METROPOLITAN COAL LONGWALLS 20-22

CATCHMENT MONITORING PROGRAM




Peabody ENERGY

METROPOLITAN COAL

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CATCHMENT MONITORING PROGRAM

Revision Status Register

Section/Page/ Annexure	Revision Number	Amendment/Addition	Distribution	DP&E Approval Date
All	CMP-R01-A	Original	SCA, DECCW, NSW Office of Water and DoP	-
All	CMP-R01-B	Minor amendments and formatting	DoP	14 May 2010
All	CMP-R01-C	Edits and additions made to address comments from the SCA and NSW Office of Water, and review following submission of the 2010 Annual Review	DoP	14 November 2011
All	CMP-R01-D	Minor amendments following submission of the 2012 Annual Review	DP&I	29 May 2013
All	CMP-RO1-E	Amendments following submission of the 2013 Annual Review/AEMR, revision of the Longwalls 20-22 Water Management Plan and development of the Longwalls 23-27 Water Management Plan.	DP&E	25 August 2014

June 2014

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1 INTRODUCTION

Metropolitan Coal is a wholly owned subsidiary of Peabody Energy Australia Pty Ltd (Peabody). Metropolitan Coal was granted approval for the Metropolitan Coal Project (the Project) under Section 75J of the New South Wales (NSW) *Environmental Planning and Assessment Act, 1979* (EP&A Act) on 22 June 2009 (the Approval). A copy of the Project Approval is available on the Peabody website (http://www.peabodyenergy.com.au).

The Project comprises the continuation, upgrade and extension of underground coal mining operations and surface facilities at Metropolitan Coal. The Approved underground mining Project layout is shown on Figure 1.

1.1 PURPOSE AND SCOPE

This Catchment Monitoring Program (CMP) has been prepared in accordance with Condition 2, Schedule 3 of the Project Approval. The Condition states:

CATCHMENT MONITORING PROGRAM

2. *The Proponent shall prepare and implement a comprehensive Catchment Monitoring Program for the project to the satisfaction of the Director-General. This program must:*
   - a) *be prepared by suitably qualified and experienced experts whose appointment has been endorsed by the Director-General;*
   - b) *be prepared in consultation with DWE, SCA and DECC;*
   - c) *be approved by the Director-General before the Proponent is allowed to carry out any second workings in the mining area; and*
   - d) *include:*
     - *detailed baseline data of existing surface and groundwater resources in the project area;*
     - *a program for the ongoing development and use of appropriate surface and groundwater models for the project; and*
     - *a program to:*
       - *monitor and assess any impacts of the project on the quantity and quality of surface and groundwater resources in the project area, and in particular the catchment yield to the Woronora Reservoir; and*
       - *validate and calibrate the surface and groundwater models.*

This CMP has been prepared by Gilbert and Associates, Heritage Computing and Metropolitan Coal.

The relationship of this CMP to the Metropolitan Coal Environmental Management Structure is shown on Figure 2. Of particular relevance, the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan have been prepared to manage the potential environmental consequences of the Longwalls 20-22 Extraction Plan and Longwalls 23-27 Extraction Plan, respectively on watercourses (including the Woronora Reservoir), aquifers and catchment yield (Figure 2).

