBIC along the Georges River to monitor the Longwall 31 to 38 SMP Areas. The shallow piezometers were installed primarily to measure groundwater levels along the plateau and associated Georges River.

Further details regarding these bores and piezometers can be found in **Table 3.6** and the groundwater assessment (**Attachment B)**.

3.4 AQUATIC ECOLOGY

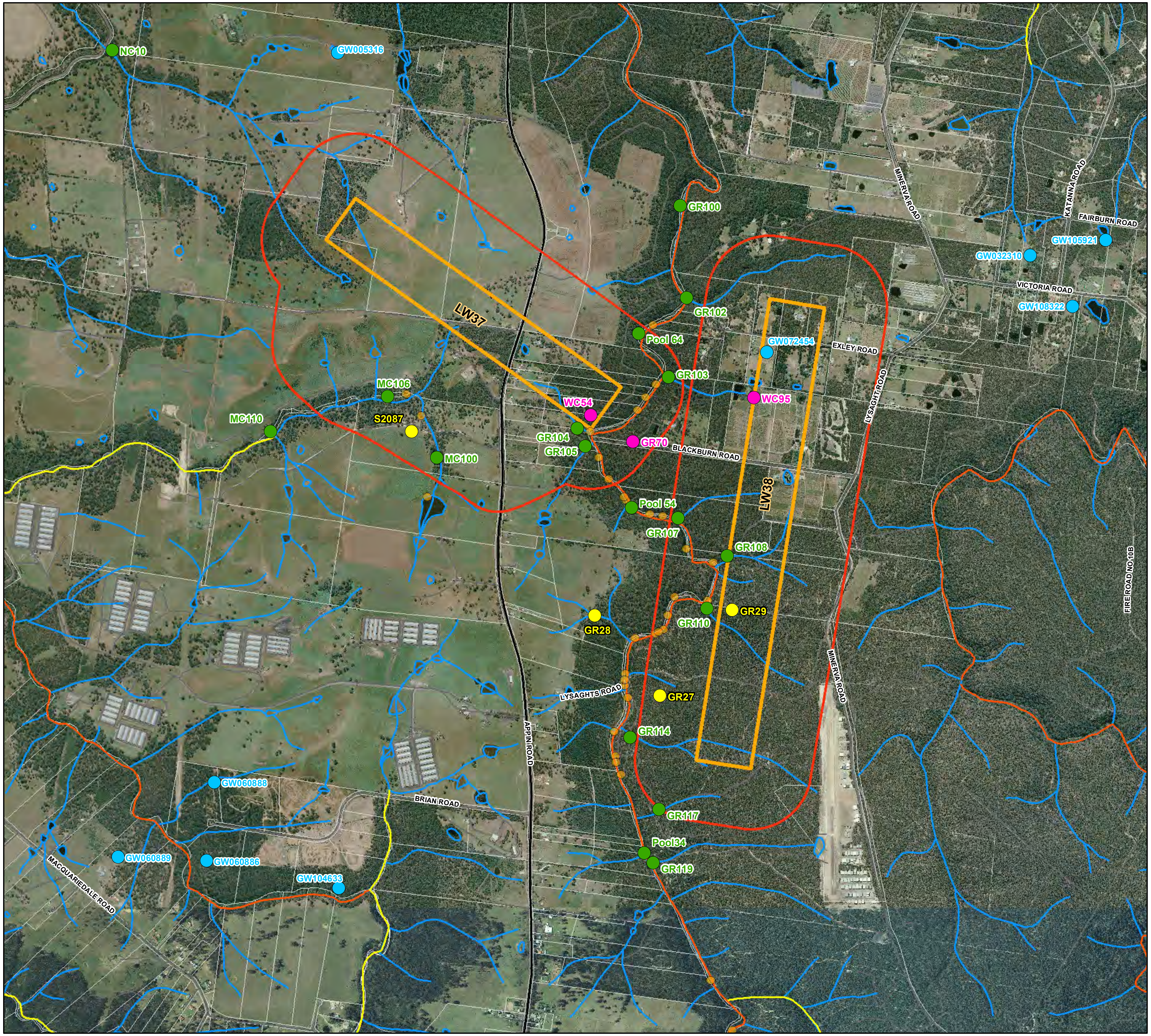
Salinity has the potential to impact aquatic ecology. Both increases and decreases in salinity can impact macroinvertebrates, with gradual changes producing lower levels of mortality.

Studies from 1995 onwards demonstrate that most macroinvertebrates are well acclimatised to levels of total dissolved solids (TDS) up to at least 2000mg/L (approximately 3200uS/cm) within the Southern Coalfield. The acclimatisation has resulted from drought conditions in the area, anthropogenic influences, as well as the soil profile primarily comprised of Wianamatta Shale sediment, which is moderately saline due to its marine origins.

The Ecology Lab (2003) assessed the potential impact of subsidence on aquatic ecology within Rocky Ponds Creek, Simpson Creek and Cataract River, all of which drain to the Nepean River. The assessment included macroinvertebrates, water quality and fish sampling, which concluded that local macroinvertebrate communities were tolerant to mild water salinity (Ecoengineers, 2013).

Studies undertaken in the Georges River by The Ecology Lab (2006) support this finding, indicating that, aquatic macroinvertebrates locally can, and do, acclimatize to some degree to salinity levels particularly within the 1000 – 4000µS/cm range (Ecoengineers, 2013).

Additionally, The Ecology Lab (2006) found that the diversity of the benthic macroinvertebrate population in the upper Georges River below the Brennans Creek confluence was comparable to reference sites around the Region (Ecoengineers, 2013).



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Water Monitoring Locations

WEST CLIFF AREA 5
LW 37 AND 38

Legend

- Study Area
- Existing and Past IC Monitoring Sites
- Groundwater Bores (MSEC, 2013)
- Existing Ground Water Monitoring Sites (BHPBIC)
- Surface Water Monitoring Sites - WMP (BHPBIC)
- Proposed Ground Water Monitoring Sites (Approx locations)
- Watercourse (MSEC, 2013)
- 3rd Order Watercourse (MSEC, 2013)
- 4th Order Watercourse (MSEC, 2013)
- West Cliff LW 37 and 38 (BHPBIC 2013)

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FIGURE 2

1:20,000 Scale at A3

Metres
0 250 500 750 1,000

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
Date: 2013-06-11
Coordinate System: GDA 1994 MGA Zone 56
Project: 112054-01
Map: G1005_WaterMonitoringLocations.mxd 07

Aerial imagery supplied by BHPBIC (2007 and 2009)

Table 3.5 – Average Baseline Water Qualities in Georges River Sites (2 August 2004 – 5 February 2010)

Site	Field pH (N)	Field EC µS/cm (N)	DO % Sat. (N)	Ca mg/L (N)	Mg mg/L (N)	Na mg/L (N)	T. Alk. mg/L as $CaCO_3$ (N)	SO_4 (N)	Cl (N)	Tot. Fe mg/L (N)	Tot. Mn mg/L (N)	Filt. Ni mg/L (N)	Filt. Zn mg/L (N)
Pool 34 (upstream of LW38)	8.40 ±0.37 (187)	1501 ±537 (185)	96 ±23 (177)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
GRQ17	8.52 ±0.35 (202)	1551 ±610 (200)	104 ±25 (193)	5 ±2 (55)	4 ±2 (55)	346 ±151 (55)	551 ±252 (54)	24 ±10 (54)	147 ±58 (55)	1.08 ±0.67 (55)	0.051 ±0.057 (55)	0.085 ±0.042 (55)	0.022 ±0.015 (55)
Pool 47	8.43 ±0.28 (68)	1493 ±517 (68)	86 ±15 (66)	5 ±1 (27)	4 1 (27)	310 ±108 (27)	478 170 (27)	20 ±6 (27)	130 ±39 (27)	1.19 ±1.37 (27)	0.081 ±0.138 (27)	0.081 ±0.033 (27)	0.021 ±0.014 (27)
Pool 49	8.58 ±0.22 (67)	1429 ±522 (67)	86 ±18 (65)	5 ±1 (24)	4 ±1 (24)	318 ±109 (24)	482 ±165 (24)	19 ±5 (24)	138 ±40 (24)	0.95 ±0.63 (24)	0.064 ±0.132 (24)	0.083 ±0.033 (24)	0.018 0.014 (24)
Pool 54	8.59 ±0.18 (60)	1420 ±524 (60)	83 ±17 (57)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
GRQ18 (upstream of LW37)	8.34 ±0.36 (69)	1287 ±513 (69)	89 ±26 (65)	5 ±2 (53)	5 ±2 (53)	308 ±127 (53)	488 ±202 (52)	20 ±10 (52)	139 ±53 (53)	1.11 ±0.76 (53)	0.082 ±0.192 (53)	0.073 ±0.035 (53)	0.019 ±0.014 (53)
GRQ100 (downstream of LW38)	8.27 ±0.49 (18)	1258 ±603 (18)	80 ±15 (18)	4 ±2 (16)	4 ±1 (16)	331 ±120 (16)	514 ±207 (16)	17 ±5 (16)	141 ±46 (16)	0.782 ±0.370 (16)	0.038 ±0.028 (16)	0.089 ±0.040 (16)	0.017 ±0.009 (16)

NA = insufficient data available.

Table 3.6 – Bores and Piezometers within or adjacent to the Longwall 37 to 38 Study Area

Borehole Reference	Northing	Easting	Surface Water Level (SWL) (mbgl)	Depth (m)	Year Drilled	Aquifer	Lithology	Yield (L/s)	Total Dissolved Solids (TDS)(mg/L)	Purpose
NoW Registered Boreholes										
GW32310	6218596	299161	35.9	152	1969	29.8 – 29.9 60.9 – 61.0	Sandstone Sandstone	0.10 0.11	n/a	Stock Domestic
GW72454	6218063	297710	24.0	162	1994	60.0 – 90.0	Sandstone	0.30	good	Domestic
GW105921	6218682	299577	44.0	183	2003	163.0 – 163.1	Sandstone	0.20	fresh	Stock/ Domestic
GW108322	6218316	299395	41.0	279	2003	44.0 – 44.1 151.0 – 151.1	Sandstone Sandstone	n/a	fresh	Stock Domestic
BHPBIC Piezometers										
GR22	6214228	297272	Various	45.4	2001	n/a	Sandstone	n/a	n/a	Monitoring
GR23	6214638	297151	Various	n/a	2001	n/a	Sandstone	n/a	n/a	Monitoring
GR24	6214935	297718	Various	36.43	2006	n/a	Sandstone	n/a	n/a	Monitoring
GR25#	6215120	296870	Various	24.24	2006	n/a	Sandstone	n/a	n/a	Monitoring
GR26#	6215664	296671	Various	21.04	2001	n/a	Sandstone	n/a	n/a	Monitoring
GR27	6216170	297121	Various	30.10	2006	n/a	Sandstone	n/a	n/a	Monitoring
GR28	6216613	296761	Various	24.31	2001	n/a	Sandstone	n/a	n/a	Monitoring
GR29	6216643	297518	Various	33.60	2001	n/a	Sandstone	n/a	n/a	Monitoring
GR50	6214378	296885	Various	n/a	2002	n/a	Sandstone	n/a	n/a	Monitoring
GR65	6214696	297369	Various	10.0	2006	n/a	Sandstone	n/a	n/a	Monitoring
GR67#	6215228	297111	Various	10.0	2006	n/a	Sandstone	n/a	n/a	Monitoring
GR68	6215276	297068	Various	10.0	2006	n/a	Sandstone	n/a	n/a	Monitoring
GR70*	6217609	296778	Various	33.5	2013	n/a	Sandstone	n/a	n/a	Monitoring
WC54*	6217720	296738	Various	51.5	2013	n/a	Sandstone	n/a	n/a	Monitoring
WC95*	6217832	297658	Various	25.0	2013	n/a	Sandstone	n/a	n/a	Monitoring

Notes: n/a – not available; mbgl – metres below ground level; # - sites have been rehabilitated, therefore no longer in use; * proposed sites for LWs 37-8 are now installed

The Ecology Lab studies in the upper Georges River (The Ecology Lab, 2005, 2007) were conducted in the context of dominant flows coming from BCD via Brennans Creek. Ecoengineers (2013) notes that the level of salinity in the upper Georges River ranges from an EC of 2300 to 3100uS/cm, which exceeds the default trigger value of 2200uS/cm for lowland rivers in south-eastern Australia as stated in the National Water Quality Guidelines (NWQGs).

The Ecology Lab (2007) assessment found that the Georges River has extensive areas of fish habitat, containing Class 1 fish habitat (major fish habitat). However, the tributaries contain Class 3 to 4 (minimal to moderate) fish habitat.

The aquatic fauna at the five upriver sites in the Georges River (Sites 1 – 5) were found to be less diverse than at the four downriver sites (Sites 6 – 9) within the Study Areas. The fauna at most of the sites within the Study Areas and at all the upstream sites were rated as slightly impoverished relative to the AUSRIVAS reference condition (Turak and Waddell, 2001). However, fauna at one site in the George River within the Study Areas and at the site in Mallaty Creek, were rated as similar to the AUSRIVAS reference condition.

The latest round of aquatic ecology monitoring undertaken between 7 and 8 December 2013 included post extraction monitoring for Longwall 35, during-extraction monitoring for Longwall 36 (although Longwall 36 had not mined near the River at this stage) and further pre-extraction monitoring for Longwalls 37 and 38. The following aquatic ecology indicators were surveyed at six study sites in the Georges River:

- Aquatic habitat, including fish habitat, aquatic macrophytes, riparian vegetation;
- In situ water quality;
- Aquatic macroinvertebrates; and,
- Fish.

The results of this survey have been compared with those obtained in May 2002, March 2005, May 2007, September 2008, May 2010, May 2012 and December 2012.

The condition of the aquatic macroinvertebrate fauna indicated that the river had experienced some degree of environmental stress before mining commenced and that it continues to do so. In the latest survey, the aquatic macroinvertebrate fauna at four of the six study sites along the Georges River was equivalent to the AUSRIVAS reference condition, while at the remaining sites was either significantly impaired or severely impaired relative to the AUSRIVAS reference condition.

A reduction in the number of macroinvertebrate taxa and desiccation of macrophytes was observed at two sites on the Georges River in November 2013. There was also evidence of a reduction in the quality of macroinvertebrate habitat at one of these sites and a reduction in the numbers of fish and larger mobile macroinvertebrates at the other. These changes are most likely due to the mining impacts of fracturing of bedrock, loss of flow and reductions in pool water levels and associated loss of aquatic habitat and reductions in river connectivity during low flow conditions. No such impacts were evident at sites further downstream, suggesting that the majority of these impacts are restricted to the areas directly affected by mining.

On the whole, species composition of the fish assemblages sampled in November 2013 was comparable with that observed during the previous surveys.

The increase in releases from BCD in response to the lowering of pool water levels below pre-mining conditions has been successful in temporarily restoring pool water levels, flow and connectivity. This measure has reduced the impact on fish and other aquatic species due to loss of aquatic habitat, flow and connectivity.

The appropriateness of releasing water from licensed discharges (e.g. BCD) to mitigate sub-bed flow diversions is supported by the comparison of the aquatic ecology monitoring sites where pool water level has been reduced with those up and downstream where there has not been these effects. According to the aquatic ecology monitoring results to date, other management options available, including allowing the river to 'dry out' temporarily would result in greater impacts then releasing mitigating flows. The aquatic ecology monitoring program (Cardno Ecology Lab, 2014) will continue to be implemented to further study this issue.

In line with Cardno Ecology Lab (2014) recommendations, increased discharges from BCD will be maintained for as long as practicable while low pool water levels and flow are experienced in the Georges River. This will reduce impacts to aquatic ecology associated with loss of habitat, flow and connectivity (**Attachment D**).

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 SURFACE WATER

4.1.1 Subsidence Effects

4.1.1.1 Georges River

The proposed longwalls are located at a minimum (closest approach) distance of 20m for Longwall 37 and 45m for Longwall 38 from the centreline of the Georges River (MSEC, 2013). **Table 4.1** provides a summary of the maximum predicted values of total subsidence, upsidence and closure along the Georges River.

Table 4.1 – Maximum Predicted Subsidence Effects for Georges River after extraction of Longwalls 37 and 38 (MSEC, 2013)

Feature	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Georges River	100	190	220

Table 4.2 provides a summary of the predicted values of tilt, hogging and sagging curvatures along the Georges River.

Table 4.2 – Predicted Maximum Non-Conventional Subsidence parameters for Georges River after extraction of Longwalls 37 and 38 (MSEC, 2013)

Feature	Tilt (mm/m)	Hogging Curvature (km^{-1})	Sagging Curvature (km^{-1})
Georges River	1.4	0.02	<0.01

4.1.1.2 Creeks and Drainage Lines

MSEC (2013) prepared subsidence predictions for drainage lines in the Study Area (refer **Table 4.3**). The creeks that have been identified within the Study Area are:

- Mallaty Creek and its tributaries (MSEC reference numbers MC3, MC4 and MC5);
- Nepean Creek and its tributaries (MSEC reference numbers NC3 and NC5);
- Woodhouse Creek; and
- Various tributaries of the Georges River (MSEC reference numbers GR101, GR102, GR103, GR104, GR105, GR107, GR108, GR108A, GR109, GR110, GR112, GR114, GR114A, GR117 and GR119).

These features could experience the full range of subsidence effects depending on their specific location in relation to Longwalls 37 and 38. Maximum predictions from MSEC (2013) for drainage lines are provided in **Table 4.3**.

Table 4.3 – Maximum Predicted Total Conventional Subsidence parameters for watercourses located directly above Longwalls 37 and 38 (MSEC, 2013)

Feature	Maximum Predicted Total Conventional Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Mallaty Creek (incl. MC5)	1125	675	725
Nepean Creek (incl. NC3)	850	130	75
Woodhouse Creek	25	50	75
Tributary GR103	95	70	110
Tributary GR104	830	190	210
Tributary GR105	1120	240	230
Tributary GR107	550	100	190
Tributary GR108	640	140	220
Tributary GR110	660	140	210
Tributary GR114	325	110	90

4.1.2 Subsidence Impacts and Consequences

MSEC (2013) has identified potential water related subsidence impacts for the Georges River and other watercourses, including:

- Changes in the natural gradient and stream alignment;
- Fracturing of the bedrock and soil sediments; and
- Subsidence induced springs.

The Georges River has a shallow gradient, with subsidence resulting in changes to the gradient of <0.1%. Consequently, increases in the levels of ponding, flooding or scouring are anticipated to be insignificant compared to changes in the river depth during times of high flow (Ecoengineers, 2013).

4.1.2.1 Fracturing and Pool Water Level Loss

Fracturing is likely to occur within streams in the Study Area, including the Georges River. Fractures could occur up to 400 metres from the proposed longwalls. However, given that fracturing of the Georges River is likely to be localised in nature, subsidence impacts or environmental consequences are unlikely to be greater than minor (Ecoengineers, 2013).

Closure is considered to be the more reliable parameter for predicting impacts along rivers and creeks (MSEC, 2013). The areas most likely to be affected are those where the predicted mine subsidence related movements are greatest, or where the rockbars are most sensitive to these movements (Ecoengineers, 2013).

Based on MSEC (2013) predictions it is anticipated that there is a low likelihood that significant fracturing would occur along Georges River. This is due to limiting the predicted closure at the mapped rockbars and riffles to less than 200mm, resulting in the setting back of the proposed longwalls by more than 150m from most rockbars and riffles. Rockbar GR-RB61 is setback 27m from Longwall 37. Additionally, it is unlikely that rockbars which are located adjacent to the proposed Longwalls 37 and 38 will fracture to such an extent that water flow diversion will be sufficient to drain pools during times of flow in the River. Therefore, due to the setbacks and closure criteria, impacts on rockbars from fracturing are expected to be negligible or minor (Ecoengineers, 2013).

The pools and rockbars identified within the Study Area are illustrated in MSEC (2013) and as **Figure 3 and Figure** 4. In the event that fractures result in pool water level loss they will be remediated using one or more of the Corrective Management Actions (CMAs) described in **Sections 7 and 8** and **Attachment A**.

4.1.2.2 Subsidence Induced Springs

There is the potential for subsidence-induced springs in the Longwalls 37 and 38 Study Area. Ecoengineers (2013) consider it possible that such springs, if pre-existing, would be more prone to be induced or enhanced in westward draining catchments in the Longwall 37 Study Area flowing into Nepean River (i.e. Mallaty Creek, Nepean Creek and Woodhouse Creek).

These westward draining streams in the Study Area are First Order streams and given the surrounding agricultural land use, it is unlikely there would be any significant impact to water quality resulting from the formation of springs in these streams over and above current anthropological effects (Ecoengineers, 2013).

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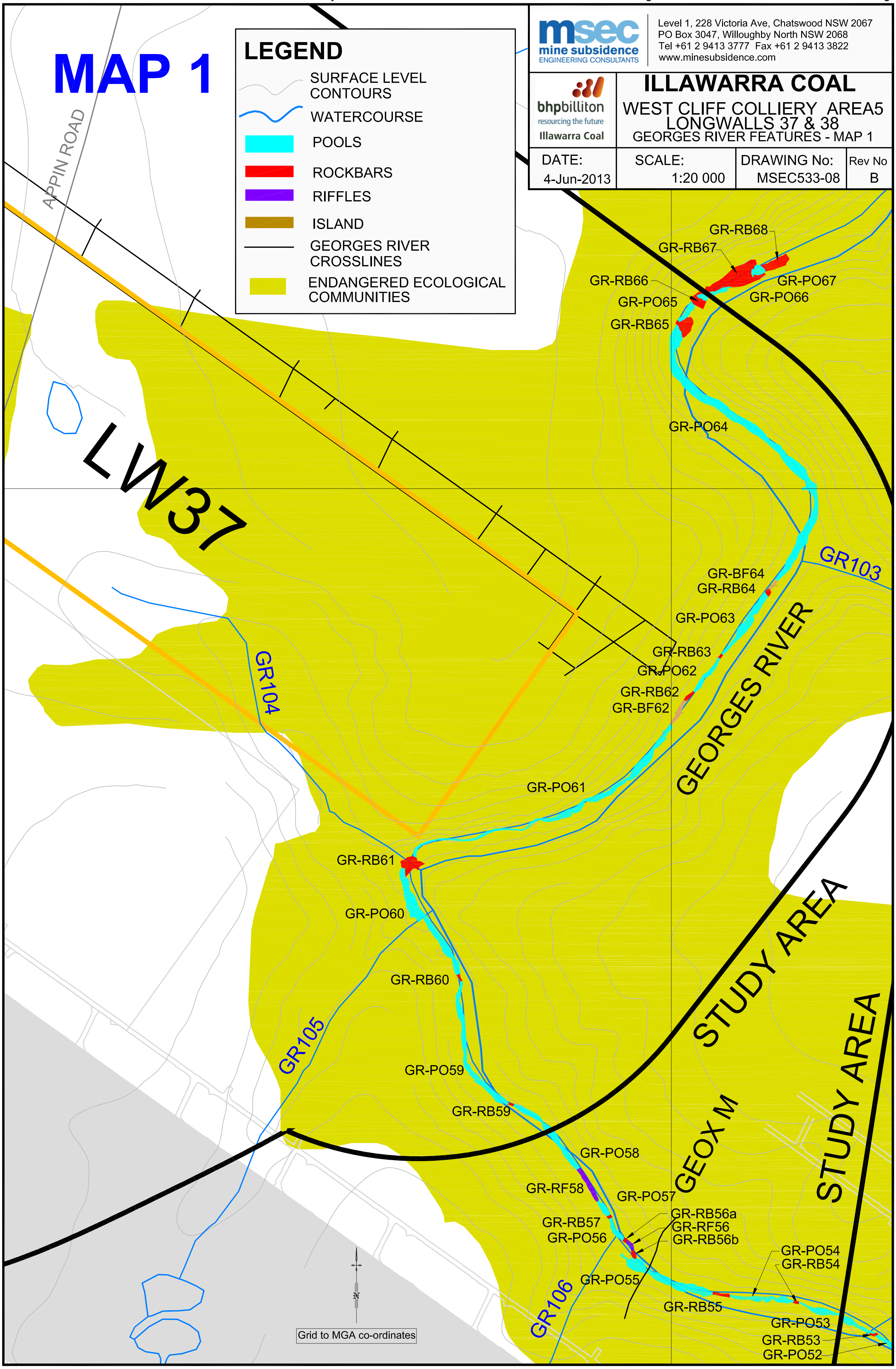

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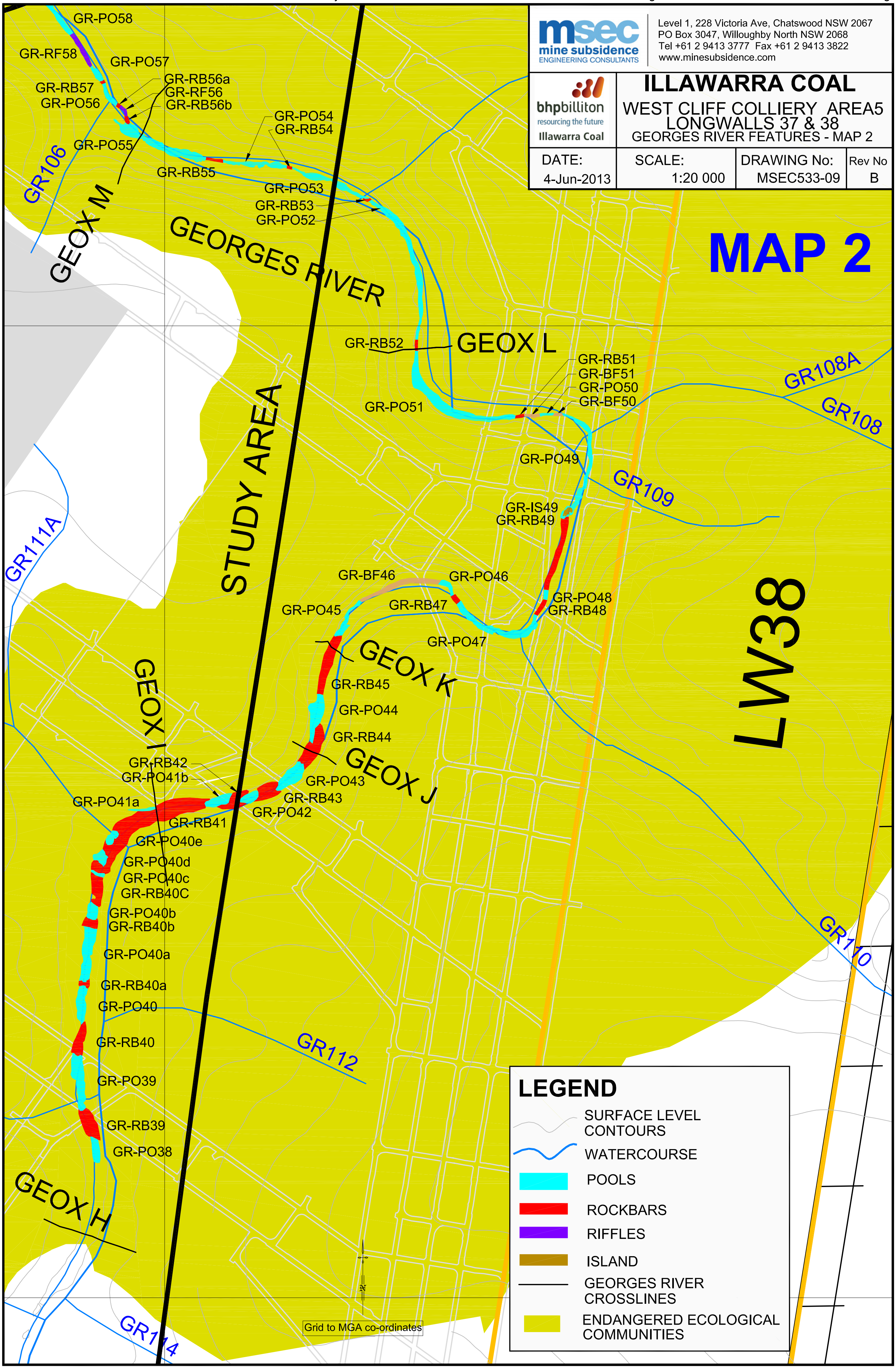

EcoEngineers (2013) predict that the proposed longwall extraction may also generate ferruginous springs in the Georges River. They also predict that they would only cause a river dissolved oxygen (DO) deficiency at their emergence points if their flow rate exceeded 0.1 ML/day and if flows in the river were concurrently <0.3 ML/day. Since August 2004, river flows of <0.3 ML/day have occurred less than 7% of the time, and therefore, the likelihood of both these conditions being met at the same time is extremely low.

4.1.2.3 Geochemical Effects

With respect to the possible induction of a ferruginous spring EcoEngineers (2013) infer the following effects, based on geochemical modelling, to be the maximum long term effects in Georges River:

- Any depletion of DO at the point of mixing of the spring with river water, to below the NWQGs trigger value, would only occur for low river flows (e.g. 0.42 ML/day, 10th percentile flow) when the spring flow rate was greater than 0.10 ML/day.
- The effect of a ferruginous spring on pH of Georges River water would likely be negligible given the buffering of bicarbonate/carbonate alkalinity.
- Oxidation of iron released by the sub-bed diversion would act to decrease the concentrations of dissolved Ni and Zn to below the concentrations observed in the Georges River.
- Similarly, oxidation of iron released by the sub-bed diversion would act to decrease the concentrations of cationic (potentially ecotoxic) Ni and Zn to below the concentrations observed in the Georges River. Cationic Zn concentrations would likely be reduced to levels below the NWQG trigger values.

These effects are related to fractures exposing siderite/rhodochrosite in weathered sandstone and possibly also marcasite (an iron sulfide) in unweathered sandstone.

Should sub-bed flow diversions occur, EcoEngineers (2013) predict that a considerable ‘mitigating effect’ against ecotoxic effects attributable to acidity, dissolved nickel and zinc is provided by the controlled release of water from BCD at West Cliff Colliery which has elevated salinity. The West Cliff release contains a concentration (typically 1000 – 1500 mg/L as CaCO3) of bicarbonate/carbonate alkalinity which:

- buffers any acidity generated by freshly fractured sandstone bedrock; and
- complexes dissolved nickel and zinc, reducing the concentration of ecotoxic forms of these metals.

The NWQGs explicitly allow for the consideration of site or region specific factors (ANZECC/ARMCANZ, 2000), therefore, pHs in the Georges River between 8.0 and 9.5, are demonstrably still within the ‘natural range’ for rivers with good access of light to the river surface where pools can support significant algal populations. This is due to algal primary productivity where the algae absorb dissolved CO_2 and bicarbonate from water and respire oxygen, thereby driving pH up. It is therefore common to observe pHs in river pools rising to levels as high as 9.5 during warm, sunny conditions. Therefore, EcoEngineers (2013) anticipate that due to the comparatively high pH of the BCD discharge, any effect on pH from extraction of proposed longwalls will be negligible.

EcoEngineers (2013) consider that due to the nature of the Georges River bed, with numerous boulder fields and rockbars, typical Re-Aeration Coefficients applying in the River would be such that any minor deficit in DO at a spring emergence point would have negligible impact.

4.2 GROUNDWATER

4.2.1 Subsidence Effects

The maximum predicted subsidence at the private bores and BHPBIC piezometers after completion of Longwalls 37 to 38 as assessed by MSEC (2013) are listed in **Table 4.4**.

Table 4.4 – Maximum Predicted Cumulative Subsidence (MSEC, 2013)

Ref	Northing	Easting	Maximum Predicted Subsidence (mm)
NoW Registered Bores			
GW32310	6218596	299161	<20
GW72454	6218063	297710	340
GW105921	6218682	299577	<20
GW108322	6218316	299395	<20
BHPBIC Piezometers			
GR22	6214228	297272	<20
GR23	6214638	297151	<20
GR24	6214935	297718	<20
GR25#	6215120	296870	<20
GR26#	6215664	296671	<20
GR27	6216170	297121	<20
GR28	6216613	296761	<20
GR29	6216643	297518	500
GR50	6214378	296885	<20
GR65	6214696	297369	<20
GR67#	6215228	297111	<20
GR68	6215276	297068	<20
GR70	6217609	296778	90
WC54	6217720	296738	250
WC95	6217832	297658	290

 # - these sites have been rehabilitated, therefore no longer in use.

4.2.2 Subsidence Impacts

GeoTerra (2013) have assessed the potential impacts from mining related subsidence on groundwater systems from Longwall 37 and 38 and have utilised data from BHPBIC ground water and surface water monitoring within or near the Study Area.

The upper reaches of the Longwall 37 streams generally have clay based alluvium developed on Bringelly Shale, Michinbury Sandstone and Ashfield Shale / Wianamatta Shale with Hawkesbury Sandstone in the eroded Mallaty Creek valley. Longwall 38 is dominated by exposed or sub cropping Hawkesbury Sandstone. The Georges River is developed within the Hawkesbury Sandstone. The Narrabeen Group sequence is developed below the Hawkesbury Sandstone and above the Illawarra Coal Measures, although it does not outcrop in the Study Area. A summary of the GeoTerra (2013) assessment is provided below.

4.2.2.1 Wianamatta Group Shale and Sandstone Groundwater Levels

Due to the lack of perennial regional scale aquifers in the Wianamatta Shales it is concluded that there is unlikely to be a significant impact to groundwater resources in the Wianamatta Shale resulting from the proposed extraction. Water levels in the Wianamatta Shale Group perched aquifers are predicted to reduce by between 5m to 10m.

4.2.2.2 Hawkesbury Sandstone Groundwater Levels

GeoTerra (2013) predict that due to the mostly temporary nature of any groundwater level reductions there is unlikely to be a significant impact to groundwater resources in the regional Hawkesbury Sandstone aquifer resulting from the proposed extraction.

4.2.2.3 Narrabeen Group and Illawarra Coal Measures Groundwater Levels

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 areas as well as the proximity of a bore to the horizontal extent of the subsidence trough. Due to the substantial depths of cover over Longwalls 37 and 38, connective cracking from the mined workings to the surface is not predicted to occur. The groundwater modelling indicates that there is anticipated to be an eventual recovery of deep groundwater system pressures over many decades following cessation of mining.

4.2.3 Consequences of Impacts to Groundwater

4.2.3.1 Reduced Bore Yield

One NoW registered bore overlying Longwall 38 (GW72454), with a water bearing zone in the Hawkesbury Sandstone between 60 – 90m below surface, may have an adverse effect on its yield or serviceability. This bore is located in an area of relatively higher predicted lateral tensile strain which may result in bedding dislocation / shearing and the bore will be monitored for subsidence effects as agreed by the property owner. Bores not overlying the longwalls, and outside the Study Area are not likely to undergo direct adverse subsidence effects.

With mitigation measures in place (replacement of water supply for the landholder and repair of any impacts – see **Attachment A**), it is unlikely that water supply to the subject property will be significantly impacted by the proposed mining of Longwalls 37 and 38.

4.2.3.2 Groundwater Quality

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

With the agreement of bore owners, monitoring of potentially affected bores will 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 would 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.

4.2.3.3 Ferruginous Springs

The generation or enhancement of shallow, ferruginous springs following subsidence have been observed in the vicinity of the proposed workings within the Georges River catchment.

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

- May be generated by a catchment as small as approximately 0.2 km^2;
- Are likely to have a life of at least 4 years with or without significant diminution in intensity; and in some cases;
- May be relatively permanent depending upon the size of the dilated catchment area providing their water supply.

Development or enhancement of ferruginous springs in the vicinity of Longwalls 37 and 38 may occur, however their extent, location and duration is not readily predictable. In the event that any springs develop, they will be remediated using one or more of the CMAs described in **Sections 7 and 8** and **Attachment A**.

4.2.3.4 Groundwater Baseflow to the Georges River

The Georges River is located in the base of the regional hydrological system and as such, no increased baseflow has been observed into the Georges River resulting from previous mining. Increased rates of low volume seepage to the River may be generated, but it would be insignificant when compared to the volume of water flowing down the River.

Groundwater modelling undertaken by Heritage Computing (2010) indicates that old and current mine workings in the West Cliff area have caused negligible changes in groundwater baseflow to streams and that approximately 1.14ML/day of baseflow enters the entire Georges River catchment.

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 of Longwalls 37 and 38 will significantly impact lower order streams, seeps, springs and would have no more than minor impacts on flow to the Georges River.

4.2.3.5 Mine Inflow

Loss of stream flow through connected fracture substrate to the mining area in Bulli Seam workings has not been observed in any mines in the Southern Coalfield at similar depths of cover to West Cliff Area 5.

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 predicted.

The Bald Hill Claystone aquaclude is anticipated to remain although an increased mine water make through drainage from the highly fractured goaf area is predicted.

4.2.3.6 Bore Gas Emissions

Due to the very limited reports of gas adversely affecting groundwater supply bores in the Southern Coalfield over longwall areas, it is not anticipated that significant strata gas will be discharged in private bores over Longwalls 37 and 38. With the mitigation and management measures implemented (provision of an alternate water supply) as part of the Property Subsidence Management Plans (PSMPs) it is unlikely there will be a significant impact to water supply from private groundwater bores.

4.3 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. This ongoing program of research and assessment has a particular focus on sub-surface impacts and impacts on groundwater resources. The program includes:

- 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 regional groundwater model; and
- regular recalibration of methodologies and models used for subsidence effect and impact prediction, as they are applied within the project area.

The results of this ongoing program are incorporated within Extraction Plans, including this Extraction Plan and the plans required under *Condition 5 (g-l), Schedule 3* of the BSO Approval. BHPBIC developed an Environmental Research Program to outline the activities which will be undertaken to address *Condition 9, Schedule 3* of the BSO Approval and this was provided to DP&I September 2012.

5 PERFORMANCE MEASURES AND INDICATORS

The BSO Approval provides Subsidence Impact Performance Measures (*Schedule 3).* **Table 5.1** details the performance measures relevant to water supply and watercourses.

In relation to the subsidence impact performance measure the term "*negligible"* is defined within the Project Approval as "*small and unimportant, such as not to be worth considering"* and the term "*minor*" is defined as "*not very large, important or serious*". The WMP has been developed to be consistent with the BSOP Consent and specifically the performance measures outlined in **Table 5.1.**

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.
Georges 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, over at least 80% of the stream length subject to vertical subsidence >20 mm. No subsidence impact or environmental consequence greater than minor.
Other Watercourses	No greater subsidence impact or environmental

	consequences than predicted in the EA and PPR.
Built Features (Condition 3 Schedule 3)	
Farm dams and other built features or improvements	Serviceability should be maintained wherever practicable. Loss of serviceability must be fully compensated. Damage must be fully repaired or fully compensated, or else the damaged built feature or damaged infrastructure component must be replaced.

In order to mitigate the potential subsidence impacts and environmental consequences from mining Longwalls 37 and 38, monitoring and recording will be undertaken prior to mining, throughout the extraction and at the completion of extraction and associated subsidence (refer **Section 6**).

In the event that any subsidence impact is recorded, BHPBIC would implement appropriate reporting, management, remediation and/or mitigation measures in consultation with and the approval of relevant stakeholders to achieve the performance measures outlined in **Table 5.1** (refer **Section 7**).

The subsidence impact performance measures are exceeded if "Exceeding Performance Measures" outlined in **Attachment A** – Table 2 West Cliff Area 5 Longwall 37 and 38 Water Trigger Action Response Plan (TARP) are triggered. BHPBIC will notify NoW, DP&I, OEH, SCA, DRE, and other key stakeholders and implement the Contingency Plan (**Section 8**) and actions as described in **Attachment A**.

5.1 NEPEAN RIVER

The Nepean River is located outside the Study Area and is at a distance of approximately 2.2km west of Longwall 37 at its closest point. It is unlikely, therefore, that the river would be subjected to any significant systematic subsidence movements resulting from the extraction of the proposed Longwalls 37 and 38.

The Nepean River could be subjected to very small far-field horizontal movements as a result of the extraction of the proposed longwalls. Far-field horizontal movements have been observed more than 1km from longwall extractions, however, these movements tend to be bodily movements associated with very low levels of strain and have not been associated with any water flow or quality-related effects.

The land in the central and western parts of the Study Area generally drains into Nepean, Mallaty or Woodhouse Creeks, which in turn drain to the Nepean River. It is possible that ferruginous saline springs may be more prone to be induced or enhanced (if pre-existing) in westward draining catchments overlying Longwall 37 that ultimately flow to the Nepean River.

The westward draining streams in the Study Area are strongly ephemeral in nature with ongoing agricultural land use, and it is unlikely there would be any significant impact to water quality resulting from the formation of springs in these streams over and above current anthropological effects (The Ecology Lab, 2007).

Therefore, the performance criteria of 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 is expected to be achieved.

The Nepean River is subject to comprehensive monitoring as required by the Appin Area 7 Subsidence Management Plan. In the unlikely event there are measurable changes in

Nepean River resulting from the extraction of Longwall 37 these would be identified by this monitoring program and appropriate actions (e.g. reporting) would be implemented.

5.2 GEORGES RIVER

Longwalls 37 and 38 do not mine directly beneath the Georges River. The minimum distance of the Georges River from Longwall 37 is 20m and Longwall 38 is 45m. The total length of the Georges River within the Study Area is 2.3km. A detailed description of the likely and potential impacts from mining Longwalls 37 and 38 is provided in **Section 4**.

An analysis of past impacts to Georges River was undertaken for Longwalls 33 to 36 (**Table 5.2**). The analysis identified fractures with flow diversion which resulted in a pool water level response (lowering to below baseline). The assessment was undertaken within the length of the River where the predicted maximum subsidence was >20mm (1950m). This includes the River from Rockbar 36 to 47 and from Rockbar 54 to 61 (see MSEC, 2013).

Table 5.2 - Analysis of Impacts from Longwalls 33 - 36

Impact ID	Location of Fracture Zone(s)	Length(s) of Fractured Zones (m)	Reference
WCA5_LW35_012	Pool 56	1	West Cliff Area 5 Longwall 35 Impact Report_130516
WCA5_LW35_010	Pool 58	1	West Cliff Area 5 Longwall 35 Impact Report_130516
WCA5_LW35_013	Rockbar 45	60	West Cliff Area 5 Longwall 35 Impact Report_130530
WCA5_Fracture_005	Pool 38	5 & 2	Georges River Impact Report_091208 West Cliff Area 5 Longwall 35 Impact Report_130925
WCA5_LW35_018	Pool 54	1, 0.7, 1.5 & 0.8	West Cliff Area 5 Longwall 35 Impact Report_130724
WCA5_LW35_019	Pool 57	0.5	West Cliff Area 5 Longwall 35 Impact Report_130822
WCA5_LW35_017	Rockbar 43	17	West Cliff Area 5 Longwall 35 Impact Report_130716
LW33_Fracture6	Rockbar 39	3	Georges River Impact Report_091215
LW33_Fracture7	Rockbar 39	5	Georges River Impact Report_091218
Total Length of Fractures with Flow Diversion		98.5m (approx 5% of the total length - 1950m)	

As can be seen from **Table 5.2** approximately 5% of the length of the River subject to a predicted maximum subsidence of 20mm has been fractured such that water flow diversion results in pool water level decline below baseline levels. On the basis that similar design criteria have been used for the proposed Longwalls 37 and 38 to that used for Longwalls 33 to 36 it is predicted that a similar level of impact would occur to a similar proportion (~ 5%) of the length of the river subject to a maximum predicted subsidence of 20mm (see MSEC, 2013 Fig E.03).

The sections of the River that are likely to experience negligible environmental consequences are those areas that are less susceptible to mining impacts and areas of less subsidence movements (**Section 4.1**). The sections of the River that are likely to experience minor environmental consequences are those areas that are more susceptible to mining impacts and are likely to experience greater subsidence movements (**Section 4.1**).

In particular, the closure movements are likely to be a key indicator of the level of subsidence impacts and environmental consequences. The greatest levels of predicted maximum closure within the Study Area are from Rockbar 48 through to Rockbar 61 (**Figure 3 and Figure 4**) and it would be expected that the features sensitive to closure movements within this length of the River would be susceptible to minor environmental consequences. Outside of this section, the River is predicted to have less closure movements and therefore, expected to have negligible environmental consequences, especially for features that are less susceptible to closure movements.

The water performance measures for the Georges River Longwalls 37 and 38 relate to water quality, pool water level, fracturing and diversion of flow within the River and these are further defined in **Attachment A**.

Where monitoring reveals impacts are greater than negligible, mitigation and management measures are proposed (**Sections 7 and 8**). These measures include a discharge capable of maintaining pool water levels e.g. approximately 1.0 ML/day within the Study Area is released from BHPBIC licensed discharges e.g. BCD. As recommended by Ecoengineers (2013) and Cardno Ecology Lab (2014) the mitigating flows will be released from the West Cliff and/or Appin Collieries whenever this is practical until such time as the flow diversions are remediated via grouting of fractures resulting in flow diversion (**Figure 3** and **Figure 4**).

Based on the observed impacts and environmental consequences from previous mining near, but not under the River, and the ability to provide mitigating flows and undertake rehabilitation, the performance criteria of 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, over at least 80% of the stream length subject to vertical subsidence >20 mm, and no subsidence impact or environmental consequence greater than minor is expected to be achieved.

5.3 OTHER WATERCOURSES

The small watercourses and drainage lines are directly mined under, and therefore the maximum predicted subsidence movements are the maximum values which occur within the Study Area.

Based on the previous experience of mining beneath drainage lines in the Southern Coalfield, it is likely that some fracturing will occur along the drainage lines, particularly those located directly above or adjacent to the proposed longwalls. It is unlikely, however, that there would be any 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 (MSEC, 2013).

Detailed discussions on the potential impacts and environmental consequences of surface cracking and changes in surface water flows are provided in the reports by Ecoengineers (2013), Cardno Ecology Lab (2013) and Niche (2013).