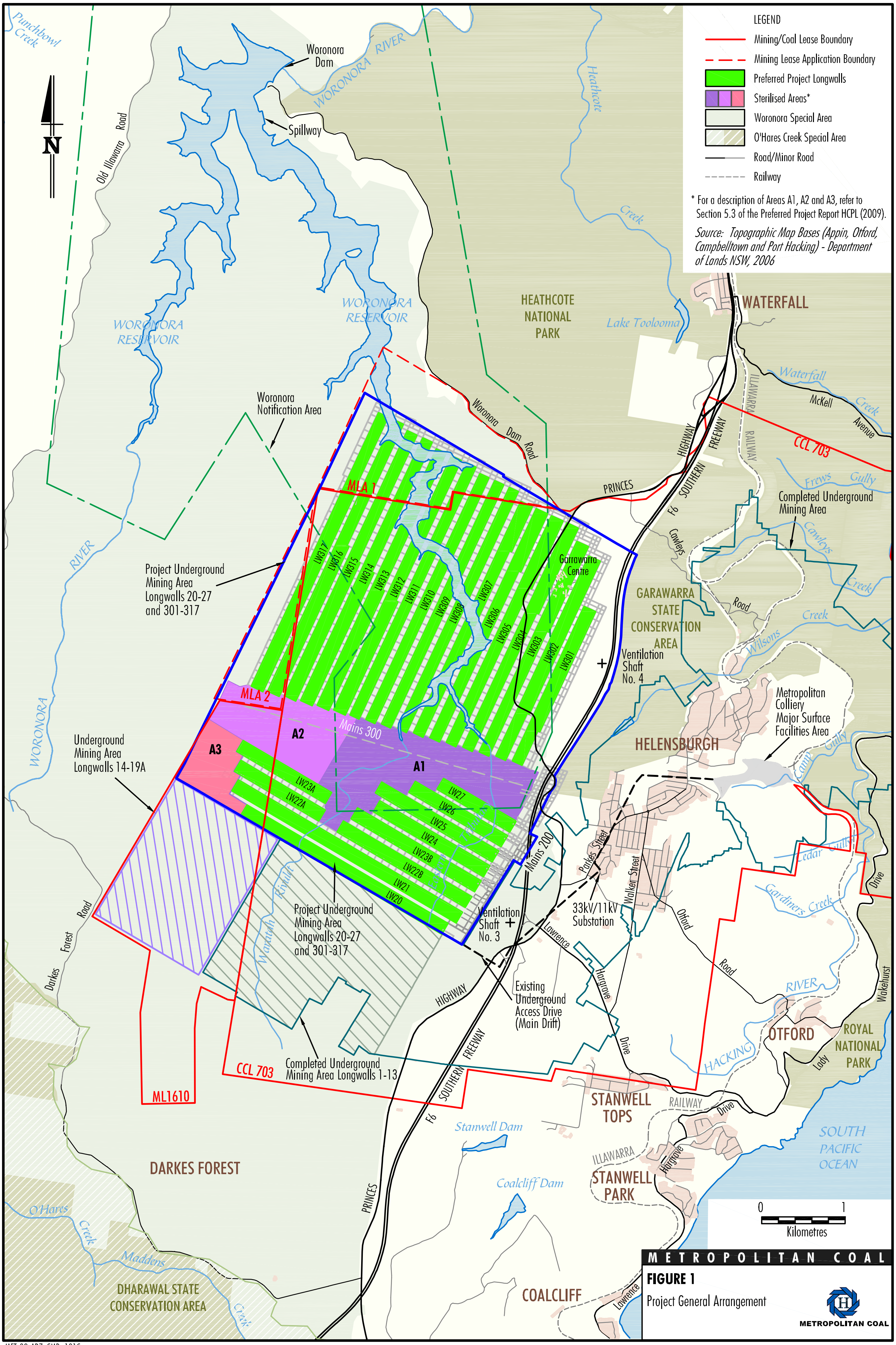

FIGURE 1
Project General Arrangement

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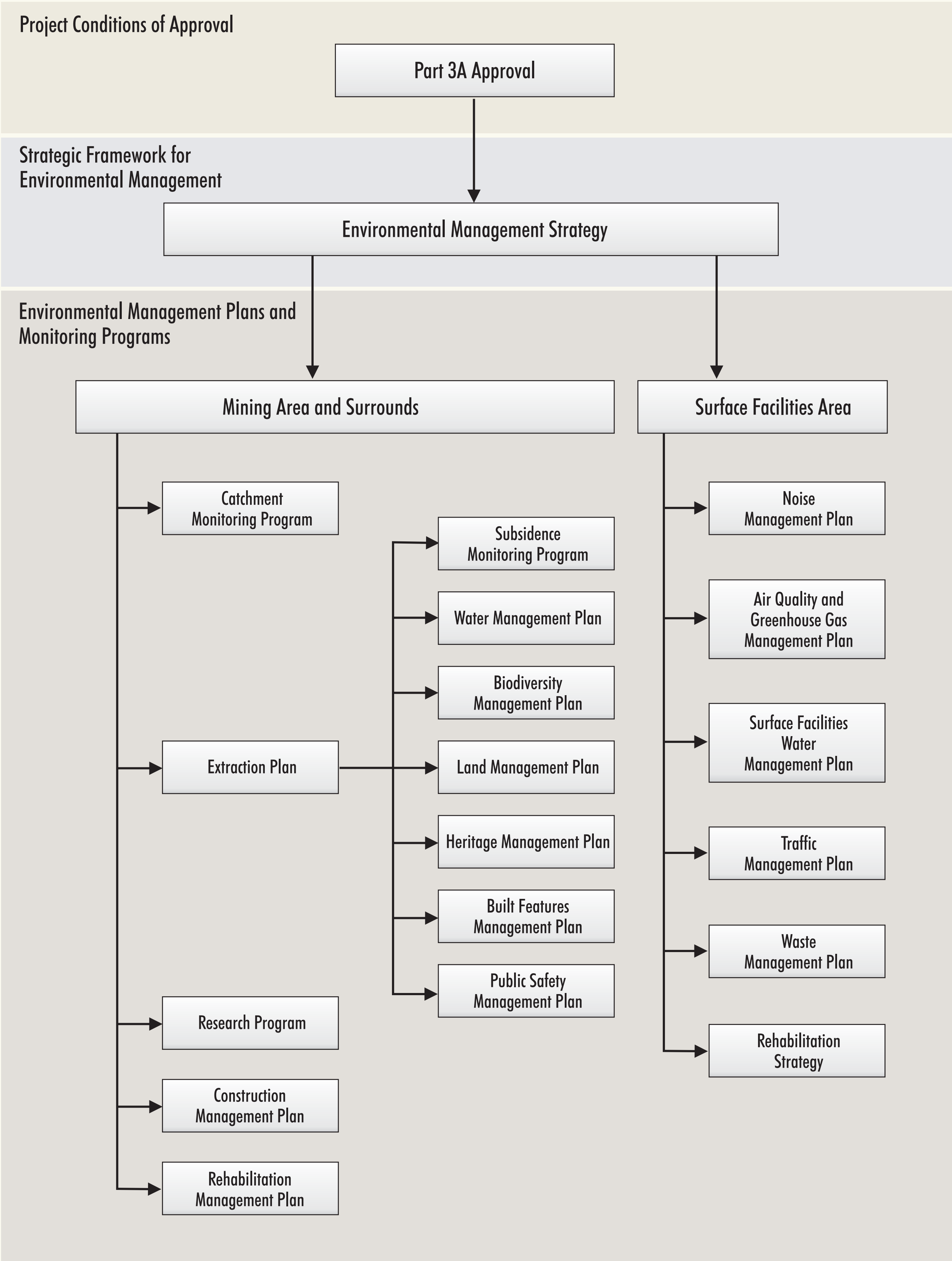

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FIGURE 2
Environmental Management Structure

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The provisional production schedule for secondary extraction in the Project area (i.e. Longwalls 20 to 317) is provided in Table 1. Longwalls 20-22 form the first mining sub-domain within the Project area, extending from May 2010 to May 2014. Extraction of Longwalls 23-27 is anticipated to occur from May 2014 to December 2016. Extraction of Longwalls 20-27 will occur from west to east. Extraction will then proceed from Longwalls 301 to 317, with extraction from north to south.