The drainage lines will be monitored during the extraction of the proposed longwalls. Management strategies described in **Sections 7** and **8** and **Attachment A** will be implemented for the drainage lines, such that any impacts can be identified and managed accordingly. With these strategies in place, it is unlikely that there would be a significant impact on the drainage lines resulting from the extraction of the proposed longwalls.

Based on the observed impacts and environmental consequences from previous mining under small watercourses and drainage lines and the ability to undertake rehabilitation, the performance criteria of; no greater subsidence impact or environmental consequences than predicted in the EA and PPR is expected to be achieved.

5.4 FARM DAMS

There are 43 farm dams identified within the Study Area (MSEC, 2013). The dams are typically of earthen construction and have been established by localised cut and fill operations within the natural drainage lines. The farm dams are generally shallow, with the dam wall heights generally less than 3m. The maximum predicted mine subsidence movements for the farm dams are similar to but slightly less than those predicted for the BSO EA.

Based on observations of mining within areas similar to the Study Area the farm dams can be managed by the implementation of suitable management strategies as described in **Sections 7** and **8** and **Attachment A**. The farm dams will be monitored during the extraction of the proposed longwalls, and CMAs will be implemented to ensure that they remain in a safe and serviceable condition. The management strategies for the farm dams within the Study Area are further addressed in the PSMPs. With these management strategies in place, the performance criteria of; serviceability should be maintained wherever practicable, loss of serviceability must be fully compensated, damage must be fully repaired or fully compensated, or else the damaged built feature or damaged infrastructure component must be replaced is expected to be achieved.

6 MONITORING AND REPORTING

6.1 SURFACE WATER AND POOL LEVEL MONITORING

BHPBIC have implemented an extensive surface water monitoring program within the Longwalls 37 and 38 Study Area and this will continue. All mapped rockbars and pools in the Study Area will be inspected and have water level monitoring prior to, during and after mining. Monitoring will be undertaken throughout the Study Area with a particular focus on Rockbars 47 to 61 which are located between Longwalls 37 and 38 (see **Figure 3** and **Figure 4**), which are predicted to experience the highest levels of closure. Detailed assessments will be undertaken of target features which are susceptible to impacts such as GR-RB61 which is located within 50m of the longwall extraction.

If pre-existing ferruginous springs are identified within the Study Area, open boreholes / piezometers will be installed near the identified springs, subject to any required approvals.

Baseline, during mining and post mining monitoring is being implemented for the Georges River, Mallaty Creek and Nepean Creek, upriver, adjacent and downstream of the proposed Longwalls 37 and 38. **Attachment A** details water monitoring locations and frequency implemented for the Study Area.

6.2 GROUNDWATER MONITORING

An extension of the current groundwater monitoring program will be used to monitor the subsidence effects from the extraction of Longwalls 37 and 38 on groundwater within the Study Area (refer Attachment A).

If significant deviations from the expected groundwater response occurs (as outlined in **Attachment A** – Table 2 West Cliff Area 5 Longwall 37 and 38 Water TARP) BHPBIC will notify NoW, DP&I, OEH, SCA, DRE, and other key stakeholders and implement the actions as described in **Attachment A.** The BSO Groundwater Model will undergo re-calibration and further investigation will be undertaken to investigate the reasons for the occurrence.

Consultation with landholders and the monitoring of bores have been incorporated into the PSMP's for relevant properties and, with the agreement of the landowner include:

- Interview with the bore owner 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;
- Interview with bore owner after a bore is mined under to compare rate and duration of pumping;
- Measurement of the bore yield, if access and pump is available;
- Observations on the presence and quantum of iron hydroxide precipitating from the pumped water before and after mining.
- Observations of any strata gas in the bores.

Table 6.1 – Monitoring in BHPBIC Piezometers

Reference	Standing water levels	Vertical profiles of potentiometric head	Groundwater Quality[4]	Geotechnical Profiles
GR68 (extensometer)				Y
GR27	Y		Y	
GR28	Y		Y	
GR29	Y		Y	
WC95[1] (297658, 6217832)	Y		Y	
GR70[1] (296778, 6217609)	Y		Y	
WC54[1] (296738, 6217720)	Y		Y	
Private Bores[2]	Y		Y	
VWPs in S2087		Y		

1. *Additional piezometers were installed in the Longwall 37/8 Study Area in December 2013.*
2. *Where access is granted, monitoring 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.*
3. *[Except for Private Boreholes] Measured and data logged at least twice daily in the pre-mining baseline, impact and post-mining period*
4. *At least one appropriately purged groundwater sample pre-mining and 2 replicate samples (1 after mining Longwall 37 and 1 after mining Longwall 38) to be tested for:*
    - *field pH, electrical conductivity, temperature;*
    - *filterable Na / Ca / K / SO_4;*
    - *Cl, F;*
    - *total / filterable Fe, Mn, Al;*
    - *filterable Ni, Zn, As, Ba, Cs, Cu, Pb, Li, Rb, Se, Sr, B;*
    - *total dissolved solids, total alkalinity, total nitrogen and total phosphorous*.

6.3 SEEPS

The presence and duration of observable seeps within the Study Area will be recorded during field monitoring as described in the Landscape Management Plan. Where available and accessible, seep water samples will be collected and assessed for the same field and laboratory parameters outlined in the notes listed under **Table 6.1**.

6.4 MINE WATER INFLOWS

Statutory inspections of the mine workings will be undertaken by BHPBIC to ensure mine safety. Due to the frequency of inspections and familiarity with normal conditions the statutory inspections are well placed to identify any abnormal water inflow to the mine. Inflows detected during statutory inspections will be sampled and tested as per BHPBIC Groundwater Bores (see Note 4 under **Table 6.1**).

A Mine Water Balance will be 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 will comprise:

- Metered water reticulated into the mine.
- Metered water reticulated out of the mine.
- Measurement of moisture content into and out of the mine through the mine ventilation system and measurement of the in-situ moisture content of the coal.

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 rolling average (e.g. 20 day) will be used to provide an estimate of water make.

6.5 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 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 (**Attachment A**).

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

7 MANAGEMENT AND MITIGATION STRATEGIES

The predicted impacts from the extraction of Longwalls 37 and 38 are unlikely to result in hydrologic or ecotoxic water quality effects in the Georges River. However, should monitoring reveal that impacts are occurring, mitigation and management measures are proposed.

7.1 TRIGGER ACTION RESPONSE PLAN

The TARPs relate to identifying, assessing and responding to the potential impacts to watercourses (including impacts greater than predicted) from subsidence. These TARPs have been prepared using knowledge gained from previous mining in West Cliff Area 5. The TARPs for Longwalls 37 and 38 watercourses are included in **Attachment 1**.

It should be noted that the TARPs represent actions to be taken upon reaching each defined trigger level. A CMA is developed in consultation with stakeholders in order to manage an observed impact in accordance with relevant approvals.

Monitoring of environmental aspects provides key data when determining any requirement for mitigation or rehabilitation. The triggers are based on comparison of baseline and impact monitoring results. Where required the triggers will be reviewed and changes proposed in impact assessment reports provided to government agencies or in End of Panel Reports.

7.2 AVOIDING AND MINIMISING

The layouts for Longwalls 37 and 38 have been developed using BHPBIC's Integrated Mine Planning Process. This process considers mining and surface impacts when designing mine layouts.

BHPBIC have assessed mining layout options for Longwalls 37 and 38 against the following criteria:

- Extent, duration and nature of the impact to surface features;
- Community, social and environmental impacts;
- Coal customer requirements;
- Roadway development and longwall continuity;
- Mine services such as ventilation;
- Recovery of the resource for the business and the State; and
- Gas drainage, geological and geotechnical issues.

The final two longwalls in West Cliff Area 5 (Longwalls 37 and 38) are part of the overall mining schedule for West Cliff Mine and has been designed to transition from Area 5 to Area 9 in 2016. The mining of these two longwalls is critical in providing continuous operations.

The layouts of Longwalls 37 and 38 have been modified to reduce the potential for impacts to surface features. Changes to a mine layout have significant flow-on impacts to mine planning and scheduling as well as economic viability. These issues need to be taken into account when optimising mine layouts. The process adopted in designing Longwalls 37 and 38 incorporated the hierarchy of avoid/minimise/mitigate as requested by DP&I and OEH during the consultation process.

The changes to the layout of Longwalls 37 and 38 limit the predicted closure at the mapped rockbars and riffles to less than 200mm, resulting in the setting back of the proposed longwalls by more than 150m from most rockbars and riffles. Additionally, it is unlikely that rockbars which are located adjacent to the proposed Longwalls 37 and 38 will fracture to such an extent that water flow diversion will be sufficient to drain pools during times of flow in the River.

7.3 MITIGATING FLOW

In line with the recommendations of Ecoengineers (2013) and Cardno Ecology Lab (2014) if mining induced flow diversion and drainage of pools results from the mining a discharge capable of maintaining pool water levels e.g. approximately 1.0 ML/day within the Study Area will be released from BHPBIC licensed discharges whenever practical. These mitigating flows will be released from the West Cliff and/or Appin Collieries until such time as the flow diversions are remediated. Pool level monitoring will continue at all pools within the Study Areas, before, during and after extraction, including up until any remediation has been successfully implemented.

7.4 FERRUGINOUS SPRINGS

As a result of reaction with atmospheric oxygen, Ecoengineers (2013) note that excessive precipitation of hydrous iron and manganese oxides and the consequent depletion of DO might occur through the induction of ferruginous springs. Should depletion of DO be observed at a long-lived mining induced spring, re-oxygenation through the deposition of heavy rocks and boulders in proximity to the spring would be implemented to increase turbulence and hence rates of oxygenation, precipitation of hydrous oxides and acid generation, allowing natural processes to ameliorate the effects of the spring (Ecoengineers, 2013).

7.5 GROUNDWATER

Longwalls 37 and 38 are unlikely to result in significant impacts to groundwater resources, largely due to the nature of groundwater level reductions, the substantial depths of cover and the mitigation measures (**Attachment 1**) proposed. Should impacts be identified to the shallow hydraulic gradient in the Georges River, this will be considered when assessing surface water impacts and rehabilitation design.

Additionally, should a significant departure from the predicted envelope of vertical potentiometric head profiles occur such as a reduction in pressure in the monitored bores (as provided in the Water TARP in **Attachment 1**), or an inconsistency in profile shape with what has been predicted, then an assessment would be undertaken to determine if the change is likely to have been caused by any connective cracking between the surface and the mine. This may be assessed by modifying the height and hydraulic properties of the fractured zone in the groundwater model until the measured profile is reasonably replicated.

7.6 REHABILITATION

If the performance measures in **Table 5.1** are not met, then following consultation with relevant Government Agencies, including the Director-General of DoPI, BHPBIC will undertake actions or measures to mitigate or remediate subsidence impacts and/or associated environmental consequences. The triggers and actions to be initiated are outlined in the TARP (**Attachment 1**). The options available for rehabilitation are discussed further below.

7.6.1 Sealing of Rock Fractures

Where the bedrock base of a pool or controlling rockbar within the Georges River are impacted from subsidence they will be sealed with an appropriate and approved cementatious (or alternative) grout. Grouting will be focused where fractures result in diversion of flow from pools or through the controlling rockbar. Significant success has been achieved in the remediation of the Georges River where four West Cliff longwalls directly mined under the river and pool water level loss was observed.

A number of grouts are available for use including cement with various additives. These grouts can be used with or without fillers such as clean sand. Grouts can be mixed on-site and injected into a fracture network or placed by hand.

Such operations do have the potential to result in additional environmental impacts and are carefully planned to avoid contamination. Mixing areas will be restricted to cleared or other open areas wherever possible. Bunds are used to contain any local spillage at mixing points. Temporary cofferdams can be built downstream of the grouting operations to collect any spillage or excess grouting materials for disposal off-site. The selection of grouting materials is based on demonstrated effectiveness and ensuring that there is no significant impact to water quality or ecology.

7.6.2 Injection Grouting

Injection grouting involves the delivery of grout through holes drilled into the bedrock targeted for rehabilitation. A variety of grouts and filler materials can be injected to fill the voids in the fractured strata intercepted by the drill holes. The intention of this grouting is to achieve a low permeability ‘layer’ below any affected pool as well as the full depth of any controlling rockbar.

Where alluvial materials overlie sandstone, grouts may be injected through grout rods to seal voids in or under the soil profile. This technique was successfully used at Pool 16 in the Georges River to rehabilitate surface flow by-pass to Pool 17. In this case 1-2m of loose sediment was grouted through using purpose built grouting pipes.

Grouting holes are drilled in a pattern, usually commencing at a grid spacing of 2m x 2m. The most efficient way to drill the holes taking into account potential environmental impact is by using handheld drills. The drills are powered by compressed air which is distributed to the work area from a compressor. The necessary equipment will be sited on cleared seismic lines or other clear areas wherever possible with hoses run out to target areas.

Grout is delivered from a small tank into the ground via mechanical packers installed at the surface. All equipment can be transported with vehicles capable of travelling on tracks. The grout is mixed and pumped according to a grout design. A grout of high viscosity will be used if vertical fracturing is believed to be present since it has a shorter setting time. A low viscosity grout will be used if cross-linking is noted during grouting. Once the grout has been installed the packers are removed and the area cleaned. After sufficient time for the product to set the area may be in-filled with additional grouting holes that target areas of significant grout take from the previous pass.

Grouting volumes and locations are recorded and high volume areas identified. Once the grout take in the area is reduced and the material has set, the grouted section of the pool is isolated and tested with local or imported clean water. The rate at which the water drains is measured and compared to pre-grouting results. The grouting process is iterative; relying on monitoring of grout injection quantities, grout backpressures and measurements of water holding capacity. In previous rehabilitation of the Georges River the majority of pools were sealed with two to three grout passes.

If flow diversion through a large rockbar occurs it may be more appropriate to implement alternative grouting techniques such as a deeper grout curtain which can be delivered via traditional or directional drilling technologies. Grouting should preferentially be undertaken at the completion of subsidence movements in the area to reduce the risk of the area being re-impacted.

7.6.3 Erosion Control and Surface Treatments

Erosion can occur along preferred flow paths where subsidence induced tilts increase a catchment area. In the unlikely event erosion results from the subsidence, ‘coir log dams’ will be installed at knick points in the flow paths or at the inception of tunnel/void spaces.

As the coir log dams silt up they are regularly added to by the placement of additional layers of logs until the pooled water behind the ‘dams’ is at or above the level of the bank of the eroded channel.

7.6.4 Gas Releases

A typical driver of gas release at the surface is pressure changes, dilation and/or fracturing of the rock mass and associated release to the surface, with or without groundwater flows. Grouting techniques discussed above can reduce these associated gas flows at specific sites. In all identified circumstances in the Southern Coalfield the gas releases have diminished over time. Typically this time is a number of months but it can be a number of years. Long running gas releases significantly reduce in quantity over time. Where vegetation is impacted by gas releases the areas affected will be revegetated once monitoring determines the gas releases have ceased or reduced to an extent that vegetation is no longer affected.

7.6.5 Alternative Remediation Approaches

BHPBIC has successfully implemented a subsidence rehabilitation program in the Georges River where there were impacts associated with mining directly under streams. This rehabilitation focused on grouting of mining induced fractures and strata dilation to reinstate the structural integrity and water holding capacity of the bedrock. Metropolitan Colliery is currently undertaking work aimed at rehabilitating areas impacted by subsidence using Poly-urethane Resin (PUR) and other grouting materials. BHPBIC is consulting with Metropolitan Colliery in relation to these new and emerging technologies. Should rehabilitation of Longwall 37 or 38 subsidence impacts be necessary, the best option available at the time of the rehabilitation work will be identified and with appropriate consultation and approval, implemented by BHPBIC.

Cracking due to subsidence will tend to seal as the natural processes of erosion and deposition act on them. The characteristics of the surface materials and the prevailing erosion and depositional processes of a specific area will determine the rate of infill of cracks and sealing of any fracture network.

7.7 MONITORING REMEDIATION SUCCESS

Baseline studies have been completed within the Study Area in order to record biophysical characteristics of the mining area. Monitoring is conducted in the area potentially affected by subsidence from Longwalls 37 and 38 extraction as well as areas away from mining to act as control sites.

A comprehensive monitoring program is in place for watercourses in the Study Area, including the Georges River. A summary of watercourse monitoring within the Study Area is provided in **Section 6**.

The monitoring program would remain in place prior to, during and following the implementation of any mitigation measures. The data from the monitoring program will assist in determining the success of any mitigation or natural reduction of mining impacts over time. Observation data will also be collected as part of the monitoring program and be used to provide contextual information. Monitoring data and observations will be mapped, documented and reported. BHPBIC will review the need to implement additional management and mitigation measures during monitoring (refer **Section 6**). The monitoring program related to water aspects and the West Cliff Area 5 Water TARP is shown in **Attachment A**.

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 in a timely fashion.
- Notify relevant stakeholders (e.g. agencies and specialists) soon as practicable.
- Conduct site visits with stakeholders as required.
- 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 stakeholders of results of investigation.
- Develop site CMA in consultation with key stakeholders if required and seek approvals.
- Implement CMA as agreed with stakeholders following approvals.
- Conduct initial follow up monitoring and reporting following completion of CMA.
- Review Management Plan, including consultation with key agencies.
- 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 CMAs available for remediating subsidence impacts are described in **Section 7** and **Attachment 1**.

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

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 DP&I 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 DP&I 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 DP&I and any relevant agencies with a detailed report on the incident.

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 community.
- Respond to complaints in accordance with the BHPBIC Community Complaints and Enquiry Procedure.
- Maintain good relations and communication lines between the community and BHPBIC.
- 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 West Cliff Mine. 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 licenses.

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 DP&I.

10 PLAN ADMINISTRATION

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

10.1 ROLES AND RESPONSIBILITIES

Statutory obligations applicable to the West Cliff Area 5 operations are identified and managed via an online compliance management system (TICKIT). The online system can be accessed by the responsible BHPBIC staff 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.

Responsibilities for environmental management of West Cliff Area 5 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 and seek appropriate approvals for any proposed amendments.
- 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 reports and maintain records in accordance with the WMP.
- Organise and participate in assessment meetings called to review mining impacts.
- 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 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 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 WMP.
- Conduct inspections in a competent and safe manner.

10.2 RESOURCES REQUIRED

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

Equipment will be needed for the TARP 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 (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 BHPBIC in the 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 '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 and approvals for these modifications sought 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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Attachment A – West Cliff Longwalls 37 and 38 Water Monitoring and TARPs

Attachment A Table 1 – West Cliff Area 5 Longwall 37 and 38 Key Water Monitoring

<table>
<tr><th colspan="2">Monitoring Site</th><th>Monitoring Type</th><th>Monitoring Frequency</th><th>Monitoring Parameters</th></tr>
<tr><td colspan="5">SURFACE WATER QUALITY</td></tr>
<tr><td rowspan="8">AREA 5</td><td colspan="3">Longwall 37</td><td rowspan="8">Water Testing:
• Field pH
• Field Temperature
• Field EC
• Field DO % Sat
• Field ORP

Laboratory Analytes:
• Filt Na, K, Ca, Mg
• Total Alk, Cl, Br, I
• Filt SO4
• TSS, TDS
• Total Fe, Mn, Al
• Filt As, Cu
• Filt Pb, Ni, Se, Zn
• Filt Fe, Mn, Al
• TKN, NH_3-N
• NO_x-N (TON)
• FRP, TP
• DOC</td></tr>
<tr><td>Georges River
Upstream monitoring site:
• Pool 54
Downstream monitoring site:
• Pool 64</td><td rowspan="4">• Field testing of water quality parameters
• Grab sample for testing of specific analytes at an accredited laboratory
• Water level measurements (using benchmarks where they can be installed and/or photos)
• Observational and photographic monitoring</td><td rowspan="4">• Monthly before and after mining
• Weekly during mining (when the longwall is within 400 m)</td></tr>
<tr><td>Mallaty Creek
Downstream monitoring sites:
• MC100, MC106 and MC110</td></tr>
<tr><td>Nepean Creek
Downstream monitoring site:
• NC10</td></tr>
<tr><td>Tributary of Georges River
Downstream monitoring site:
• GR104 and 105</td></tr>
<tr><td colspan="3">Longwall 38</td></tr>
<tr><td>Georges River
Upstream monitoring site:
• Pool 34
Adjacent monitoring site:
• Pool 54
Downstream monitoring site:
• GR100</td><td rowspan="2">• Field testing of water quality parameters
• Grab sample for testing of specific analytes at an accredited laboratory
• Water level measurements (using benchmarks where they can be installed and/or photos
• Observational and photographic monitoring</td><td rowspan="2">• Monthly before and after mining
• Weekly during mining (when the longwall is within 400 m)</td></tr>
<tr><td>Tributaries of Georges River
Upstream monitoring site:
• GR119
Adjacent monitoring sites:
• GR107, GR108, GR110
Downstream monitoring sites:
• GR102, GR103, GR114 and GR117</td></tr>
</table>

	Monitoring Site	Monitoring Type	Monitoring Frequency	Monitoring Parameters
GROUNDWATER				
AREA 5	**BHPBIC piezometers:** • GR27 • GR28 • GR29 • GR70 • WC54 • WC95	• Field testing of water quality parameters and grab sample for testing of specific analytes at an accredited laboratory (where access is available to the water) • Water level (measured and logged at least twice daily)	• At least one pre-mining sample • One sample following the completion of Longwall 37 • One sample following the completion of Longwall 38	**Water Testing:** • Field pH • Field EC • Field Temperature • Lab analytes TDS, filterable Na, Ca, K and SO_4; Cl, F, total alk., total and filterable Fe, Mn and Al; filterable Ni, Zn, As, Ba, Cs, Cu, Pb, Li, Rb, Se, Sr and B; • Total nitrogen and phosphorous
	Private bores: • GW32310 • GW72454 • GW105921 • GW108322	• Monitoring as agreed in Property Subsidence Management Plans or as requested by landholder	• One pre-mining level measurement and water sample • One post mining level measurement and water sample	**Water Testing:** • Field pH • Field EC • Field Temperature • Lab analytes TDS, filterable Na, Ca, K and SO4; Cl, F, total alk., total and filterable Fe, Mn and Al; filterable Ni, Zn, As, Ba, Cs, Cu, Pb, Li, Rb, Se, Sr and B; • Total nitrogen and phosphorous
	BHPBIC piezometer: • S2087	• Vibrating wire piezometers within a cemented hole (note that some are damaged due to ground shear)	• Monitoring of functional piezometers	
	Groundwater inflows to the mine	• Mine water budget • Statutory inspections	• Flow meters	• Water flow from the goaf to the mine (20 day average)
LANDSCAPE FEATURES, VEGETATION AND WATERCOURSES				
	All mapped cliffs, steep slopes and pools within the mining areas, including: • Cliffs GR-CL01 and GR-CL02 • Georges River – all mapped pools and rockbars (GR-RB42, GR-RB43, GR-RB44, GR-RB45, GR-RB47, GR-RB48, GR-RB49, GR-RB51, GR-RB52, GR-RB53, GR-RB54, GR-RB55, GR-RB56a, GR-RB56b, GR-RB57, GR-RB59, GR-RB60, GR-RB61, GR-RB62, GR-RB63, GR-RB64, GR-RB65, GR-RB66, GR-RB67) • Tributaries (GR103, GR104, GR105, GR107, GR108, GR110, GR114)	Site inspections include: • General inspection of active subsidence areas • Re-visits to identified impact sites • Measurement of pool water level	• Monthly before and after mining • Weekly during mining (when the longwall is within 400 m)	**Inspections will target observations, measurements and photos of:** • Pool water levels and diversion of flow • Drainage areas and inundation • Disturbance at a site, erosion and aggradations • Rock falls, fracturing and soil cracking • Changes in vegetation • Impacts to fauna/fish • Gas releases • Water cloudiness and iron staining

Attachment A – Table 2 West Cliff Area 5 Longwall 37 and 38 Water TARP

<table>
<tr><th>Monitoring</th><th>Trigger</th><th>Action</th></tr>
<tr><td colspan="3">WATER QUALITY</td></tr>
<tr><td rowspan="4">Adjacent and downstream sites for Longwalls 37 and 38.
• Georges River:
- Pool 54
- Pool 64
- GR100</td><td>Level 1 *
• Temporary reduction in water quality (observed for 2 consecutive months) at any site when comparing the baseline period to mining period for that site i.e. :
– pH drop between 0.5 and 1.0 units from the minimum baseline value</td><td>• Continue monitoring program
• Report trigger to key stakeholders
• Summarise impacts and report in the End of Panel Report and AEMR</td></tr>
<tr><td>Level 2 *
• Temporary reduction in water quality (observed for 2 consecutive months) at any site when comparing the baseline period to mining period for that site i.e.:
– pH drop between 1.0 and 1.5 units from the minimum baseline value</td><td>• Actions as 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. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts</td></tr>
<tr><td>Level 3 *
• Reduction in water quality (observed for more than 2 consecutive months) when comparing the baseline period to mining period for that site i.e.:
– pH drop of 1.5 units from the minimum baseline value</td><td>• Actions as stated for Level 2
• Notify DP&I, DPI, 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:
- Emplacement of sandstone rocks in constricted stream flow areas to increase the aeration capacity where it is appropriate to do so
- Grouting of fractures which result in flow diversion
• Completion of works following approvals
• Issue CMA report within 1 month of works completion
• 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. cracking at the surface with insignificant consequences may not require specific CMAs other than ongoing monitoring to confirm there are no ongoing impacts</td></tr>
<tr><td>Exceeding Performance Measures
• Subsidence impacts or environmental consequences greater than minor</td><td>• Actions as stated for Level 3
• Investigate reasons for the exceedance
• Update future predictions based on outcomes of the investigation
• Provide environmental offset if CMAs are unsuccessful</td></tr>
</table>

<table>
<tr><th>Monitoring</th><th>Trigger</th><th>Action</th></tr>
<tr><td colspan="3">GROUNDWATER</td></tr>
<tr><td rowspan="4">BHPBIC Piezometers:
• GR27
• GR28
• GR29
• GR70
• WC54
• WC95

Private bores:
• GW32310
• GW72454
• GW105921
• GW108322

Mine water budget</td><td>Level 1 *
• Increase in water flow from the goaf between 2.7-3 ML/day (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</td><td>• Continue monitoring program
• Report trigger to key stakeholders
• Summarise impacts and report in the End of Panel Report and AEMR</td></tr>
<tr><td>Level 2 *
• Rise in water flow from the goaf between 3-3.4ML (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</td><td>• Actions as stated for Level 1
• Review monitoring program
• Review impacts against the Performance Measures
• Notify relevant technical specialists and seek advice on any CMA required
• Implement agreed CMAs as approved</td></tr>
<tr><td>Level 3 *
• Abnormal rise 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
• Total loss of groundwater level within a private bore</td><td>• Actions as stated for Level 2
• Notify DP&I, DPI, 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:
- Any actions agreed to in the Property Subsidence Management Plan
- Provision of alternate water supply where this has been impacted by mining
• Completion of works following approvals
• Issue CMA report within 1 month of works completion
• Review the TARP and Management Plan in consultation with key stakeholders</td></tr>
<tr><td>Exceeding Performance Measures
• Subsidence impacts or environmental consequences greater than minor</td><td>• Actions as stated for Level 3
• Investigate reasons for the exceedance
• Update future predictions based on outcomes of the investigation
• Provide environmental offset if CMAs are unsuccessful</td></tr>
<tr><td colspan="3">APPEARANCE AND POOL WATER LEVEL</td></tr>
<tr><td>Georges River:
• All mapped pools in the mining area</td><td>Level 1 *
• Fracturing with no observable surface water diversion
• Pool water level lower than baseline in any mapped pool located in the mining area (within 400m of the longwall)
• Increase in turbidity, iron staining, algal growth, or other visible water quality parameters determined by comparing baseline photos with photos during the mining period</td><td>• Continue monitoring program
• Report trigger to key stakeholders
• Summarise impacts and report in the End of Panel Report and AEMR</td></tr>
</table>

Monitoring	Trigger	Action
	Level 2 * • Pool water level lower than baseline in the majority of mapped pools located in the mining area (within 400m of the longwall) • Fracturing with observable surface water diversion	• *Actions as stated for Level 1* • Review monitoring program • Review impacts against the Performance Measures • 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. Prevailing rainfall and catchment conditions will be taken into account when assessing pool water level response and the need for CMAs*
	Level 3 * • Pool water level lower than baseline in all mapped pools in the mining area (within 400m of the longwall) • Fracturing with observable water diversion results in any mapped pool becoming dry during a mitigation flow in the River	• *Actions as stated for Level 2* • Notify DP&I, DPI, 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: - Grouting of fractures which result in flow diversion • Completion of works following approvals • Issue CMA report within 1 month of works completion • Review the 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. Prevailing rainfall and catchment conditions will be taken into account when assessing pool water level response and the need for CMAs*
	Exceeding Performance Measures • More than negligible diversion of flows or changes in the natural drainage behaviour of pools over more than 20% of the stream length subject to vertical subsidence >20mm • More than negligible increase in water cloudiness over more than 20% of the stream length subject to vertical subsidence >20mm • More than negligible increase in iron staining over more than 20% of the stream length subject to vertical subsidence >20mm • Subsidence impacts or environmental consequences greater than minor	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on outcomes of the investigation • Provide environmental offset if CMAs are unsuccessful

LANDSCAPE FEATURES		
Cliffs: • GR-CL01 and • GR-CL02 **Steep slopes** **Georges River – including pools and rockbars:** • GR-RB42 • GR-RB43 • GR-RB44 • GR-RB45 • GR-RB47 • GR-RB48 • GR-RB49 • GR-RB51 • GR-RB52 • GR-RB53 • GR-RB54 • GR-RB55 • GR-RB56a • GR-RB56b • GR-RB57 • GR-RB59 • GR-RB60 • GR-RB61 • GR-RB62 • GR-RB63 • GR-RB64 • GR-RB65 • GR-RB66 • GR-RB67	***Level 1*** * • Rock fall from a cliff where the cliff is left mostly intact (<10% length of the cliff) • Surface movement or rock displacement where any exposed soil surface is stable • Crack at the surface which does not result in ongoing erosion or ground movement • Erosion which stabilises within the period of monitoring without CMA • Crack or fracture up to 100mm width • Crack or fracture up to 10m length	• Continue monitoring program • Report trigger to key stakeholders • Summarise impacts and report in the End of Panel Report and AEMR
	Level 2 * • Rock fall from cliff where the characteristics of the cliff change (>10% length of the cliff) • Ground disturbance that is unlikely to stabilise within the period of monitoring without CMA • Mass movement of a slope causing areas of exposed soil • Crack or fracture between 100 and 300mm width • Crack or fracture between 10 and 50m length	• *Actions as stated for Level 1* • Review monitoring program • Review impacts against the Performance Measures • Notify relevant technical specialists and seek advice on any CMA required • Provide safety signage and barricades as appropriate • 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 * • Cliff collapse (100% length of cliff) • Ground disturbance that does not stabilise within the period of monitoring • Mass movement of a slope causing areas of exposed soil that does not stabilise within the period of monitoring • Crack or fracture over 300mm width • Crack or fracture over 50m length	• *Actions as stated for Level 2* • Notify DP&I, DPI, 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: - Erosion prevention works - Establishment of vegetation • Completion of works following approvals • Issue CMA report within 1 month of works completion • Review the 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*

	Exceeding Performance Measures • For cliffs of 'special significance' - more than negligible environmental consequences (i.e. more than occasional rockfalls, displacement or dislodgement of boulders or slabs, or fracturing, that in total impact more than 0.5% of the total face area of such cliffs within any longwall mining domain) • Other cliffs - more than minor environmental consequences (that is occasional rockfalls, displacement or dislodgment of boulders or slabs or fracturing, that in total impact more than 3% of the total face area of such cliffs within any longwall mining domain)	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation

* These may be revised in consultation with DP&I and DPI and other key stakeholders following analysis of natural variability within the pre-mining baseline data. These TARPs relate to West Cliff Area 5 Longwalls 37 and 38.

Office of Environment and Heritage (OEH)

Department of Planning and Infrastructure (DP&I)

Department of Primary Industries: including Division of Resources and Energy, Office of Water, Fisheries (DPI)

Attachment B – West Cliff Longwalls 37 and 38 Groundwater Assessment (Geoterra, 2013)

GeoTerra

BHP BILLITON ILLAWARRA COAL PTY LTD

WEST CLIFF
LONGWALLS 37 AND 38
GROUNDWATER ASSESSMENT

Appin, NSW

BHP8-R1E
24 MAY, 2013

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

Suite 4 186-192 Canterbury Road Canterbury NSW 2193

PO Box 220 Canterbury NSW 2193

Phone: 02 97879137 Fax: 02 9787 1874 Mobile 0417 003 502 Email: geoterra@iinet.net.au

BHP8-R1E (24 MAY 2013)

GeoTerra

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

Attention: Gary Brassington

Gary,

RE: BHP Billiton West Cliff Longwalls 37 and 38 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**

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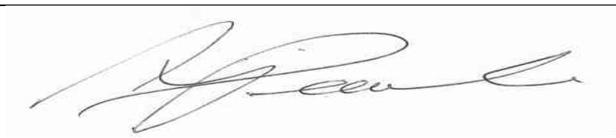
PO Box 220 Canterbury NSW 2193

Phone: 02 97879137 Fax: 02 9787 1874 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
16/05/2012		Initial Draft
07/06/2012	A	Incorporate reviewer comments
15/06/2012	B	Incorporate reviewer comments
24/12/2012	C	Update mine plan
31/01/2013	D	Incorporate reviewer comments
24/05/2013	E	FINAL

GeoTerra PTY LTD ABN 82 117 674 941

Suite 4 186-192 Canterbury Road Canterbury NSW 2193

PO Box 220 Canterbury NSW 2193

Phone: 02 97879137 Fax: 02 9787 1874 Mobile 0417 003 502 Email: geoterra@iinet.net.au

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FIGURES

TABLES

1. INTRODUCTION

BHP Billiton Illawarra Coal (BHPBIC) propose to extract the Bulli Seam from Longwalls 37 and 38 within the West Cliff Colliery near the township of Appin, which is situated to the west of Wollongong in the Southern Coalfield of New South Wales.

Longwall 37 is located to the north of the completed Longwalls 30 to 34 and proposed Longwall 35 and 36, whilst Longwall 38 is located to the northwest of the completed Longwalls 20 to 24 (**Figure 1**).

Longwall 37 is planned to be 282m wide and 1795m long, with 32m wide chain pillars, whilst Longwall 38 is planned to be 305m wide and 2575m long.

The two panels lie on either side of the northerly flowing Georges River. At their closest points, Longwall 37 lies approximately 25m west, whilst Longwall 38 is situated approximately 45m east of the Georges River centreline as shown in **Figure 1**.

The Georges River valley in the vicinity of Longwalls 37 and 38 has a minimum of approximately 450m depth of cover, and it is intended to extract the full seam thickness (2.2 - 2.6m) from the proposed workings.

The Study Area is defined as the surface area predicted to be affected by the proposed subsidence from Longwalls 37 and 38, and encompasses the following limits (MSEC, 2012);

- 35^0 Angle of Draw for the maximum depth of cover (i.e. a horizontal distance of up to 380m 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 Georges 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 37 and 38.

BHPBIC are currently extracting Longwall 35, and have previously mined other longwalls in the Study Area as shown in **Figure 1** and **Table 1**.

Table 1 Longwalls 20 to 24 and 30 to 35 Extraction Dates

Longwalls	Start	Finish
20 - 24	31/8/1993	1/03/1999
30 - 34	29/7/2004	14/9/2011
35	13/10/2011	ongoing

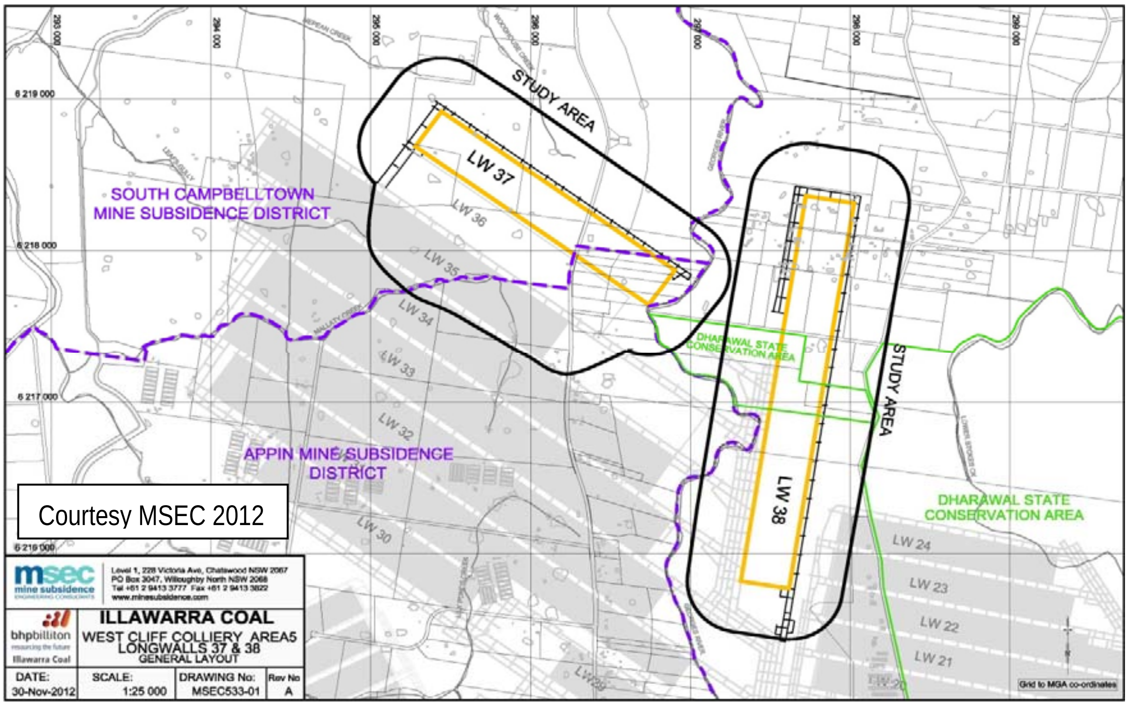


Figure 1 Proposed Layout of Longwalls 37 and 38

2. SCOPE OF WORK

Geoterra was commissioned by BHPBIC to assess potential hydrogeological impacts and management measures relating to subsidence during extraction of Longwalls 37 and 38.

3. PREVIOUS STUDIES

The relevant previous studies conducted in the Study Area include:

- BHPBIC, 2010 West Cliff Colliery Longwall 33 End of Panel Report
- BHPBIC, 2011 End of Panel Report Illawarra Coal Environmental Field Team West Cliff Mine Longwall 34
- Cardno Forbes Rigby, 2008 West Cliff Area 5 Longwalls 34 to 36 Subsidence Management Plan Application for BHP Billiton Illawarra Coal
- Ecoengineers, 2012 Assessment of Water Quality Effects and Water Quality Monitoring Plan West Cliff Longwalls 37 and 38 Extraction Plan
- Heritage Computing, 2010 A Hydrogeological Assessment In Support of the Bulli Seam Operations Environmental Assessment
- MSEC, 2012 Subsidence Predictions and Impact Assessments for West Cliff Longwalls 37 and 38

In addition, this report draws on groundwater and surface water monitoring by BHPBIC in both open standpipe and vibrating wire piezometers (VWPs) within or near the Study Area.

4. EXISTING ENVIRONMENT

4.1 Rainfall and Evapotranspiration

Daily rainfall recorded at West Cliff Colliery since August 2004 is shown in **Figure 2**.

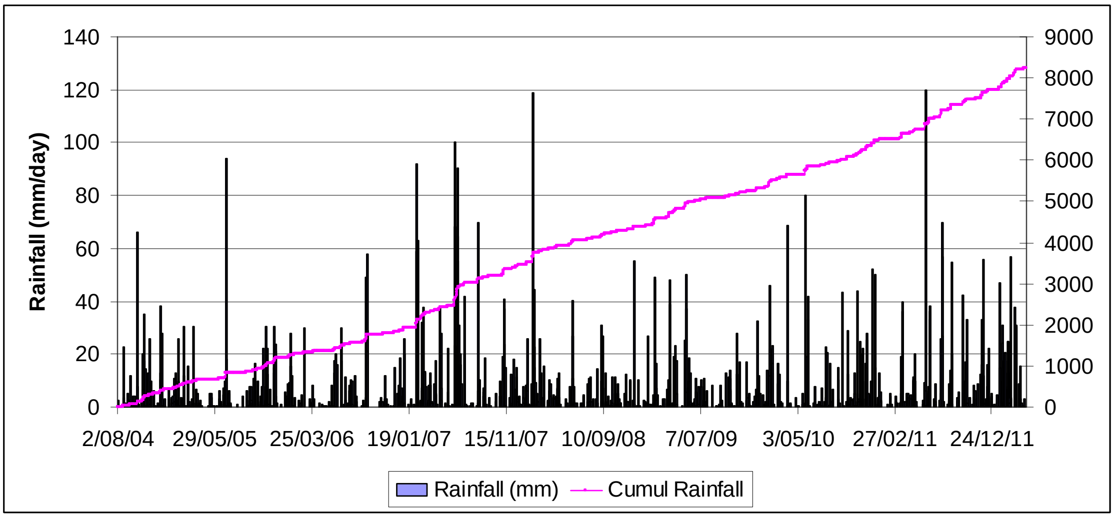


Figure 2 West Cliff Colliery Daily Rainfall

4.2 Land Use and Geomorphology

The land over Longwall 37 is primarily composed of grazing pasture with minor fringing undeveloped woodland to the south.

Longwall 38 is located near the Georges River with undeveloped woodland over the majority of the panel, along with agricultural areas to the north of the proposed longwall.

4.3 Topography and Drainage

4.3.1 Plateau

The plateau over the Study Area rises from the Georges River in the centre to the sandstone and Wianamatta dominated plateau on either side of the gorge.

The Georges River gorge is up to approximately 20m deep with steep sided sandstone cliffs and scree slopes in some areas.

Ground levels vary from approximately 165 - 220mAHD and 205 - 245mAHD over Longwall 38.

The headwaters of the ephemeral Mallaty, Nepean and Woodhouse Creeks overlie Longwall 37, which drain to the west into the Nepean River, whilst unnamed 1st and 2nd order watercourses drain to west into the Georges River over Longwall 38.

There are no upland swamps in the Study Area.

A number of earth wall farm dams are located in the creeks and drainage lines over Longwalls 37 and 38, and are used as water sources on the rural properties.

The upper reaches of the Longwall 37 streams generally have clay based alluvium developed on Bringelly Shale, Michinbury Sandstone and Ashfield Shale / Wianamatta Shale with Hawkesbury Sandstone in the eroded Mallaty Creek valley, whilst Longwall 38 is dominated by exposed or sub cropping Hawkesbury Sandstone.

The Georges River gorge is developed within the Hawkesbury Sandstone.

4.3.2 Georges River

The proposed longwalls do not underlie the river gorge, with the closest point of Longwall 37 lying approximately 25m west, whilst Longwall 38 is situated approximately 50m east of the Georges River centreline as shown in **Figure 3**.

The river has dissected the Woronora plateau, forming sandstone dominated scarps on the east and west banks. Cliffs are usually formed in competent sandstone which can contain stratigraphically controlled cavernous zones, with ephemeral seeps in some areas.

Interspersed boulder fields, exposed sandstone bedrock and sandy alluvium are prevalent along the stream bed.

The near perennial river flow is derived from catchment runoff and licensed discharges from Appin and west Cliff mines located upstream of the Study Area.

The Georges River and its tributaries within the Study Area do not form part of the SCA Drinking Water Catchment Area and is not a Declared Special Area.

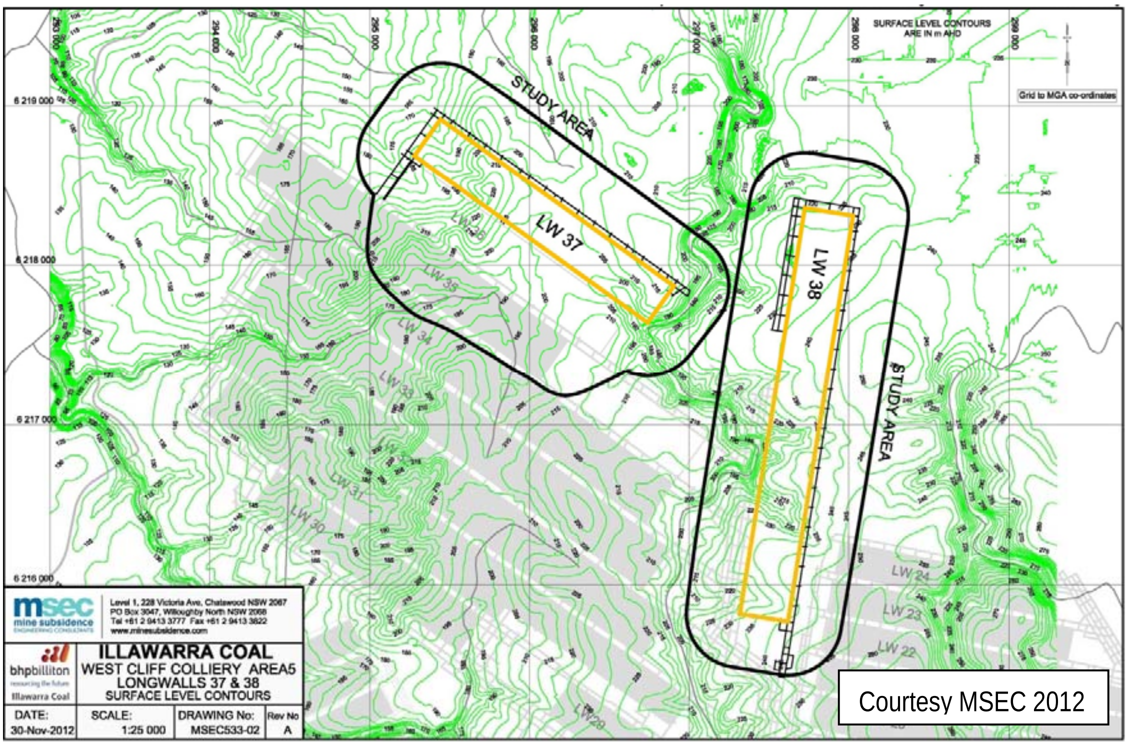


Figure 3 Study Area Topography and Creeks

4.4 Geology

The Bulli Seam dips gently at an approximate gradient of 0.02 to the south east, with the depth of cover ranging from approximately 490 - 520m over Longwall 37 and 470 - 5(over Longwall 38.

4.4.1 Stratigraphy

4.4.1.1 Plateau to Georges River

The Hawkesbury Sandstone predominantly outcrops adjacent to and underlies the Georges River gorge, with the western plateau capped by outcropping Wianamatta Shale as shown in **Figure 4**.

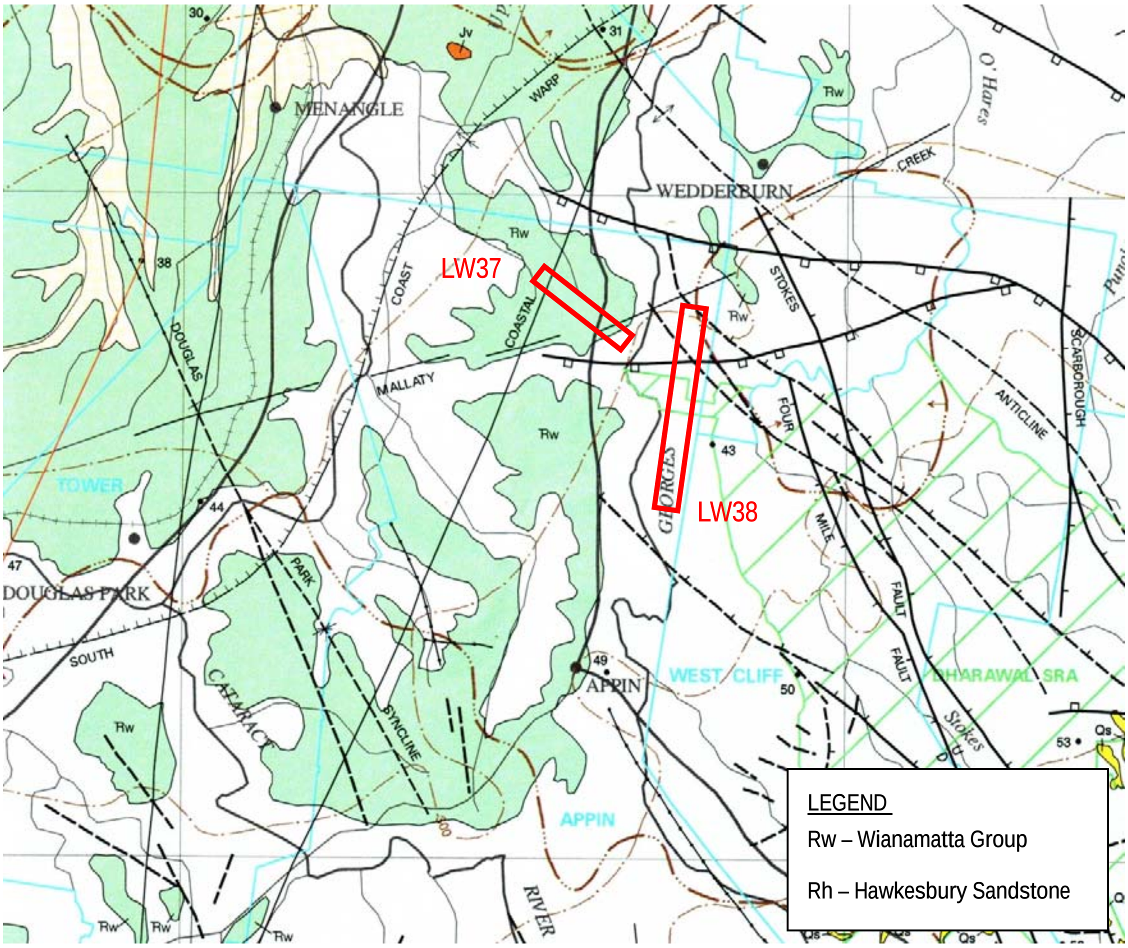


Figure 4 Local Geology

The Hawkesbury Sandstone 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 over the southern and mid portions of Longwall 37.

The sequence of shale over sandstone is underlain by the generic sequence illustrated in **Figure 5**, with the Wianamatta Group being the uppermost unit in the sequence.

Cavernous zones in the Georges 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.

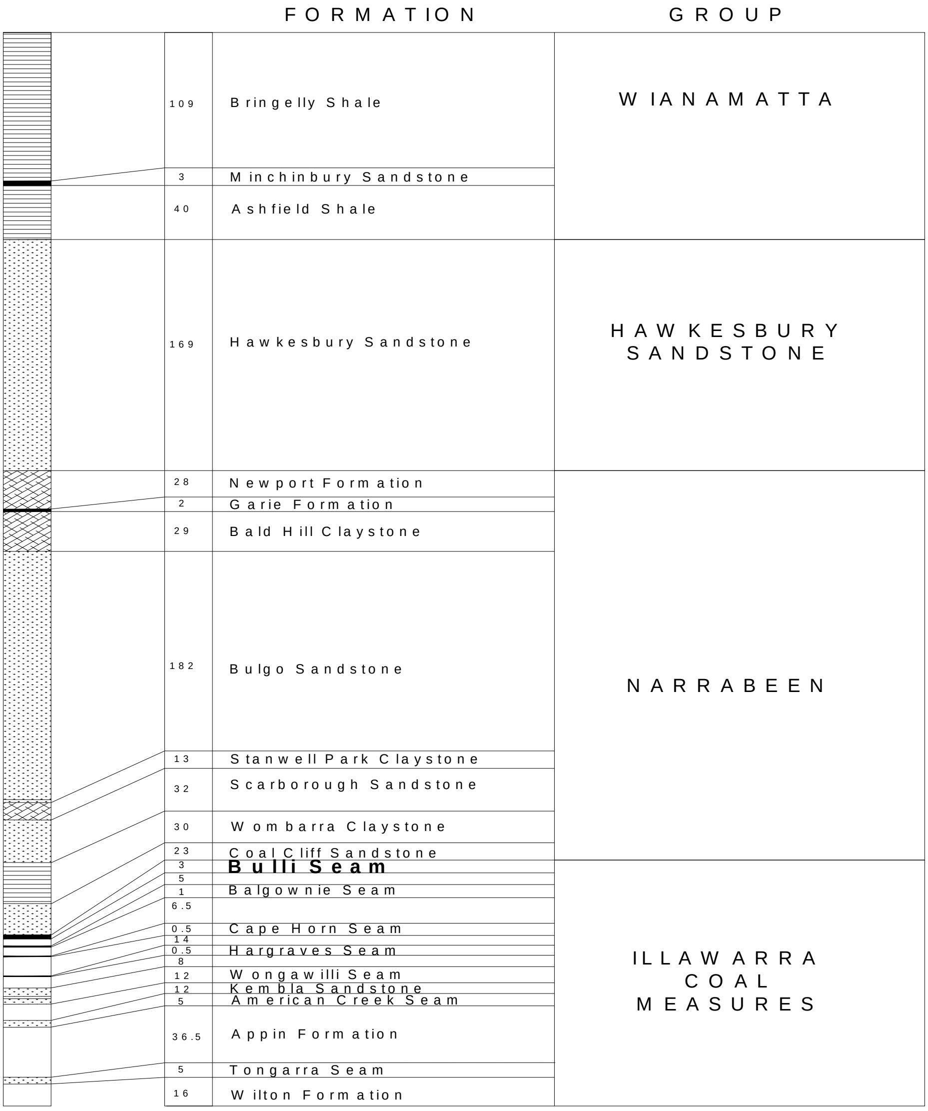


Figure 5 Generic Regional Stratigraphy

4.4.1.2 Georges River to Bulli Seam

The Hawkesbury Sandstone outcrops within the walls and floor of the Georges River gorge and 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.

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

The Newport Formation consists of interbedded grey shales and sandstones.

The Bald Hill Claystone consists of the Garie Claystone, a generally hard, grey-brown "oolitic" claystone, which is underlain by the characteristic brownish-red coloured "chocolate shale", that is a physically weak but lithologically stable unit. 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 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 consists of greenish-grey mudstones and sandstones. These "green shales" are very weak lithologically and fret easily on exposure. The absence of this lesser aquitard may influence the movement of strata gas following mining.

The Scarborough Sandstone consists of thickly bedded sandstone with shale and sandy shale lenses up to several metres thick.

The Wombarra Shale has similar properties to the Stanwell Park Claystone described above.

Away from the coast, within the Coalcliff Sandstone, the sandstone diminishes and in many areas the original roof strata of the Bulli Seam, which is a shale / mudstone unit that 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 proposed workings are positioned to the east of the “South Coast Warp”.

The south east / north west trending “O’Hares Fault” location has been projected from exploration data and may cut across the northern portion of Longwall 38 and to the north of Longwall 37 as shown in **Figure 4** (courtesy, MSEC 2012).

Surface lineaments due to differential weathering on joint planes are well developed on outcropping Hawkesbury Sandstone as 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 include a north west / south east trending set and an east / west set of faulting which is developed on the eastern plateau of the Georges River.

Major faulting is not apparent at the surface 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.

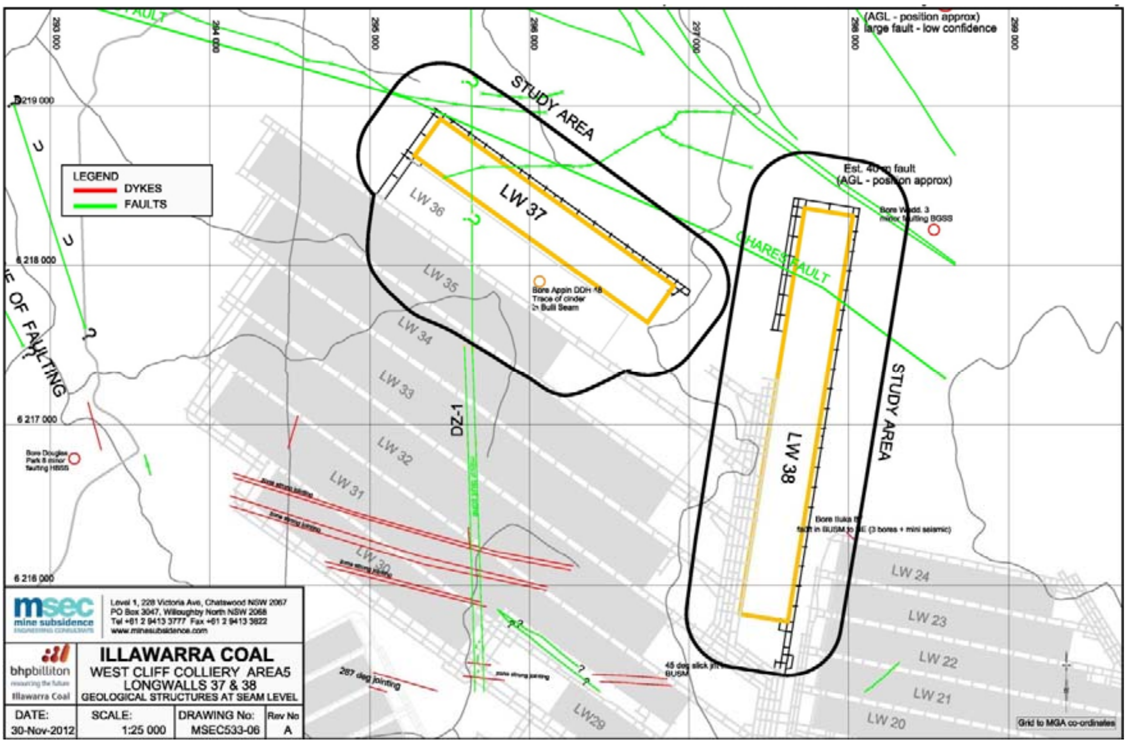


Figure 6 Local Geological Structures

4.4.3 Igneous Intrusions

No dykes or other intrusions of significance are known in the Study Area.

4.5 Hydrogeology

The Georges River is a system that is generally "losing" during dry periods, along with groundwater flow from the plateau under a regional hydraulic gradient to the river during and following significant rainfall recharge events.

These flows are dominantly horizontal, and are determined by confined flow along discrete layers underlain by fine grained or relatively impermeable strata within the Hawkesbury Sandstone, or along the Hawkesbury Sandstone / Wianamatta Shale interface.

No systematic study of near-surface groundwater systems has been conducted other than in piezometers within or near the Georges River in the south of the Study Area near Longwall 38, with the piezometers designed to measure the combined near surface water system hydraulic potential to 10m below the river.

The deeper piezometers confirmed the sub-horizontal and "perched" nature of individual near surface water storage zones in the Longwall 5A1 to 5A4 area and assessed that significant vertical permeability enhancement was not induced by extraction of 5A1 to 5A4.

As a result, the vertical fracturing of previously competent sandstone between pre-existing bedding planes was not observed to be significant (BHPBIC, 2010).

The depression of the near surface water table just north of Jutts Crossing coincided with a similar depression in the lower perch, which was caused by either a localised vertical fracture system or an accidental borehole connection between the two systems.

Past observations and measurements of surface water and the near surface groundwater systems in the Georges River identified:

- natural pre-existing sub-bed flow diversions;
- localised compressive failure of the bed of the river due to mining;
- horizontal permeability enhancement in shallow strata on the flanks of the river due to mining;
- discrete zones of horizontal permeability enhancement due to mining;
- interaction between surface water and the near surface groundwater systems;
- minimal systematic vertical conduits between upper and lower fracture zones;
- pre-extraction permeability profiles which did not necessarily agree with post extraction profiles; and
- the general river system is "losing" during dry periods and "gaining" during wet periods.

It is suspected that the river would consist of a series of disconnected or drained pools during extended periods of low rainfall if the Appin and West Cliff licensed discharges did not enter the river (Ecoengineers, 2012). This is confirmed by data obtained during pre-mining assessments for West Cliff Longwalls 5A1 – 5A4 in 1999 – 2000.

4.6 Existing Private Bores and BHPBIC Piezometers

4.6.1 Private Bores

Four NSW Office of Water (NOW) registered bores are located within or adjacent to the Study Area as shown in **Figure 7**, with selected details in **Table 2**, with only one bore (GW 72454) contained within the Study Area.

All private bores were drilled between 152 - 279m below surface, with water obtained primarily from dual porosity sandstone aquifers.

Yields of up to 0.3L/sec were obtained from inflow zones in the sandstone which range from 29.8 - 163m 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 below the elevation of the Georges and Nepean Rivers.

Table 2 Private Bores

GW	N	E	SWL (mbgl)	Depth (m)	Drilled	Aquifer (mbgl)	Lithology	YIELD (L/s)	TDS (mg/L)	Purpose
32310	6218596	299161	35.9	152	1969	29.8 – 29.9 60.9 – 61.0	sandstone sandstone	0.1 0.11	n/a	Stock Domestic
72454	6218063	297710	24.0	162	1994	60 - 90	sandstone	0.3	good	Domestic
105921	6218682	299577	44.0	183	2003	163 – 163.1	sandstone	0.2	fresh	Stock Domestic
108322	6218316	299395	41	279	2003	44 - 44.1 151 – 151.1	sandstone sandstone	n/a	fresh	Stock Domestic

Note: n/a not available mbgl metres below ground level TDS total dissolved solids

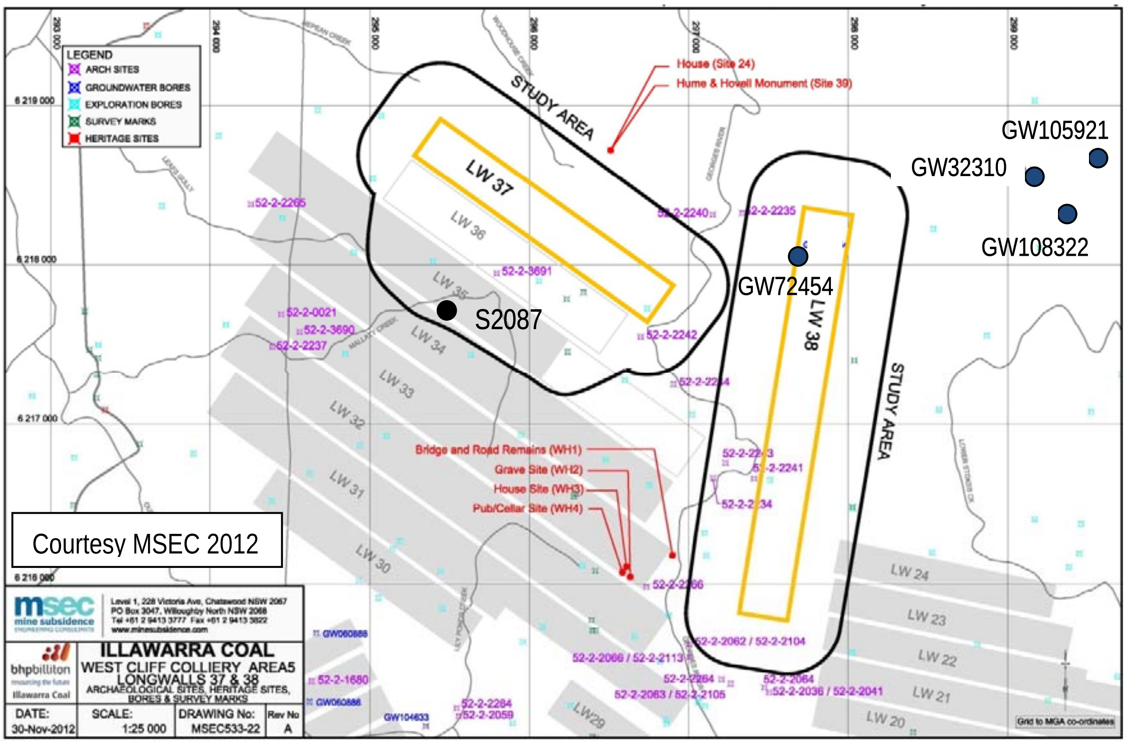


Figure 7 Private Bores and BHPBIC Vibrating Wire Piezometers

4.6.2 Shallow Open Standpipe Piezometers

A suite of BHPB Georges River stream bed and flanks piezometers were installed to monitor the Longwall 31 to 33 SMP area. However, some of the piezometers have been rehabilitated and removed (GR25, 26, 66, 68) and are no longer available for use.

The shallow piezometers were installed primarily to measure groundwater levels along the plateau and associated Georges River.

Locations of the remaining available and up to three potential new piezometer sites are shown in **Figure 8**, with the existing piezometers summarised in **Table 3**.

Table 3 BHPBIC Piezometers

	N	E	Date Installed	Depth (m)	Lithology
GR27	6216170	297121	Jan 06	30.1	sandstone
GR28	6216613	296761	Dec 01	24.31	sandstone
GR29	6216643	297518	Dec 01	33.6	sandstone

The proposed piezometer sites are indicative only, and may be relocated as required for operational or logistical reasons, whilst maintaining a similar “spread” of up to three new monitoring locations.

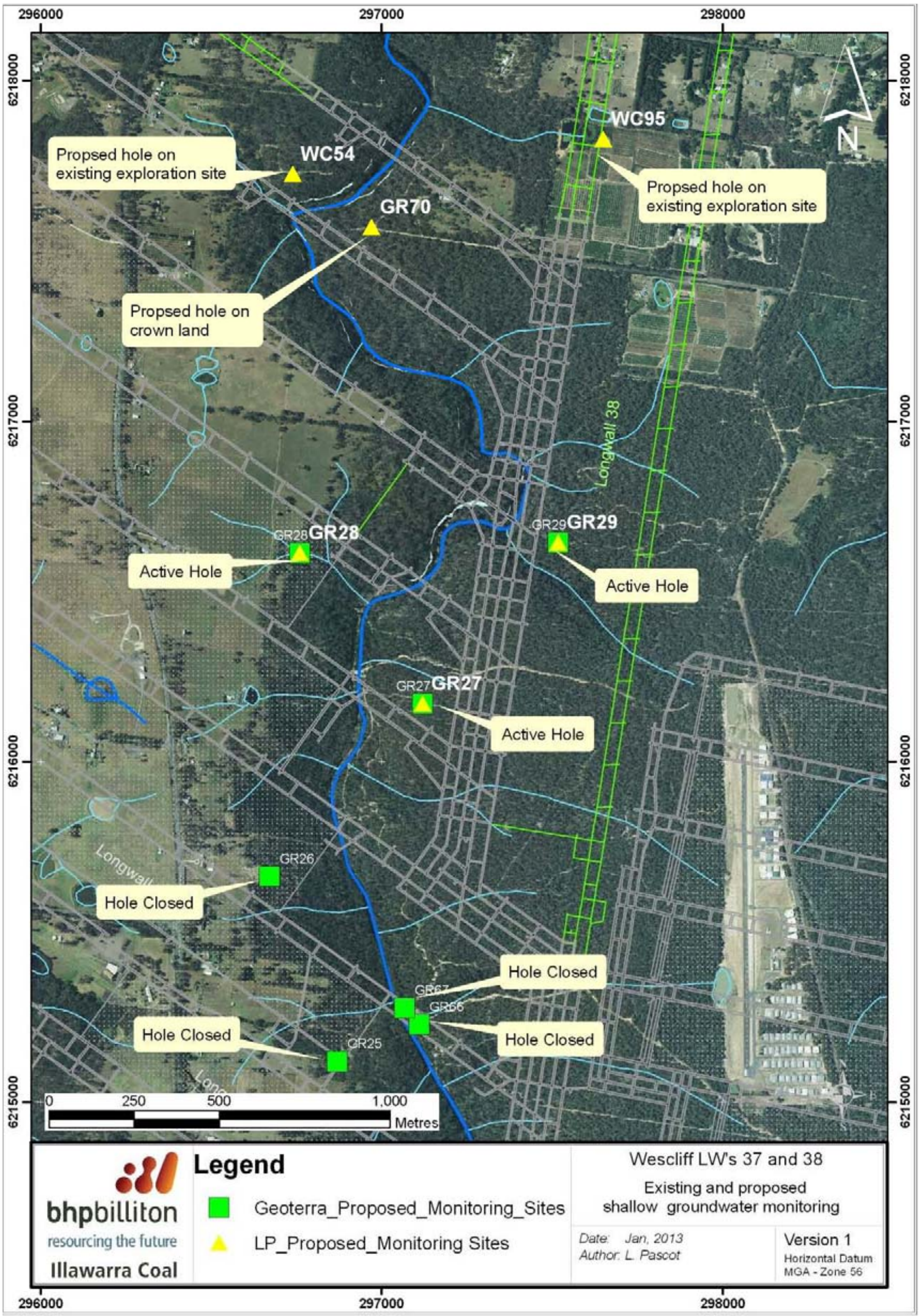


Figure 8 Existing, Decommissioned and Potential New Shallow Piezometers

A more detailed discussion of trends in the water levels of the BHPBIC shallow piezometers is contained in Section 6.1.

4.6.3 Vibrating Wire Piezometers

A VWP array is located in bore S2087 over Longwall 35 as shown in **Figure 7**.

All VWP bores are fully cemented to surface after installation of the piezometer intakes.

Eight VWP intakes were installed in S2087 on 5 July 2010 over Longwall 35, as shown in **Table 4**.

Table 4 BHPBIC Vibrating Wire Piezometers

Formation	S2087 Intake Depth (mbgl)
Hawkesbury Sandstone	55
Hawkesbury Sandstone	95
Hawkesbury Sandstone	185
Bulgo Sandstone	238
Bulgo Sandstone	313.5
Bulgo Sandstone	394
Scarborough Sandstone	419
Scarborough Sandstone	440

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 hydrostatic groundwater pressures in the sequence,
- understand any association between the plateau groundwater system and the Georges River,
- assist in developing a numerical groundwater model (Heritage Computing, 2010) to assess the potential impact of mining Longwalls 37 and 38 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 VWP bores were installed 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.

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 VWPs. 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 injected drilling water.

4.7 Surface Water / Groundwater Interaction

Surface water drainage on the plateau is via ephemeral tributaries which flow into Nepean, Woodhouse and Mallaty Creeks and subsequently to the Nepean River, as well as via first order unnamed streams that drain into the Georges River.

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.

Some water may discharge 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.

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.

Based on field monitoring by BHPBIC, the Georges River has been observed to be a “losing” system, where stream water flows under gravity to the underlying groundwater system during extended dry periods over Longwalls 5A1 to 5A4 (Ecoengineers, 2012) and adjacent to the proposed Longwall 38 (G Brassington, pers comm.).

Site inspections to date have identified one seepage point adjacent to Longwall 37 and four adjacent to Longwall 38 along the Georges River within the Study Area (Cardno Forbes Rigby, 2008).

As the Georges and Nepean Rivers are the largest regional surface water feature in the Study Area, all drainage from surrounding groundwater systems and tributary streams is toward the base of the respective gorges.

A detailed assessment of the shallow groundwater system and its relationship to the Georges and Nepean Rivers is discussed in (Ecoengineers, 2012).

4.8 Groundwater Chemistry

Groundwater in the NOW registered bores, is generally fresh, although no salinity details are quoted.

Limited groundwater chemistry sampling was conducted, as discussed in Section 5.3.

4.9 Strata Gas

Gas emissions at the surface have typically occurred within river valleys such as the Nepean, Cataract and Georges 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 most likely direct source is the Hawkesbury Sandstone.

Gas emission on the plateau and/or within groundwater bores is possible, and some observations in the West Cliff area include;

- gas at Marnhyes Hole over Longwall 5A4;
- gas in the pools adjacent to Jutts Crossing;
- gas release in Georges River during the extraction of Longwall 29 (completed July 2004) and Longwall 31 (completed December 2006).

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).

4.10 Mine Water Discharge Licensing

A Water Access Licence for the West Cliff mine was applied for in August 2008. Draft licence conditions have been supplied by the Department of Water and Energy (which was subsequently called the NSW Office of Water) for 762ML/annum, however the license has not yet been finalised by NOW (G Brassington, pers comm.).

5. LONGWALL 37 AND 38 GROUNDWATER ASSESSMENTS

The hydrogeological investigations conducted by BHPBIC are outlined previously in this report.

5.1 Private Bore Investigations

One private bore (GW72454) overlies the northern end of Longwall 38 and will be inspected as part of developing a Property Subsidence Management plan for the property.

As the other three bores identified in this assessment do not overlie any proposed workings, and are not assessed to be close enough to be affected by the extraction of Longwalls 37 and 38, they do not require any ongoing monitoring.

5.2 Hydraulic Parameters

Permeability testing of the S2087 and the shallow Georges River piezometers was not conducted.

5.3 Hydrogeochemistry

Field assessment of the suite of existing and decommissioned shallow Georges River piezometers has been conducted as summarised in **Table 5**.

In general, baseflow groundwater seepage from the eastern plateau of the Georges River, which is dominated by Hawkesbury Sandstone, with lesser Wianamatta Shale, has a salinity of less than 400µS/cm.

Runoff from the western plateau, which is dominated by Wianamatta Shale and shale derived soils can exceed 10,000µS/cm in Mallaty, Leafs Gully and Nepean Creeks (Ecoengineers, 2008).

Table 5 BHPBIC Piezometer Salinity and pH

	EC (µS/cm)	pH	No. of samples
GR22	888 – 1284	3.55 – 3.95	3
GR23	1127 – 1380	6.0 – 6.1	3
GR24	n/a	n/a	0
GR25	668 – 702	4.81 – 4.91	2
GR26	n/a	n/a	0
GR27	426 – 473	4.36 – 4.45	3
GR28	2772 - 8826	6.46 – 6.75	4
GR29	1700 – 1741	5.62 – 5.91	2
GR50	1922	5.52	1
GR65	704 – 706	5.8 – 5.93	2
GR66	425 – 440	3.89 – 4.25	2
GR67	581 – 590	6.83 – 6.88	2

The available initial water quality sampling indicates that the shallow plateau sandstone groundwater is relatively fresh and moderately acidic, with the higher salinities and more basic pH more prevalent in the shale dominated lithologies.

Groundwater samples from the VWP bore were not collected or analysed as it was sealed with cement / bentonite after installation of the VWPs.

6. GROUNDWATER RESPONSE TO PREVIOUS MINING

6.1 Shallow Open Standpipe Piezometers

Selected water level plots for the plateau piezometers are shown in **Figures 9** to **11.**

A plot of the piezometer water levels along the river bed is shown in **Figure 12**.

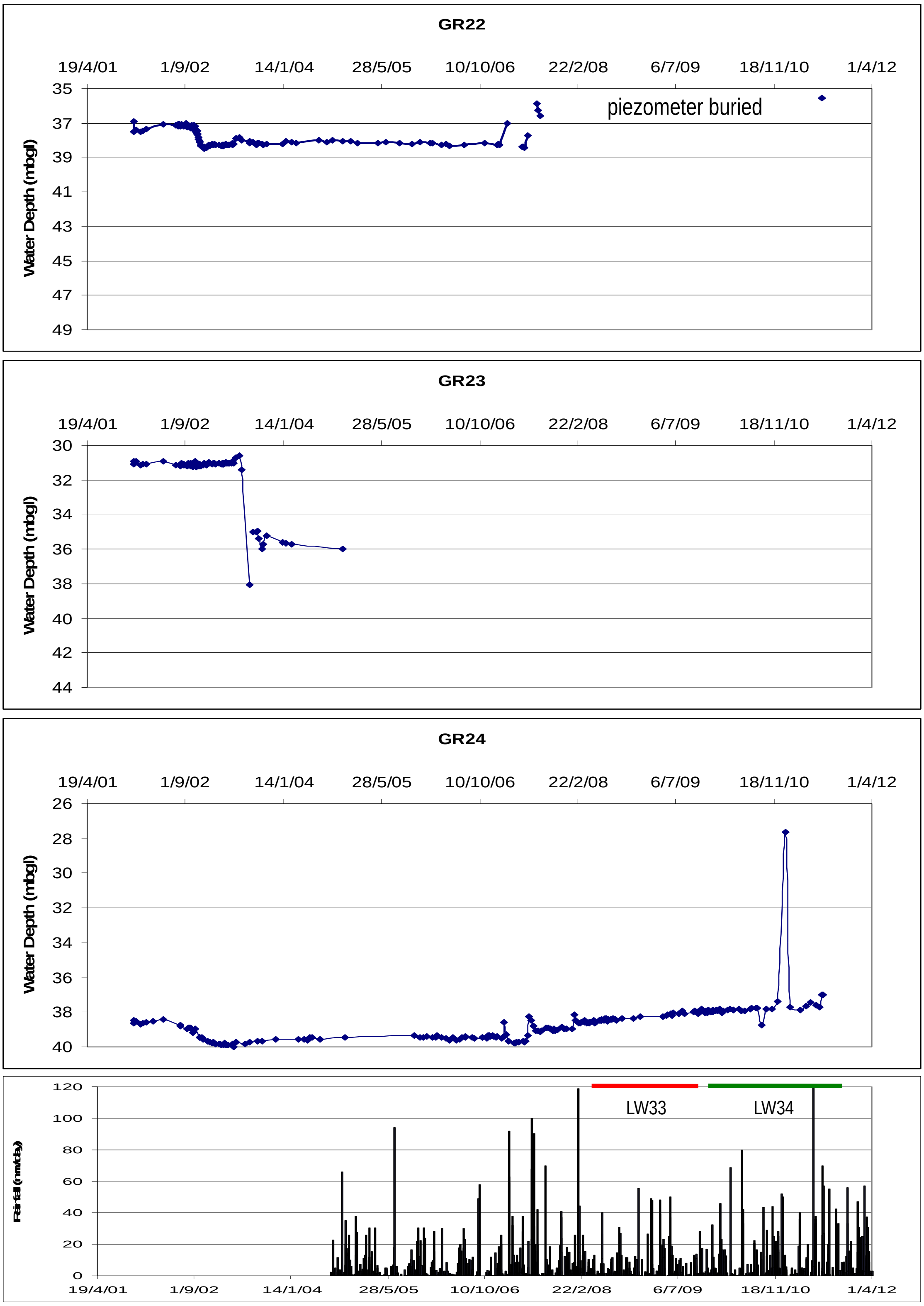


Figure 9 BHPBIC Georges River Plateau Groundwater Levels (GR22 – 24)

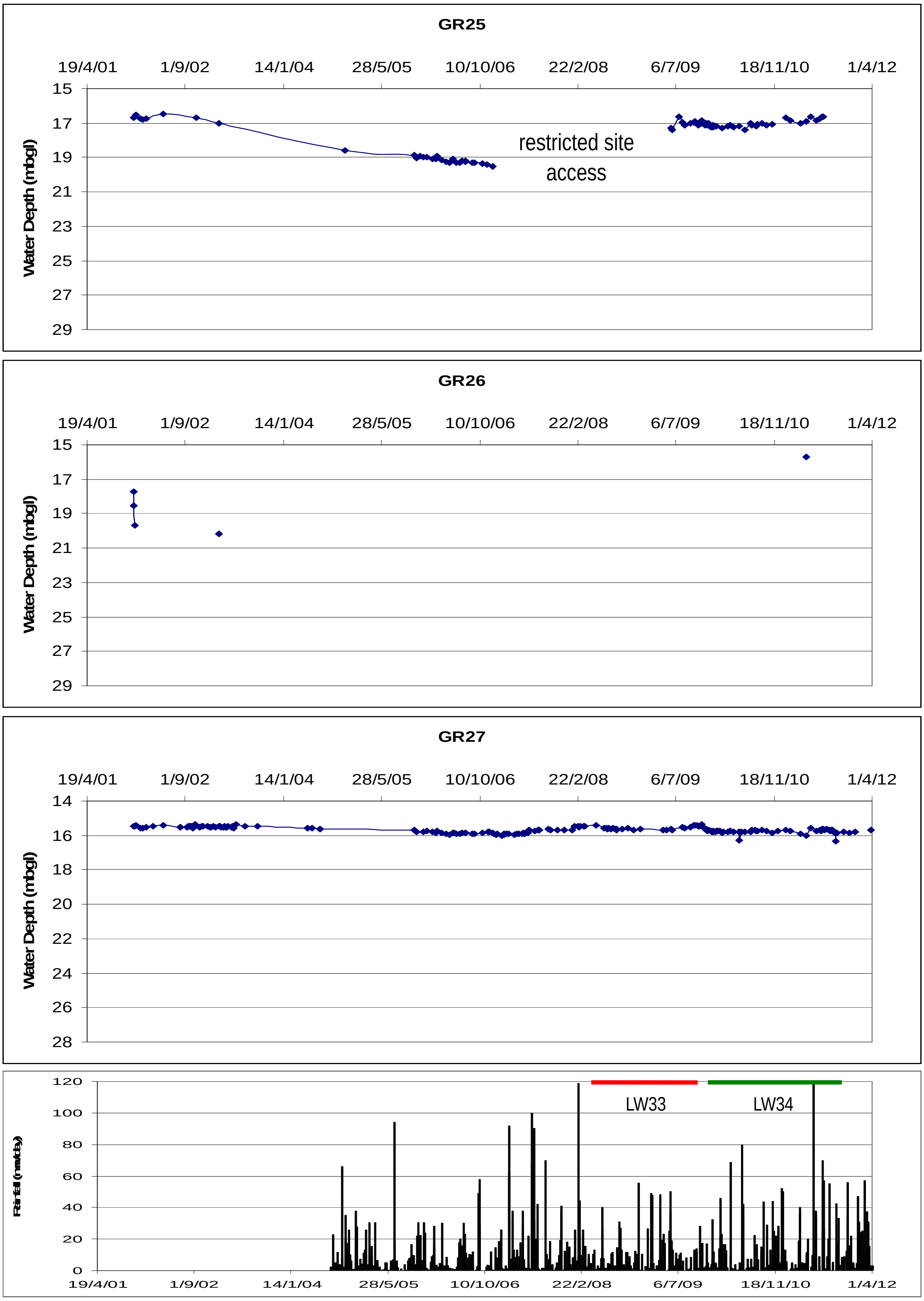


Figure 10 BHPBIC Georges River Plateau Groundwater Levels (GR25 – 27)

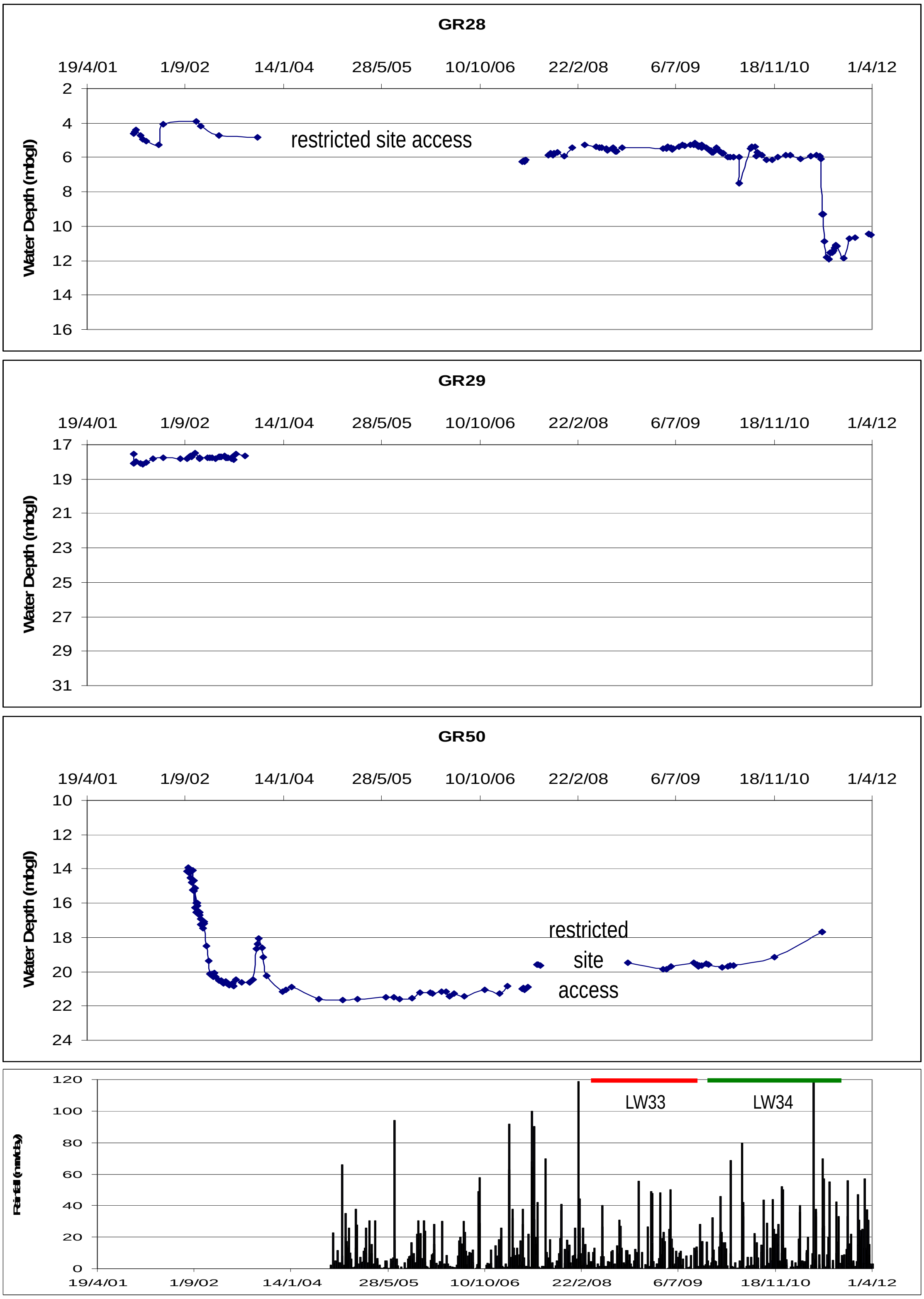


Figure 11 BHPBIC Georges River Plateau Groundwater Levels (GR28, 29, 50)

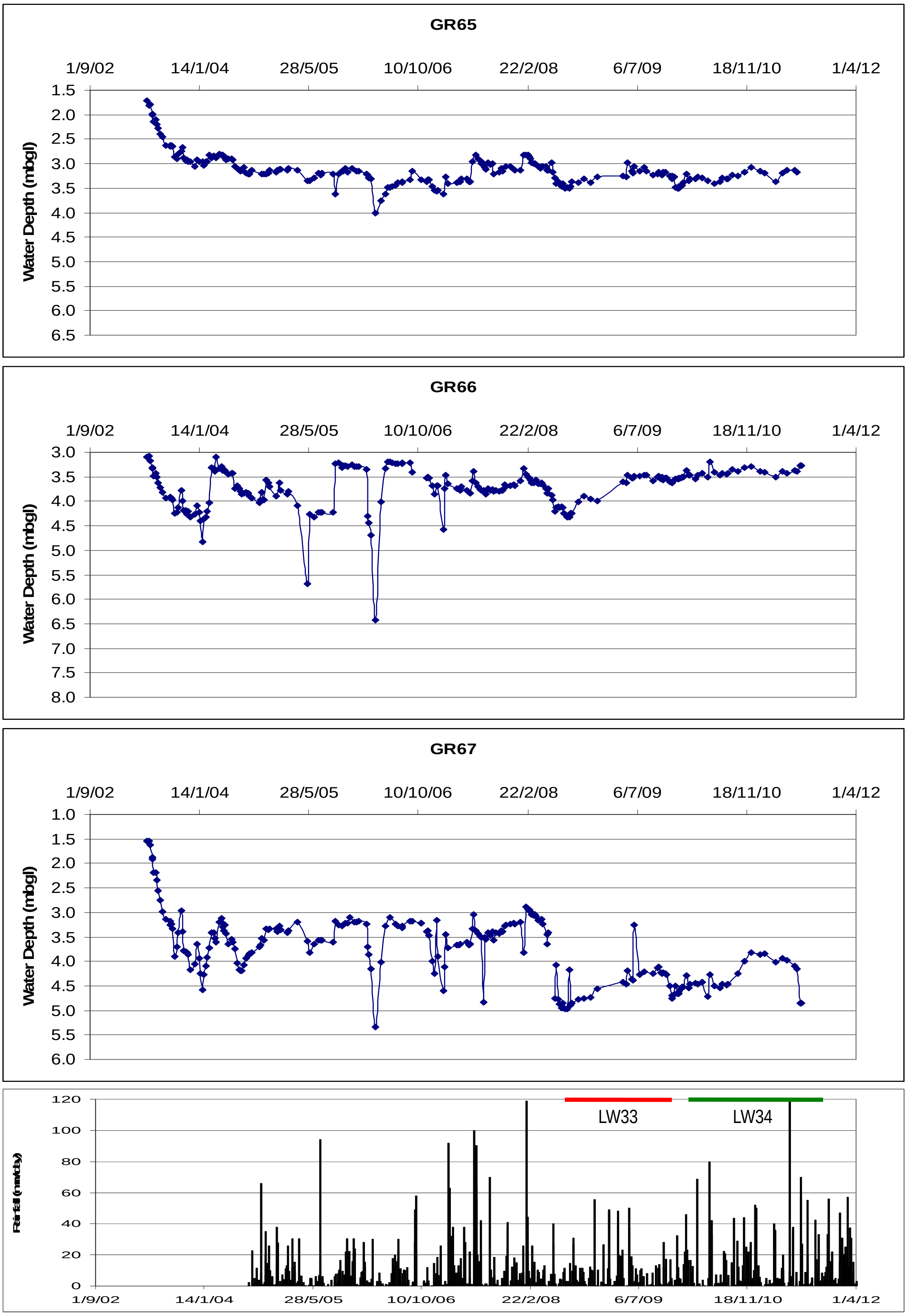


Figure 12 **BHPBIC Georges River Piezometer Water Levels (GR65 - 67)**

Longwall 33 was mined in 2009, and a mining effect is observable in the 36m deep piezometer GR23, which overlies the eastern end of Longwall 29, whose water level dropped by 7m, then settled 5m lower.

Piezometers GR25, 26, 27, 28, 65 and 67 indicated water level reduction towards the end of Longwall 33, but only GR27 and GR28 had water levels that were lower at the end of the panel compared to the start

All bores also showed a general correlation with rainfall.

The 10m deep GR67, which is adjacent to Pool 34 at the north-eastern corner of Longwall 31a, is very responsive to rainfall but as its water level appears to be often lower than river level, the river appears to be losing water to shallow groundwater storage at that location.

Away from the river, the groundwater level is much higher than the river (Heritage Computing, 2010).

During extraction of Longwall 34, an approximately 6m reduction in water level occurred toward the end of the panel extraction in GR28, with a subsequent approximate 2m recovery. The water level is currently still reduced by approximately 4m compared to before the panel started.

6.2 Vibrating Wire Piezometers

Monitoring has been conducted in a multi-level VWP array in S2087, which extended from the upper Hawkesbury Sandstone down to the Scarborough Sandstone, and was situated approximately over the middle of Longwall 35 as shown in **Figure 13**.

Longwall 34 passed close to the VWP array on 7 December 2010, and all except the two shallowest Hawkesbury Sandstone VWPs failed, probably due to shearing of the equipment.