Table 1
Provisional Extraction Schedule

Longwall	Start	Finish
20	May 2010	September 2011
21	October 2011	April 2013
22A	April 2013	October 2013
22B	October 2013	May 2014
23 – 27	May 2014	December 2016
301 – 306	2017	2021
307 – 315	2021	2027
316 – 317	2027	2032

1.2 STRUCTURE OF THE CMP

The remainder of the CMP is structured as follows:

Section 2: Describes the review and update of the CMP.

Section 3: Provides the detailed baseline data of existing surface water and groundwater resources.

Section 4: Provides a program for the ongoing development and use of appropriate surface and groundwater models and a program to validate and calibrate the surface and groundwater models.

Section 5: Provides a program to monitor and assess impacts of the Project on the quantity and quality of surface and groundwater resources, and in particular the catchment yield to the Woronora Reservoir.

Section 6: Lists the references cited.

2 REVIEW AND UPDATE

In accordance with Condition 4, Schedule 7 of the Project Approval, this CMP will be reviewed within three months of the submission of:

- an audit under Condition 8 of Schedule 7;
- an incident report under Condition 6 of Schedule 7;
- an annual review under Condition 3 of Schedule 7; and

if necessary, revised to the satisfaction of the Director-General of the Department of Planning and Environment (DP&E), to ensure the CMP is updated on a regular basis and to incorporate any recommended measures to improve environmental performance.

The CMP will also be reviewed within three months of approval of any Project modification and if necessary, revised to the satisfaction of the DP&E.

The revision status of this CMP is indicated on the title page of each copy. The distribution register for controlled copies of the CMP is described in Section 2.1.

2.1 DISTRIBUTION REGISTER

In accordance with Condition 10, Schedule 7 of the Project Approval 'Access to Information', Metropolitan Coal will make the CMP publicly available on the Peabody website. A hard copy of the CMP will also be maintained at the Metropolitan Coal site.

Metropolitan Coal recognises that various regulators have different distribution requirements, both in relation to whom documents should be sent and in what format. An Environmental Management Plan and Monitoring Program Distribution Register will be established in consultation with the relevant agencies and infrastructure owners that indicates:

- to whom the Metropolitan Coal plans and programs, such as the CMP, will be distributed;
- the format (i.e. electronic or hard copy) of distribution; and
- the format of revision notification.

Metropolitan Coal will make the Distribution Register publicly available on the Peabody website.

Metropolitan Coal is responsible for maintaining the Distribution Register and for ensuring that the notification of revisions is sent by email or post as appropriate.

In addition, Metropolitan Coal employees with local computer network access will be able to view the controlled electronic version of this CMP on the Metropolitan Coal local area network. Metropolitan Coal will not be responsible for maintaining uncontrolled copies beyond ensuring the most recent version is maintained on Metropolitan Coal's computer system and the Peabody website.

3 BASELINE DATA

Sections 3.1 to 3.3 describe the baseline data available of relevance to water resources and watercourses.

Metropolitan Coal will maintain a monitoring register of water monitoring sites that includes: the location; date the site was established and relevant comments. The monitoring register will be made publicly available on the Peabody website and updated as required.

3.1 METEOROLOGY

Regional and local meteorological data is available from the Bureau of Meteorology (BoM) weather stations at Lucas Heights (Station Number 66078), Helensburgh (Station Number 68028), Darkes Forest (Station Number 68024), and 'Reverces' (Station Number 568069) (Table 2). Rainfall data is also available from Metropolitan Coal pluviometers situated in the Waratah Rivulet catchment (site PV1) and Woronora River catchment (site PV2) (Figure 3).

Evaporation data is available from the discontinued Sydney Catchment Authority (SCA) station at the Woronora Dam (Table 2 and Figure 3).