The data over the recording period was poor to good, whilst the deeper piezometers were affected by electronic noise which responded to site adjustments but was not completely eliminated.

There was a two month stabilization period up to September 2010, after which the Narrabeen piezometers had a slow depressurisation until December when the piezometer at 238m had a marked drop until it failed ten days after the longwall passed through.

The other five VWPs that failed in the Narrabeen and basal Hawkesbury Sandstone did not show any significant fall in piezometric head prior to their failure, shortly after the passing of Longwall 34.

Two piezometers at 55m and 95m in the Hawkesbury Sandstone remained operational, and the relative head in each is higher than the six lower piezometers which commonly showed a relative level of the order of 100m to 115m.

The two upper piezometers have a more variable head but do not appear to show more than a coincidental relationship with the passing of Longwall 34, and appear to be influenced by seasonal rain levels and intensity (BHPBIC, 2011).

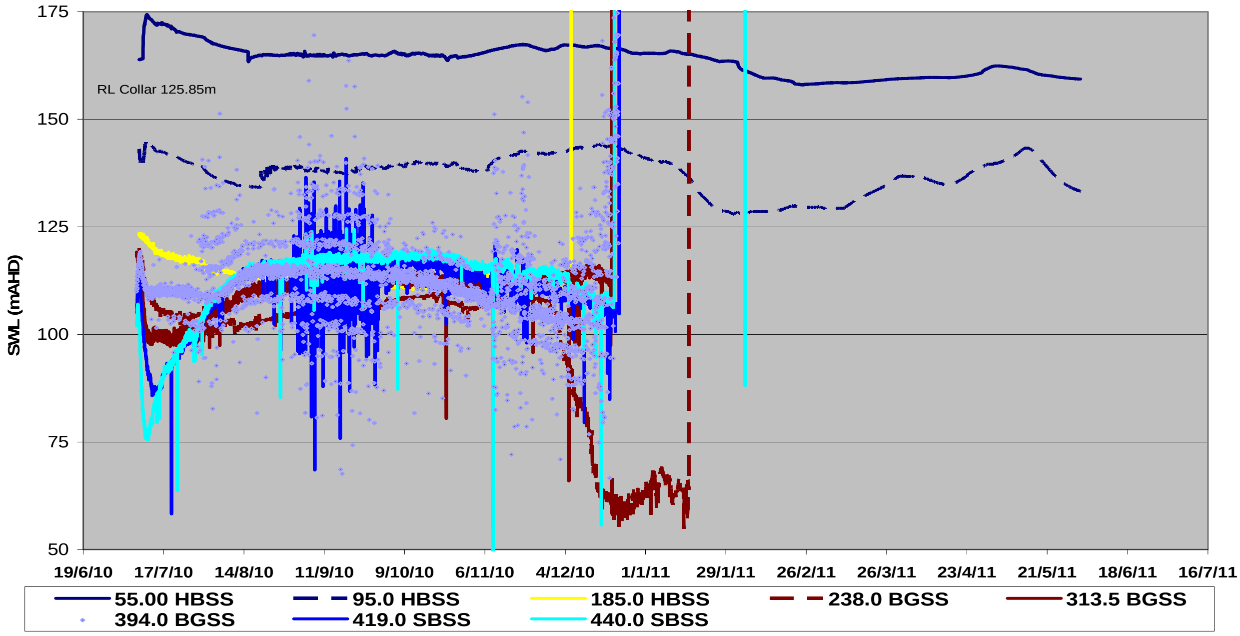


Figure 13 S2087 Water Head Pressures

6.3 Mine Inflows

No reported inflows to the mine have occurred along geological structures and no significant inflow to the mine has occurred during the extraction of Longwalls 33 and 34 (Cardno Forbes Rigby, 2008; BHPBIC, 2010; BHPBIC, 2011).

7. POTENTIAL SUBSIDENCE IMPACTS

7.1 Groundwater Related Subsidence Predictions

The maximum predicted subsidence for the private bores and BHPBIC piezometers after completion of Longwalls 37 and 38 is shown in **Table 7** (MSEC, 2012).

Table 6 Maximum Predicted Cumulative Subsidence

GW	Maximum Predicted Subsidence (mm)
PRIVATE	BORES
32310	<20
72454	500
105921	<20
108322	<20
BHPBIC	PIEZOMETERS
GR27	<20
GR28	<20
GR29	500

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 14** (MSEC, 2012).

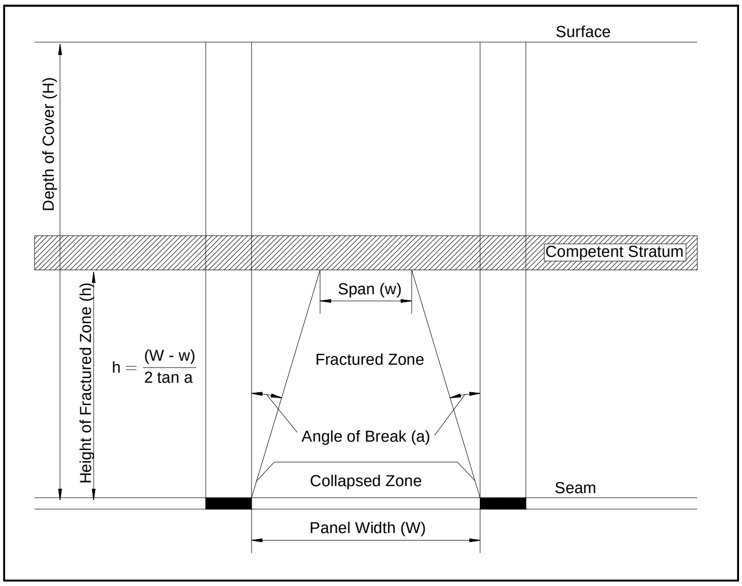


Figure 14 Theoretical Model Illustrating the Development and Limit of the Fractured Zone

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 282m panel width, then it is predicted that up to 345m would be required above the seam to reduce the effective span to 30 metres (MSEC, 2012).

The depth of cover directly above the proposed longwalls varies from 470 - 520m 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. 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 15 indicates results from a literature study conducted (MSEC, 2012) 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.

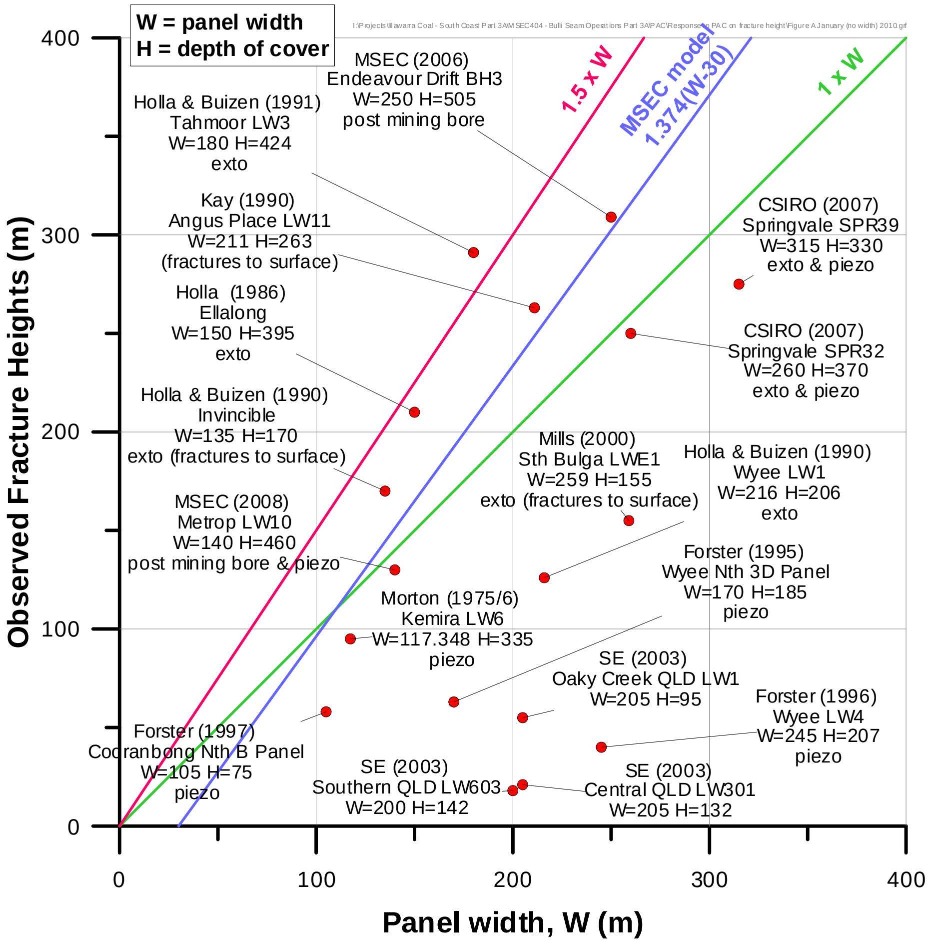


Figure 15 Observed Fracture Heights versus Panel Width

7.3 Groundwater Levels

7.3.1 General

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).

7.3.2 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.

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 are predicted to reduce by between 5 – 10m.

Although groundwater level reductions are predicted, due to the lack of perennial, regional scale aquifers in the Wianamatta Shales, it is unlikely that significant impacts to groundwater resources will be observed in the Wianamatta Shale resulting due to the proposed extraction.

7.3.3 Hawkesbury Sandstone Groundwater Levels

Even though the regional piezometric surface lies beneath the potential 20m deep fracture zone in the plateau areas, 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 previous observations over Appin and West Cliff Collieries, the regional Hawkesbury Sandstone aquifer groundwater levels may temporarily reduce by 10m.

One NOW registered bore overlying Longwall 38 (GW72454), with a water bearing zone in the Hawkesbury Sandstone between 60 - 90m below surface, may be adversely affected by subsidence.

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 37 and 38 mining area, although there is a substantial predicted drawdown in the Bulli Seam of around 100 – 200m.

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 an extracted 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 generally recovers after 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.

Any river water diversion that does potentially occur would be replenished by flow down the river.

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

7.3.4 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 5 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.

Due to the substantial depths of cover over Longwalls 37 and 38, 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.

7.4 Bore Yield and Serviceability

7.4.1 General

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.

Although water level falls have been observed, only limited instances of reduced bore yields have been observed over the subject collieries. 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.

No reported adverse changes to bore yields have been recorded over the West Cliff workings, although it is noted that few private bores actually overly the mine.

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.

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.

7.4.2 Longwalls 37 and 38

One bore (GW72454) overlying the proposed workings may have a potential adverse affect on its yield or serviceability as it is located in an area of relatively higher predicted lateral tensile strain or bedding dislocation / shearing.

The bore is located close to the end or longitudinal edge of a subsidence trough, where the panel "falls in" to itself, and where the highest tilts and strains are located.

Bores not overlying the longwalls, and outside the Study Area are not 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 recommended mitigation measures in place it is unlikely that water supply to the subject property will be significantly impacted in the long term by the proposed mining of Longwalls 37 and 38.

7.5 Ferruginous Springs

The generation or enhancement of shallow, ferruginous springs following subsidence have been observed in the vicinity of the proposed workings within the Georges River catchment.

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., Pool 11 over Longwall 5A4 in the Georges River).

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).

The surface water study conducted for Longwalls 37 and 38 (Ecoengineers, 2012) indicates 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 based 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.

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, 2012). 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, 2012).

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 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 some cases;
- 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 Spring 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).

Development or enhancement of ferruginous springs in the plateau or Georges River streams in the vicinity of Longwalls 37 and 38 may occur, however their extent, location and duration is not readily predictable. In the event that any springs develop, the impacts can be mitigated, and no significant adverse impacts are anticipated.

7.6 Groundwater Baseflow to the Georges 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 Georges 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.

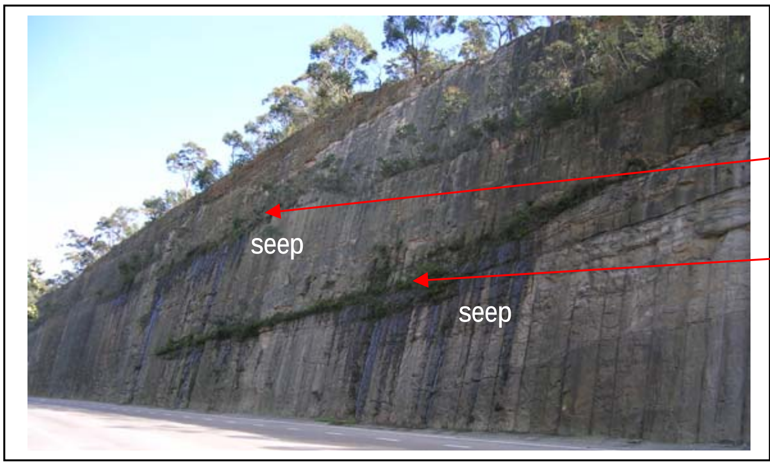
The change results from the effects of subsidence, valley closure and upsidence in the base of gorges increasing permeability and interconnection between the river bed and banks.

Well-documented reductions in groundwater level below river level occurred when the Georges River was undermined in the vicinity of Jutts Crossing and Marnhyes Hole over Longwalls 5A1 to 5A4. This occasioned a remediation programme to restore surface pool water levels and flow.

Monitoring indicates that the natural gaining status of the rivers in the Study Area has been maintained during recent mining (Heritage Computing, 2010).

Groundwater flow to the Georges 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.

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 16**. 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.



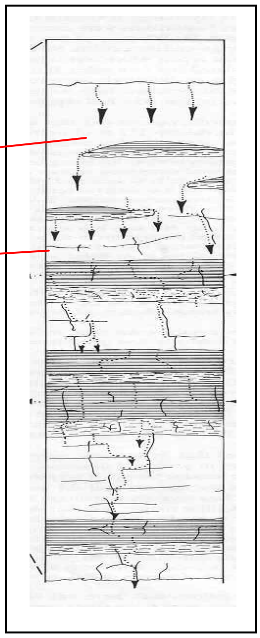


Figure 16 Dual Layered Seep on the F3 Freeway

Groundwater modelling (Heritage Computing, 2010) indicates that old and current mine workings in the West Cliff area have caused negligible changes in groundwater baseflow to streams and that approximately 1.14ML/day of baseflow enters the entire Georges River catchment (Heritage Computing, 2010).

Lowering of the outflow seepage elevation of perched ephemeral seeps along the cliffs and steep slopes of the Georges River valley 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.

Four seeps have been identified in proximity to Longwalls 37 and 38, however the scree slopes and thick vegetation cover along the valley 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 37 and 38, 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.

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

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 Nepean, Mallaty or Leafs Gully Creek 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 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 of Longwalls 37 and 38 will significantly impact lower order streams, seeps, springs and flow to the Georges River.

7.7 Potential Inflow to the Mine Workings

No significant inflows have been observed to enter the West Cliff workings to date (R Walsh, pers comm.).

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 4 - 6ML/day of inflow could occur into the combined Appin and West Cliff collieries.

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 37 and 38 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.

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.

Loss of stream flow or connected fracture substrate groundwater flow through the mining area into the Bulli Seam workings has not been observed in any mines in the Southern Coalfield at similar depths of cover that exist in Area 5.

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 may increase as flows from the highly fractured and free draining lower goaf zone develop.

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.

7.8 Groundwater Quality

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

Increased iron and manganese hydroxide precipitation may occur 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 recommended 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 the Longwalls 37 and 38 Study area should be conducted prior to, during and after development of subsidence at specific bore locations.

If groundwater quality impacts resulting from subsidence are identified, it is recommended that alternate supplies of water 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.

7.9 Gas

There has been very limited reports of gas adversely affecting groundwater supply bores in the Southern Coalfield over longwall subsided areas, with one instance at the Morrison Dairy in 1998 (Ecoengineers, 1998). The subject bore was drilled to 509mbgl, into and below the Bulli Seam, which is significantly different to the depth of private bores over Longwalls 37 and 38, which are all completed within the Hawkesbury Sandstone.

There is some potential for strata gas emissions into private bores, and any emissions that may occur should be managed as outlined in each property subsidence management Plan.

It is not anticipated that significant strata gas will be discharged in private bores over Longwalls 37 and 38. With the mitigation and management measures implemented as part of the Property Subsidence Management Plans it is unlikely there will be a significant impact to water supply from private groundwater bores.

8. RECOMMENDED MONITORING

8.1 BHPBIC Piezometer Standing Water Levels and Pressures

Standing water levels should continue to be measured and logged at least twice daily in the pre-mining baseline, impact and post-mining period in the shallow piezometers GR27, 28 and 29 as well as up to three new shallow piezometers, which are indicatively shown in **Figure 8**.

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.

It is recommended that two additional open standpipe piezometers be installed on the plateau between the central northern end of Longwall 38 and the eastern end of Longwall 37. They should be installed by dry percussion drilling to the first water make where the dust cuts out, or the base of the Georges River (which ever occurs at the deepest level) and then drilled a further 10m. The dry drilling method (or other suitable method) should enable assessment of the depth of the highest perched or regional aquifer and targeting of the piezometer intake at 10m below the Georges River within the Hawkesbury Sandstone.

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

Notwithstanding its limited remnant operational intakes, the VWPs in S2087 should continue to be monitored. The limited vertical profile can still 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 fall.

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

8.2 BHPB Piezometer Groundwater Quality

At least one appropriately purged groundwater sample should be collected from piezometers GR27, 28, 29 and the proposed open piezometers 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 Longwall 37, then after mining Longwall 38 for the same suite of analytes to enable ongoing assessment of any subsidence related changes in groundwater quality.

8.3 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 the private bore GW72454, as well as at least once after the bore is undermined.

At least one appropriately purged groundwater sample should be collected from GW72454 in the pre and post mining phase and analysed as per the BHPBIC piezometer holes.

8.4 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.

8.5 NOW Registered Bore Gas

It is recommended the owner of bore GW72454s should be asked to report on any observed gas into their bores as part of the Property Subsidence Management Plans.

8.6 Cliff Seeps

The presence and duration of observable cliff seeps within the Study 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 8.1.

8.7 Georges River Water Levels

The water level of the Georges River should be monitored weekly when the longwall is within 400m of the river at a downstream, mid-stream (i.e., adjacent to the middle of Longwalls 37 and 38) and an upstream location within the Study Area.

More detail on this monitoring is recommended in Ecoengineers, 2012.

8.8 Mine Water Inflows

It is recommended that statutory visual inspections and the mine water balance 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).

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 shoud be sampled and tested as per BHPBIC standard practice. The water chemistry can define if the water is sourced from groundwater or surface water sources.

Log transformations (i.e. base 10 logs of the water quality concentrations) may be used to calculate the arithmetic means and standard deviations.

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 rolling average (e.g. 20 day) should be used to provide an estimate of water make.

8.9 Groundwater Model Update

It is recommended that significant excursions from the predicted model outcomes result in model re-calibration and/or further investigation.

9. PERFORMANCE MEASURES AND INDICATORS

The Project Approval requires BHPBIC not exceed the subsidence impact Performance Measures, which include;

- 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;

with the effect occurring over at least 80% of the Georges River length subject to vertical subsidence of >20mm, as well as;

- no subsidence impact or environmental consequences greater than minor

In addition, in watercourses other than the Georges River, the Performance Measure shall be;

- no greater subsidence impact or environmental consequences than predicted in the EA and PPR.

Monitoring results should be used to assess the Project against the Performance Indicators and measures detailed in **Table 7**, and as discussed in the following sections.

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 Measure has been exceeded BHPBIC should implement suitable measures and continue to monitor the relevant sites and parameters.

If required, the data analyses and monitoring program may be revised in consultation with the DoPI, NOW and DII.

Table 7 Groundwater Related Performance Indicators and Measures

Performance Measure	Performance Indicator(s)
Diversion of flows or changes in the natural drainage behaviour of pools	No more than negligible change in stream flow for 80% of the Georges River compared to pre mining, No more than minor change in stream flow for 20% of the Georges River compared to pre mining; and; No more than negligible change in the variability of pool level / drainage rates of 80% of pools in the Georges River compared to pre-mining; No more than minor change in the variability of pool level / drainage rates of 20% of pools in the Georges River compared to pre-mining; and; For all other watercourses, no greater subsidence impact or environmental consequences than predicted in the EA and PPR (as described for each stream in this SMP).
Shallow groundwater levels	No significant reversal or reduction in the shallow hydraulic gradient to the river when compared to pre-mining conditions such that flows in the Georges River are impacted.
Groundwater quality	Impacts from mining do not result in water for a property (e.g. supplied from a private bore) becoming unfit for purpose, taking into account the company providing an alternate water supply.
Groundwater flows to the mine	Visual inspection does not identify abnormal water flow from the goaf, geological structure, or the strata generally; and The 20 day average mine water make does not exceed 3 ML/day.

NOTE: The Georges River Performance Measures of negligible apply to 80% of the stream length subject to vertical subsidence >20mm, and minor applies to the remaining 20%. Negligible is defined as “small and unimportant, so as to be not worth considering”. Minor is defined as “not very large, important or serious”.

9.1 Stream Flow and Pool Levels

The Performance Measure, *negligible diversion of flows or changes in the natural drainage behaviour of pools over at least 80% of the stream length subject to vertical subsidence >20mm*, will be exceeded if the change in stream flow and / or pool levels on the Georges River is more than negligible.

This should be assessed by monitoring at selected stream flow constriction points and selected pools in the Georges River and other watercourses, as outlined in **Section 8**.

The Performance Indicators may be revised in consultation with the DoPI, NOW, and DII.

9.2 Groundwater Levels

It is recommended that shallow groundwater levels be monitored in GR27, 28, 29 and up to three new piezometers as well as GW72454, if access is available, which should be compared to measured water levels in the Georges River.

In addition, water head pressures in the vibrating wire array in bore S2087 should be monitored.

Analysis of the water level data from the bores should be conducted during EoP Report assessments to assess whether the groundwater head of the plateau is higher than the Georges River water level.

If data analysis indicates that there is a reversal or significant reduction in the shallow hydraulic gradient to the river when compared to pre-mining conditions, this should be considered in any assessment of surface water impacts and rehabilitation design.

If the 7 day average potentiometric head in the shallow piezometer/s located between Longwalls 37 and 38 and the river is less than the river water level for greater than one month an investigation of the cause of this occurance should be initiated.

9.3 Groundwater Quality

The groundwater quality Performance Indicator should identify if there has been a significant change in the quality of groundwater in a private bore or the existing or proposed open standpipe piezometers in relation to mining Longwalls 37 and 38. 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 37 and 38.

The Performance Indicators may be revised in consultation with the DoPI, NOW, and DII.

Where the water supplied from a private bore becomes not fit for purpose, BHPBIC shall provide an alternate water supply, either as an interim or longer term measure, or alternatively, replace the water supplied from the subject bore by modification or addition to the bore and/or its pumping equipment.

9.4 Potential Connective Cracking and Mine Inflows

The monitoring data outlined in **Section 8** should be used to assess any correlation between potential connective cracking and mine inflows and the Performance Measures outlined in **Table 7**.

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 monitoring indicates a Performance Indicator has been exceeded, an assessment should be made to assess if thre is a correlation to the Performance Measures outlined in **Table 7**.

The Performance Measure should be deemed to have been exceeded if analysis of the monitoring results confirms that Longwalls 37 and 38 has resulted in direct connective cracking between the surface and the mine.

The Performance Indicators may be revised in consultation with the DoPI, NOW, and DII.

Vertical groundwater head profiles in S2087 should also be used to indicate if there has been connective cracking between the surface and Longwall 37 (and possibly Longwall 38).

Data analysis should be conducted during preparation of the EoP Reports to assess whether significant departures from the predicted envelope of vertical potentiometric head profiles has occurred.

A significant departure should be considered to have occurred 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 a month) lies significantly to the left of the predicted high-inflow model curve.

If a significant departure from the predicted groundwater pressure profile is observed, it should be assessed to determine if the change is likely to have been caused by any connective cracking between the surface and the mine.

If required, this may 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 *no subsidence impact or environmental consequence greater than minor* should be considered to have been exceeded if the re-modelled overburden indicates extension of the fractured zone to surface level.

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Attachment C – Assessment of Water Quality Effects and Water Quality Monitoring Plan, West Cliff Colliery Longwalls 37 and 38 Extraction Plan (Ecoengineers, 2013)

ASSESSMENT OF WATER QUALITY EFFECTS AND WATER QUALITY MONITORING PLAN

WEST CLIFF COLLIERY LONGWALLS 37 AND 38

EXTRACTION PLAN

for

BHP BILLITON ILLAWARRA COAL

JANUARY 2013

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PROJECT: Area 5
TITLE: Assessment of Water Quality Effects West Cliff Colliery Longwalls 37 to 38
DOCUMENT REFERENCE NO: 2007/12A

PROJECT MANAGER: S. Short	**FILE: Assessment of Water Quality Effects Proposed West Cliff Area 5 Longwalls 37 – 38 Rev1.doc**
SPELL CHECK BY:	**SUBJECT: West Cliff Colliery**

Document Details		**Preparation & Self Check**	**Independent Review By:**	**Corrective Action**	**Approved By:**
REVISION 1	**Name:** **Date:** **Signature:**	D. Ward 12/04/12	S. Short 16/04/12	K. Bowles 20/12/12 9/01/13	S. Short 9/01/13

Reviewers Comments:

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EXECUTIVE SUMMARY

BHP Billiton Illawarra Coal proposes to continue its underground mining operations at West Cliff Colliery, located in the Southern Coalfield of New South Wales, by extracting coal from the Bulli Seam using longwall mining techniques.

Ecoengineers Pty Ltd were engaged by BHP Billiton Illawarra Coal, to provide an assessment of water quality effects that may arise in Georges River or any other watercourse from the proposed extraction of two longwalls for the Extraction Plan.

The proposal comprises two Longwalls designated 37 and 38, located immediately north and east respectively of previously approved Longwalls 29 to 36, none of which mined directly under the Georges River. The proposed location of Longwall 37 is to the west of and approximately perpendicular to the Georges River, while Longwall 38 will lie parallel and to the east of the river.

The most recently completed West Cliff Longwall 34 in the Longwalls 29 to 36 series was mined between 6 February 2010 and 14 September 2011. Longwall 35 is currently being extracted. This assessment of potential impacts for Longwalls 37 and 38 draws substantially on the empirical data from the Longwall 34 monitoring program.

Water Quality

The SMP Approval (Condition 13.1) for Longwalls 34 – 36 states that the Georges River Management Plan is triggered when mining is within 400 m of the Georges River. On 11 July 2011 the centre of Longwall 34 was 409 m from the river, and this date was conservatively chosen as the date triggering the Georges River Management Plan and associated Trigger Action Response Plan (TARP).

Water quality parameters greater than three standard deviations from the mean (i.e. the Level 3 trigger) were observed upriver of, adjacent-to, and downriver of Longwall 34 prior to the longwall being mined within 400 m of the river. This indicated such variations occur in the River irrespective of the mining of Longwall 34.

No significant water quality impacts were observed or measured within the Georges River as a result of mining Longwall 34. This conclusion is based on the observation of only one minor occurrence of iron staining identified in Pool 40D, and that after 11 July 2011, no water quality parameters recorded in the Georges River exceeded two standard deviations from the mean.

There was no evidence of sub-bed flow diversions in the Georges River as a result of Longwall 34.

No significant impacts on the water quality of the Nepean River tributary Leafs Gully were identified as arising from the mining of Longwall 34. Water quality parameters remained largely within expected levels (<2 standard deviations from the pre-mining mean) in Leafs Gully during the extraction of Longwall 34.

No significant impacts on the water quality of the Nepean River tributary Mallaty Creek were identified as arising from the mining of Longwall 34. Water quality remained largely within expected levels (within two standard deviations of the mean) throughout the mining period.

Minor compression fracturing and surface flow diversions were observed at Mallaty Creek site MC09 by the BHP Billiton Illawarra Coal Environmental Field Team on

3 November 2010. Localised reduction in pool water level occurred as a result of that impact (BHP Billiton, 2011).

There was no decline in water quality detected at Mallaty site MC110, the monitoring site directly downstream of MC109 with respect to pH, dissolved oxygen, sulfate, total iron and manganese, and filterable nickel and zinc in the months preceding or immediately following discovery of that fracture zone.

In the context of the above assessment of impacts from Longwall 34, potential water quality effects associated with the proposed future Longwalls 37 and 38 in West Cliff Colliery Area 5 are comprehensively assessed in this report.

The two principal mechanisms identified that might give rise to water quality impacts from mining Longwalls 37 and 38 are river sub-bed flow diversions resulting from fracturing of controlling rock bars, and the inducement of ferruginous springs or exacerbation of pre-existing ones.

River Bed Flow Diversions

River sub-bed flow diversions due to river bed fracturing, apart from impacting water flows, also have distinct geochemical effects that can impact water quality. These effects are related to fractures exposing siderite/rhodochrosite in weathered sandstone and possibly also marcasite (an iron sulfide) in unweathered sandstone river bedrock.

Significant river bed flow diversions and water quality effects have not been observed for Longwalls 29 through to the current Longwall 35 which, like proposed Longwalls 36 – 38, did not and do not mine directly under the Georges River. Recent experience with Longwalls 301 and 302 for Appin Colliery adjacent to Cataract River also support the inference that not mining directly under a river avoids such effects.

Nevertheless, should such sub-bed flow diversions occur, a considerable ‘mitigating effect’ against ecotoxic effects attributable to acidity, dissolved nickel and zinc (the principal, potentially ecotoxic trace metals in the Georges River waters) is provided by the controlled release of weakly saline waters from Brennans Creek Dam at West Cliff Colliery since August 2004 which was made (in part) to maintain an environmental base flow in the Georges River. The West Cliff release contains a concentration (typically 1000 – 1500 mg/L as $CaCO_3$) of bicarbonate/carbonate alkalinity which incidentally serves to:

- ‘buffer out’ any acidity generated by mining-induced freshly fractured sandstone bedrock; and also
- complexes dissolved nickel and zinc, greatly reducing the concentration of ecotoxic forms of these metals.

Ferruginous Springs

A ferruginous spring (Pool 11 spring) adjacent to the Georges River was induced when Longwalls 5A1 and 5A2 were mined directly beneath the River. However, subsequent extraction of Longwalls 29 and 31, which were not mined directly under the River, did not result in the creation of any ferruginous springs. This applies even though they mined under an upland catchment on the western side of the river of significant size (0.72 km^2).

Given the nature of the Georges River bed, it is believed that typical aeration applying in the River would be such that, for discrete ferruginous spring flows into the River below 0.15 ML/day, and concurrent river flows above 0.42 ML/day, the minor deficit in dissolved oxygen at any spring emergence point would have negligible impact. Geomorphological considerations suggest the river water should be quickly re-aerated over a very short distance. It is estimated that such springs would cause a considerable dissolved oxygen deficiency in the river at their emergence points only if their flow rate exceeded 0.1 ML/day and if upstream flows in the river were concurrently <0.3 ML/day. Since August 2004, river flows of <0.3 ML/day have occurred less than 7% of the time.

Such springs do not usually contain enough dissolved iron and manganese to cause a significant depression of river pH through the oxidation and precipitation of hydrous Fe and Mn oxides because the River water contains significant bicarbonate alkalinity (capable of neutralising acid) deriving from the BCD discharge from West Cliff Colliery.

Based on past observations of springs and borehole water, it is possible that ferruginous saline springs may be more prone to be induced or enhanced (if pre-existing) in westward draining catchments overlying Longwall 37 that ultimately flow to the Nepean River, e.g. Mallaty Creek, Nepean Creek and Woodhouse Creek.

Notwithstanding, the westward draining streams are clearly strongly ephemeral in nature with ongoing agricultural land use, and it is unlikely there would be any significant impact to water quality resulting from the formation of springs in these streams over and above current anthropological effects (The Ecology Lab, 2007).

Geochemical modelling suggests that an effect of both sub-bed diversions and ferruginous springs would be to locally decrease the dissolved (and potentially ecotoxic) Ni and Zn concentrations currently observed in the Georges River. This is due to adsorption of metal cations onto hydrous ferric oxide particles created by oxidation of ferrous iron from fractured sandstone.

Recommended Water Quality Monitoring

Baseline surface flow and water quality monitoring (including laboratory analysis and field parameters) are already being conducted in the Georges River, Mallaty Creek and Nepean Creek upriver and adjacent to proposed Longwalls 37 and 38. Limited data are currently available to demonstrate baseline water quality for selected monitoring sites.

For Longwall 37 it is recommended that water quality be monitored:

- in the Georges River upstream and downstream of Longwall 37 at Pool 54 and Pool 64, respectively,
- in Mallaty Creek at sites MC100, MC106, and MC110,
- in Nepean Creek at site NC10, and
- in the tributary GR105, just upstream of the confluence with the Georges River.

For Longwall 38 it is recommended that water quality be monitored:

- in the Georges River upstream, adjacent to, and downstream of Longwall 38 at Pool 34, Pool 54, and GR100, respectively,
- in the following tributaries, just upstream of the confluence with the Georges River: GR102, GR103, GR104, GR107, GR108, GR110, GR114, GR117, and GR119.

It is recommended that the sampling sites be monitored on a monthly basis.

The locations of recommended monitoring sites to be utilized during the extraction of Longwalls 37 and 38 are shown in **Figure 5.1** of this report and tabulated in **Table 5.1**.

In the event, considered by Ecoengineers to be unlikely, that future water monitoring shows greater than minor hydrologic or water quality impacts which are potentially ecotoxic within the Study Area or immediately downstream in Georges River, then some management and mitigation measures may be required.

Any flow diversions that might occur can be fully or partially restored by remediation works such as those which have been previously undertaken successfully in the Georges River (International Environmental Consultants Pty Ltd., 2004).

We recommend that the current licensed release of water from West Cliff Colliery (of at least 1 ML/day) be maintained to allow comparison of baseline flow data with data derived during and after the mining period. A continued flow of water from the West Cliff licensed discharge would also have the benefit of neutralising any acid produced in the unlikely event of sub-bed diversion or induction of a ferruginous spring in the Georges River.

1. INTRODUCTION

BHP Billiton Illawarra Coal (BHPBIC) proposes to continue its underground mining operations at West Cliff Colliery, located in the Southern Coalfield of New South Wales, by extracting coal from the Bulli Seam using longwall mining techniques. West Cliff Colliery is one of three operating underground mines managed by BHPBIC south of Sydney, the other two mines being Appin Colliery and Dendrobium Colliery.

Ecoengineers Pty Ltd ('Ecoengineers') were engaged by BHPBIC to provide an assessment of water quality effects that may arise in Georges River or any other watercourse due to the proposed extraction of two longwalls in the existing West Cliff Colliery Area 5, which the Colliery has been mining since May 1999.

The proposal comprises two longwalls designated 37 and 38, located immediately north and east respectively of approved Longwalls 29 to 36. The proposed location of Longwall 37 is to the west of and approximately perpendicular to the Georges River, while Longwall 38 is to the east and parallel to the river.

The regional location of the 'Study Area' for Longwalls 37 and 38 is defined by Mine Subsidence Engineering Consultants (MSEC, 2012) to be that area that is likely to be affected by the proposed longwalls at West Cliff. The extent of the Study Area has been calculated by combining the areas bounded by the following limits:-

- the 35 degree angle of draw line from the proposed extents of Longwalls 37 and 38,
- the predicted vertical limit of subsidence, taken as the 20 mm subsidence contour; and
- features sensitive to far-field movements.

The 35 degree angle of draw line is described as the "surface area defined by the cover depths, angle of draw of 35 degree and the limit of the proposed extraction area in mining leases of the Southern Coalfield", as stated in Section 6.2 of the Department of Primary Industries (DPI) Guideline 2003.

Given that the depth of cover above the proposed longwalls varies between 455 m and 540 m, the 35 degree angle of draw line has been conservatively determined by drawing a line that is a horizontal distance, varying between 320 m and 380 m from the proposed extraction areas of Longwalls 37 and 38.

Two Study Areas have been defined separately, one for each of the proposed longwalls. The Longwall 37 Study Area is located largely on the western side of the Georges River. The Study Area for Longwall 38 is predominately located on the eastern side of the Georges River.

Figures 1.1 and 1.2 show the general layout of the proposed longwalls, indicating the extents of the MSEC-defined Study Areas and also showing the relative positions of previously extracted longwalls, the current Longwall 35 and approved, upcoming Longwall 36.

Our investigation of possible mechanisms inducing water quality effects has been principally restricted to the identification, classification and quantification of effects caused within the so-defined Study Area. However, the report considers and assesses potential far-field and downstream effects where appropriate.

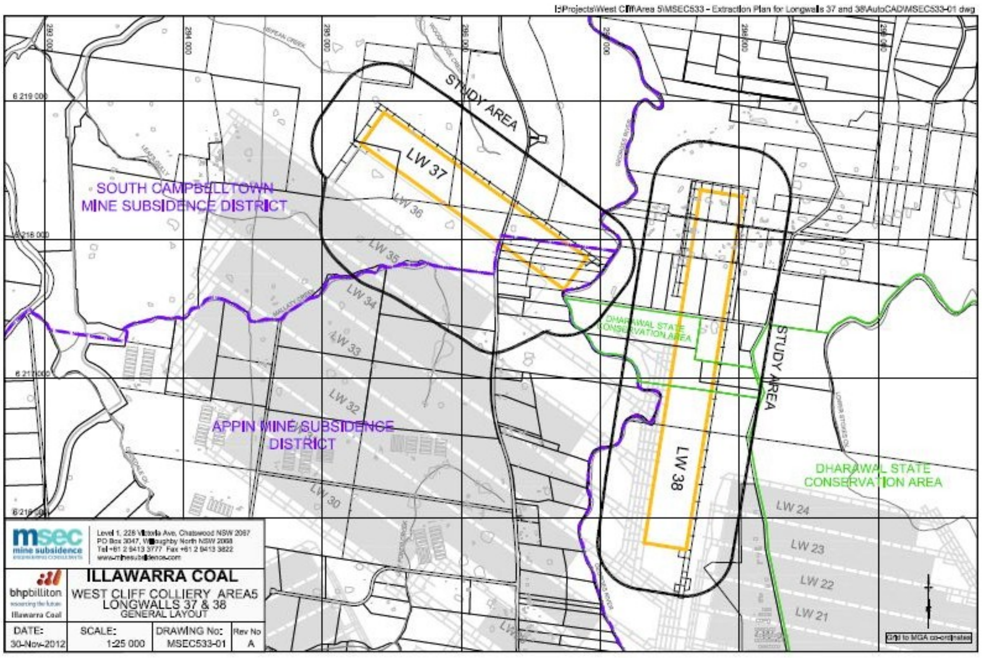


Figure 1.1 General Layout of Proposed Longwalls 37 and 38.

Figure 1.2 Aerial Photograph of Longwalls 37 and 38 and their Study Areas

1.1 REGULATORY CONTEXT

The Georges River is categorised as an area of environmental sensitivity for the purposes of the Extraction Plan approval process as its waters were previously classified as Class C from their source to Captain Cook Bridge under Part 3 of the Clean Waters Act 1970 (State Pollution Control Commission, 1980). The Clean Waters Regulations 1972 made under the Clean Waters Act 1970 were from 1 July 1999 taken to be regulations made under the Protection of the Environment Operations Act 1997 POEO Act No. 156.

Specifically, Part 5, Clause 6 of Schedule 6 of the POEO Act specifies that any waters classified under Part 3 of the Clean Waters Act 1970 continue to have the classification they had on repeal of that Act and that the standards applicable under The Clean Waters Regulations 1972 to waters so classified are to stand (under Part 5 of the POEO Act).

The Protection of the Environment Operations Amendment Bill 2005, ratified by the NSW Parliament on 1 May 2006, repealed the Clean Waters Regulations 1972 (and Part 5 of Schedule 6 of the POEO Act 1997 No. 156) and established a general requirement that environmental values of water (being the values set out in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000) be considered when licensing functions are exercised or prevention notices issued under the POEO Act.

The Georges River is also the subject of the Greater Metropolitan Regional Environmental Plan No. 2 – Georges River Catchment (GMREP 2). The Plan requires consideration of environmental effects which include:

- acid sulfate soils;
- bank disturbance;
- flooding;
- industrial discharges;
- land degradation;
- on-site sewage management;
- river-related uses;
- sewer overflows;
- urban/stormwater runoff;
- urban development areas;
- vegetated buffer areas;
- water quality and river flows; and
- wetlands.

While mining is not directly referred to in GMREP 2, this report aims to address the water quality and river flow-related matters the Plan raises.

This assessment is based upon past experience in the investigation and assessment of water quality effects induced by mining in the Illawarra Region and from:

- specific hydrologic and water quality monitoring studies conducted in Georges River above Area 5 by BHPBIC since May 1998 (e.g. BHP Billiton 2002a, 2002b, 2004a, 2004b) and by Coffey Geosciences between 1998 and 2002 (Coffey Geosciences 1998, 1999, 2000a,b,c, 2001a,b, and 2002);
- regional aquatic ecological studies conducted in Georges River, and tributaries of the Nepean River namely; Ousedale Creek, Mallaty Creek and Upper Nepean Creek since 2003 by The Ecology Lab (e.g. The Ecology Lab 2004a,b,c,d,e, 2005, 2006a,b and 2007); and
- regional water quality and geochemical studies conducted at West Cliff Colliery, in Georges River and Cataract River since 2003 by Ecoengineers Pty Ltd (e.g. Ecoengineers 2005a, b, c, d, 2006a, b, 2007, 2012).

There are no Water Quality Objectives 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).

2. BACKGROUND

2.1 LOCAL GEOMORPHOLOGY, SOILS AND NEAR-SURFACE GEOLOGY

Figure 2.1 shows the surface topography in the Study Areas.

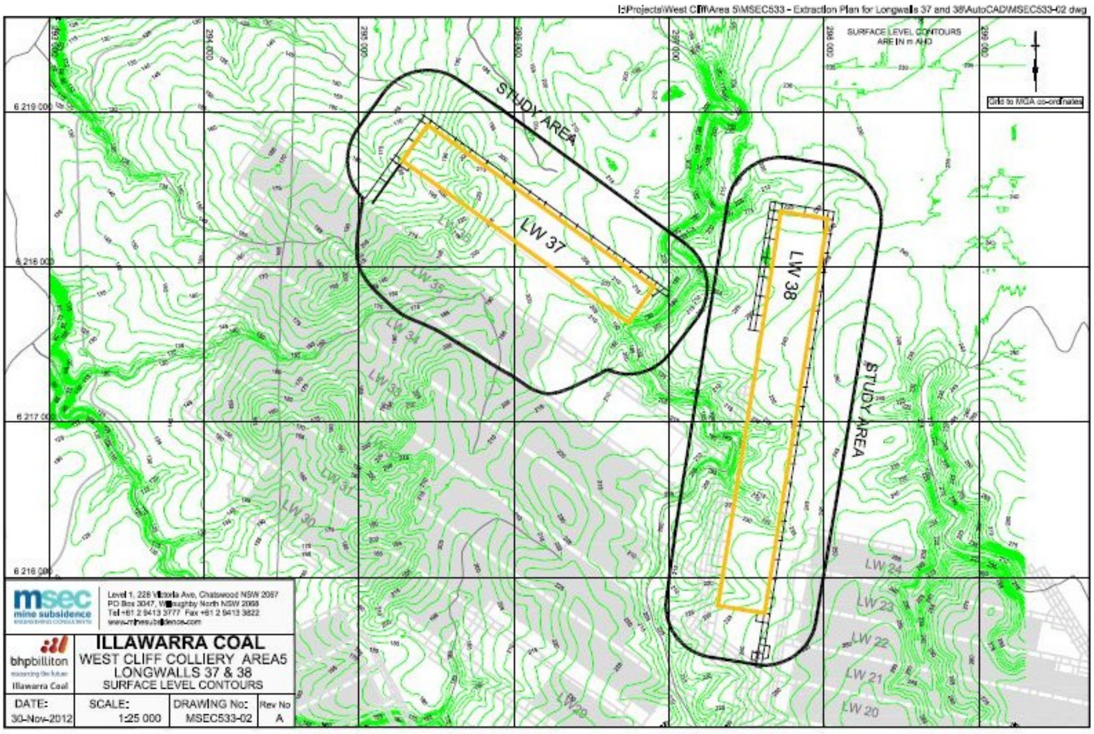


Figure 2.1 Surface Topography in the Study Areas.

The land in the eastern part of the Longwall 37 Study Area generally drains into the Georges River, while the land in the central and western parts of the Area generally drain into Nepean, Mallaty or Woodhouse Creeks, which in turn drain into the Nepean River. The Study Area associated with Longwall 38 drains west to the Georges River via several small tributaries.

Figure 2.2 shows the watercourses within and adjacent to the proposed longwalls.

The Georges River arises about 5 km south east of Appin, and flows broadly north towards Liverpool in a tortuous fashion through a shallow river valley that becomes increasingly incised as it proceeds north.

The section of the Georges River skirting around the eastern ends of Longwalls 37 and the western margin of Longwall 38 within the Study Area is moderately incised with Hawkesbury Sandstone outcropping to the east of the River and Wianamatta Shale to the west. The bedrock of the River is Hawkesbury Sandstone. The total length of the Georges River within the Study Areas is 2.3 km.

Figure 2.2 Watercourses within the Longwall 37 and 38 Study Areas

The average natural gradients of the Georges River within the Study Area surrounding Longwalls 37 and 38 are 5 mm/m and 11 mm/m respectively. Maximum gradients are approximately 140 mm/m, just upstream of Pool 67, and 100 mm/m, just downstream of Pool 43, respectively. Minimum gradients in the Study Areas are < 1 mm/m (MSEC 2012).

A number of tributaries of the Georges River are located within the Study Areas. These sites (as shown in **Figure 2.2**) are identified as GR101, GR102, GR103, GR104, GR105, GR107, GR108, GR108A, GR109, GR110, GR112, GR114, GR114A, GR117, and GR119.

Tributaries GR107 and GR108A are located within the Dharawal State Conservation Area.

The following creeks drain from the Longwall 37 Study Area to the Nepean River:

- Nepean Creek and its tributaries NC3 and NC5;
- Mallaty Creek and its tributaries MC3, MC4 and MC5; and
- Woodhouse Creek.

Nepean Creek lies west of the Longwall 37 Study Area and enters the Nepean River just above Menangle Weir. This tributary flows northwest from a small farm dam (with an area of ~50 m^2) through cattle pasture. There is a thin riparian strip in the upper reaches, flowing through tea trees within eucalypt woodland. The creek is ephemeral with only small standing pools. The natural gradient of the creek in the vicinity of the proposed longwalls varies between 10 mm/m and 150 mm/m, with an average gradient of approximately 40 mm/m.

Mallaty Creek is an ephemeral creek which is located directly above the proposed Longwall 37. The creek generally flows in a westerly direction until it joins Ousedale Creek, to the south-west of Longwall 37. The natural gradient of the creek within the Study Area varies between 10 mm/m and 100 mm/m, with an average gradient of approximately 30 mm/m.

Woodhouse Creek is an ephemeral creek which arises in the north of the Study Area and flows north towards the Nepean River. The natural gradient of the creek within the Study Area varies between 0 mm/m and 45 mm/m, with an average gradient of approximately 15 mm/m.

A number of areas containing steep slopes have been identified within the Study Area. The reason for identifying steep slopes is to highlight areas in which existing ground slopes may be marginally stable. For the purposes of this report, a steep slope has been defined as an area of land having a natural gradient between 1 in 3 (i.e. a grade of 33 %, or an angle to the horizontal of 18°) and 2 in 1 (i.e. a grade of 200 %, or an angle to the horizontal of 67°). 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.

A cliff is defined by MSEC (2012) as a continuous rock face having a minimum height of 10 metres and a minimum slope of 2 to 1, i.e. having a minimum angle to the horizontal of 67°. The locations of cliffs within the Study Area were determined from site investigations and from the 2 metre surface level contours which were generated from an aerial laser scan of the area.

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.

Figure 2.3 shows the disposition of steep slopes and cliffs within the Study Area.

The upper catchments of Mallaty, Nepean and Woodhouse Creeks are all characterised by outcropping Wianamatta Shale. The landscape types are classified as Cumberland Plains Lowlands and Hawkesbury-Nepean River Valley.

Wianamatta Shales dominate and are at their thickest along the ridgelines. Lower valley slopes and walls of creeks are characterised by Hawkesbury Sandstone outcropping with the lower creek lines being incised into the Sandstone as shown in **Figure 2.4**.

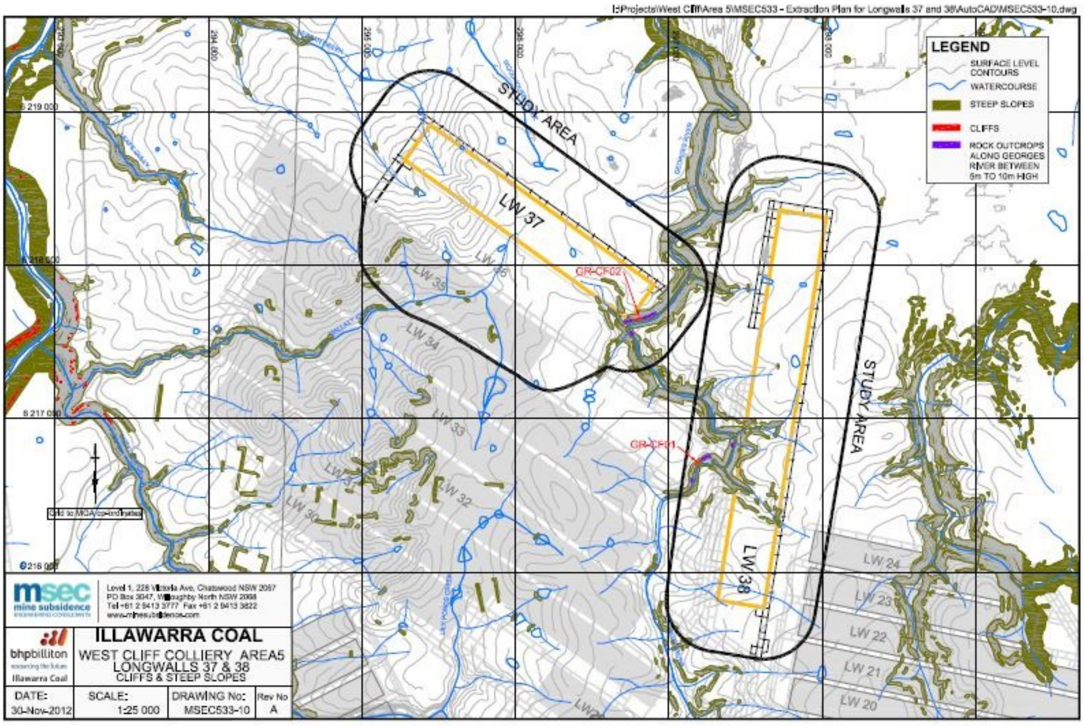


Figure 2.3 Cliff and Steep Slopes within the Study Area

Soils within the Study Area have been mapped by the Soil Conservation Service of NSW and are described by Hazelton and Tille (1990) to be of only two soil landscape types:

1. **Hawkesbury type** developed on very steep slopes of Hawkesbury Sandstone within creek main valleys and lower sections of tributaries; local relief 100 - 200 m with slopes > 25 %. The soils are shallow (typically < 50 cm) discontinuous lithosols/siliceous sands associated with rock outcrops, earthy sands, yellow earths and locally deep sands on the inside of benches, along joints and fractures and narrow valley flats. There are some localised yellow and red podzolics associated with shale lenses. These soils may be found in proximity to Georges River and Nepean River and the lower sections of Mallaty Creek and Leafs Gully.
2. **Blacktown type** developed on gentle undulating country of Wianamatta Group Shales: broad, rounded crests and ridges with gently inclined slopes; local relief to 30 m, slopes usually < 5 %. The soils are shallow to moderately deep (< 150 cm), red and brown on crests, upper slopes and well-drained areas; deep (150 – 300 cm) yellow podzolics and soloths on lower slopes and in drainage depressions and localised areas of poor drainage. These are moderately reactive soils, with highly plastic subsoils.

Figure 2.4 shows the extent of the proposed longwalls overlain on the Geological Series Sheet 9029-9129 published by Department of Primary Industries, indicating the mapped general extents of Hawkesbury Sandstone (pale blue) and Wianamatta Shale (green) surface outcropping in the local area.

Figures 2.5 to 2.7 below show the disposition of geomorphological features in Georges River within and adjacent to the Study Area.

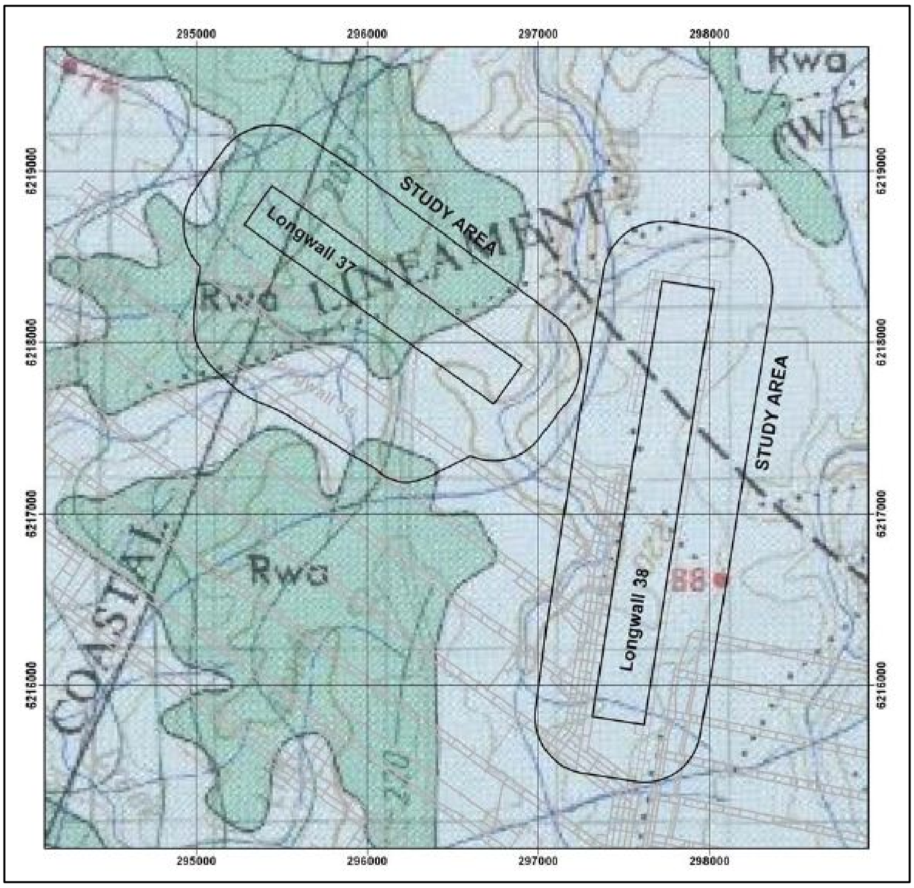


Figure 2.4 Surface Geology within and adjacent to the Study Area.

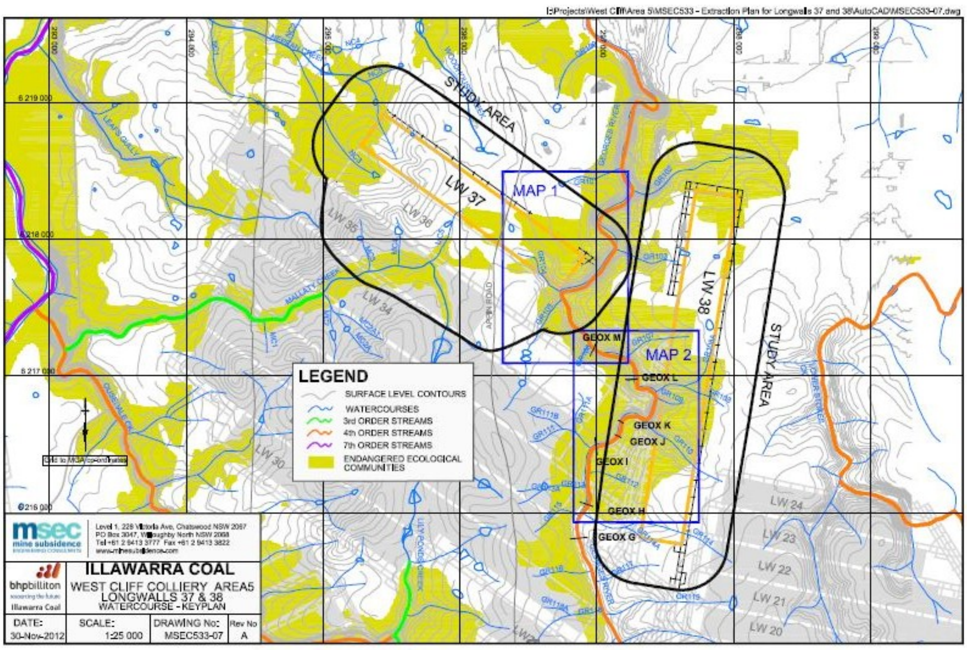
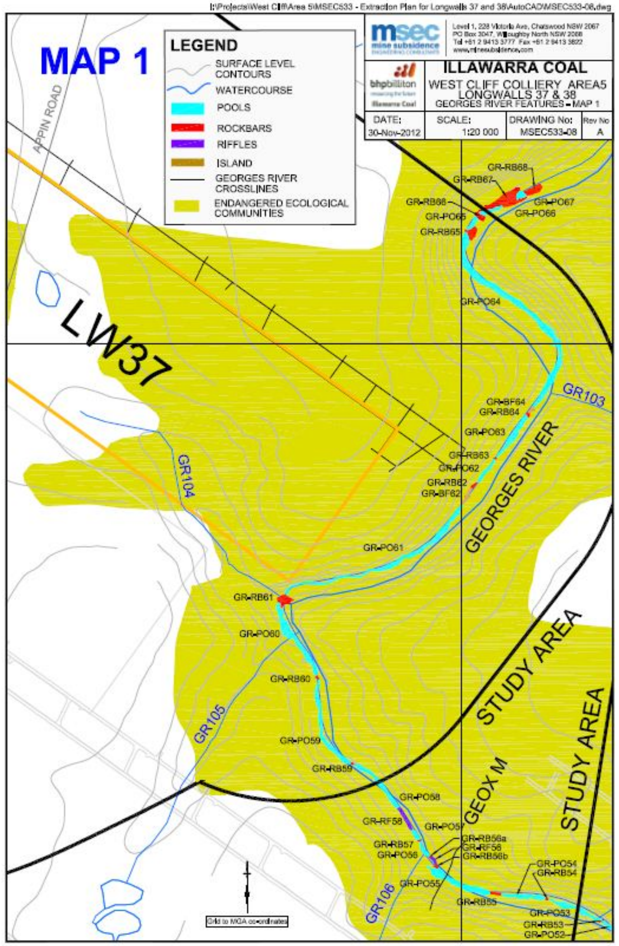


Figure 2.5 Disposition of geomorphological features in Georges River in the vicinity of the Study Area (see Figure 2.7 for Legend)



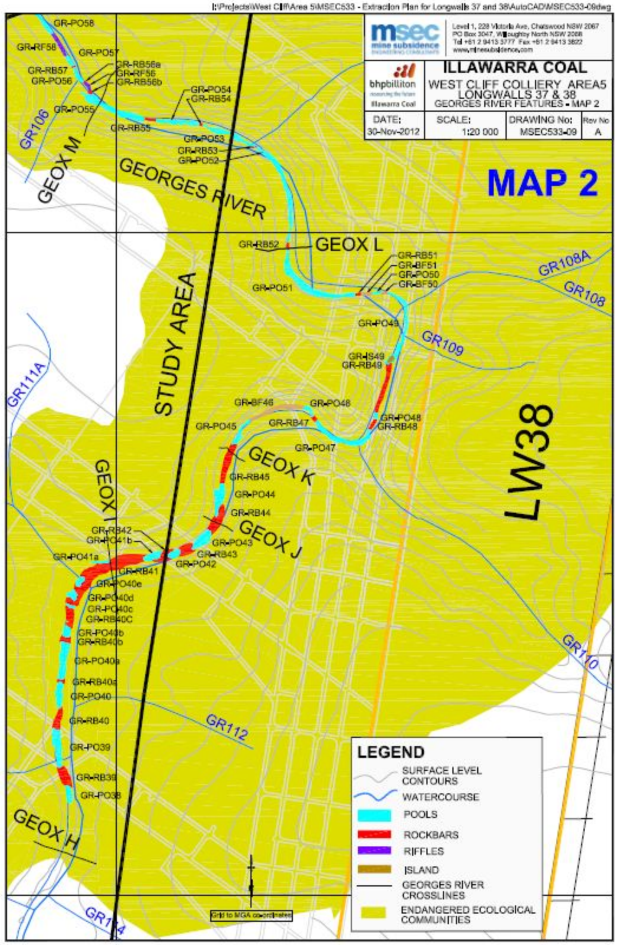


Figure 2.6: The location of watercourses, stream features and steep slopes in relation to the finishing end of Longwall 37, where the longwall is closest to the Georges River.

Figure 2.7: The location of watercourses, stream features and steep slopes in relation to Longwall 38, where the longwall is closest to the Georges River.

2.2 LOCAL HYDROLOGY

Table 2.1 shows the annual rainfall recorded at West Cliff Colliery since 1998. It is noted that the record for 2012 at the time of preparation of this report finished on 6 December.

TABLE 2.1 ANNUAL RAINFALLS AT WEST CLIFF COLLIERY SINCE 1998

Year	Rainfall (mm)
1998	1263
1999	1307
2000	790
2001	865
2002	651
2003	903
2004	856
2005	766
2006	681
2007	1577
2008	952
2009	855
2010	1162
2011	1234
2012 (to 20 December)	876
Average 1998 - 2011	**990±273**

As shown in **Table 2.1**, between 2000 and 2006, the area was in drought and experienced significantly lower than average rainfalls than applied over the previous decade. Annual rainfall in the upper river catchment as measured at West Cliff Colliery averaged about 787 mm over those 7 years.

This is more than 20% lower than the long term median annual rainfall at nearby Cataract Dam which, over the 108 years since recording commenced in 1904 has been about 1000 mm, a value that is similar to the mean rainfall for the last 10 years at West Cliff which was approximately 990 mm.

However, the Bureau of Meteorology (BOM) national map for Annual Areal ET for the period 1960 – 1991 indicates that Woronora Plateau catchments should have a lower mean annual ET in the 500 – 600 mm/year range, refer:

http://reg.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/index.jsp#maps

If actual ET in the Upper Georges River Catchment averages around 500 - 600 mm/year, during the drought period 2000 – 2006 there would have been little excess water available to sustain a base flow in the upper Georges River.

The water flows in the Georges River within the Study Area are derived from two main sources:

(a) flows sourced from the catchment areas; and

(b) flows sourced from the Office of Environment and Heritage (OEH) Licensed Discharges from Appin and West Cliff Collieries.

Water flows upstream of the licensed discharges have been routinely measured since October 2002 by BHPBIC and its consultants at a site called Upper Flow Station, and the results are summarised in **Table 2.2**.

TABLE 2.2 SUMMARY OF FLOW RATES RECORDED AT GEORGES RIVER UPPER FLOW STATION

Period of Data	16.10.2002 – 8.11.2012
Total No. of Recordings	136
Minimum Flow	0.00 ML/day
Maximum Flow	4.00 ML/day
Mean Flow	0.35 ML/day
Median Flow	0.10 ML/day

Table 2.2 indicates that the flows upstream of the licensed discharge points are relatively low (however it is noted that drought conditions existed between 2000 and 2006).

The upper Georges River, including that passing through the Study Area, had been regarded as a naturally ephemeral watercourse since at least the year 2000 (when the 2000 -2006 drought commenced) but can no longer be so regarded since the implementation of a regular discharge from West Cliff Colliery in early August 2004.

Catchment seepage water is likely to migrate both laterally down the hydraulic gradient of any perched water storages and vertically through the Hawkesbury sequence to discharge to the Georges River. The highest permeabilities are expected in a horizontal direction, usually along bedding planes, and paleo-deposition or paleo-erosion surfaces. Vertical migration is dependent on the local vertical permeability (variable through the sequence) and on the horizontal surface area of 'leakages' between adjacent stacked strata.

Natural water sources on the upland areas to the west of the Georges River are restricted to shallow gullies. Some of these gullies drain towards the River. Surface drainage in upland areas is consistent with only partial direct runoff. Significant direct infiltration of precipitation into overlying soils is predicted in areas of Wianamatta Shale outcrop on the western side of the River. Significant water storage is believed likely in the clay-rich Wianamatta Shale soils to the west of the River.

In general, water flows along the Georges River within the Study Area are continuous as there is almost always some water being discharged into the River, particularly from the OEH-licensed discharges from Appin and West Cliff Collieries which were the main source of flow for the section of River within the Study Area until about late September 2006. Both discharge points are located well upriver of the Study Area. Since 2006, the discharge from West Cliff Colliery remains the main source of flow.

After mid-2004, discharges from Appin Colliery were made up largely of stormwater runoff. The runoff that accumulates on the Colliery site increases in salinity due to exposure to stockpiled coal and other site runoff so that it occasionally is mixed with lower salinity water to achieve a discharge salinity <1000 µS/cm.

Licensed discharges from Appin Colliery after 2005 only occurred when the site's stormwater dam was nearly full. After 2005, when revised water management measures at Appin Colliery were implemented, licensed discharges from the Colliery have been negligible by comparison with discharges from West Cliff Colliery.

West Cliff Colliery does not have a town water supply and of necessity operates a relatively sophisticated water management (and recycling) system (WMS) based on the harvesting of runoff from Brennans Creek catchment and of ground water inflows to underground workings.

As part of the WMS, water is released nearly continuously to the Georges River from Brennans Creek via the Bottom Drain valve at the base of Brennans Creek Dam (BCD) wall. This controlled discharge component of the WMS has been operated and monitored continuously since 2 August 2004 (Ecoengineers Pty Ltd, 2005b).

The aims of the discharge are to:

1. restrict discharges from OEH licensed Point 10 to the Georges River to a maximum pH limit of 9.0 whenever possible under the revised conditions of West Cliff Colliery's Environment Protection Licence (EPL) No. 2504;
2. steadily reduce overall salinity levels within the WMS (which derive from the groundwater inflow component and the washing of raw coal); and
3. provide a stable environmental flow in the Georges River especially during periods of drought (as occurred from 2000 to 2006).

In order to meet these aims, water is continuously discharged from the base of the BCD dam wall so that an OPSIM model-designed optimal level (Water Solutions, 2004) of around 10.5 – 11.0 m is maintained in BCD, maximizing storm water runoff capture and minimizing uncontrolled flows over the spillway.

This regular discharge, along with other minor waters such as leakage through the dam wall and natural groundwater seeps into a small reclaim pond, is released from Licensed Discharge Point 10 into Brennans Creek and flows into the Georges River. In addition to this flow, BCD very occasionally overtops its spillway (located above 12.5 m maximum dam depth) during large rainfall events.

This regime has proved to be relatively successful with salinity of water discharged from West Cliff Colliery as expressed by Electrical Conductivity (EC) being reduced from an average value around 4000 µS/cm in 2004 to an average value of around 2000 µS/cm in 2011/2012, despite drought conditions applying over the first three years. This 'best practice' mode of operation of the West Cliff WMS will continue into the foreseeable future.

Given that the flow conditions within the Georges River have been thus modified, and due to the dry conditions that applied in the area between 2000 and 2006, the controlled discharge from BCD (Point 10) has constituted the major flow component of Georges River over the last 8 years since its inception.

Daily discharges to the River were examined for the period between 2 August 2004 and 27 November 2012 at Appin Colliery and 2 August 2004 and 22 November 2012 at West Cliff Colliery, and are summarised in **Table 2.3**. It should be noted there are small gaps in the data where no measurements could be made due to, for example, remediation works or flooding of Brennans Creek.

TABLE 2.3 LICENSED DISCHARGES FROM APPIN AND WEST CLIFF COLLIERIES, 02.08.2004 – 27.11.2012

	Appin Discharge	**West Cliff Colliery Licensed Discharge Point 10**	**Brennans Creek Dam Overflows (Licensed Discharge Point 1)**	**Combined Discharges & Overflows**
Period of Data:	1.01.2004 – 27.11.2012	2.08.2004 - 22.11.2012		
Total No. of Recordings	3127 days	1014 days	2974 days	1014 days
Total No. of Days of Zero Flow	2233 days	40 Days	1201 days	37 days
Estimated Minimum Flow Rate	0.0 ML/day	0.0 ML/day	0.0 ML/day	0.0 ML/day
Estimated Maximum Instantaneous Flow Rate [1]	1.9 ML/day	8.3 ML/day	360.8 ML/day	370 ML/day [2]
Estimated Mean Flow Rate	0.1 ML/day	1.7 ML/day	2.2 ML/day	4.0 ML/day
Estimated Median Flow Rate	0.0 ML/day	1.1 ML/day	0.0 ML/day	1.1 ML/day

[1] Instantaneous Flow Rate measured at a single point in time. This measurement does not imply the flow rate was sustained for an entire day.

[2] Brennans Creek was flooded and no measurement from Point 10 was possible.

The water flows in the Georges River within the Study Area are largely derived from two main sources:

- flows sourced from the upriver catchment areas; and
- flows sourced from the OEH Licensed Discharges Point 1 and Point 10 at West Cliff Mine.

Calculated frequencies for the estimated combined controlled licensed discharge (Point 10) and of uncontrolled BCD spillway overflow rates (Point 1) from West Cliff Colliery are shown in **Table 2.4** below.

It can be seen from **Table 2.4** that controlled discharges from West Cliff lie typically in the range 0.6 to 3.1 ML/day. Flows less than or equal to 0.57 ML/day have occurred for less than 15% of the time.

It is noted that the lowest frequency high flow rates, i.e. >99 percentile (less than 1% of the time) were weighted towards very high discharge rates. This is a consequence of high rates of overflow from BCD due to very high rainfalls in the Upper Georges River catchment in June 2007, February 2008, and March 2012, and hence high rates of runoff from the West Cliff Pit Top and Coalwash Emplacement Areas.

TABLE 2.4 ESTIMATED PERCENTILES OF TOTAL RECORDED DISCHARGE FROM WEST CLIFF COLLIERY FOR THE PERIOD 2.08.2004 – 22.11.2012 (N = 1210 MEASUREMENTS).

FLOW RATE (ML/day)	PERCENTILE
0.42	10.0
0.57	15.0
0.68	20.0
0.75	25.0
0.83	30.0
0.90	40.0
1.07	50.0
1.31	60.0
1.81	70.0
2.16	75.0
2.44	80.0
3.06	85.0
4.60	90.0
7.80	95.0
30.24	99.0

Total (cumulative) water loss by spilling at Point 1 is estimated at approximately 2274 ML from the daily V notch weir observations made. This is equivalent to 7.4 times the volume of BCD (307 ML to the spillway).

If the licensed West Cliff Colliery discharge from BCD was not released into the River, water flows would not be continuous along many sections of the upper Georges River. In times of dry weather, the River would most likely consist of a series of disconnected pools, some of which may completely or partially drain and/or dry out. It has been observed that the drying out process leads to a natural increase in salinity in disconnected pools (Jarvis, 1997). It is also likely that surface flow diversions in the River have occurred as a result of natural weathering and erosion.

Water flows in the Georges River have generally been determined by calculating measured cross-sectional areas and velocities of the stream in a defined channel. In some cases, water flows have been measured by calculating the depth of water passing through a temporary or permanent V-notch weir.

The monitoring of water flows has been restricted to where flow monitoring was physically possible. It is only possible to measure such flows under dry weather conditions up to about 3.0 ML/day and the average precision of such measurements has been estimated by us to be about ± 0.17 ML/day (± 2 L/s) at the one standard deviation level in local riverine terrain.

These dry weather flows averaged very close to 1.0 ML/day upstream of the Longwall 37 and 38 Study Areas. Dry weather low flows in the Georges River upstream, adjacent to, and immediately down river of the Study Areas are therefore very similar in magnitude to the median dry weather flows released from the West Cliff Colliery Point 10 licensed discharge, i.e. when BCD is not overflowing (refer **Tables 2.3** and **2.4** above).

Previous work has suggested the river system may generally be described as a 'losing' system for most of the time, where the predominant flow direction is from surface to groundwater storage (BHP Billiton, 2004a). The river may reasonably be expected to become a gaining system during extended periods of higher than average rainfall.

There is one registered groundwater bore in the Study Area for Longwalls 37 and 38, the location of which is shown in Drawing No. MSEC533-22 (MSEC, 2012) and details provided in Section 8.11 of MSEC (2012). The registered use for the bore is domestic irrigation. There has been no systematic study of near-surface groundwater systems in the Study Area other than in close proximity to Georges River. The groundwater systems relevant to the Study Area are discussed in detail in Geoterra (2012).

2.3 BASELINE WATER QUALITY FOR LONGWALLS 37 AND 38

Figure 2.8 below shows selected water quality monitoring sites established by BHPBIC in Georges River upriver, adjacent to and down river of the proposed Longwall 37 – 38 Study Area.

Table 2.5 shows the major mean (± 1 standard deviation (sd)) characteristics of baseline water quality at the selected sites between August 2004 and February 2010 (or part thereof if the record is shorter). N = number of field and laboratory measurements (generally monthly for lab.). February 2010 was when extraction of Longwall 34 commenced.

There are insufficient data from Mallaty and Nepean Creeks to form a comparative dataset prior to the start of mining of Longwall 34. For comparative purposes, **Tables 2.6 and 2.7** show the major characteristics (mean ± 1 sd) of baseline water quality in Mallaty Creek (MC), and Nepean Creek (NC) for a more recent period. N = number of field and laboratory measurements (generally monthly for lab).

Figure 2.9 shows existing water quality monitoring sites established by BHPBIC in Mallaty Creek, Nepean Creek and Leafs Gully.

Baseline data (i.e. prior to mining of Longwall 37) is continuing to be collected for monitoring sites established in Upper Nepean Creek and downstream Georges River. It is understood these sites will continue to be monitored to allow baseline water quality data to be accumulated well before any commencement of extraction from the proposed longwalls.

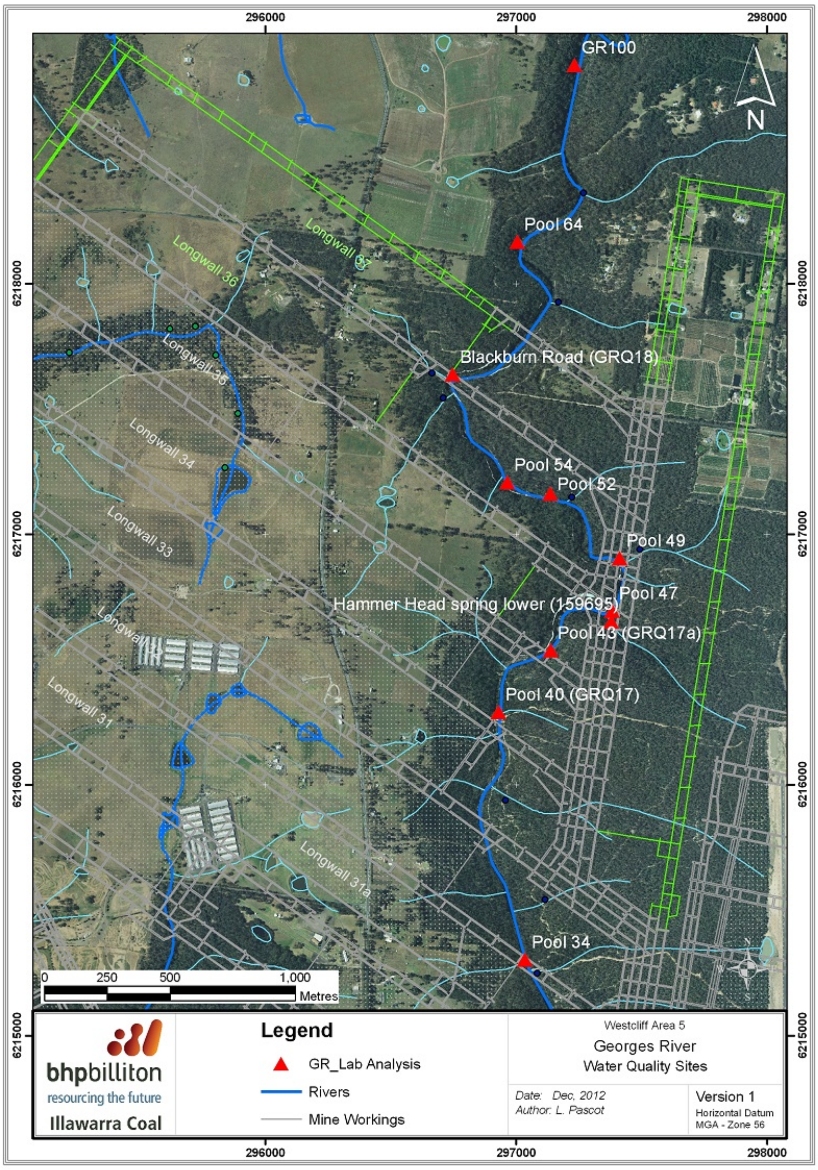


Figure 2.8 Established Water Quality Monitoring Sites in Georges River

TABLE 2.5 AVERAGE BASELINE WATER QUALITIES IN GEORGES RIVER SITES 2 AUGUST 2004 – 5 FEBRUARY 2010

Site	Field pH (N)	Field EC µS/cm (N)	DO % Sat. (N)	Ca mg/L (N)	Mg mg/L (N)	Na mg/L (N)	T. Alk. mg/L as $CaCO_3$ (N)	SO_4 (N)	Cl (N)	Tot. Fe mg/L (N)	Tot. Mn mg/L (N)	Filt. Ni mg/L (N)	Filt. Zn mg/L (N)
Pool 34 (upstream of LW38)	8.40 ±0.37 (187)	1501 ±537 (185)	96 ±23 (177)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
GRQ17	8.52 ±0.35 (202)	1551 ±610 (200)	104 ±25 (193)	5 ±2 (55)	4 ±2 (55)	346 ±151 (55)	551 ±252 (54)	24 ±10 (54)	147 ±58 (55)	1.08 ±0.67 (55)	0.051 ±0.057 (55)	0.085 ±0.042 (55)	0.022 ±0.015 (55)
Pool 47	8.43 ±0.28 (68)	1493 ±517 (68)	86 ±15 (66)	5 ±1 (27)	4 ±1 (27)	310 ±108 (27)	478 ±170 (27)	20 ±6 (27)	130 ±39 (27)	1.19 ±1.37 (27)	0.081 ±0.138 (27)	0.081 ±0.033 (27)	0.021 ±0.014 (27)
Pool 49	8.58 ±0.22 (67)	1429 ±522 (67)	86 ±18 (65)	5 ±1 (24)	4 ±1 (24)	318 ±109 (24)	482 ±165 (24)	19 ±5 (24)	138 ±40 (24)	0.95 ±0.63 (24)	0.064 ±0.132 (24)	0.083 ±0.033 (24)	0.018 0.014 (24)
Pool 54	8.59 ±0.18 (60)	1420 ±524 (60)	83 ±17 (57)	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
GRQ18 (upstream of LW37)	8.34 ±0.36 (69)	1287 ±513 (69)	89 ±26 (65)	5 ±2 (53)	5 ±2 (53)	308 ±127 (53)	488 ±202 (52)	20 ±10 (52)	139 ±53 (53)	1.11 ±0.76 (53)	0.082 ±0.192 (53)	0.073 ±0.035 (53)	0.019 ±0.014 (53)
GRQ100 (downstream of LW38)	8.27 ±0.49 (18)	1258 ±603 (18)	80 ±15 (18)	4 ±2 (16)	4 ±1 (16)	331 ±120 (16)	514 ±207 (16)	17 ±5 (16)	141 ±46 (16)	0.782 ±0.370 (16)	0.038 ±0.028 (16)	0.089 ±0.040 (16)	0.017 ±0.009 (16)

NA: Insufficient data available to establish a baseline at the time this report was written.

TABLE 2.6 AVERAGE BASELINE FIELD-MEASURED WATER QUALITIES IN MALLATY (14.09.11 – 11.09.12) AND NEPEAN CREEKS (13.08.09 – 2.08.12).

Site	N	Field pH	Field EC µS/cm	DO % Sat.
MC105	24	7.46 ± 0.19	522 ± 91	47.7 ± 18.1
NC10	31	7.25 ± 0.47	3014 ± 1889	34.9 ± 19.4

TABLE 2.7 AVERAGE BASELINE LAB-MEASURED WATER QUALITIES IN MALLATY (14.09.11 – 11.09.12) AND NEPEAN CREEKS (13.08.09 – 2.08.12).

Site	N	Ca mg/L	Mg mg/L	Na mg/L	T. Alk. mg/L as $CaCO_3$	SO_4 mg/L	Cl mg/L	Tot. Fe mg/L	Tot. Mn mg/L	Filt. Ni mg/L	Filt. Zn mg/L
MC105	2	19 ±15	44 ±45	197 ±203	113 ±88	31 ±4	363 ±360	2.84 ±2.68	0.444 ±0.455	0.002 ±0.000	0.028 ±0.026
NC10	15	20 ±7	90 ±41	467 ±222	149 ±60	26 ±18	898 ±436	1.95 ±2.08	0.445 ±0.504	0.001 ±0.001	0.017 ±0.009

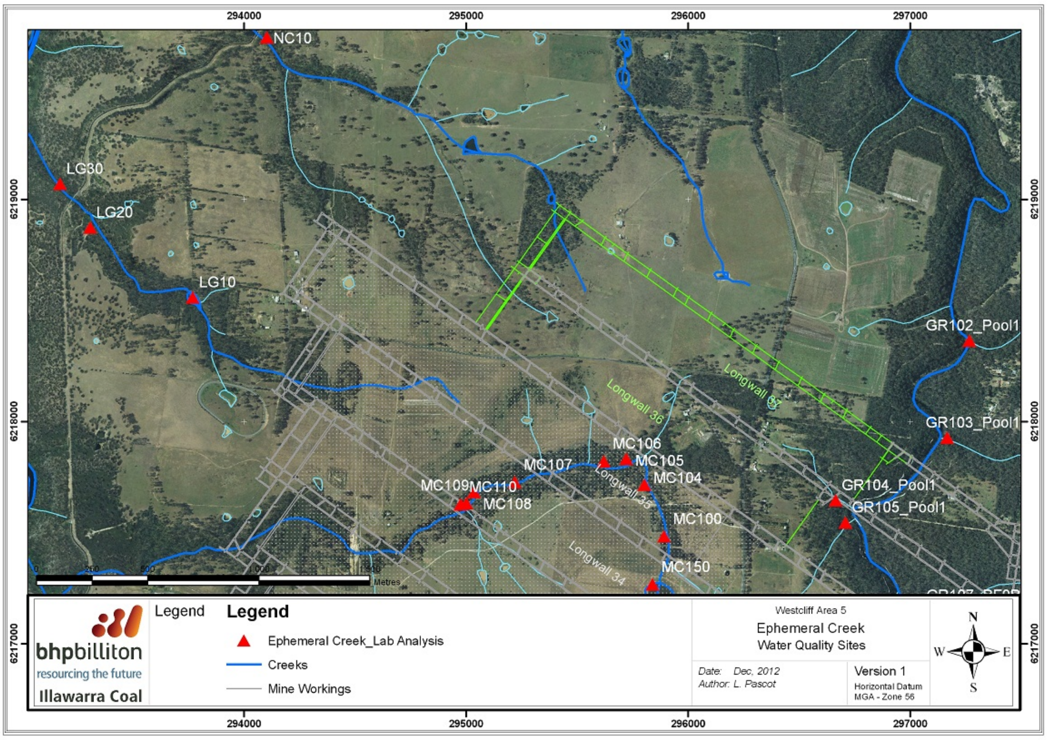


Figure 2.9 Established Water Quality Monitoring Sites in Mallaty Creek, Nepean Creek and Leafs Gully.

The issue of salinity is relevant to the assessment of potential impact(s) on aquatic ecology for Longwalls 37 – 38 because two chemically very different regimes of aquatic geochemistry exist in the study areas, and which may be affected to differing degrees by mine subsidence-related effects:

1. The lower salinity (lowland river) context of Georges River where runoff into the River is dominated by a mix of Hawkesbury Sandstone Woronora Plateau landscape (on the eastern side of the River) and Cumberland Plain (Lowlands) landscape (on the western side of the River and on the eastern side from Wedderburn north), salinity of the river water expressed in Electrical Conductivity (EC) units, even taking into account the West Cliff Colliery environmental discharge from BCD is unlikely to ever exceed about 4000 µS/cm and chloride and sulfate concentrations are unlikely to frequently exceed about 250 and 25 mg/L respectively.
2. The water quality context of Mallaty, and Nepean Creeks which arise 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 these creeks frequently exceed 10,000 µS/cm and chloride and sulfate concentrations are likely to frequently exceed 1500 mg/L and 50 mg/L respectively.

As noted in **Section 1.1**, there are no Water Quality Objectives regarding salinity arising from the Independent Inquiry in to 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 Upper Georges River should be regarded 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 past studies collecting data from 1995 onwards e.g. Jarvis, 1997; Marine Pollution Research, 1999, the latter also reviewing studies by Campbelltown City Council. These studies have shown that the salinity of unconnected pools in the River almost invariably rise above the 30 – 350 µS/cm range set down for upland rivers in in the National Water Quality Guidelines during extended dry weather. These studies have shown that; below Brennans Creek the River has long been affected not only by discharges from Appin and West Cliff Collieries but also by drainage Appin township, agricultural land uses and small natural saline and ferruginous springs.

The western side of the River’s catchment is dominated throughout by Wianamatta Shale-derived soils, the Shale being a marine sediment (Hazelton and Tille, 1990). It is well known that such marine sediments contribute salinity to runoff and groundwater seepages (interflow, throughflow, etc.).

The Upper Nepean River is also considered to be a lowland river due to the known occurrence of large areas of the River catchment, i.e. Cumberland Plains Lowlands and Hawkesbury-Nepean Valley mantled with Wianamatta Shale-derived soils.

It can easily be demonstrated that some tributaries of the Upper Nepean River into which it flows naturally contribute relatively saline water to the River.

For example, we have previously shown (Ecoengineers, 2006b) that the long term mean salinity of lower Elladale Creek west of Appin at site NR8, a catchment which is largely mantled by Wianamatta Shale-derived soils (and drains to Nepean River), is 2899 ± 1775 µS/cm (mean ± sd), a value which is not only highly variable with respect to salinity but most of the time significantly exceeds the default trigger value (2200 µS/cm) even for lowland rivers for southeastern Australia in the national water quality guidelines (ANZECC/ARMCANZ, 2000).

Operation of the West Cliff WMS along the lines adopted in August 2004 has had the effect of significantly minimising both the salinity and volume of uncontrolled discharges from the Brennans Creek Catchment which would otherwise occur via the spillway of BCD.

3. MINING-RELATED POTENTIAL AQUATIC STRESSORS

The mechanisms of mining-induced effects such as subsidence, upsidence, and closure are described in detail in MSEC (2012). A discussion of the baseline ecological status of Study Areas is provided by Cardno Ecology Lab (2012). Potential groundwater impacts are discussed by Geoterra (2012).

The mining-induced effects listed by MSEC (2012) are discussed below in relation to their hydrological and geochemical consequences. We have previously comprehensively discussed the mine subsidence-related mechanisms driving the induction and maintenance of ferruginous springs in a number of reports (Ecoengineers, 2005b, 2005c, 2006a, 2006b, 2007, 2011).

Strains due to differential subsidence, leading to ‘upsidence’ and ‘valley closure’ caused by longwall mining 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 pools in no and low flow situations.
2. Diversion of stream flows through 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 Pty Ltd., 2005b, 2005c; 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/rhodochrosite (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.

3.1 STRATA DILATION EFFECTS OF SUBSIDENCE

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 ferruginous 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).

Geochemically, Wianamatta Shale, being a 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 may be 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 and manganese oxides (after siderite and rhodochrosite).

Dilation of the strata between the Sandstone and the Shale 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. Significant, pronounced water storage at the Wianamatta/ Hawkesbury interface has been evidenced 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. 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: a very high magnesium/calcium (Mg/Ca) mole ratio of +3.6 – +5.0 (noting it is +5.2 in seawater), a very low strontium/calcium mole ratio (Sr/Ca) of 0.004 – 0.009 (noting it is 0.009 in seawater), a narrow log bromide/chloride (log(Br/Cl)) mole ratio of -2.85 – -2.95 (noting it is -2.81 in seawater), a narrow log boron/chloride (log(B/Cl)) mole ratio of -11 – -18 (noting it is -12 in seawater), and a narrow log sulfate/chloride ($\log(SO_4/Cl)$)

mole ratio of typically -1.3 – 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 sodium, Na, potassium, 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 rhodochrosite) 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 weakly acidic pHs when properly sampled *in situ* or immediately upon emergence and if not subsequently passed through bulk fractured sandstone.

Table 3.1 gives the major chemical characteristics of key examples of such water samples that have been analysed in the Southern Coalfield over the last eight years.

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 (also known as oxyhydroxides), generating acidity and consuming oxygen.

Fe and Mn oxidation and precipitation of hydrous oxides creates acidity principally through the following reactions:

$$2Fe^{2+} + 0.5O_2 + 3H_2O \rightarrow Fe_2O_3.H_2O + 4H^+$$

$$Mn^{2+} + 0.5O_2 + H_2O \rightarrow MnOOH + 2H^+$$

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, ecotoxic effects can obviously be caused by low dissolved oxygen levels induced where such springs enter a watercourse.

TABLE 3.1 WIANAMATTA SHALE WATERS OBSERVED IN SOUTHERN COALFIELD BOREHOLES AND FERRUGINOUS SPRINGS

Sample Name	Date	pH	EC µS/cm	Ca mg/L	Mg mg/L	Na mg/L	Filt. Fe mg/L	Filt. Mn mg/L	Cl mg/L	SO_4 mg/L	Mg/Ca mole ratio
Georges River Borehole GRIP1	**12/05/99**	7.20	531	5.1	12	46	21.2	1.2	97	4	3.9
Georges River Borehole GRIP2	**12/05/99**	6.96	1301	4.4	11	240	21.8	0.64	130	14	4.12
Cataract Tunnel Seepage	**17/05/00**	7.07	9780	151	415	1450	<0.01	0.21	2930	171	4.53
Cataract Tunnel 404 Seepage	**22/06/01**	6.76	9230	118	354	1590	0.41	0.27	2980	146	4.95
Borehole Appin 72	**03/04/01**	7.80	9200	149	358	1360	0.01	0.30	2740	128	3.96
Borehole Appin 69	**08/08/01**	6.87	7360	147	319	1360	6.97	0.33	2760	130	3.58
Borehole Tower 22	**13/08/01**	6.65	5800	113	271	981	40.9	0.42	1930	166	3.95
Georges River Pool 11 Spring	**07/07/02 – 12/07/05 (n=13)**	7.79	1055	2.7	4.5	225	6.5	0.198	129	18	2.75
Cataract River Spring SW2	**19/07/05 – 04/04/07 (n=21)**	5.63	517	5.24	15.05	68.8	20.7	1.95	155	9.3	4.74
Site IT30 Ingham's Trib (of Ousedale Creek)	**15/11/05 – 04/12/07 (n = 25)**	6.64	8353	102	272	1029	1.30	0.83	2199	105	4.40

In summary:

1. The ferruginous springs referred to are highly visible due to the substantial 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) 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 oxidized, and if it discharges to a creek or river, it consumes dissolved oxygen (DO) in the creek or river water at and immediately downstream of the point of entry to the creek. This could have ecotoxic effects both due to a smothering effect in the creek or river bed (ANZECC/ARMCANZ, 2000).
4. If the magnitude of such a spring was sufficiently large and it were detected, detained and treated in some way within the catchment, then creek waters containing significant concentrations of dissolved Fe and Mn could also pass either indirectly or directly into Nepean River or Georges River. This in turn consumes dissolved oxygen at the point of entry which has the potential to discharge DO from the water and cause bed smothering immediately downstream.