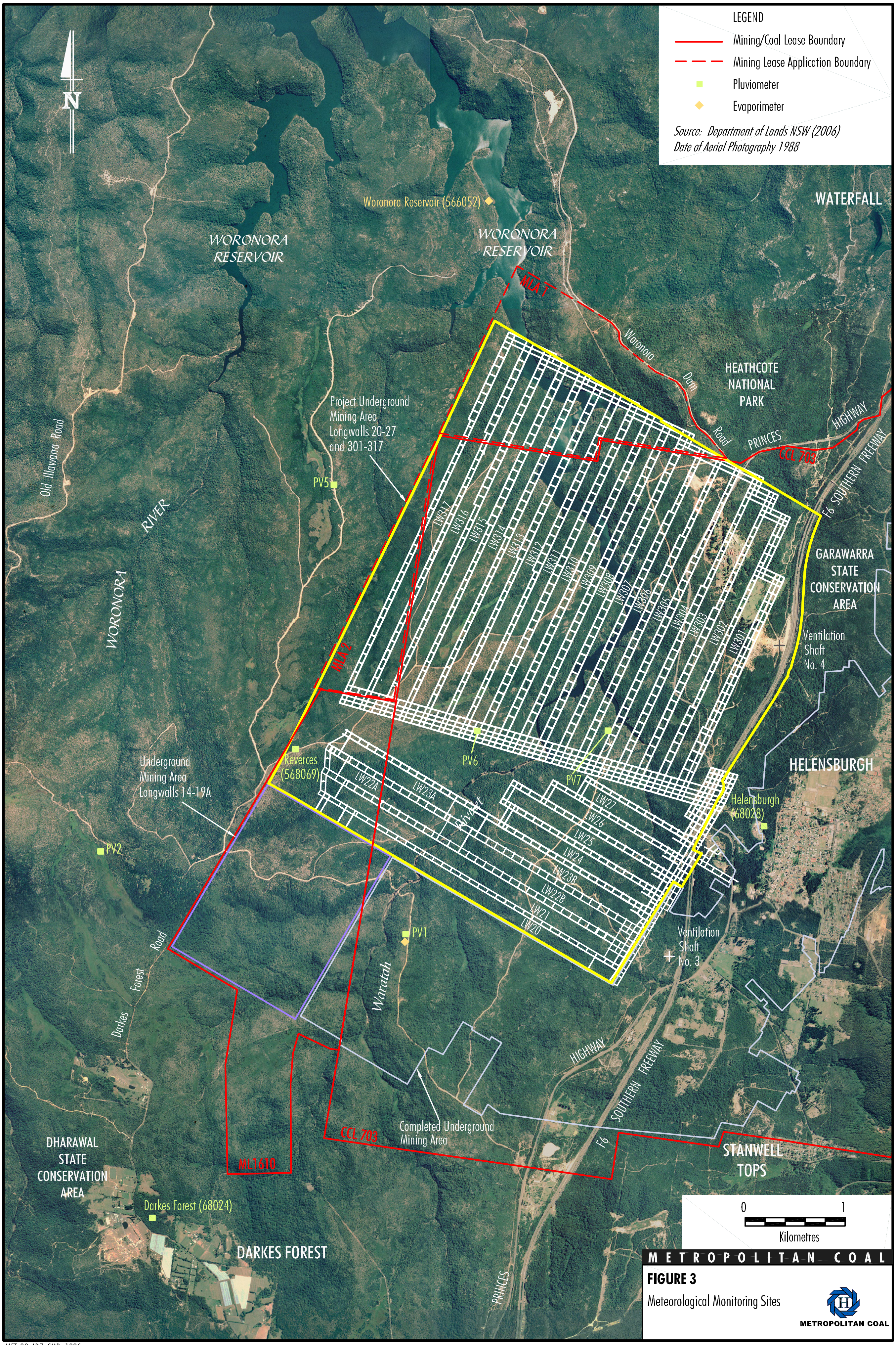

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FIGURE 3

Meteorological Monitoring Sites

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Table 2
Existing Meteorological Monitoring Station Locations and Recording Periods