The most important aspect of assessment and management of the above geochemical effects is acid-base accounting (e.g. Environment Australia, 1997). This involves making an inventory of the capacity of any material or collection of materials that can generate H_2SO_4 and an inventory of the capacity of the same material(s) or complementary material(s) that might be mixed, layered or underlined with the acid-generating material (e.g. local country rock, limestone, dolomite, etc.) to generate a neutralizing basicity (alkalinity).

Another possible source of alkalinity may simply be that pre-existing in a natural watercourse.

Alkalinity is usually found to be provided by calcium and magnesium carbonates which provide carbonate alkalinity but alkalinity can also be provided by sodium, potassium and other elements potentially releasable from less basic rocks such as plagioclases (feldspars). Calcium and magnesium carbonate ($CaCO_3$ and $MgCO_3$) will neutralize the acidity generated by the reaction:

$$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2$$

One mole of sulfate (a mole being the molecular weight expressed in grams) or 96 g of SO_4 is equivalent to one mole of sulfuric acid (or 98 g of H_2SO_4) which is neutralized by one mole of calcium carbonate (or 100 g of $CaCO_3$). These equivalents are often rounded to 100 g each.

A critical characteristic of Hawkesbury Sandstone in the context of upsidence-induced acid generation in Illawarra Region waterways 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.

Therefore the H_2SO_4 released by oxidation of the marcasite in the Sandstone is generally largely attenuated naturally downstream principally by dilution, and to a very much lesser extent by reaction with the low concentration of carbonate alkalinity in the passing creek or river water in which the H_2SO_4 dissolves and the release of sodium from the weathering of the kaolinite in the Sandstone under acidic conditions. This also releases dissolved aluminium, possibly also occurring at ecotoxic levels under low flow conditions.

However, this is not actually the case in the Georges River situation as the greater part of the water passing down the River through the Study Areas derives from the controlled release of water from West Cliff Colliery as detailed in **Section 2.1** above.

Frequent monitoring of the quality of the water released from BCD shows that the water flowing out of Brennans Creek into Georges River contains considerable bicarbonate alkalinity, typically in the range 1000 – 1500 mg/L expressed as calcium carbonate ($CaCO_3$) (Ecoengineers Pty Ltd., 2005a).

This alkalinity is available to neutralize any H_2SO_4 acidity released by weathering of marcasite in the fractures of sandstone exposed through the cracking of river bed and/or rock bars or through the immediate downstream precipitation of iron and manganese oxyhydroxides.

The situation in Georges River differs fundamentally from that in other rivers such as Cataract and Bargo Rivers in that the proposed Longwalls 37 and 38 layouts do not pass under the river. In addition to this, the situation in the Georges River in that, even if mining-induced sub-bed diversions and marcasite dissolution in the River does occur:

1. it is very unlikely that significantly acidic pHs could be induced (noting this possibility is quantitatively investigated by geochemical modeling above); and
2. potentially ecotoxic Aluminium (Al) will not be released from kaolinite in the sandstone as both the mineral and Al itself are very insoluble within the pH 6.5 – 8.5 range.

It should be noted that in relation to nickel (Ni) and zinc (Zn), which may be released from marcasite during dissolution, the water released from BCD also contains trace concentrations of these metals. Consequently, in the Georges River there is a potential for an increase in the total concentration of Ni and Zn should fracturing occur. It may also be noted, however, that the site-specific chemistry of the water from West Cliff Colliery is such that any potential ecotoxicity from metals is significantly mitigated not only by carbonate (as stated above), but also by particulate matter (hydrous ferric oxides), and humic matter (Ecoengineers 2012a, 2012b, 2012c).

3.2 EFFECTS ON POOL HABITATS

Associated with the phenomenon of upsidence fracturing of the river bed and consequent possible sub-bed flow diversions are ‘flow on’ effects that may impact ecologically on large pools in the River.

These pools generally constitute the major habitats for the aquatic biota, in particular attached algae, benthic macroinvertebrates, fish, insect larvae and other organisms as they contain the greatest density of refugia for organisms from the turbulent and erosive effects of high flows and drying out under conditions of low flows.

Upsidence-induced fracturing particularly occurs at rock bars where tensile stresses are highest, and it is these structures which tend to confine the most significant habitat pools along the stream or river.

As a consequence of rock bar fracturing, the confined pool may drain down to a much lower minimum volume, especially under low flows that do not exceed the hydraulic maximum sub-bed flow rate. In some cases the pool can be drained completely under low or no flow conditions.

If pools lie immediately downstream of fractured rock bars they can be subjected to chemical stressors from flow of the sub-bed diverted waters into them.

These potential stressors are:

1. reduced pH (i.e. increased acidity);
2. dissolved oxygen (DO) depletion though oxidation of ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions;
3. possible ‘smothering’ of pool boulder and bed surfaces by the consequent precipitated Fe and Mn hydrous oxides although it is noted this ‘effect’ is common in the natural aquatic environment and are usually accompanied by large volumes of highly permeable masses of algae, bacteria and associated biofilm; and
4. possible ecotoxic effects from metals, principally aluminium (Al), nickel (Ni) and zinc (Zn) released from kaolinite and marcasite in the sandstone or from other outcropping strata (e.g. Wianamatta Shale).

The potential ecological consequences of these effects is discussed by Cardno Ecology Lab (2012), noting that to date there is no site specific evidence that any of the mining-related stressors listed in 1 – 4 above have been directly responsible for the current ecological status of the Georges River (The Ecology Lab, 2007).

3.3 EROSIVE EFFECTS OF CLOSURE IN GEORGES RIVER

Closure of steeply sided valley walls or gorges may lead to erosion and loss of soil materials into the creek or river though rock falls or slumping of steep talus slopes. However, these landforms are not significant in the Study Areas and erosion of material into the creeks and the Georges River is likely to be negligible.

Monitoring and inspection of mining areas in the region over the past five years suggests there has been no visual evidence in the more heavily incised catchments studied by BHPBIC and its consultants (specifically Cataract River, headwater catchments of Cordeaux River and of Lake Avon) that this erosion effect is significant.

Within the Southern Coalfields there have been very few observations of cliff failure or significant slope instability relating to longwall mining unless the cliff or steep slope has been directly mined beneath. As the Georges River will:

- not be directly mined beneath by the proposed longwalls; and
- the River is not deeply incised into the surrounding countryside; and
- slopes on either side of the River are relatively gentle and well vegetated,

it is likely that only minor cracking would occur at the top and on the sides of steep slopes. Increased erosion of rock or movement of talus slope material into the River is considered very unlikely (MSEC, 2012). Consequently this potential effect on river water quality was not considered further.

3.4 PRIOR LONGWALL MINING AND RELATED EFFECTS IN AREA 5

West Cliff Colliery Longwalls 5A1 to 5A4 and 29 to 34 have previously been mined to the southwest of the proposed Longwalls 37 and 38 mining area. Recently, Longwall 34 was extracted between February 2010 and September 2011 with the extraction of Longwall 35 beginning on 13 October 2011. As of 24 November 2012, the face of Longwall 35 had progressed approximately 2338 m.

The impacts of prior longwall mining in the Southern Coalfield have most recently been summarized in Section 5 and Table 5.13 in MSEC (2012).

The Georges River has previously been directly mined beneath by Longwalls 24 to 26 at Appin Colliery and by Longwalls 5A1 to 5A4 at West Cliff Colliery. Longwalls 20A to 23 at Appin Colliery and Longwalls 1 to 10, 16 to 24 and 29 to 35 at West Cliff Colliery have been mined adjacent to the Georges River.

Impacts previously associated with mining in Area 5 have been greatest where longwalls passed directly under the Georges River. The layouts of proposed Longwalls 37 and 38 have been deliberately set-back from the River so that any impacts are negligible to minor, in keeping with other extracted longwalls which did not mine directly beneath the River. Nevertheless, a brief summary of impacts where the River was directly undermined is included here for comparison.

3.4.1 Observed Geochemical Impacts in Area 5 where Directly Undermined

The locations and timing of observed impacts during the mining of Longwalls 5A1 to 5A4 which mined directly beneath the Georges River were summarized in Sections D.2.1 and D.2.2 of MSEC (2007) as follows:

- Gas in the pools adjacent to Jutts Crossing and from Marhnyes Hole;
- Fracturing of rock bars, including rockbar RB10 at Jutts Crossing and rockbars RB15 and RB16 at Marhnyes Hole;
- Reduction in the water level of some pools during times of low and no flow;
- Greater interaction between surface water and groundwater;
- Formation of a long lived ferruginous, weakly saline spring at Pool 11 over Longwall 5A2; and
- Oxidation of ferrous iron, producing reduced dissolved oxygen levels and the formation of ferruginous precipitates in the river.

The Georges River Pool 11 spring arose in November/December 2000, was responsible for the long duration release of ferruginous material into the Georges River, and only completely dried up in early 2006.

The Pool 11 Spring lay in the centre of an area that was mined under by West Cliff Longwall 5A1 from May 1999 to January 2000 and by Longwall 5A2 from February 2000 until November 2000. Both of these longwalls mined across and under the River.

It was inferred the Spring derived its water from the mined-under diverted portion (estimated to be about 0.2 km^2) of a 1.1 km^2 catchment of a small creek flowing into the River nearby at Pool 12. The catchment providing the water supply for the Spring occupied a significant portion of the urban area of Appin which contained a considerable drainage network (Ecoengineers Pty Ltd., 2005b).

Water quality monitoring carried out over the period from when those longwalls mined under the river up to the present day failed to identify any significant degree of fracturing of pristine sandstone in the river bed leading to the oxidative dissolution of marcasite and hence measurable geochemical effects on river water.

This is ascribed to the hydrogeologically complex nature of the River. It is concluded that the principal effect of upsidence and subsidence on the river bed from the mining of Longwalls 5A1 to 5A4 was to produce lateral movement and dilation of only pre-existing, well weathered bedding planes (causing sub-bed flow diversions) but conversely with very little (vertical) fracturing of pristine sandstone between such planes.

Some minor mobilization of iron may have occurred as a result of reducing conditions developing within the shifted and dilated bedding planes (e.g. from dissolution of siderite following anaerobic decomposition of organic matter accumulated in them).

Fracturing of rockbars in Georges River observed following extraction of Longwalls 5A3 and 5A4 may have also contributed to the appearance of ferruginous precipitates in the River and reduced observed dissolved oxygen levels due to dissolution of siderite.

This effect is known to also occur under natural conditions. It is known that much Hawkesbury Sandstone contains siderite (ferrous carbonate) as cement, and as discrete more massive bodies resulting from diagenetic alteration of original sedimentary conglomerate clastic material. Although siderite is distributed very heterogeneously in the Sandstone it is believed to occur overall at an average level of around 4%.

On the basis of experience with the Georges River Pool 11 Spring, 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.

In 2005 we made an assessment and modelling of the potential magnitude of the above geochemical effects using data obtained over past years from Lower Cataract River (Appin Colliery), from Bargo River (Tahmoor Colliery) and, in most detail, from Native Dog Creek (Elouera Colliery).

In summary, we found that:

1. the estimated <u>maximum</u> daily rate of acid generation in any discrete sub-bed flow diversion 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
2. prior experience in Native Dog Creek over the nearby Elouera Colliery founded on closely similar Hawkesbury Sandstone terrain and at other

mining-affected locations in the region shows that this maximum possible peak rate is not sustained for any more than a few months.

Given the fact that the layouts of Longwalls 37 and 38 have been proposed to avoid undermining the Georges River, any oxidative effects due to sandstone fracturing are expected to be greatly diminished from these observations. Recent examples of reductions in impacts include Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River and West Cliff Area 5 Longwalls 31 to 34 adjacent to Georges River.

3.4.2 Observed Hydrological Impacts in Area 5 where Directly Undermined

Previous piezometer arrays established close to Georges River, i.e. associated with Longwalls 5A1 - 5A4, were originally designed to measure the combined near-surface water system hydraulic potential to 10 metres below the River base. Subsequent installation of deeper piezometers confirmed the sub-horizontal and "perched" nature of individual near surface water storage zones.

The fact that separate perches were identified after the extraction of Longwalls 5A1, 5A2, 5A3 and 5A4 confirms that significant vertical permeability enhancement was not induced by their extraction. In other words, it appears that vertical fracturing of pristine (i.e. previously competent) sandstone between pre-existing bedding planes had not been significant.

A depression of the near surface water table just north of Jutts Crossing coincided with a similar depression in the lower perch. This was caused by either a much localised vertical fracture system or an accidental borehole connection between the two systems.

3.4.3 Observed Geochemical Impacts in Area 5 without Direct Undermining

MSEC (2012) note that the majority of observed mining-induced fractures in stream and river beds were located directly above extracted longwalls and that only a small number of mining-induced fractures have been observed in riverbeds that have not been mined directly beneath.

In terms of predicting the likely impacts of Longwalls 37 and 38, it is therefore most relevant to consider past impacts from Longwalls 29 to 34 which did not mine directly beneath the Georges River.

The layout of Longwalls 29 and 31 in relation to the Georges River is shown in **Figure 3.1** below taken from Figure D.6 in MSEC (2007). It is noted that Longwall 29 was offset from the Georges River by a minimum of 55 m at its northeastern corner and Longwall 31 was offset from the River by a minimum of 30 m.

Only minor gas release was observed during the extraction of Longwall 29 (completed July 2004) and Longwall 31 (completed December 2006).

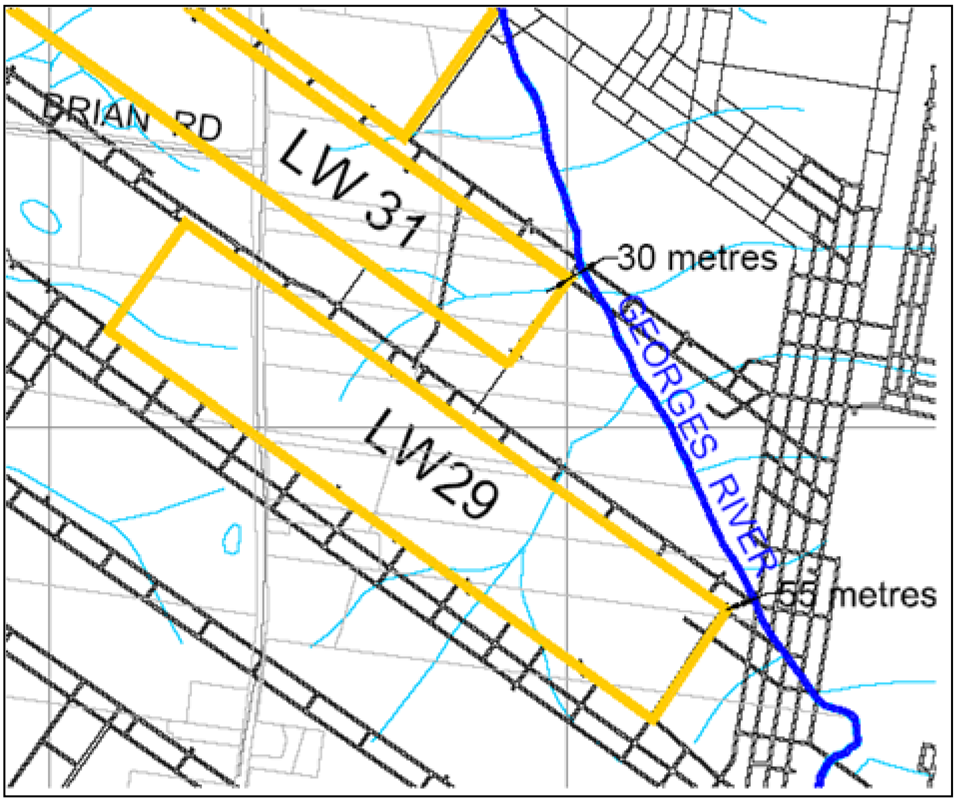


Figure 3.1 Layout of West Cliff Longwalls 29 and 31 in relation to Georges River

Longwalls 32, 33, 34, 35 and the proposed 36 were designed to completely avoid coal extraction directly beneath the Georges River. These longwalls under-laid undulating areas to the west of the Georges River that drain largely to the Nepean River.

Longwall 30, which did not mine close to Georges River, did however mine under the upper catchment of the arbitrarily named Ingham's Tributary of Ousedale Creek (which flows into Nepean River) as shown in **Figure 3.2**. It is expected that the upper part of the catchment of Ingham's Tributary is mantled by Wianamatta Shale or soils derived from the Shale (refer **Figure 1.3**).

A ferruginous, moderately saline spring was detected in November 2005 at site IT30 in Ingham's Tributary (**Figures 3.2 and 3.3**), five months after completion of Longwall 30.

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 as describe in detail in **Section 3.1**. Such springs do not appear to occur in terrain where Wianamatta Shale and Shale-derived soils do not outcrop.

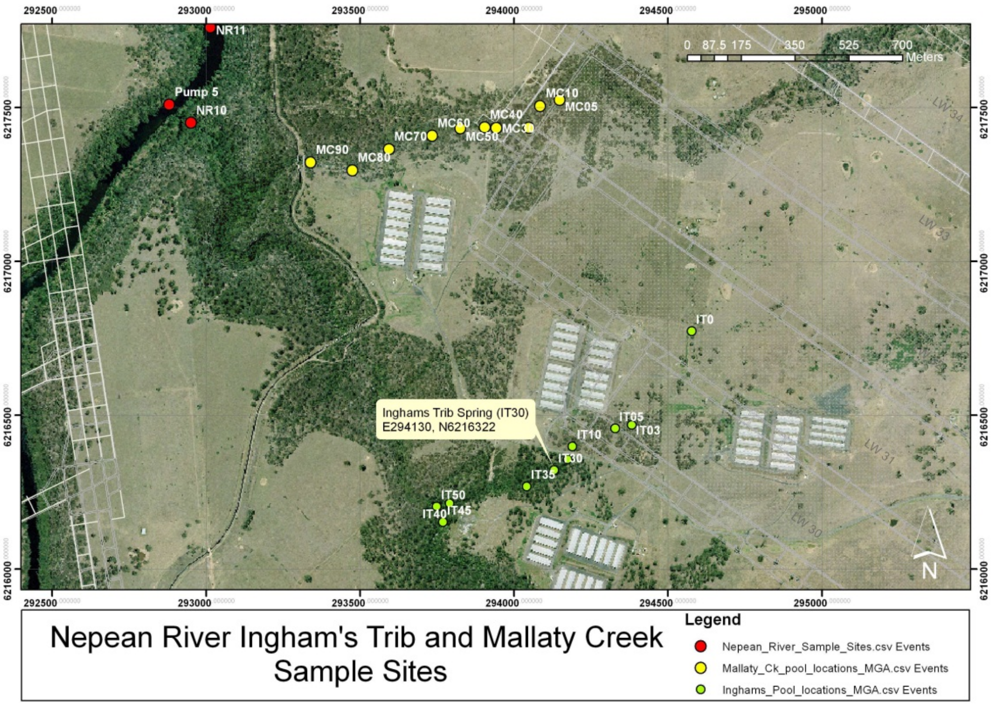


Figure 3.2 Location of Water Quality Monitoring Sites in Ingham's Tributary (of Ousedale Creek) Including Location of Ferruginous Spring (IT30).

Figure 3.3 Ingham's Tributary IT30 Spring site 18 December 2007

Most recently, the mining related impacts of Longwall 34 extraction on Georges River and the ephemeral Mallaty Creek and Leafs Gully were assessed by us (Ecoengineers, 2011).

No impacts to water quality were found to have occurred as a result of the mining activity associated with Longwall 34 in any of the monitored watercourses. However, minor fracturing was found to occur in both the Georges River (at Rockbar 41) and Mallaty Creek (at site MC09) on the 28 October and 3 November 2011, respectively. Localised reduction in pool water level was only observed to occur at MC09 in Mallaty Creek.

There is, however, evidence for the occurrence of pre-existing springs within, or in close proximity to the vicinity of the Longwall 37 Study Area.

Iron floc was observed by The Ecology Lab (2007) in Upper Nepean Creek within the Study Area. This is possibly indicative of the presence of a pre-existing ferruginous spring in the upper reaches of Nepean Creek.

Further, over 5 - 8 November 2007, The Ecology Lab established an aquatic ecology monitoring site variously designated Site 10 or Site 5, in the middle area of Mallaty Creek in an apparently semi-permanent series of pools just upstream of the Eastern Gas Pipeline (refer Table 3 and Plate 5a of The Ecology Lab, 2007). The site is near the western end of an earlier SMP Area for Longwall 31 (MSEC, 2005) and corresponds to the BHPBIC water quality monitoring site MC130. They assessed these pools as a Class 3 (moderate) habitat for fish i.e. suitable for yabbies and eels.

The Ecology Lab (2007) reported that the water quality of this site was such that the mean pH was 7.54 ± 0.06 and the mean EC was 285.5 ± 4.5 µS/cm. This site is situated over the northern side of Longwall 32 about 5 cut throughs from its western end. The site would have been previously mined under at the time of The Ecology Lab field studies. It is noted that The Ecology Lab had also recorded a pH of 7.86 ± 0.01 and an EC of 1333 ± 1 µS/cm at this site on 16 May 2002 (refer Table 3; The Ecology lab, 2003).

On 5 November 2007 the BHPBIC field team recorded a pH of 6.69 and an EC of 5612 µS/cm at site MC05 some 500 m downstream of the aforementioned The Ecology Lab (2003, 2007) site. Again on 14 November they recorded a pH of 6.34 and an EC of 5612 µS/cm at the MC05 site. These pHs are a full pH unit lower than recorded by The Ecology Lab at the upstream site. The BHPBIC field team also recorded that DO at site MC05 was 37.3% of saturation on 5 November 2007, and only 8.9% on 14 November 2007, confirming that lower pHs are associated with lower DO as expected from its consumption through oxidation/precipitation of dissolved Fe and Mn.

These observations indicate quite clearly that a significant saline spring must be located in mid Mallaty Creek somewhere in between The Ecology Lab Site 5 and BHPBIC site MC05 which was subject to dilution under conditions of active runoff and flow in the Creek around 20 August 2007.

Judging from previous water quality data obtained by BHPBIC prior to February 2007, this unidentified spring appears to have been in place well prior to the commencement of mining of Longwall 32 (from the western end) on 2 February 2007.

3.4.4 Observed Hydrological Impacts in Area 5 without Direct Undermining

BHPBIC Environment Team monitored two groundwater bores near to Georges River (GR27 and GR28) during the extraction of Longwall 34 (BHPBIC 2011). Water levels in Bore GR27 were stable during the monitoring period. Water levels in Bore GR28 declined towards the end of the Longwall 34 extraction period but showed some recovery following rainfall events at the end of the monitoring period.

Six piezometers at different depths in a bore hole in the Mallaty Creek catchment were also monitored by BHPBIC Environment Team during the extraction of Longwall 34 (BHPBIC 2011). The two shallowest piezometers (at 55 m and 95 m depth) remained active during the period of mining and showed no systematic declines in groundwater heads during the extraction period.

The results of the bore and piezometer monitoring during extraction of Longwall 34 indicate only minor impact to near-surface groundwater systems.

4. PREDICTED WATER-RELATED EFFECTS FROM LONGWALLS 37 AND 38

4.1 PREDICTED WATER-RELATED EFFECTS ON GEORGES RIVER AND NEPEAN RIVER

Predicted impacts of the mining of Longwalls 37 and 38 on Georges River are presented in Section 5.2 of MSEC (2012) and discussed below.

The Nepean River is located outside the general Study Area and is at a distance of approximately 2.2 km west of Longwall 37 at its closest point. It is unlikely, therefore, that the river would be subjected to any significant systematic subsidence movements resulting from the extraction of the proposed Longwalls 37 and 38.

The Nepean River could be subjected to very small far-field horizontal movements as a result of the extraction of the proposed longwalls. Far-field horizontal movements have, in the past, been observed more than 1 kilometre from longwall extractions, however, these movements tend to be bodily movements associated with very low levels of strain and in any event have not been associated with any water flow or quality-related effects. Therefore, there is no further discussion of impacts on the Nepean River and further discussion focuses on the Georges River.

4.1.1 Effects Resulting from Tilt

Although the Georges River has a relatively shallow natural gradient within the Study Area, it is unlikely that there would be any significant increases in the levels of ponding, flooding, or scouring of the river banks, as the maximum predicted changes in grade along the River are very small, being less than 0.1%. It is possible, however, that there could be some very localised increased levels of ponding or flooding where the predicted maximum tilts coincide with existing pools, steps or cascades along the river, however, any changes are expected to result in negligible impacts.

The predicted changes in the cross-bed gradients are very small and are expected to be an order of magnitude smaller than the natural River cross-bed gradients. The potential impacts associated with changes in the stream alignment, resulting from the extraction of the proposed longwalls are therefore expected to be minor or negligible. The potential impacts of the changes in the stream alignment are expected to be minor when compared to the changes in the River depth and width that occur during times of high flow. The potential impacts of scouring are also likely to be negligible due to the nature of the sandstone river bed.

4.1.2 Impacts from Fracturing

The experience gained from previous longwall mining in the Southern Coalfield indicate that mining induced fracturing in bedrock and rock bars are commonly found in sections of rivers and creeks that are located directly above extracted longwalls. However, minor fracturing has also been observed in locations beyond extracted longwall goaf edges, the majority of which have been within the limit of systematic subsidence. In a few isolated cases, minor fracturing has been observed up to 400 m outside extracted longwall goaf edges.

The proposed Longwalls 37 and 38 mine up to, but not beneath, the Georges River. At their closest point, Longwalls 37 and 38 remain 20 and 45 m from the centreline of the Georges River, respectively.

The maximum predicted closure movements along the Georges River, resulting from the extraction of proposed Longwalls 37 and 38 are therefore generally less than those back predicted for all case studies which had observed significant impacts such as river flow diversions (MSEC, 2012).

MSEC (2012) defines >200 mm closure as the criterion for >10% chance of a Type 3 impact (i.e. observed pool water loss). The setback of Longwalls 37 and 38 is proposed to be > 50 m from the majority of rockbars and all boulder fields, limiting predicted closure to 200 mm (MSEC 2012). The one exception to this is rockbar GR-RB61 which is set back 27 m from the proposed Longwall 37.

Due to these set-backs, any impacts due to fracturing of rockbars are expected to be negligible or minor. It is possible that minor fractures could occur up to 400 metres from the proposed longwalls.

Given that any fracturing of the river bed is likely to be minor and localised in nature, it is unlikely that any remediation would be required following mining. In the unlikely event that any large surface fractures were to occur that resulted in pool water loss, MSEC (2012) recommends that they be remediated.

Successful remediation has occurred in the Georges River at rock bars that have been directly mined beneath by previous longwalls. As described in Section 2.4.2 of MSEC (2007), natural flow diversions have been observed along sections of the Georges River which have not been affected by mining. It is therefore possible, but unlikely, that the extraction of the proposed Longwalls 37 and 38 could slightly increase the current rate of surface water flow diversions in the River.

Recent studies into the depth of dilation of the near-surface strata due to upsidence and closure have been reported by Mills and Huuskes (2004). Extensometer readings were taken at five depths up to a maximum of 27.2 m across a creek valley with a valley depth of approximately 60 m. The valley was directly mined beneath by a series of longwalls. Maximum incremental subsidence across a nearby monitoring line was approximately 500 mm, with maximum observed total subsidence of approximately 1300 mm. In this case, extensometer readings indicated that the bedrock had dilated vertically from deeper strata by 140 mm at the surface, but the extent of dilation was extended to a depth of only 9 metres from the surface.

There have been very few instances of increases in surface flow diversions in rivers which have been previously mined adjacent to, but not directly beneath.

4.1.3 Effects Due to Ferruginous Springs

It is well known that a ferruginous, weakly saline spring developed along the Georges River at Pool 11, located directly above Longwall 5A2, after the river was directly mined beneath by this longwall in 1999. No springs developed during the extraction of Longwalls 29 to 34, none of which mined directly beneath the Georges River. There is longstanding geochemical evidence of low level, mostly visually undetectable saline springs along the River from Pool 11 northwards. However, there have been no distinct natural springs identified along the Georges River within the Longwalls 37 and 38 Study Area.

Although the proposed longwalls do not mine directly beneath the Georges River, it is possible that temporary mining-induced springs could develop following extraction. The chemical characteristics of mining-induced springs suggest that the water passes through upland Wianamatta Shale and permeates through natural or mining-induced fractures in the Hawkesbury Sandstone before emerging in the Georges River.

Vertical dilation between Wianamatta Shale and Hawkesbury Sandstone is possible along the tributaries to the Georges River, particularly if the thickness of the Shale is less than 10 metres, 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 Georges River, however, the vertical dilation is expected to be small as they are located at the ends of the proposed longwalls.

4.2 PREDICTED WATER-RELATED EFFECTS ON CREEKS AND TRIBUTARIES FROM LONGWALLS 37 AND 38

Predicted impacts on Nepean and Woodhouse Creeks are presented in Section 5.3 of MSEC (2012).

4.2.1 Effects Resulting from Tilt

The maximum predicted systematic tilts along the alignments of Mallaty, Nepean and Woodhouse Creeks are 4.9 mm/m (i.e. 0.5 %), 3.4 mm/m (i.e. 0.3 %) and 0.1 mm/m (i.e. <0.1 %), respectively, or changes in grade of 1 in 200, 1 in 300 and greater than 1 in 1000, respectively. The maximum predicted systematic tilt along the alignments of the tributaries within the Study Area is 6.0 mm/m (i.e.: 0.6 %), or a change in grade of 1 in 170.

The natural grade along the alignment of Mallaty Creek within the Study Area varies between a minimum of 10 mm/m and a maximum of 100 mm/m, with an average natural grade of 30 mm/m. The natural grade along the alignment of Nepean Creek within the general Study Area varies between a minimum of 10 mm/m and a maximum of 150 mm/m, with an average natural grade of 40 mm/m. The natural grade along the alignment of Woodhouse Creek within the general Study Area varies between a minimum of 0 mm/m and a maximum of 45 mm/m, with an average natural grade of 15 mm/m.

The predicted systematic tilts along the alignments of the creeks are therefore small when compared to the existing natural grades and are unlikely, therefore, to result in any significant increase in the levels of ponding, flooding or scouring. The predicted changes due to mining-related movements in creeks and tributaries resulting from the extraction of Longwalls 29 to 36 are also illustrated in Fig. E.04 to E.13 in MSEC 2012.

If the predicted systematic tilts along the alignments of the creeks and gullies were increased by factors of up to 2 times, the maximum predicted changes in gradient would be in the order of 1%, which is still small when compared to the existing natural gradients. It is possible that there could be localised areas along the creeks and gullies which could experience a small increase in the levels of ponding and flooding, however, any changes are expected to be minor.

The maximum tilt predicted in the Bulli Seam Operations – Environmental Assessment (BSOP EA) for West Cliff Area 5 was 7 mm/m. Therefore, the tilts predicted above are within the predictions for the BSOP EA.

4.2.2 Effects Due to Strain

MSEC (2012) predicts closure in Mallaty Creek (725 mm), and the Georges River tributaries GR104 (210 mm), GR105 (230 mm), GR108 (220 mm) and GR110 (210 mm) to exceed the 200 mm criterion for <10% chance of an impact such as pool water loss after mining Longwalls 37 and 38.

MSEC (2012) indicate that compressive strain of greater than 2 mm is likely to occur across the alignment of Mallaty Creek in particular, and to a lesser extent the tributaries noted above.

MSEC (2012) consider it possible, therefore, that some compressive buckling and dilation of the uppermost bedrock could occur along the alignments of Mallaty Creek and to a lesser extent, along the alignments of Nepean Creek, Woodhouse Creek and associated tributaries within the Study Area. It has been observed in the past, that the depth of buckling and dilation of the uppermost bedrock resulting from valley related movements is generally less than 10 to 15 metres.

It is noted that the upper sections of Mallaty, Nepean and Woodhouse Creeks are characterised by Wianamatta Shale outcrop. The Shale has an estimated maximum depth of about 20 m.

If the predicted systematic strains at the creeks and gullies were increased by factors of up to 2 times, the likelihood and extent of cracking in the beds and the likelihood and extent of fracturing and dilation in the bedrock would increase accordingly directly above the proposed longwalls. It is noted, however, that the method used to determine the valley related movements is conservative.

4.3 SITES AT HIGHEST RISK OF IMPACT

Fracturing within the River is most likely where the predicted mine subsidence related movements are the greatest or where the bedrock is more susceptible to increases in strain due to closure, e.g. rock bars with a large change in relative level or cross-bedded rock strata.

On the basis of the predictions of mine subsidence effects in the Georges River (refer **Section 5.2.1** in MSEC, 2012) it is believed that as a generalization:

1. It is unlikely that rock bars which are located adjacent to the proposed Longwalls 37 and 38 will fracture to such an extent that water flow diversion will be sufficient to drain pools. This is due to the 200 mm closure criteria resulting from the proposed longwalls being set back more than 50 m from mapped rockbars and riffles.
2. The rockbar most likely to fracture due to proximity to proposed Longwalls 37 and 38 is GR-RB61. All other rockbars are 150 m or greater from the closest point of mining.

As regards the induction of ferruginous springs or exacerbation of existing springs, the areas of highest risk are those in shale catchments, and in particular, at the interface between exposed shale and sandstone.

The drainage lines most likely to see impacts due to springs are therefore Mallaty Creek and its tributary MC5, both of which cross the interface between catchments mantled by sandstone and shale. The Nepean Creek and Woodhouse Creek, within the Study Area are largely in shale dominated catchments and could also incur impacts from ferruginous springs.

4.4 MODEL-PREDICTED MAXIMUM EFFECT OF SUB-BED DIVERSION IN RIVER

The estimated typical river water quality obtained just upstream of the Longwall 37 Study Area (at site GRQ17, i.e. of River water entering the Study Area) between August 2004 and January 2010 is given in **Table 4.1**.

We have assumed that up to a flow of 1.81 ML/day through the Study Areas (i.e. the 70 percentile flow from West Cliff Colliery – refer **Table 2.4**) all water has the composition given in **Table 3.1**.

TABLE 4.1 ESTIMATED RIVER WATER QUALITY IMMEDIATELY UPSTREAM OF THE LONGWALL 37 STUDY AREA (SITE GRQ17)

Parameter	Value
pH	8.52 ± 0.35 (n=202)
EC (µS/cm)	1551 ± 610 (n=200)
Na (mg/L)	346 ± 151 (n=55)
K (mg/L)	2.8 ± 1 (n=55)
Ca (mg/L)	5.0 ± 2 (n=55)
Mg (mg/L)	3.7 ± 2 (n=55)
Total Alkalinity as $CaCO_3$ (mg/L)	551 ± 252 (n=54)
Cl (mg/L)	147 ± 58 (n=55)
SO_4 (mg/L)	24 ± 10 (n=54)
Dissolved Ni (mg/L)	0.085 ± 0.042 (n=55)
Dissolved Zn (mg/L)	0.022 ± 0.015 (n=55)

In line with the discussion on river flows in **Section 2.2** above, we have adopted 0.42 ML/day as the 10 percentile flow, 1.07 ML/day as the 50 percentile flow and 1.81 ML/day as the 70 percentile flow in the River through the Study Areas. Note that Dissolved Oxygen is referred to as DO.

The model data presented in **Table 4.2** below are to be considered 'worst case' estimates of water chemistry effects immediately downriver that is, at the 'emergence and mixing point' of the acid-generating effects of discrete sub-bed flow diversion zones in the Study Areas of any fracture-impacted sub-bed flow diversion area for the 10, 50 and 70 percentile flows in the River.

These estimates have been obtained by geochemical modelling using the United States Geological Survey (USGS) open source model PHREEQC 2.18 (Parkhurst and Appelo, 1999) reacting marcasite of composition $Fe_{0.729}Mn_{0.125}Zn_{0.125}Ni_{0.021}S_2$ at 50 mole/day (yielding 100 moles/day H_2SO_4) with various sub-bed diversion flows. Formation constants for Ni and Zn carbonate species were updated in keeping with recent improvements in understanding of Ni carbonate solute speciation (Baeyens and Bradbury, 2003) and Zn carbonate solute speciation (NIST 46.8, 2004).

It is noted from **Table 4.1** above that water in the Georges River (released from West Cliff Colliery) already exceeds the default trigger values in the National Water

Quality Guidelines (for protection of 95% of all aquatic species) for dissolved Ni and Zn.

However, not all species of Ni and Zn are believed to be ecotoxic (Tessier and Turner, 1995; Slaveykova and Wilkinson, 2005). As a conservative measure, we have assumed all cationic species of Ni and Zn (such as Ni^{2+}, $NiOH^+$ and $NiHCO_3^+$, Zn^{2+}, $ZnOH^+$ and $ZnHCO_3^+$) have the potential to exert an ecotoxic effect.

In accord with the well-established 'decision tree approach' recommended in the national water quality guidelines (ANZECC/ARMCANZ, 2000), where firstly:

- total concentrations of a toxicant are considered; then
- dissolved concentrations are considered; then finally
- the chemically actively toxic component is estimated by speciation modelling or direct methods such as anodic stripping voltammetry,

we also modelled the aqueous speciation of the total Ni and Zn concentrations resulting from the mixing of river water with water passing through a sub-bed diversion. **Table 4.2** summarises modelled estimates of the dissolved concentrations of Ni and Zn (i.e. the sum of all dissolved species) and predicted concentrations of the cationic fraction of the dissolved Ni and Zn, which may be conservatively used to represent an "ecotoxic fraction".

From **Table 4.2** below the following may be inferred:

1. Dissolved oxygen would likely be slightly below the NWQG trigger value (85%) at low river flows (e.g. 0.42 ML/day, 10^{th} percentile flow).
2. Only in the case where 0.42 ML/day or more is diverted through freshly fractured bedrock, <u>and</u> with no diluting surface flow, would emerging waters be significantly devoid of DO.
3. There would be negligible impact on river pH due to sub-bed diversions at any of the magnitudes modelled.

In terms of the metals Ni and Zn:

1. the concentrations of both dissolved Ni and Zn and cationic Ni and Zn species are higher for higher sub-bed diversion flow rates;
2. the concentrations of cationic Ni and Zn species were in every case higher than the NWQG trigger values (albeit to a minor degree in some cases); <u>but</u>
3. the estimated concentrations of dissolved Ni and Zn were <u>in every case less than</u> the measured dissolved Ni and Zn at GRQ17 (see **Table 4.1**). This is due to adsorption of Ni and Zn cations onto hydrous ferric oxide particles, produced in part by the oxidation of iron released during the sub-bed flow diversion.

The modelling indicates negligible impacts of sub-bed diversion, in most likely flow circumstances, due to changes in pH or dissolved oxygen. Concentrations of dissolved and ecotoxic Ni and Zn would likely be reduced compared to concentrations already existing in the Georges River water. The reduction in dissolved metals is due to any sub-bed diversion leading to the formation of hydrous ferric oxide particles.

4.5 MAXIMUM EFFECTS OF UPLAND-DERIVED SPRINGS ON GEORGES RIVER

4.5.1 Experience of the Pool 11 Spring

Pool 11 was mined under directly by Longwalls 5A1 and 5A2, and thus has only limited relevance in terms of impacts to the proposed Longwalls 37 and 38 which are set back from the river. Nevertheless the Pool 11 spring was a good example of a ferruginous spring in the Georges River and provides useful data for estimating the likely worst-case effects of an induced spring.

The Pool 11 Spring was first inspected and sampled by Ecoengineers on 8 January 2001. Although flow rate of the spring was not measured at the time, visually it appeared to be about 2 L/s, i.e. ~0.17 ML/day.

The Pool 11 Spring lay in the centre of an area that was mined under by West Cliff Longwall 5A1 from May 1999 to January 2000 and by Longwall 5A2 from February 2000 until November 2000. November 2000 was a relatively wet month of some 205 mm of rain, including a significant rainfall event occurring in the area in mid-November 2000 in which some 118 mm fell over a period of 11 days, with the bulk falling on 17 – 20 November. The preceding month of October was also relatively wet.

Shortly thereafter the spring first appeared and discharged a considerable volume of ferruginous water into the river resulting in a heavy coating of hydrous Fe oxides down river (including Marhnyes Hole) for a distance of about 2 – 2.5 km.

It is presumed the spring derived its water from the mined-under diverted portion (estimated to be about 0.2 km^2) of the 1.1 km^2 of catchment of the small creek flowing into the river nearby at Pool 12. We conclude this is a similar mechanism to the spring in Cataract River which apparently derives its water from a diverted portion of ~1.0 km^2 of the Back Gully Creek catchment over Appin Longwalls 21B, 22B and 23 (Ecoengineers, 2005b).

As noted in **Section 2.2,** annual rainfall in 2000 was 790 mm/year (= 2.15 mm/day). Evapotranspiration (ET) in the catchment which provides water for the spring would have averaged about 500 mm/year or 1.37 mm/day. This yields a <u>mean</u> infiltration of about 0.78 mm/day or some 156 m^3/day or 0.16 ML/day for a 0.2 km^2 catchment.

Some fraction of all potential infiltration would have occurred on days in which the soil's capacity for infiltration would have been exceeded due to significant antecedent rain (noting that Shale subsoils typically have a maximum permeability of the order of 30 mm/day). As previously noted the Pool 11 Spring flow rate reduced progressively over 4 years and no longer exists.

TABLE 4.2: MODELLED IMMEDIATE DOWNSTREAM 'WORST CASE' pH, DISSOLVED OXYGEN AND HEAVY METAL CONCENTRATIONS FOR DISCRETE SUB-BED FLOW DIVERSIONS AT PEAK RATE OF ACID GENERATION.

Percentile Flow in River [1]	River Flow (ML/day)	Assumed Sub-bed Diverted Flow (single location)	Estimated SO_4 (mg/L)	Estimated pH	Estimated DO % Saturation	Estimated Dissolved Ni (mg/L)	Estimated Cationic Ni (mg/L)	Estimated Dissolved Zn (mg/L)	Estimated Cationic Zn (mg/L)
10	0.42	0.21	29	8.38	70	0.043	0.024	0.069	0.018
10	0.42	0.31	31	8.31	55	0.057	0.034	0.114	0.033
10	0.42	0.42	34	8.23	37	0.075	0.048	0.175	0.057
50	1.07	0.21	26	8.47	90	0.055	0.028	0.052	0.011
50	1.07	0.31	27	8.44	84	0.061	0.032	0.076	0.017
50	1.07	0.42	28	8.41	77	0.069	0.037	0.104	0.025
70	1.81	0.21	25	8.49	95	0.061	0.030	0.043	0.009
70	1.81	0.31	26	8.48	92	0.065	0.033	0.058	0.012
70	1.81	0.42	26	8.46	88	0.070	0.036	0.077	0.017
NWQG [2]			NA	6.5 – 8.5	>85	0.011	0.011	0.008	0.008

[1] from West Cliff Colliery Licensed Discharge

[2] Trigger value for NSW lowland rivers, 95% protection level

Table 4.3 below lists the analysis of the spring water when first sampled on 8 January 2001 and compares this with analyses of 13 further samples collected between 7 June 2002 and 12 July 2005.

These data demonstrate that the water quality of the spring did not vary greatly over time. The data also show that the Pool 11 Spring discharged (Wianamatta Shale-derived) weakly saline waters to Upper Georges River also invariably contained Ni and Zn above default trigger values from the National Water Quality Guidelines for the protection of 95% of all aquatic species (ANZECC/ARMCANZ, 2000).

TABLE 4.3 CHEMICAL ANALYSES OF POOL 11 SPRING ON 8.01.2001 AND THIRTEEN SAMPLES TAKEN OVER 2002 – 2005

Parameter	Analysis of 8.01.2001	Analyses 7.06.2002 – 12.07.2005 (mean ± 1 sd, n=13)
pH	7.08	7.79 ± 0.24
EC	1270	1055 ± 390
Na	274	225 ± 195
K	2.5	1.6 ± 0.7
Ca	2.5	2.7 ± 1.7
Mg	6.9	4.5 ± 3.6
SO_4	26	18 ± 7
Cl	88	129 ± 29
T. Alk. mg/L as $CaCO_3$	448	327 ± 184
Tot. Fe	15.9	6.5 ± 2.1
Filt. Mn	No data	0.198 ± 0.071
Filt. Ni	0.109	0.066 ± 0.034
Filt. Zn	0.008	0.017 ± 0.015

4.5.2 Model-Predicted Maximum Point Source Effect of a Ferruginous Spring

The upland valleys within the Georges River catchment on the western side of the River, where Wianamatta Shales occur, are relatively small.

Consequently the area of potential subsidence and dilation of near surface strata is expected to be comparable to the ~0.2 km^2 (20 ha) that was mined under by Longwalls 5A1 and 5A2 to create the Pool 11 spring.

From the considerations in **Section 3** we conclude that longwall mining-induced subsidence effects on upland catchments in the Study Area might generate individual ferruginous springs from upland catchments discharging to the river up to a maximum recharge/discharge rate of about 0.2 ML/day and a mean recharge/discharge rate of about 0.1 ML/day.

We modelled the effects of the mixing of 0.2, 0.15, 0.1 and 0.05 ML/day of spring waters emanating from catchment over Longwalls 37 and 38 with 0.42 and 0.107 ML/day of River water, i.e. river base flows equivalent to the 10 and 50 percentile flows in the River (refer **Section 2.2** above) using PHREEQC 2.18 (Parkhurst and Appelo, 1999). Formation constants for Ni and Zn carbonate species were updated in keeping with recent improvements in understanding of Ni carbonate solute speciation (Baeyens and Bradbury, 2003) and Zn carbonate solute speciation (NIST 46.8, 2004).

This was done in order to obtain probabilistic information regarding the impact of a possible spring on the River.

We have assumed by analogy with the Pool 11 Spring, as given in **Table 4.3** above, that any subsidence-induced springs discharging to the River would have an average dissolved Fe concentration of the order of 6.5 mg/L, an average dissolved Mn concentration of 0.2 mg/L, an average Ni concentration of 0.066 mg/L and an average dissolved Zn concentration of 0.017 mg/L.

We have also assumed that for River flows up to 1.07 ML/day the upstream River water would have a composition closely similar to that given in **Table 4.1,** i.e. the average site GRQ17 chemistry just upriver of the Study Areas.

The following **Table 4.4** shows the outcomes of that modelling, giving the estimated DO, Ni and Zn levels in the River at the point of mixing of spring and River waters.

The modelling results presented in **Table 4.4** indicate that when river flow is low (10^{th} percentile) and with a high spring flow rate (0.15 ML/day or greater) minor impacts with respect to DO are likely at the point of emergence of the spring. Due to re-aeration in the river, such minor DO depletions are likely to have negligible impact on the bulk river water.

The estimated concentrations of dissolved Ni and Zn were in every case less than the measured dissolved Ni and Zn at GRQ17. Furthermore, increasing the modelled flow rate of the spring had the effect of decreasing the concentrations of dissolved and cationic Ni and Zn.

As with sub-bed flow diversions (**Section 4.4**), this effect is due to the oxidation of iron leading to formation of hydrous ferric oxide which acts as a surface on which Ni and Zn can adsorb. The adsorptive effect is very strong in the case of the ferruginous spring due to the quantity of iron released (being relatively higher than for the sub-bed flow diversion modelled in **Section 4.4** above). Adsorption in all the modelled flow scenarios had the effect of reducing cationic Zn concentrations to well below the NWQG trigger values.

The impacts of any ferruginous spring arising would, therefore, likely be aesthetic, with negligible impacts due to dissolved oxygen, and the potential for an increased ameliorative effect on any potential Ni and Zn ecotoxicity in the Georges River.

TABLE 4.4: MODELLED DISSOLVED OXYGEN SATURATION, NICKEL AND ZINC CONCENTRATIONS AT POINTS OF MIXING OF A FRESH FERRUGINOUS SPRING IN GEORGES RIVER UNDER 10 AND 50 PERCENTILE RIVER FLOW CONDITIONS (refer Table 2.4)

	Estimated Value in River at Point of Mixing 10 percentile river flow (0.42 ML/day)					Estimated Value in River at Point of Mixing 50 percentile river flow (1.07 ML/day)				
Spring Flow Rate (ML/day)	**DO (% saturation)**	**Estimated Diss. Ni (mg/L)**	**Estimated cationic Ni (mg/L)**	**Estimated Diss. Zn (mg/L)**	**Estimated cationic Zn (mg/L)**	**DO (% saturation)**	**Estimated Diss. Ni (mg/L)**	**Estimated cationic Ni (mg/L)**	**Estimated Diss. Zn (mg/L)**	**Estimated cationic Zn (mg/L)**
0.05	93	0.061	0.033	0.015	0.003	100	0.069	0.035	0.017	0.004
0.1	83	0.052	0.030	0.012	0.003	95	0.063	0.033	0.015	0.004
0.15	75	0.046	0.029	0.010	0.003	91	0.059	0.032	0.014	0.003
0.20	68	0.042	0.028	0.008	0.003	87	0.055	0.031	0.013	0.003
NWQG	>85	0.011	0.011	0.008	0.008	>85	0.011	0.011	0.008	0.008

[1] Trigger value for NSW lowland rivers

4.6 TIMESCALES OF POTENTIAL WATER-RELATED EFFECTS

The principal reasons for the decline in acid generation after an initial peak within one year of mining impacts are believed to be due to:

- the depletion of readily available siderite/rhodochrosite and marcasite in the accessible fractured Sandstone; and
- build-up of armouring over residual siderite/rhodochrosite and marcasite by precipitated hydrous Fe and Mn oxides.

The following examples are noted for springs induced in areas directly undermined by longwalls:

- The Pool 11 spring in Georges River, which contributed substantial ferruginous staining to the water and bed of the upper Georges River, declined over a period of just under 4 years.
- The peak acid generation rate of the fractured rock bar NDC2A in upper Native Dog Creek over Elouera Colliery longwalls occurred in mid May 2003. The acid generation rate of the rock bar declined strongly over several years thereafter.
- Acid generation in Wongawilli Creek, a headwater catchment of Cordeaux River (below Cordeaux Dam) declined sharply over about five years despite persistence of sub-bed flow diversions over sections of that Creek (e.g. Ecoengineers Pty Ltd., 2003, 2004).
- A relatively large spring in Cataract Gorge (SW2) arose between early 1991 and mid 1992 during the mining of Appin Longwalls 21B, 22B and possibly part of Longwall 23. The spring appears to have been active for about 20 years.

It is therefore concluded that if they do occur, such springs might generally decline over a period of a number of years, but in rare cases might in fact be relatively permanent once established.

5. ASSESSMENT AND RECOMMENDATIONS

5.1 ASSESSMENT OF LIKELY EFFECTS ON GEORGES RIVER

With respect to possible sub-bed flow diversions due to river bed fracturing (exposing siderite/rhodochrosite and possibly also significant marcasite in unweathered sandstone), such diversions arising from development of Longwalls 37 and 38 are considered unlikely for the reasons given above.

However, if they should occur, a considerable mitigative effect against ecotoxicity attributable to acidity, Ni and Zn is provided by the waters released from Brennans Creek Dam, which contain a significant concentration (1000 – 1500 mg/L typically) of bicarbonate/carbonate alkalinity which not only serves to:

- 'buffer out' any acidity generated by any dissolution of marcasite in mining-induced freshly fractured sandstone bedrock; but also
- form complexes with dissolved Ni and Zn, reducing the net concentration of the ecotoxic, cationic forms of these metals.

The following effects have been inferred, using geochemical modelling, to be the maximum short term effects at the peak rate of dissolution of marcasite in the Hawkesbury Sandstone bedrock of the river:

1. Only in the case where no surface flow to dilute water diverted through freshly fractured bedrock would emerging waters be highly reduced (Oxidation Reduction Potential; ORP <0 mV) and largely devoid of DO.
2. The effect of sub-bed diversion on pH of Georges River water would likely be negligible given the current levels of bicarbonate/carbonate alkalinity.
3. Oxidation of iron released by the sub-bed diversion would act to decrease the concentrations of dissolved Ni and Zn to below the concentrations observed in the Georges River (primarily derived from West Cliff Colliery).
4. Similarly, oxidation of iron released by the sub-bed diversion would act to decrease the concentrations of cationic (potentially ecotoxic) Ni and Zn species to below the concentrations observed in the Georges River.

The National Water Quality Guidelines explicitly allow for the consideration of site or region specific factors (ANZECC/ARMCANZ, 2000) and, in our view pHs in the Georges River between 8.0 and 9.5 are demonstrably still within the 'natural range' for lowland rivers with good access of light to the river surface and many pools that can support significant algal populations.

This is because when flows in the river under 'steady state' conditions, i.e. when pool depths remain constant due to controlled release from BCD then pHs in the river already lie in the 8.0 – 9.5 range 'naturally' especially under warm, sunny conditions.

Algal primary productivity in river pools maximizes under those circumstances and algae absorb dissolved CO_2 and bicarbonate from water and respire oxygen – thereby driving pH up. It is therefore common to observe pHs in pools in the river rising to levels as high as 9.5 during warm, sunny conditions.

Due to the comparatively high pH of the BCD discharge, it is predicted that any effect on pH from extraction of proposed longwalls will be negligible.

Because the extraction of Longwalls 29 through 34, which were not mined directly under the River, has not led to the creation of any obvious ferruginous springs, even though they have mined under an upland catchment on the western side of the river of significant size (0.72 km^2), it is inferred that the smaller catchments further to the north proposed to be mined under by Longwalls 37 and 38 are at very low risk from this phenomenon.

With respect to the possible induction of a ferruginous spring, <u>if it should occur,</u> then the following effects are inferred, on the basis of geochemical modelling, to be the maximum long term effects <u>in Georges River</u>:

1. Any depletion of dissolved oxygen at the point of mixing of the spring with river water, to below the NWQG trigger value, would only occur for low river flows (e.g. 0.42 ML/day, 10^{th} percentile flow) when the spring flow rate was greater than 0.10 ML/day.
2. The effect of a ferruginous spring on pH of Georges River water would likely be negligible given the current levels of bicarbonate/carbonate alkalinity.
3. Oxidation of iron released by the sub-bed diversion would act to decrease the concentrations of dissolved Ni and Zn to below the concentrations observed in the Georges River.
4. Similarly, oxidation of iron released by the sub-bed diversion would act to decrease the concentrations of cationic (potentially ecotoxic) Ni and Zn to below the concentrations observed in the Georges River. In the case of Zn, cationic Zn concentrations would likely be reduced to levels below the NWQG trigger values.

Given the nature of the Georges River bed, with numerous boulder fields and rockbars, it is believed that typical Re-Aeration Coefficients applying in the River would be such that any minor deficit in DO at the spring emergence point would have negligible impact. Geomorphological considerations suggest the river water should be quickly re-aerated over very short distances, likely only a few metres (USEPA, 1985).

It is concluded that such springs would only cause a considerable river DO deficiency at their emergence points <u>if</u> their flow rate exceeded 0.1 ML/day <u>and if</u> flows in the river were concurrently <0.3 ML/day. Since August 2004, river flows of <0.3 ML/day have occurred less than 7% of the time, and therefore, the likelihood of both these conditions being met at the same time is extremely low.

It is predicted that any effect of mining Longwalls 37 and 38 on pH, DO, and concentrations of Ni and Zn in the Georges River would be minor and largely aesthetic in nature.

5.2 ASSESSMENT OF LIKELY EFFECTS ON WESTERN CREEKS

It is possible ferruginous saline springs may be more prone to be induced or, if pre-existing, enhanced in westward draining catchments overlying Longwall 37 that ultimately flow to the Nepean River, e.g. Mallaty Creek, Nepean Creek and Woodhouse Creek.

This possibility has already been suggested by:

1. the drilling of Tower Colliery borehole 22 in August 2001 in which a considerable 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; and
2. detection of a spring in Ingham's Tributary of Ousedale Creek at site IT30 which was detected after completion of Longwall 30 and possibly induced or enhanced by mining of that longwall; and
3. detection of a pre-existing spring in Mallaty Creek between sites MC05 and site MC130.

Due to predicted closures of greater than 200 mm, MSEC (2012) consider it possible that some compressive buckling and dilation of the uppermost bedrock could occur along the alignments of Mallaty Creek and to a lesser extent, along the alignments of Nepean Creek, Woodhouse Creek and associated tributaries within the Study Area. Therefore, there would appear to be a possibility of induction of, or enhancement of existing ferruginous springs in the upper Mallaty and Nepean Creek catchments as a consequence of the mining of Longwall 37.

Notwithstanding, the westward draining streams are clearly strongly ephemeral in nature with ongoing agricultural land use and it is unlikely there would be any significant impact to water quality resulting from the formation of springs in these streams over and above current anthropological effects (The Ecology Lab, 2007).

Tilts predicted by MSEC (2012) for these creeks are within the maximum tilts predicted in the Bulli Seam Operations – Environmental Assessment (BSOP EA) for West Cliff Area 5. Effects of tilt on ponding, flooding and scouring are likely to be minor.

5.3 RECOMMENDATIONS

5.3.1 Hydrogeological and Geological Monitoring

The environmental monitoring proposed for the Longwalls 37 and 38 Study Areas should be based on knowledge gained from previous water quality, hydrologic and hydrogeological investigations associated with the extraction of former Longwalls 5A1 - 5A4, and in particular Longwalls 29, 31 and 32 – 36 which have also been set back from the Georges River.

Surface to near surface water interaction has been demonstrated by existing piezometer results in the Jutts Crossing area and elsewhere. At that time it was found that Georges River could be a 'losing river' that is, at least in some sections it tended to recharge groundwater and hydraulic gradient tends to slope away from the River especially under the prolonged drought conditions which applied locally between 2000 and 2006.

However, as 2007 was a year of very high rainfall of at least 90 percentile magnitude in the catchment of upper Georges River and high natural flows in the River ensued, it is likely that on balance the River became a gaining river. Since 2007, rainfall has varied from near average conditions to slightly greater than average conditions and may generally have been a gaining river.

Rock bar GR-RB61 is the only rockbar in the Study Area within 50 m of a longwall and is therefore the most likely to experience fracturing. It may be desirable to examine any available core in the vicinity of this rockbar to check for the presence of any conglomerate that contains siderite clasts and, in particular, inspected for the presence of a distinctive low strength layer of the order of 50 to 150 mm in thickness characterised by a conglomerate comprised of small quartz pebbles and various other lithic clasts.

The presence of such a layer has been identified by us as a particular element of environmental risk from the perspective of failure due to upsidence and valley closure effects (leading to sub-bed diversions) due to

- its low strength; and because
- the conglomerate contains clasts which have completely altered to siderite, noting that siderite cement in the conglomerate appears to be the major locus of marcasite and minor pyrite in Hawkesbury Sandstone.

If any pre-existing ferruginous springs were found to exist anywhere in the Study Areas, it would be prudent to install several open boreholes/piezometers through the Shale, any Mittagong Formation material between the Shale and Hawkesbury Sandstone and well into the upper Hawkesbury in their vicinity. This should occur prior to mining to enable pre- and post-mining estimation of strata dilation and permeability effects via downhole video logging.

5.3.2 Baseline and Ongoing Water Quality Effects Monitoring

Baseline surface flow and water quality monitoring (including laboratory analysis and field parameters) is already occurring in Georges River, Mallaty Creek and Nepean Creek upriver and adjacent to proposed Longwalls 37 and 38. We note that limited data from selected existing monitoring sites were available to allow the calculation of baseline water quality parameters in this report.

For Longwall 37 it is recommended that water quality be monitored (**Figure 5.1**):

- in the Georges River upstream and downstream of Longwall 37 at Pool 54 and Pool 64, respectively,
- in Mallaty Creek at sites MC100, MC106, and MC110,
- in Nepean Creek at site NC10, and
- in the tributary GR105, just upstream of the confluence with the Georges River.

For Longwall 38 it is recommended that water quality be monitored (**Figure 5.1**):

- in the Georges River upstream, adjacent to, and downstream of Longwall 38 at Pool 34, Pool 54, and GR100, respectively,
- in the following tributaries, just upstream of the confluence with the Georges River: GR102, GR103, GR104, GR107, GR108, GR110, GR114, GR117, and GR119.

It is recommended that the sampling sites be monitored on a <u>monthly basis</u>.

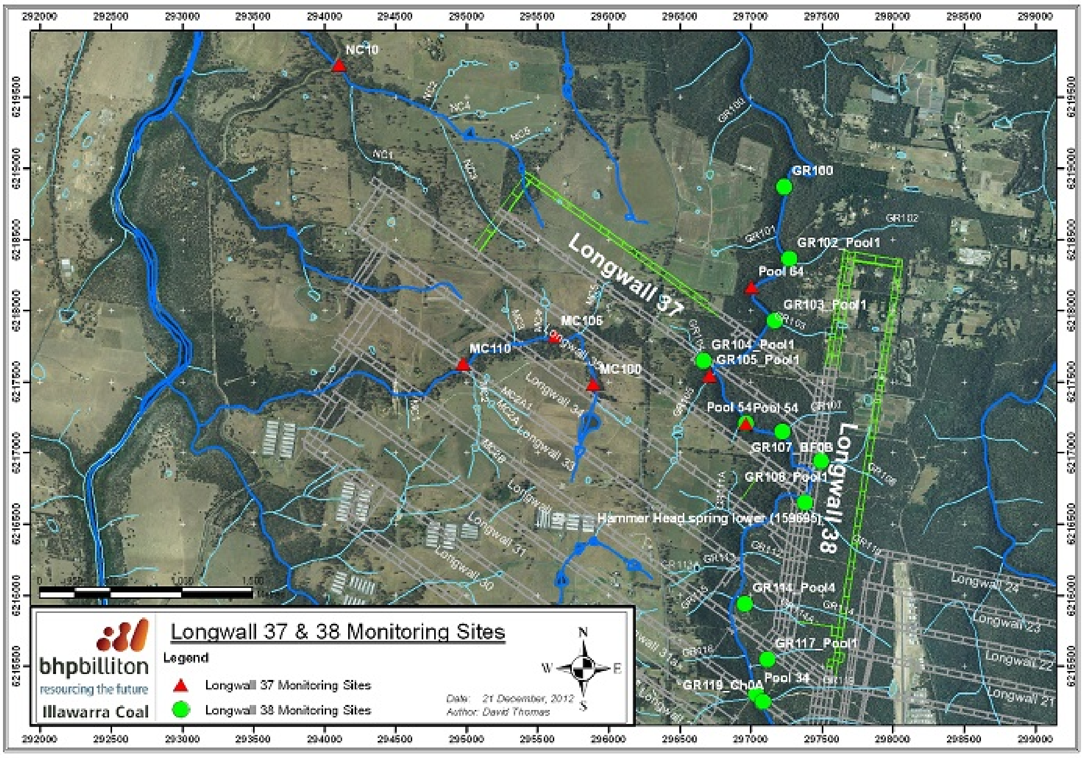


Figure 5.1 Recommended water quality monitoring sites for Longwalls 37 & 38

It is recommended that a Trigger Action Response Plan (TARP) be developed by BHPBIC to deal with the possibility of a ferruginous upland spring arising within the Study Areas, particularly in Georges River and upstream of, or within a farm dam or other commercial water storage dam in the catchments of the three western creeks.

The TARP should include a defined methodology for timely assessment of the magnitude of spring occurrence (i.e. flow rates, iron and manganese loads) pre- and post-mining and, if necessary a conceptual response methodology for modifying the geomorphology of a significant spring to affect maximum oxygenation and hence maximal iron and manganese precipitation as close to the source as possible as outlined in the following **Section 5.3.3**.

Table 5.1: Proposed water quality monitoring program for the Georges River (and associated tributaries), Mallaty Creek, Nepean Creek and Woodhouse Creek.

Georges River	
Longwall 37 • Upstream monitoring site: Pool 54 • Downstream monitoring site: Pool 64 Longwall 38 • Upstream monitoring site: Pool 34 • Adjacent monitoring site: Pool 54 • Downstream monitoring site: GR100	• Monthly monitoring of field parameters (pH, EC, DO, ORP) and sample collection for lab analysis.
Proposed monitoring sites for tributaries draining to Georges River	
• GR102 • GR103 • GR104 • GR105 • GR107 • GR108 • GR110 • GR114 • GR117 • GR119	• Monthly monitoring of field parameters (pH, EC, DO, ORP) and sample collection for lab analysis.
Mallaty Creek	
• Upstream monitoring site: MC100 • Downstream monitoring site: MC110 • Monitoring site immediately downstream of confluence with MC5: MC106	• Monthly monitoring of field parameters (pH, EC, DO, ORP) and sample collection for lab analysis.
Nepean Creek	
• Downstream monitoring site: NC10	• Monthly monitoring of field parameters (pH, EC, DO, ORP) and sample collection for lab analysis.

5.3.3 Best Practice Water Effects Management

In the event, considered by Ecoengineers to be unlikely, that future water monitoring shows significant hydrologic or water quality impacts which are potentially ecotoxic within the Study Area or immediately downstream in Georges River, then some management and mitigation measures may be required.

Any flow diversions that might occur can be fully or partially restored by remediation works such as those which have been previously undertaken successfully in the Georges River (International Environmental Consultants Pty Ltd., 2004).

On the basis of experience over the period 2004 – 2006 it is suspected that the Georges River would consist of a series of disconnected or drained pools during periods of low rainfall if the West Cliff licensed discharge did not enter the River. Consequently, if any upriver licensed discharges were changed during the mining period, it would be difficult to compare flow conditions with baseline data.

A continued flow of water from the West Cliff licensed discharge would also have the benefit of neutralising any acid produced in the unlikely event of sub-bed diversion or induction of a ferruginous spring in the Georges River.

Current River flow conditions, based on the release of at least 1.0 ML/day from Brennans Creek Dam in accord with the West Cliff Water Management System (WMS), should be maintained throughout the Longwall 37 - 38 mining period if impacts are observed in the River.

In the unlikely event that:

1. discharges from West Cliff Colliery cease for operational purposes; and
2. antecedent rainfall conditions are such that flows in the River above the Brennans' Creek confluence cease; and
3. a sub-bed flow diversion adjacent to Longwalls 37 and/or 38 is detected (through paired flow measurements and/or pool level monitoring), then

it is recommended that mitigating flows be released from the West Cliff or Appin Collieries until such time as the flow diversions are remediated.

Depth monitoring at pools within the Study Areas before, during, and following the mining of Longwalls 37 and 38, would assist in the identification of any sub-bed diversion.

With respect to excessive precipitation of hydrous iron and manganese oxides and the consequent depletion of dissolved oxygen such as might occur through the induction of ferruginous springs, it is noted that this occurs as a result of reaction with atmospheric oxygen.

In some instances, the precipitation/acid generation effect could occur relatively far down slope from the actual spring. If such a case resulted in impacts on a well-recognised pool in the Georges River, lower Mallaty Creek or Nepean Creek, or leads to a ferruginous discharge in the River, the location of the zone of maximal oxygenation could be moved upslope, closer to the spring source.

This would involve the deposition of heavy rocks and boulders closer to the spring. This material could usually be obtained from local Hawkesbury Sandstone outcrops nearby and moved to the spring emergence point by manual labour. The effect of this would be to greatly increase turbulence and hence rates of oxygenation, precipitation of hydrous oxides and acid generation allowing natural processes downslope to play a greater role in amelioration of the effects of the spring.

Modification of drainage line and stream hydrology by deposition of boulders and local rock 'rip rap' and/or neutralization with modest masses of limestone rock are accepted 'green engineering' methods widely employed worldwide in the mining and quarrying industries for improvement of environmental performance.

It is emphasized that the various mitigation measures briefly outlined above are proposed as contingent measures should adverse effects requiring such measures occur.

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Attachment D – West Cliff Longwalls 33 - 38 Aquatic Ecology Monitoring 2002 - 2013 (Cardno Ecology Lab, 2014)

West Cliff Longwalls 33-38

Aquatic Ecology Monitoring 2002-2013

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Executive Summary

BHP Billiton Illawarra Coal (BHPBIC) is using longwall mining techniques to extract coal from the Bulli Seam in Area 5 of the West Cliff Colliery in the Southern Coalfield of New South Wales. Cardno Ecology Lab was commissioned by BHPBIC to design and implement a monitoring program to detect potential changes in aquatic ecology that may arise due to the impact of mining-related subsidence on the physical and chemical characteristics of sections of the Georges River.

The latest round of aquatic ecology monitoring undertaken between 7 and 8 December 2013 included post-extraction monitoring for Longwall 35, during-extraction monitoring for Longwall 36 (although Longwall 36 had not mined near the River at this stage) and further pre-extraction monitoring for the proposed Longwalls 37 and 38. The following aquatic ecology indicators were surveyed at six study sites in the Georges River:

> Aquatic habitat, including fish habitat, aquatic macrophytes, riparian vegetation;

> *In situ w*ater quality;

> Aquatic macroinvertebrates; and,

> Fish.

The results of this survey have been compared with those obtained in May 2002, March 2005, May 2007, September 2008, May 2010, May 2012 and December 2012.

There have been no significant changes to the riparian habitat in the Georges River since monitoring commenced. The riparian strip is in good condition with relatively few introduced species, many mature trees and few breaks in vegetation.

The condition of the aquatic macroinvertebrate fauna indicated that the river had experienced some degree of environmental stress before mining commenced and that it continues to do so. In the current survey, the aquatic macroinvertebrate fauna at four of the six study sites along the Georges River was equivalent to the AUSRIVAS reference condition, while at the remaining sites was either significantly impaired or severely impaired relative to the AUSRIVAS reference condition.

Three native and one introduced species of fish were caught in the river, and freshwater crayfish and shrimp were observed at most sites sampled.

A reduction in the number of macroinvertebrate taxa and desiccation of macrophytes was observed at two sites on the Georges River in November 2013. There was also evidence of a reduction in the quality of macroinvertebrate habitat at one of these sites and a reduction in the numbers of fish and larger mobile macroinvertebrates at the other. These changes are most likely due to the mining impacts (fracturing of bedrock, loss of flow and reductions in pool water levels and associated loss of aquatic habitat and reductions in river connectivity) associated with the extraction of Longwall 35. No such impacts were evident at sites further downstream, suggesting that the majority of these impacts are restricted to the areas directly affected by mining. However if impacts to migratory fish species due to loss of connectivity between pools did occur, these would likely be experienced some distance upstream and downstream of the affected areas. On the whole, species composition of the fish assemblages sampled in November 2013 was comparable with that observed during the previous surveys.

Analysis of water quality and flow data collected up to early August 2013 as part of the End of Panel Report for Longwall 35 did not suggest any changes due to the identified mining impacts. There was also no evidence of water quality impacts in the limited data collected by Cardno Ecology Lab.

The increase in releases from Brennans Creek Dam in response the lowering of pool water levels below pre-mining levels has been successful in temporarily restoring pool water levels, flow and connectivity. This measure has reduced the impact on fish and other aquatic species due to loss of aquatic habitat, flow and connectivity.

There is no evidence to suggest that extraction of Longwall 36 has had any physical impact or impact on aquatic ecology to date.

It is recommended that increased discharges from Brennans Creek Dam are maintained for as long as practicable while low pool water levels and flow are experienced in the Georges River. This will reduce impacts to aquatic ecology associated with loss of habitat, flow and connectivity.

It is also recommended that further post-extraction monitoring be undertaken for Longwall 35, that further monitoring be done as extraction of Longwall 36 progresses and for at least two years thereafter, and that further baseline data be collected for Longwalls 37 and 38. The next survey should be undertaken during the 2014 Spring AUSRIAVS sampling season. The collection of additional during and post mining data will facilitate the assessment of the impact of the longwall extraction, if any, on the aquatic habitat and biota in the Georges River. It will also provide information that will help assess any further impacts to aquatic ecology associated with the extraction of Longwall 35, and help determine the degree of potential remediation and recovery of impacted aquatic ecology.

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Appendices

1 Introduction and Aims

BHP Billiton Illawarra Coal (BHPBIC) is using longwall mining techniques to extract coal from the Bulli Seam in Area 5 of the West Cliff Colliery in the Southern Coalfield of New South Wales. Longwalls 31-33 were extracted between July 2005 and September 2011. Mining of Longwall 34 commenced in February 2010, with extraction of Longwall 34 completed in September 2011. Mining of Longwall 35 commenced in October 2011 and was completed in July 2013. Extraction of Longwall 36 commenced in August 2013 and had progressed approximately 500 m by 19 October 2013.

Cardno Ecology Lab (formerly The Ecology Lab Pty Ltd) was commissioned by BHPBIC to assess the potential impact of longwall mining-related subsidence on the aquatic ecology of the Georges River and other nearby watercourses within the West Cliff Area 5 mine area through the implementation of an aquatic ecology monitoring programme. The aims of the monitoring programme are to:

> Assess the relative abundance of fish and macroinvertebrates and condition of aquatic habitat that may be affected by subsidence related impacts; and,
>
> Determine whether any changes observed in aquatic habitat or biota may be linked to subsidence related impacts.

In this report, the results of investigations undertaken in November 2013 in accordance with the recommendations made in the Subsidence Management Plans (SMPs) for Longwalls 34-36 are presented. The specific aims of the November 2013 investigations were:

> Undertake the first year of post-extraction monitoring for Longwall 35 and during-extraction monitoring for Longwall 36;
>
> Determine whether any changes in aquatic habitat or biota have occurred by comparing the findings of the November 2013 investigation with those from previous investigations;
>
> Determine if any changes are due to potential subsidence-related impacts; and,
>
> Provide recommendations for further work, if required, and ongoing monitoring.

The investigations also continue the pre-extraction monitoring for Longwalls 37 and 38.

2 Previous Investigations

The Ecology Lab Pty Ltd has produced a number of reports on the aquatic habitat and biota associated with the Georges River and other watercourses in the vicinity of West Cliff Area 5. These have incorporated the results of baseline surveys, predictions of mine-subsidence impacts, threatened species assessments and results of during and post-mining monitoring. The potential effects of subsidence on aquatic habitats and biota within the watercourses potentially affected by mining of Longwalls 29 to 33 were assessed in The Ecology Lab (2003). A separate report on aquatic habitats and biota potentially subject to impacts from the proposed mining of Longwalls 31 to 33 was included in the Subsidence Management Plan (SMP) submitted to The Department of Primary Industries (Mineral Resources), as part of the approvals process (The Ecology Lab 2005). This report comprised:

> A review of existing information on aquatic habitats and biota, including any threatened species that may occur in the area;

> A baseline assessment of aquatic habitats and biota within the proposed SMP Area;

> An assessment of impacts to aquatic ecology due to potential subsidence impacts; and,

> Recommendations about ongoing monitoring of aquatic ecology during and after extraction of Longwalls 31A, 32 and 33.

The potential impacts on aquatic ecology resulting from mine subsidence within the SMP Area for Longwalls 34-36 were assessed in The Ecology Lab (2008a). This assessment included:

> A review of existing information; and,

> A description of existing habitats and biota based on field investigations of the watercourses within the SMP Area.

The results of ongoing monitoring undertaken during and/or immediately after the extraction of Longwalls 31A, 32, 33, 34 and 35 have been described in their respective End of Panel Reports (The Ecology Lab 2007, 2008b; Cardno Ecology Lab 2010a; 2011) and in the 2008, 2010, 2011 and 2012 Aquatic Ecology Monitoring reports (The Ecology Lab 2008c; Cardno Ecology Lab 2010b, 2012a and 2013).

The results of additional aquatic ecology sampling undertaken in May 2012 as part of the Aquatic Flora and Fauna Assessment for Longwalls 37 and 38 are described in Cardno Ecology Lab (2012b).

2.1 Predictions

The predictions of potential impacts to aquatic ecology due to the extraction of Longwalls 31-33, 34-36 and 37-38 are summarised below:

Longwalls 31-33

> There may be (i) flow diversion and pool drainage linked to fracturing, and (ii) spring discharge of groundwater to the Georges River due to upland subsidence (MSEC 2005);

> These in turn may result in reductions in water quality, acidification, and increased metal concentrations, with the magnitude of these impacts being dependent on the volumes of any diversions, discharges and flow within the river (Ecoengineers 2005); and,

> The loss of aquatic habitat and biota due to pool drainage and flow diversions would be limited and temporary, assuming water levels returned to background levels not long after the impact (The Ecology Lab 2005). Drained pools would constitute barriers to fish passage. However, licensed discharges and ameliorative measures should allow flow to resume, resulting in only transient impacts, if any, to migratory fish.

Longwalls 34-36

> There may be minor localised increases in levels of ponding and flooding in the Georges River, very small changes in river alignment and minor fracturing, but no significant water loss (MSEC 2007). Compressive buckling and dilation of the topmost bedrock may occur along the alignments of Mallaty Creek and Leafs Gully and, to a lesser extent, along the alignments of Nepean Creek. In areas with exposed bedrock, there may be some sub-surface diversion of flows and drainage of pools;

> Fracturing due to subsidence in Georges River and Mallaty Creek may result in some sub-surface diversion of flows and drainage of pools (MSEC 2007);

> These impacts were expected to have only minor, localised impacts on aquatic biota in the Georges River (The Ecology Lab 2008a);

> Any water loss in Mallaty Creek would result in the loss of aquatic habitat and biota from the affected area. Once flow is re-established, re-colonisation by aquatic flora and fauna should occur (The Ecology Lab 2008a);

> Flow diversions could lead to minor, short-term and localised increases in the acidity of water, reductions in dissolved oxygen levels and increased concentrations of heavy metals (Ecoengineers 2007); and,

> Low dissolved oxygen levels and increased heavy metal concentrations are likely to have significant impacts on aquatic ecology only if they coincide with low flows. Any concurrent impacts on aquatic biota and ecology are otherwise likely to be minor, localised and short term (The Ecology Lab 2008a).

Longwalls 37-38

> There would be no significant impacts on the physico-chemical features of the Georges River due to the extraction of Longwalls 37 and 38 (MSEC 2012). While fracturing and flow diversion may occur, these impacts are expected to be short-lived, minor and localised in their extent;

> There would be negligible diversion of flows, negligible changes in the natural drainage behaviour of pools, negligible iron staining and negligible increases in turbidity in at least 80% of the Georges River;

> The predicted changes in ponding, flooding and stream alignment due to vertical subsidence will be negligible.

> Fracturing of the river bed and the induction or enhancement of ferruginous springs would be localised and would have negligible effects on aquatic habitats or biota in the Georges River;

> If fracturing occurs, there may be some diversion of surface flows and draining of pools in areas with exposed bedrock, however, in areas with alluvial beds fractures are likely to be filled with alluvial materials during subsequent flow events.

> Flow diversions and draining of pools in drainage lines would result in localised reductions in aquatic habitat. These would be temporary if infilling of fractures occurred. Due to the relatively limited aquatic ecology supported by ephemeral habitat and its abundance in the local area, such effects would likely be negligible in a local and regional context.

2.2 Findings

The results from the monitoring undertaken in relation to Longwalls 33-35 are summarised below:

Longwall 33

> Monitoring undertaken by the Illawarra Coal Environmental Field Team (ICEFT) indicated rock fractures, flow diversions and low water levels, iron staining and gas releases in the Georges River (Comur Consulting 2010);

> No significant impact on water quality due to gas releases, although a small loss of flow associated with flow diversions was observed (Ecoengineers 2010). Transient elevated levels of manganese and zinc and reductions in dissolved oxygen in the Georges River occurred and may be linked to iron staining;

> No evidence of concurrent impacts on aquatic ecology. Changes in the condition of aquatic habitats and biota were not linked with surface water quality data (Cardno Ecology Lab 2010a); and,

> No definitive evidence to suggest that the small changes in the condition of the aquatic macroinvertebrate fauna observed following extraction of Longwall 33 are related to the impact of mining induced subsidence on the Georges River (Cardno Ecology Lab 2012a and 2013). Nor is there any evidence of any adverse effects on aquatic habitat or fish populations in the Georges River.

Longwall 34

> Monitoring undertaken by ICEFT indicated two zones of minor fracturing in the Georges River at Rockbars 40, 41 43 and an associated zone of minor iron staining in Pool 40d, above Rockbar 41 (Comur Consulting 2012). No flow diversions were identified in these areas and pool water levels were consistent with baseline levels. In Mallaty Creek, minor compression fracturing, surface flow diversions and

localised reductions in pool water levels were observed at Pool MC 109, but water was present at the pools upstream and downstream; and,

> No significant water quality impacts were observed in either watercourse (Ecoengineers 2011) and no evidence of any impacts to aquatic ecology in the Georges River were observed during extraction of Longwall 34 (Cardno Ecology Lab 2010b). No definitive evidence to suggest that the small changes in the condition of the aquatic macroinvertebrate fauna observed following extraction of Longwall 34 are related to the impact of mining induced subsidence on the Georges River (Cardno Ecology Lab 2012a and 2013). Nor is there evidence of any adverse effects on aquatic habitat or fish populations in the Georges River.

Longwall 35

> Monitoring undertaken by ICEFT between February and November 2013 indicated fracturing in Pools 56 and 57 and a reduction in water levels below baseline levels in Pools 38, 44, 51, 54, 56, 57, 58 and 60 (BHPBIC 2013a-c). Gas releases and iron staining were observed in some of these pools. In response, releases from Brennans Creek Dam were increased and pool water levels returned to pre-mining levels during the releases. However, following cessation of increased releases, pool water levels fell below baseline levels. On 20 November 2013, following the latest increase in releases from Brennans Creek Dam, pool water levels were at or above pre-mining levels (BHPBIC 2013c).

> Analysis of flow and water quality data collected up to 5 August 2013 did not identify any significant water quality impacts in the Georges River due to extraction of Longwall 35 (Ecoengineers 2013). There was only negligible diversion of flows, changes in the natural drainage behaviour of pools, gas releases, iron staining and increases in water cloudiness over at least 80% of the river length subject to vertical subsidence >20mm up to this date. At this stage, analyses and interpretation of water quality and flow data collected post 5 August were not available for inclusion in this report.

> Aquatic ecology monitoring data collected up to December 2012 provided no evidence of any impact on aquatic ecology due to the commencement of extraction of Longwall 35(Cardno Ecology Lab 2013).

As two or more years of post-extraction data have been collected for Longwalls 33 and 34 (Cardno Ecology Lab 2012a), and there is no evidence of more than minor and transient impacts to aquatic ecology (that may or may not be related to identified mining impacts), no further ongoing monitoring in relation to these longwalls is considered necessary. Notwithstanding this, identification of any mining impacts (such as fracturing and reductions in pool water levels) potentially associated with these longwalls would trigger additional surveys of aquatic ecology.

3 Study Methods

3.1 Field Methods

3.1.1 Study Sites and Sampling Dates

The following sites on Georges River were sampled on 7-8 November 2013 (see **Figure 1**):

> Site 6: upstream reference site;

> Site 7: upstream reference site;

> Site 8: adjacent to Longwalls 35 and 38;

> Site 9: adjacent to Longwalls 35 and 36;

> Site 10: adjacent to Longwalls 36 and 37; and,

> Site 11: downstream reference site.

Monitoring of Sites 1-4 adjacent to Longwalls 29-32 ceased after the autumn 2010 monitoring event and monitoring at Site 5 adjacent to Longwall 32 and at Site 12 on Mallaty Creek ceased after the spring 2011 sampling event. Although at least two years of post-extraction monitoring for Longwalls 33 and 34 has been completed, monitoring at Sites 6 and 7 has been continued to provide upstream comparative data for Longwalls 35-38.

Each study site is approximately 100 m long. Their GPS co-ordinates are listed in **Table 3.1** and the timing of the aquatic surveys relative to the extraction of each longwall is shown in **Table 3.2**.

Table 3-1 GPS coordinates of aquatic ecology monitoring sites on the Georges River sampled 7 and 8 November 2013. Datum: WGS 84, Zone 56H.

Site	6	7	8	9	10	11
Easting	296877	296886	297145	296970	296709	297204
Northing	6216094	6216418	6216736	6217230	6217614	6218446

Table 3-2 Timing of aquatic ecology surveys relative to extraction of West Cliff Longwalls 33-36. (Pre, Dur and Pos indicate whether surveys were done pre, during or post-extraction of each Longwall).

Longwall	Start	Finish	May 2002	Mar 2005	May/Nov 2007	Sep 2008	May 2010	Nov 2011	Dec 2012	Nov 2013
32	Feb 07	Jun 08	Pre	Pre	Dur	Pos	Pos	Pos	Pos	Pos
33	Jul 08	Dec 09	Pre	Pre	Pre	Dur	Pos	Pos	Pos	Pos
34	Feb 10	Sep 11			Pre	Pre	Dur	Pos	Pos	Pos
35	Oct 11	Jul 13			Pre	Pre	Pre	Dur	Dur	Pos
36	Aug 13	Underway				Pre	Pre	Pre	Pre	Dur
37	Not yet commenced				Pre*	Pre	Pre	Pre	Pre	Pre
38	Not yet commenced				Pre*	Pre	Pre	Pre	Pre	Pre

*Sites 6, 7, 10 and 11 only.

3.1.2 Habitat Assessment

A qualitative assessment of the condition of aquatic habitats was compiled for each watercourse, based on the following attributes:

> Instream features such as sequence of pools, runs and riffles (shallow areas with broken water);

> Stream substratum;

> Potential refuge areas during periods of low flow (e.g. large deep pools);

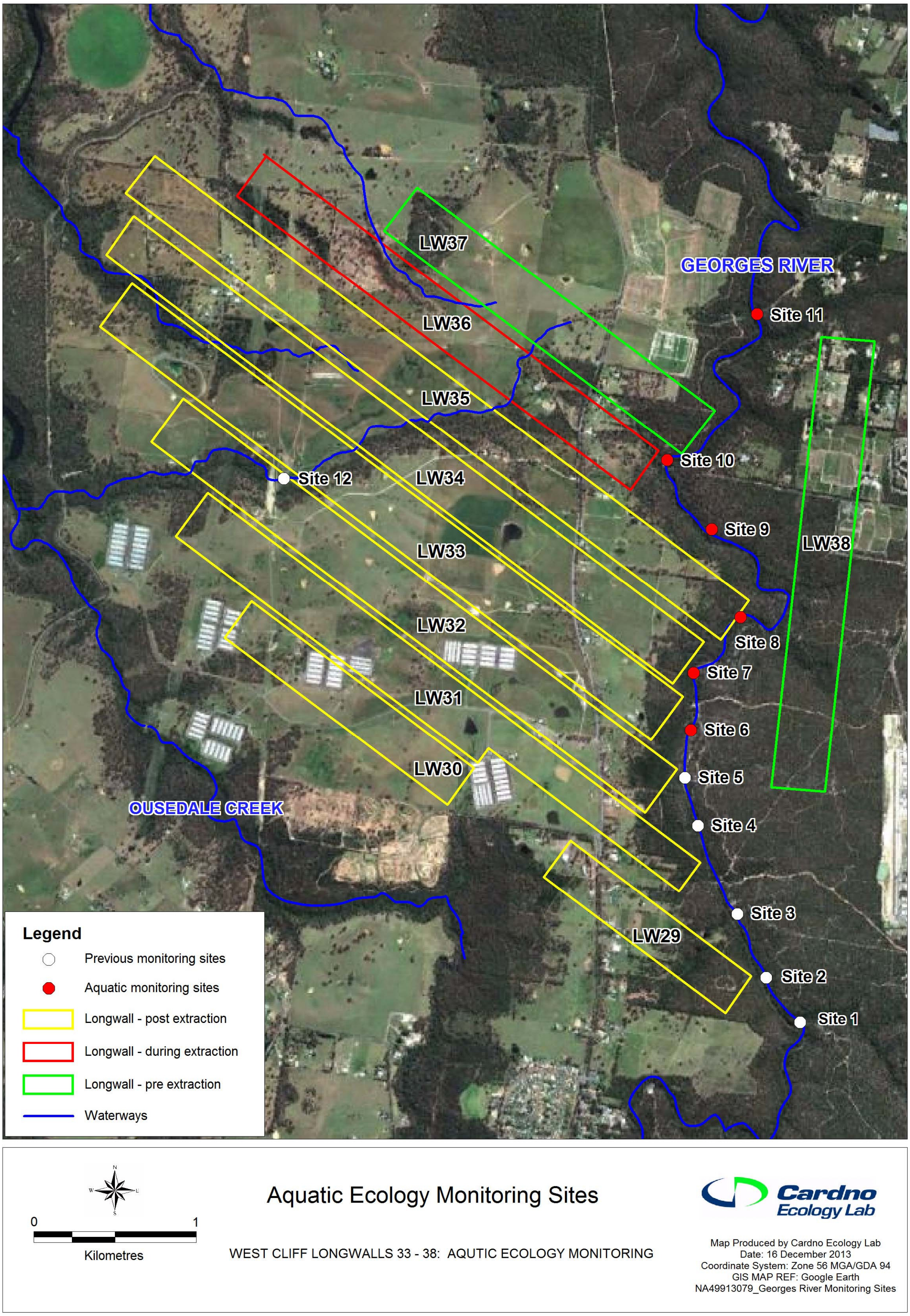

Figure 3-1 Aquatic Ecology Monitoring Sites for the West Cliff Area 5 Aquatic Ecology Monitoring Program

> Presence of fish habitat including snags, bank undercuts and aquatic plants, and,

> Presence of any barriers to fish passage.

A photographic record of the watercourse at each site was made using a digital camera to assist in the descriptions.

3.1.3 Water Quality

Water quality was measured with a YSI 6920 multiprobe. The probe was calibrated using standard calibration solutions provided by the manufacturer prior to sampling. Water quality sampling was completed before the sampling of aquatic fauna to avoid disturbance to the waterway. The following variables were recorded:

> Temperature (℃);

> Conductivity (µs/cm);

> pH;

> Dissolved oxygen (% saturation);

> Oxidation reduction potential (ORP) (mV); and,

> Turbidity (ntu).

Two replicate readings were taken just below the surface. Six replicate turbidity readings were taken as this measure can be variable.

The measurements of water quality are relevant only to the time of sampling and were taken to assist with interpretation of patterns in aquatic macroinvertebrate and fish data.

3.1.4 Aquatic Macroinvertebrates

Aquatic macroinvertebrates associated with edge habitats were sampled using the Australian River Assessment System (AUSRIVAS) rapid assessment methodology (Turak *et al.* 2004). Riffle habitat was not sampled, because this habitat was not represented in all the stretches of river surveyed. Samples were collected with dip nets (250 µm mesh) over a period of 3-5 mins from a 10 m length of habitat at each study site. The dip net was used to agitate and scoop up material from vegetated river edge habitats. Where the habitat was discontinuous, patches of habitats with a total length of 10 m were sampled. Each sample was rinsed from the net onto a white sorting tray from which animals were picked using forceps and pipettes. Each tray was picked for a minimum period of forty minutes, after which they were picked at ten minute intervals for either a total of one hour or until no new specimens had been found. Care was taken to collect cryptic and fast moving animals in addition to those that were conspicuous or slow. The animals collected at each site were placed into a labelled jar containing 70% alcohol / water for subsequent identification in the laboratory.

Environmental variables, such as alkalinity, modal river width and depth, percentage boulder or cobble cover, latitude and longitude, which are required for running the spring AUSRIVAS predictive model for edge habitat, were recorded in the field. Distance from source, altitude, and land-slope were determined from appropriate topographic maps. Mean annual rainfall was determined from the regional precipitation maps presented in the AUSRIVAS Sampling and Processing Manual (Turak *et al.* 2004).

3.1.5 Fish

Fish and large mobile invertebrates, such as freshwater crayfish, occurring at each site were sampled using a back-pack electrofisher (Model Smith-Root LR24). The back-pack electrofisher was operated around the edge of pools, around snags and aquatic vegetation, overhanging banks and rocky crevices. Electrofishing was conducted in sets of four, two minute shots. Fish were collected in a small scoop net, identified and measured. Native species were released unharmed, non-indigenous species were not returned to the water, as per the conditions of our scientific collection permit.

3.2 Laboratory Methods

AUSRIVAS samples were sorted under a binocular microscope (at 40 X magnification) and identified to family level with the exception of Oligochaeta and Polychaeta (to class), Ostracoda (to subclass), Nematoda and Nemertea (to phylum), Acarina (to order) and Chironomidae (to subfamily). Up to ten animals of each family were counted, in accordance with the latest AUSRIVAS protocol (Turak *et al.* 2004).

3.3 Data Analysis

3.3.1 Water Quality

Mean water quality measurements were compared with the Australia and New Zealand Environment Conservation Council (ANZECC/ARMCANZ 2000) default trigger values (DTVs) for physical and chemical stressors for slightly disturbed upland rivers in southeast Australia.

3.3.2 Aquatic Macroinvertebrates

A predictive model of the occurrence of aquatic macroinvertebrates at undisturbed, reference sites in the internet-based AUSRIVAS software package was used to determine the environmental condition of the sites on each waterway (Ransom *et al.* 2003). The health of each site was assessed by comparing the observed freshwater macroinvertebrate assemblages (i.e. those collected in the field) with macroinvertebrate assemblages expected to occur in reference waterways with similar environmental characteristics. The data from this study were analysed using the NSW models for pool edge habitat sampled in spring. The AUSRIVAS predictive models generated the following indices:

> OE50Taxa Score – The ratio of the number of macroinvertebrate families with a greater than 50% predicted probability of occurrence that were actually observed (i.e. collected) at a site to the number of macroinvertebrate families expected with a greater than 50% probability of occurrence. OE50 taxa scores provide a measure of the impairment of macroinvertebrate assemblages at each site, with values close to 0 indicating an impoverished assemblage and values close to 1 indicating that the condition of the assemblage is similar to that of the reference streams.

> Overall Bands derived from OE50Taxa scores which indicate the level of impairment of the assemblage. These bands are graded as follows:

Band X = Richer invertebrate assemblage than reference condition;

Band A = Equivalent to reference condition;

Band B = Sites below reference condition (i.e. significantly impaired);

Band C = Sites well below reference condition (i.e. severely impaired); and,

Band D = Impoverished.

The SIGNAL2 biotic index (Stream Invertebrate Grade Number Average Level) developed by Chessman (2003) was also used to determine the environmental quality of sites on the basis of the presence or absence of families of macroinvertebrates. This method assigns grade numbers between 1 and 10 to each macroinvertebrate family, based largely on their responses to chemical pollutants. The sum of all grade numbers for that site was then divided by the total number of families recorded in each site to obtain an average SIGNAL2 index. The SIGNAL2 index therefore uses the average sensitivity of macroinvertebrate families to present a snapshot of biotic integrity at a site. SIGNAL2 values are as follows:

> SIGNAL > 6 = Healthy habitat;

> SIGNAL 5 – 6 = Mild pollution;

> SIGNAL 4 – 5 = Moderate pollution; and,

> SIGNAL < 4 = Severe pollution.

4 Results

4.1 Habitat Assessment and General Observations

The section of the Georges River within the study area is fed by a number of tributaries which drain rural properties, urban development and vegetated areas. The upstream section of the river (Site 6) is characterised by long shallow pools connected by sections of shallow flow over bedrock. Further downstream (Sites 7-11) the river consists of deeper pools with connecting flow through boulder fields. The substratum throughout the study area includes large areas of sandstone bedrock, accumulations of sand and silt within pools, as well as sections of boulder and cobble.

The riparian vegetation on each bank of the Georges River is in good condition. It consists predominantly of native species such as mat rush (*Lomandra* sp.) and sawgrass (*Gahnia* sp.) plus a few introduced taxa. Mature trees are common and gaps in vegetation are generally found only at road crossings. Relatively undisturbed riparian strips help to stabilise river banks, which in turn helps to prevent significant erosion and sediment mobilisation. Riparian vegetation is also a source of instream woody debris, which provides important habitat for many species of aquatic fauna, including fish.

At least 20 species of aquatic macrophytes have been recorded in the reach of the Georges River within and adjacent to the Study Area (**Appendix A**) (Bioanalysis 2009; Cardno Ecology Lab 2012b and references therein). During the current investigation, large dense beds of cumbungi (*Typha* sp.) and smaller patches of spike rush (*Juncus* sp.) and clubrush (*Isolepis* sp) were the most common emergent aquatic macrophytes. Pondweed (*Potamogeton* sp.) was also present at Sites 7 and 8 and *Vallisneria* sp. at Site 6. These macrophytes fulfil many important ecological roles, including the provision of refuge and nursery habitat for aquatic fauna, serve as a source of food and are important in nutrient cycling. All of these species have been observed in previous investigations.

Under normal flow conditions, the deep pools present at the majority of study sites would provide habitat for fish and may be important refuge areas for them during extended dry periods with low flows. The only artificial structure that may impede fish passage is the culvert at the Blackburn Road crossing near Site 10. During normal flows, this culvert would prevent most fish species from traversing upstream, however, it probably would not do so during high flows. Natural features, such as small waterfalls and cascades, that may impede fish passage during low to moderate flows, are also present at many of the sites sampled. During high flows, fish should be able to traverse these sections with little difficulty. Eels (*Anguilla* sp.) and Cox's gudgeon (*Gobiomorphus coxii*) are likely to be able to do so even during periods of relatively low flow.

During the current survey, a loss of flow and reductions in pool water levels (including total drainage of some pools) was observed at Sites 8 and 9 (**Plates 1-3**). At both sites, the low pool water levels had led to desiccation of macrophytes (**Plate 4**). This was not observed during the December 2012 survey. Where flow disappeared at sites 8 and 9, it re-appeared towards the downstream extent of the site.

Plate 1. Loss of flow and reductions in pool water levels at Site 8.

Plate 2. Loss of flow and fractured bedrock at Site 9

Plate 3. Dry pool at Site 9.

Plate 4: Desiccation of macrophytes at Site 8

4.2 Water Quality

The mean water quality data for the 2002 to 2013 surveys of the Georges River and data collected in May 2012 as part of the Aquatic Flora and Fauna Assessment for Longwalls 37 and 38 are presented in **Table 4.1**.

1.1.1 November 2013

The main findings were:

> Temperature ranged from 16.6 to 20.7° C, with values at Sites 6-8 being slightly greater than at Sites 9-11;

> Conductivity levels declined from 2069 µS/cm at Site 6 to 1469 µS/cm at Site 11 and were thus above the upper DTV at each site;

> The pH ranged from 7.6 to 8.5 and was above the upper DTV at each site apart from Site 10;

> The Oxidation Reduction Potential (ORP) ranged from 50 to 81 mV;

> Dissolved oxygen levels ranged from 52.4% to 107.5% saturation. Values recorded at Sites 7 and 9 were slightly below, and that at Site 10 well below, the lower DTV; and,

> Turbidity ranged from 1.7 ntu at Site 6 to 28.9 ntu at Site 10 and was below the lower DTV at Site 7 and above the upper DTV at Site 10.

4.2.1 2002 to 2012 Surveys

The main findings across the surveys were:

> Temperatures ranged from 10.3° to 24.0° C and reflected seasonal trends. The measurements taken during particular surveys varied by between 2° and 5° C across sites, but there were no obvious trends along the river;

> Conductivity ranged from 748 to 2353 µS/cm and exceeded the upper DTV on each occasion. The lowest and highest levels were recorded in September 2008 (i.e. during extraction of Longwall 33) and May 2010 (i.e. during extraction of Longwall 34), respectively. Conductivity levels were similar across sites during November 2011 and May 2012 but differed during the other surveys. Conductivity was relatively high in May 2010, December 2012 and November 2013. This finding may have been related to releases from Brennans Creek Dam.

> pH ranged from 7.6 to 9.2 and was above the upper DTV on all but two occasions (Site 8, May 2010 and Site 10, November 2013);

> Dissolved oxygen levels in the Georges River ranged from 52.4% to 121.3% saturation. Levels were below the lower DTV at each site on at least one occasion. Values in excess of the upper DTV were recorded on one occasion at Sites 6 and 8. The 52.4% saturation level recorded at Site 10 in November 2013 was by far the lowest recorded at any site during the monitoring program;

> Oxidation reduction potential (ORP) ranged from 50 to 465 mV. ORP levels were fairly similar across sites in each sampling event. The ORP values recorded in September 2008, December 2013 and the current survey were considerably lower than during the other surveys; and,

> Turbidity ranged from 0.2 to 59.4 ntu. The turbidity dropped below the lower DTV at least once at all the sites on the Georges River. Values in excess of the upper DTV were recorded once at Sites 7 and 10.

It should be noted that the water quality data collected by Cardno Ecology Lab is intended to assist in the interpretation of aquatic ecology data and allows only limited conclusions to be drawn about temporal variation in the various indicators. Much more frequent water quality data is collected and interpreted by Illawarra Coal and Ecoengineers Pty. Ltd.

Table 4-1 Mean water quality data for Sites 6-11 on the Georges River sampled between May 2002 and November 2012. (SE=Standard Error), n=2, except for turbidity where n=6). Default Trigger Values (DTVs) are for the protection of slightly disturbed upland rivers of South-east Australia (ANZECC/ARMCANZ 2000). Shading indicates mean values are outside of DTVs. (1)The Ecology Lab (2002), (2)The Ecology Lab (2005), (3)The Ecology Lab (2007), (4)The Ecology Lab (2008), (5)Cardno Ecology Lab (2010), (6)Cardno Ecology Lab (2011), (7)Cardno Ecology Lab (2012a), (8)Cardno Ecology Lab (2013) and (9)current report.

Variable	DTV	May 2002(1)		March 2005(2)		November 2007(3)		September 2008(4)		May 2010(5)		November 2011(6)		May 2012(7)		December 2012(8)		November 2013(9)	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Site 6																			
Temperature (°C)		n/a	n/a	24.0	n/a	18.0	0.0	19.8	0.0	12.9	0.0	20.5	0.0	10.5	0.0	20.5	0.4	20.1	0.3
Conductivity (µS/cm)	30-350	748	0	1578	n/a	1239	2	841	0	2353	7	1356	1	1028	0	2054	0	2069	5
pH	6.5-8.0	8.0	0.0	8.7	n/a	8.8	0.0	8.8	0.0	9.2	0.0	8.5	0.0	8.3	0.0	8.8	0	8.5	0.0
ORP (mV)				249	n/a	429	1	144	0	414	1	398	2	447	2	77	9.1	59.3	2.4
DO (% Sat)	90-110	100.3	0.2	103.9	n/a	80.9	0.1	n/a		121.3	3.9	100.4	1.6	106.9	1.6	86.8	18.2	106.3	2.05
Turbidity (NTU)	2-25	8.1	0.8	18.0	n/a	4.1	0.0	14.0	2.6	1.0	0.1	10.6	0.7	5.8	0.9	0.2	0.1	2.1	0.0
Site 7																			
Temperature (°C)						17.4	0.0	15.9	0.0	13.8	0.0	20.2	0.0			22.0	0.1	20.7	0.2
Conductivity (µS/cm)	30-350					1033	3	823	0	2275	1	1325	2			1905	12	1998	2
pH	6.5-8.0					8.9	0.0	8.9	0.0	8.8	0.0	8.3	0.0			8.4	0.0	8.4	0.0
ORP (mV)						451	0	118	1	422	1	411	1			94	2.6	50.4	1.7
DO (% Sat)	90-110					90.8	0.8	95.0	0.1	77.4	3.9	76.6	0.5			88.1	10	86.5	1.9
Turbidity (NTU)	2-25					37.9	0.8	5.9	0.2	0.8	0.0	21.9	0.7			2.0	0.3	1.7	0.2
Site 8																			
Temperature (°C)						17.1	0.0	16.4	0.0	14.5	1.0	19.7	0.0	10.7	0.2	21.0	0.3	20.5	0.6
Conductivity (µS/cm)	30-350					1043	0	844	1	2035	0	1285	5	1007	1	1824	5	1761	30
pH	6.5-8.0					8.8	0.0	9.1	0.0	8.0	0.0	8.5	0.0	8.3	0.0	8.7	0	8.1	0.0
ORP (mV)						436	1	119	0	442	0	392	2	465	7	95	0.5	57.5	3.0
DO (% Sat)	90-110					79.6	0.5	97.6	0.1	97.9	1.6	96.6	0.1	81.6	0.7	114.9	8.5	98.1	3.5
Turbidity (NTU)	2-25					2.7	0.0	5.8	0.1	11.3	0.1	22.0	0.4	1.1	0.2	1.1	0.1	6.0	0.2

Variable	DTV	May 2002[1]		March 2005[2]		November 2007[3]		September 2008[4]		May 2010[5]		November 2011[6]		May 2012[7]		December 2012[8]		November 2013[9]	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Site 9																			
Temperature (°C)						16.6	0.0	16.5	0.0	11.5	0.0	21.6	0.0	10.6	0.4	20.0	0.0	18.5	0.0
Conductivity (µS/cm)	30-350					1043	3	969	1	2167	3	1293	0	1013	5	1801	2.0	1728	0
pH	6.5-8.0					8.8	0.0	9.0	0.0	8.8	0.0	8.6	0.0	8.4	0.0	8.8	0.0	8.4	0.0
ORP (mV)						411	2	135	0	432	0	415	1	421	2	105	1	66.6	0.4
DO (% Sat)	90-110					83.3	0.3	107.3	0.0	92.6	2.0	94.6	0.5	100.5	3.0	93.1	0.7	81.7	0.2
Turbidity (NTU)	2-25					3.4	0.7	7.1	0.0	0.9	0.0	11.1	0.2	7.2	0.2	1.4	0.4	3.6	0.1
Site 10																			
Temperature (°C)								15.4	0.0	11.5	0.0	21.5	0.0	10.3	0.0	19.8	0.5	16.6	0.0
Conductivity (µS/cm)	30-350							950	1	2187	5	1292	2	1033	3	1826	5.5	1556	1
pH	6.5-8.0							9.0	0.0	8.8	0.0	8.5	0.0	8.5	0.0	8.8	0	7.6	0.0
ORP (mV)								103	2	438	1	423	1	447	2	63	7.2	80.5	1.0
DO (% Sat)	90-110							90.7	0.1	100.4	0.2	80.6	0.3	89.8	0.8	92.1	8.6	52.4	0.3
Turbidity (NTU)	2-25							6.8	0.0	1.2	0.0	8.0	0.4	0.7	0.1	2.6	0.6	28.9	0.0
Site 11																			
Temperature (°C)								14.6	0.0	11.6	0.0	20.6	0.0	10.7	0.0	19.1	0.1	17.8	0.3
Conductivity (µS/cm)	30-350							751	2	2190	1	1274	5	1034	3	1775	2.5	1469	4
pH	6.5-8.0							8.8	0.0	8.7	0.0	8.6	0.0	8.6	0.0	8.8	0.0	8.3	0.0
ORP (mV)								138	0	465	15	465	1	443	1	106	1	53.4	0.1
DO (% Sat)	90-110							106.0	0.1	105.2	1.3	101.0	2.0	95.8	0.5	87.7	1.0	107.5	1.4
Turbidity (NTU)	2-25							9.6	0.1	0.9	0.0	10.0	0.4	5.9	0.3	1.1	0.3	9.3	0.4

4.3 Aquatic Macroinvertebrates

4.3.1 Spring 2012

A total of 48 macroinvertebrate taxa were recorded (**Table 4.2**). Chironominae (non-biting midges), Dytiscidae (diving beetles) and Hydrophilidae (water scavenger beetles) were the only taxa present at all sites. All these taxa are pollution tolerant (Gooderham and Tsyrlin 2002). These taxa live near the pool edge and can survive for some time out of water. Relatively few pollution sensitive taxa were found in the Georges River, with Telephlebiidae (dragonflies) and Leptophlebiidae (prong-gilled mayflies) being found at every site, except Site 9, and Austrocorduliidae (dragonflies) recorded at Site 10.

Table 4-2 Macroinvertebrate taxa found in AUSRIVAS samples collected from edge habitat at Sites 6-11 on the Georges River in November 2013.

Taxa	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Aeshnidae	x				x	
Araneae	x			x		x
Atyidae			x		x	x
Austrocorduliidae					x	
Baetidae	x	x	x			x
Caenidae	x	x	x		x	x
Calamoceratidae		x		x	x	x
Ceinidae					x	
Ceratopogonidae	x	x		x	x	x
Chironomidae/Chironominae	x	x	x	x	x	x
Chironomidae/Orthocladiinae	x	x	x			x
Chironomidae/Tanypodinae	x	x	x		x	
Cladocera	x	x	x			
Coenagrionidae	x	x			x	x
Copepoda		x		x	x	
Cordulephyidae			x			
Corixidae			x	x	x	
Culicidae			x			x
Dugesiidae		x				
Dytiscidae	x	x	x	x	x	x
Ecnomidae	x	x	x		x	
Elmidae		x		x		x
Gelastocoridae	x					x
Gomphidae	x		x	x	x	x
Gyrinidae	x	x	x			
Hemicorduliidae	x	x	x		x	x
Hydracarina	x	x	x		x	x
Hydraenidae	x					
Hydrometridae	x					
Hydrophilidae	x	x	x	x	x	x
Hydroptilidae		x	x		x	
Isostictidae					x	x
Leptoceridae	x	x			x	x
Leptophlebiidae	x	x	x		x	x

Megapodagrionidae				x	x	
Notonectidae	x	x	x		x	x
Oligochaeta			x			
Ostracoda		x			x	x
Physidae	x				x	x
Protoneuridae						x
Psephenidae				x		
Psychodidae			x			
Sialidae						x
Stratiomyidae	x					
Synlestidae	x	x				x
Synthemistidae				x		
Telephlebiidae	x	x	x		x	x
Veliidae	x	x	x		x	

There was considerable variation in the number of taxa found, with numbers ranging from 13 at Site 9 to 28 at Sites 6 and 10 (**Table 4.3**). The fauna at Sites 6, 7, 9 and 11 was equivalent to the AUSRIVAS reference condition but at Sites 10 and 8 was significantly and severely impaired, respectively, relative to the reference condition as indicated by their B and C-ratings. The OE50 taxa scores ranged from 0.37 to 0.96. Sites 10 and 8 lacked 21% and 63%, respectively, of the taxa expected to occur in reference streams with similar environmental characteristics.

The SIGNAL2 Index for the fauna at Sites 6, 7, 9, 10 and 11 ranged from 4.0 to 4.4 and was indicative of moderate pollution. The SIGNAL2 Score at Site 8 was 3.8 which is indicative of severe pollution, but only marginally so.

Table 4-3 Total numbers of macroinvertebrate taxa found in AUSRIVAS samples collected from edge habitat at Sites 6-11 on the Georges River from 7 to 8 November 2013 and their respective AUSRIVAS band, OE50 Taxa Score and SIGNAL 2 Index.

Site Number	Number of Taxa	OE50 Taxa Score	AUSRIVAS Band	SIGNAL2 Index
6	28	0.89	A	4.0
7	26	0.96	A	4.4
8	24	0.37	C	3.8
9	13	0.87	A	4.3
10	28	0.79	B	4.2
11	27	0.88	A	4.3

4.3.2 2002 to 2013 Surveys

The objective of the following comparisons of macroinvertebrate data among surveys and sites is to determine whether any changes to aquatic ecology may have occurred following the mining related impacts (fracturing of bedrock and reductions in pool water levels) identified in the Georges River from February to November 2013, following the previous survey in December 2012 and just prior to the current survey (see Section 2.2). Potential changes in aquatic ecology associated with the physico-chemical impacts that occurred during mining of Longwalls 33 and 34 were considered in Cardno Ecology Lab (2012a and 2013) and summarised in Section 2.2.

4.3.2.1 Number of Tax

The number of taxa found ranged from 9 to 32. Sites 6, 8 and 9 show the greatest temporal variation in numbers, with that at Site 6 being the greatest. The number of taxa sampled at Site 9 in November 2013 (13) was the lowest of all the sites surveyed during that survey and the lowest during most of the previous surveys except for Site 6 in March 2005 (9 taxa) and November 2011 (13 taxa). At the remaining sites, the number of taxa sampled in November 2013 was comparable to that found in earlier surveys. Prior to

November 2013, the number of taxa sampled at Site 9 was relatively consistent compared with the other sites.

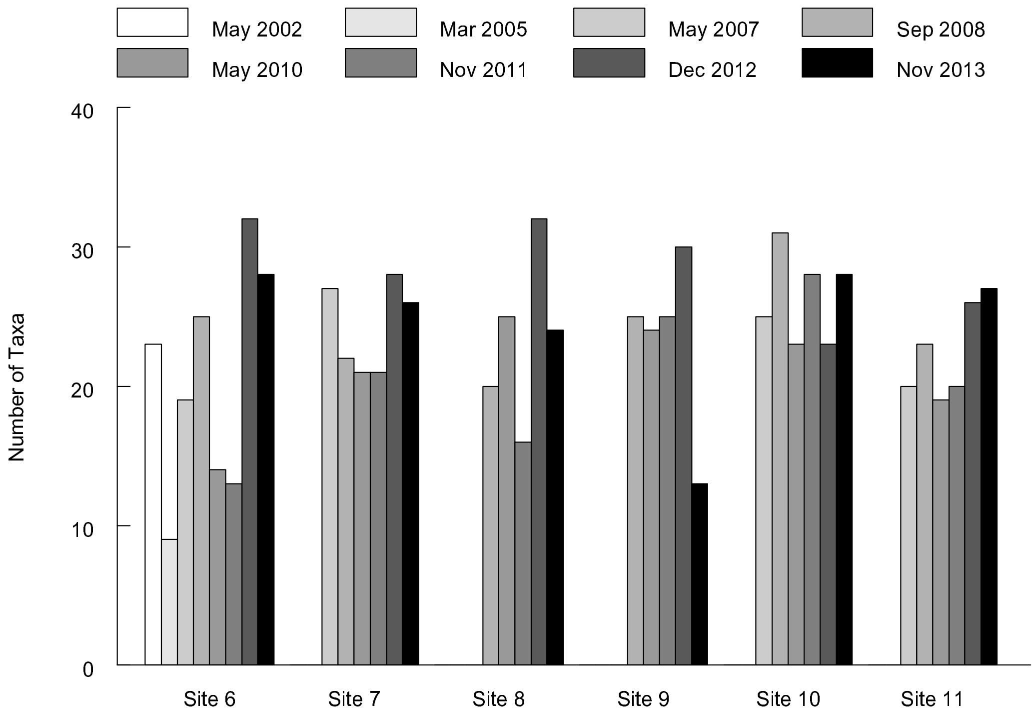

Figure 4-1 Number of Macroinvertebrate found in AUSRIVAS Samples Collected from Edge Habitat at Sites 6 to 11 on the Georges River from 7 to 8 November 2013.

4.3.2.2 OE50 Taxa Scores

OE50 Taxa Scores ranged from 0.32 to 1.02, indicating that the number of taxa observed was considerably less on most occasions than would be expected relative to the AUSRIVAS reference watercourses. At most sites, the OE50 Taxa Scores in November 2013 were relatively high compared to previous surveys. The OE50 Taxa Score for Site 8, however, was the lowest recorded at the sites sampled in November 2013 and at all other sites sampled in all previous surveys apart from Site 6 in May 2010 (0.35) and November 2011 (0.32). The temporal variation in OE50 Taxa Scores was greatest at Sites 6, 7 and 8.

4.3.2.3 AUSRIVAS Bands

The trends in AUSRIVAS Bands reflect those in OE50 Taxa Scores upon which they are based. The condition of the aquatic macroinvertebrate fauna at the sites on the Georges River has ranged from Band A (equivalent to AUSRIVAS reference condition) to Band C (severely impaired). At all the study sites, changes in the condition of the fauna equivalent to at least one AUSRIVAS Band have occurred. In November 2013 AUSRIVAS Bands ranged from A to C, and, in general, were towards the upper end of the range observed previously.

4.3.2.4 SIGNAL2 Index

The SIGNAL2 Index ranged from 2.8 (indicative of severe degradation) to 4.7 (indicative of moderate pollution). A large proportion of SIGNAL2 Indexes were less than 4 indicating macroinvertebrate assemblages dominated by pollution tolerant taxa. In general, the SIGNAL2 Indices at the sites sampled in November 2013 were within the range of SIGNAL2 Indexes sampled previously. The SIGNAL2 Index at Site 9, however, was the highest yet recorded at this site.

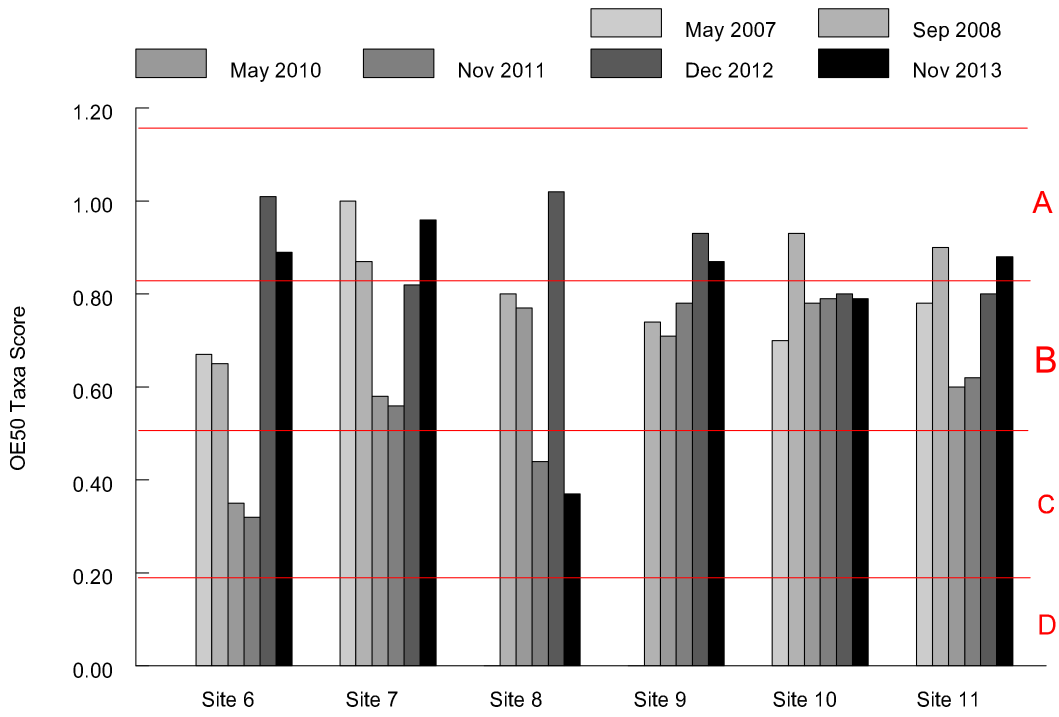

Figure 4-2 OE50 Taxa Scores and their Respective Band Scores (A-D) from AUSRIVAS Samples Collected from Edge Habitat at Sites 6 to 11 on the Georges River from 7 to 8 November 2013

4.4 Fish

Four fish species were caught by electrofishing in November 2013 (**Table 4.4**). Several freshwater eels were observed, but not caught whilst electrofishing. These could have been either long-finned (*Anguilla reinhardtii*) or short-finned (*Anguilla australis*) eels. The native Cox's gudgeon was the most common species, and the introduced eastern gambusia (*Gambusia holbrooki*) the most abundant species. No fish were sampled at Site 9. Carp gudgeon (*Hypseleotris* spp.) were sampled at Site 6 only. All of these species have been recorded during previous surveys for the West Cliff Area 5 Aquatic Ecology Monitoring Program (**Table 4.5**)

Freshwater crayfish (Family Parastacidae) and freshwater shrimp (Family Atyidae) were also observed and caught in AUSRIVAS dip nets and whilst electrofishing at each site apart from Site 9.

Table 4-4 Number of fish caught by electrofishing at Sites 6-11 on the Georges River between 7 and 8 November 2013.

Scientific Name	Common Name	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Anguilla sp.	Freshwater eel	1	1		*No fish*		2
Anguilla reinhardtii	Long-finned eel						1
Gambusia holbrooki	Eastern gambusia	4	>50			>50	
Gobiomorphus coxii	Cox's gudgeon		2	5		2	5
Hypseleotris spp.	Carp gudgeon	4					

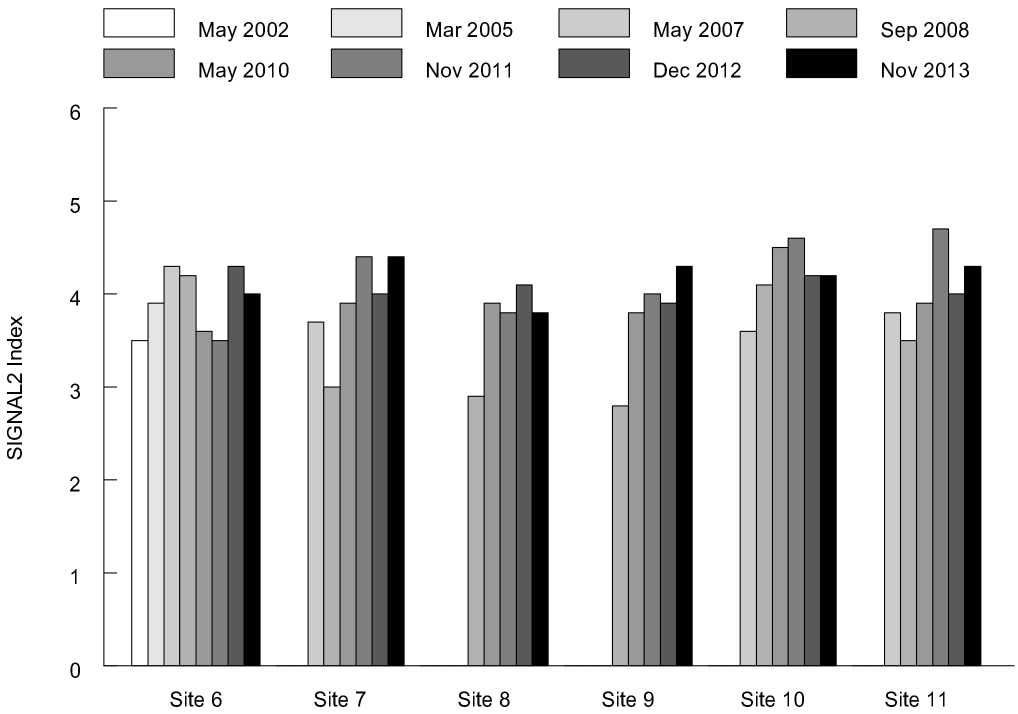

Figure 4-3 SIGNAL2 from AUSRIVAS Samples Collected from Edge Habitat at Sites 6 to 11 on the Georges River from 7 to 8 November 2013

Table 4-5 Fish species caught by backpack electrofishing in the Georges River during the aquatic ecology monitoring undertaken for the West Cliff Longwalls between March 2002 and November 2013. (1)The Ecology Lab (2002), (2)The Ecology Lab (2005), (3)The Ecology Lab (2008), (4) Cardno Ecology Lab (2010), (5) Cardno Ecology Lab (2011), (6)Cardno Ecology Lab (2012b), (7) Cardno Ecology Lab (2012a) and (8) current survey.

Scientific Name	Common Name	May 2002(1)	Mar 2005(2)	Sep 2008(3)	May 2010(4)	Nov 2011(5)	May 2012(6)	Dec 2012(7)	Nov 2013(8)
Anguilla sp.	Freshwater eel							x	x
Aguilla australis	Short-finned eel							x	
Anguilla reinhardtii	Long-finned eel	x	x	x		x	X	x	x
Gambusia holbrooki	Eastern gambusia	x	x	x	x	x	X	x	x
Gobiomorphus coxii	Cox's gudgeon					x	X	x	x
Hypseleotris spp.	Carp gudgeon	x	x	x	x	x	X	x	x

5 Discussion

The aquatic macroinvertebrate fauna in the Georges River appears to have experienced some degree of environmental stress prior to mining and continues to do so. This is supported by the observation that several of the water quality indicators measured and particularly conductivity were outside ANZCECC/ARMANZ (2000) guidelines. The quality of water within this reach of the upper Georges River is determined by rainfall, rural and urban runoff and licensed discharges of mine water from Appin East and West Cliff pit tops, in addition to any potential effects associated with mine-induced subsidence. A change in the relative contributions of the major inputs to the river is most likely responsible for the relatively high conductivity levels noted in the Georges River in May 2010, December 2012 and November 2013.

The recent mining related physical impacts (fracturing of bedrock and resulting diversion of flows and reductions in pool water levels) observed in the Georges River by the Illawarra Coal Environmental Field Team (ICEFT) between February and November 2013, and by Cardno Ecology Lab in November 2013, have led to concurrent impacts on aquatic ecology in the Georges River. Reductions in pool water levels and the complete drying of some pools at Sites 8 and 9 have led to a direct loss of aquatic habitat and possibly some biota. The desiccation of macrophytes represents both a loss of aquatic biota and also habitat, as these plants will provide shelter and food for many other aquatic species. Other impacts to aquatic ecology associated with the physical impacts include the loss of longitudinal connectivity during low flow conditions due to the drying of pools and loss of flow over rockbars.

The relatively low number of macroinvertebrate taxa in the AUSRIVAS sample collected at Site 9 and the relatively low OE50 Taxa Score from Site 8 in November 2013 could be related to the physical impacts described above and in Section 2.2. Site 8 is just downstream of Pool 44, and Site 9 is downstream off Pools 51 and Pool 54 and encompasses part of Pool 56 (**Figure 5.1**). Reductions in water levels have been observed in all of these pools (see Section 2.2). The loss of connectivity and flow associated with the drying of these pools could explain why fewer taxa were found at these sites. Colonisation of pools by macroinvertebrates could be hindered or prevented by a lack of connectivity during low flow conditions, and while relatively mobile taxa may be able to colonise disconnected pools, others may not. It would also take some time for taxa to colonise previously dry pools, especially pools that were disconnected from upstream and/or downstream flow, and the amount of habitat available for colonisation.

While relatively few taxa were sampled at Site 9, the macroinvertebrate assemblage that was sampled was indicative of undisturbed habitat, as seen by the high OE50 Taxa Score and AUSRIVAS Band (Band A). The relatively large decrease in the OE50 Taxa Score at Site 8 in November 2013, compared with previous surveys, suggest that the fauna at this site has become impoverished, supporting fewer taxa than reference streams (as selected by the AUSRIVAS model) with similar physical attributes. Despite fewer taxa being found at this site than what may otherwise be expected, there was no evidence in the SIGNAL2 Index data to suggest that the macroinvertebrate fauna at this, or any other site sampled, was becoming increasingly dominated by pollution tolerant taxa.

The absence of fish and larger mobile invertebrates (freshwater crayfish and shrimp) from Site 9 suggests these fauna have also experienced impacts associated with the extraction of Longwall 35. It is possible that some of the pools at this site had drained earlier in the year and that fish and larger mobile invertebrates have not yet had the opportunity to re-colonise these pools. At the time of sampling, several of the pools were disconnected from upstream or downstream flow, or both. On the whole, species composition of the fish assemblages sampled in November 2013 was comparable with that observed during the previous surveys. Carp gudgeons are relatively undescribed and several species may be present on the east coast of Australia. At least two species have been identified from the Georges River over the course of the monitoring program, likely firetailed gudgeon (*Hypseleotris galii*) and possibly also lake's carp gudgeon (*Hypseleotris* sp.). Other species within this genus may also have been sampled, however, due to many overlapping characteristics and in the absence of published taxonomic keys it is impossible to identify them with any confidence.

As well as the direct physical impacts related with extraction of Longwall 35, changes to water quality associated with physical impacts could have contributed to the changes in aquatic ecology indicators described above. While no impacts to water quality and flow were noted in data collected up to 5 August (Ecoengineers 2013), it is possible that changes to water quality have occurred since then. Although relatively low dissolved oxygen and high turbidity levels were recorded at Site 10 by Cardno Ecology Lab in November 2013, there was no evidence of any changes in macroinvertebrates, fish or macrophytes here. The quality of water at the remaining sites (including Sites 8 and 9) was comparable to previous surveys.

These water quality data should be interpreted with caution, however, as changes could have occurred between 5 August and 7 to 8 November.

Despite the changes to aquatic ecology indicators observed at Sites 8 and 9, similar changes were not apparent downstream at Sites 10 and 11. AUSRIVAS results for Sites 10 and 11 were comparable to those from previous surveys, and most fish species sampled in previous survey were recorded. Carp gudgeon was not sampled at Sites 10 and 11, but was also absent from sites further upstream. The high turbidity at Site 10 could also have prevented this species being sighted.

The results suggest that impacts to aquatic ecology are restricted to the areas directly affected by mining impacts. Although a loss of river connectivity during low flow conditions could impact the passage of migratory fish species (e.g. eels and the Cox's gudgeon), with potential consequences for these species upstream and downstream of the affected areas, at this stage, there is no data to suggest an impact to fish has occurred outside of Site 9. The increased releases from Brennans Creek Dam appear to have been successful in temporally restoring pool water levels and flow in the affected areas to pre-mining levels. This measure will help maintain connectivity among stretches of river and pools affected by the recent mining impacts.

There is no evidence to suggest the commencement of extraction of Longwall 36 has had any impact on aquatic ecology. This is not surprising considering that no physical impacts had been observed by December 2013 and that at the time of the survey extraction of the longwall was taking place several hundred metres away from the Georges River.

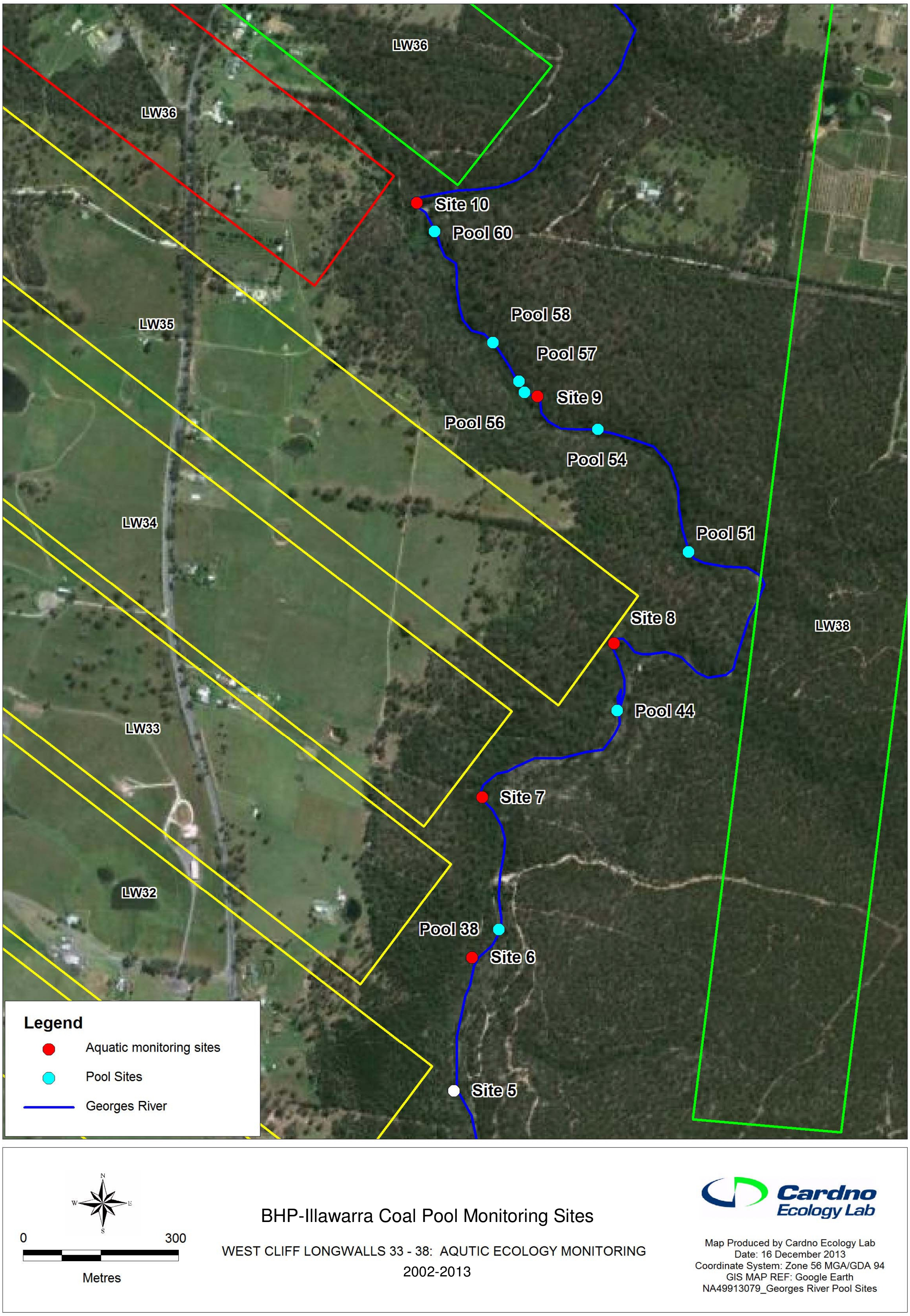

Figure 5-1 BHP-Illawarra Coal Pool Monitoring Sites where Mining Impacts have been Identified.

6 Conclusion and Recommendations

The recent physical mining impacts (fracturing, diversion of flows and lowering of pool water levels and associated loss of river connectivity during low flow conditions) associated with the extraction of Longwall 35 that were observed in the Georges River between February and November 2013 have impacted on aquatic ecology. These impacts include reductions in numbers of macroinvertebrate taxa, evidence of a lowering of habitat quality and the desiccation of macrophytes. There also appears to have been a reduction in the numbers of fish and larger mobile macroinvertebrates at one of the affected sites. These changes are linked with the direct loss of aquatic habitat and river connectivity associated with the lowering of pool water levels and loss of flow during dry periods. Impacts to river connectivity would also be expected to affect migratory fish species upstream and downstream of the affected areas, although there is no evidence of this in the data collected during this study. Potential changes to water quality due to physical impacts could also be a contributing factor, however, there is no data to support this at this stage.

No changes to aquatic ecology were evident at sites further downstream and impacts to aquatic ecology appear restricted to the areas directly affected by mining. Increased releases from Brennans Creek Dam in response to the lowering of pool water levels appear to have been successful in temporarily restoring pool water levels to normal. This measure would have reduced impacts to river connectivity and aquatic ecology. It is recommended that increased discharges from Brennans Creek Dam be maintained for as long as practicable while low pool water levels and flow resulting from mining are experienced in the Georges River. This will help minimise impacts to aquatic ecology associated with loss of habitat, flow and connectivity.

It is also recommended that further monitoring be undertaken to provide additional post-extraction data for Longwall 35 and data as extraction of Longwall 36 progresses and for at least two years thereafter. The next survey should be undertaken during the 2014 Spring AUSRIVAS sampling season. This survey would also provide further baseline data for Longwalls 37 and 38. The collection of additional during and post mining data will facilitate the assessment of the impact of the longwall extraction on the aquatic habitat and biota in the Georges River. It will also provide information that will help further assess the impacts to aquatic ecology associated with the extraction of Longwall 35, and help determine the degree of potential remediation and recovery of impacted aquatic ecology.

The influence of the licensed discharge from West Cliff Colliery, stormwater runoff from Appin Colliery and rainfall in the catchment on the quality of water and magnitude of the flows within the Georges River should also be taken into account when evaluating the effects of longwall mining on aquatic ecology.

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APPENDIX A

AQUATIC MACROPHYTE TAXA RECORDED IN THE GEORGES RIVER

Taxa	Bioanalysis (x009) (Site GR1))	Bioanalysis (x009) (Site GRx)	Cardno Ecology Lab (x)
Baumea articulata			X
Baumea juncea			X
Chorizandra cymbaria	x		
Eleocharis sphacelata	x		
Eleocharis sp.			X
Fimbristylis sp.		x	
Gahnia clarkei	x		
Hemarthria uncinata		x	
Isolepis prolifer			X
Isolepis inundata	x	x	
Isolepis sp.			X
Juncus fockei		x	
juncus usitatus			X
Juncus polyanthemus	x		
Lepidosperma filiforme	x	x	
Potamogeton sulcatus	x		
Potamogeton ticarinatus			X
Potamogeton sp.			X
Schoenus melanostachys		x	
Tristaniopsis laurina		x	
Typha orientalis	x		
Typha spp.			X
Vallisneria sp.			X