Station Number	Data Type	Period of Record
Lucas Heights (BoM Station Number 66078)	Evaporation, ground minimum temperature, air maximum temperature, air temperature, dew point, mean sea level pressure, total cloud amount, wind speed, maximum wind gust speed, rainfall and rainfall intensity	1958 to present
Darkes Forest (BoM Station Number 68024)	Rainfall (BoM daily read converted to pluviometer)	1894 to present
Helensburgh (BoM Station Number 68028)	Rainfall (BoM daily read converted to pluviometer)	1889 to 2005
'Reverces' (BoM Station Number 568069)	Rainfall (pluviometer)	2000 to present
Waratah Rivulet (site PV1)	Rainfall (Metropolitan Coal pluviometer)	2006 to present
Woronora River (site PV2)	Rainfall (Metropolitan Coal pluviometer)	2007 to present
Woronora Reservoir (566052)	Evaporation data (SCA station)	from 1976 (discontinued)

Additional pluviometers were installed in the Honeysuckle Creek catchment (site PV5), Waratah Rivulet catchment (site PV6) and the Eastern Tributary catchment (site PV7) in June 2010 (Figure 3). Pan evaporation equipment was also installed at the pluviometer situated in the Waratah Rivulet catchment (site PV1) in August 2010 (Figure 3).

3.2 STRATIGRAPHY AND LITHOLOGY

The Southern Coalfield lies in the southern part of the Sydney Basin, which is infilled with sedimentary rocks of Permian age (<270 million years ago) and of Triassic age (<225 million years ago). A cross-section of the stratigraphic sequence within the Project area is shown on Figure 4 and summarised below.

Hawkesbury Sandstone - outcrops over the Project area and consists of thickly bedded or massive quartzose sandstone (with grey shale lenses up to several metres [m] thick); maximum geological thickness is about 170 m.

Newport Formation - the uppermost stratum of the Narrabeen Group, consisting of interbedded grey shales and sandstones.

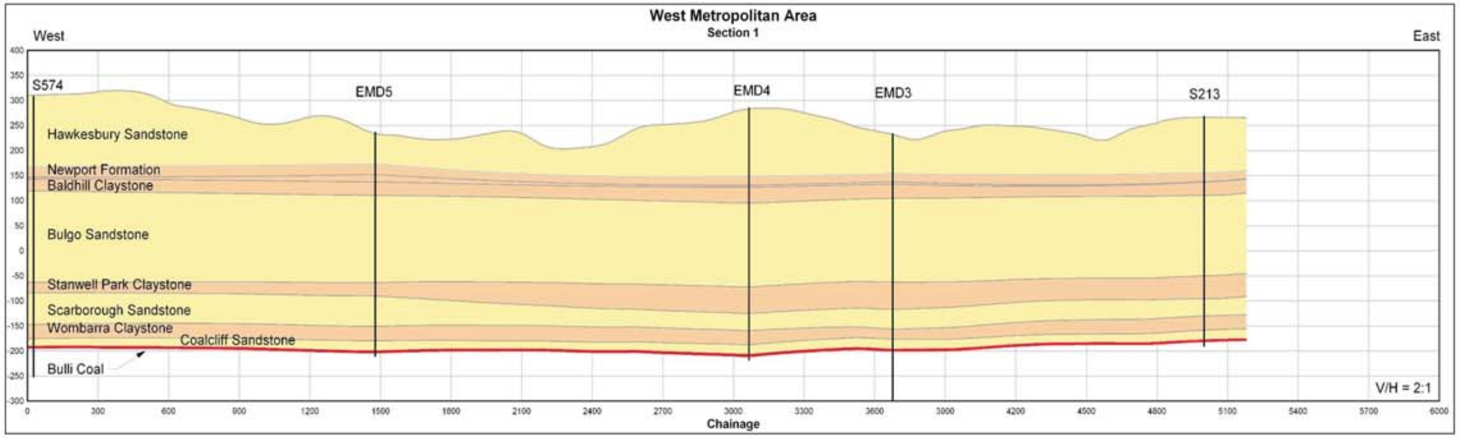
Garie Formation - consists of cream to brown, massive, characteristically oolitic claystone.

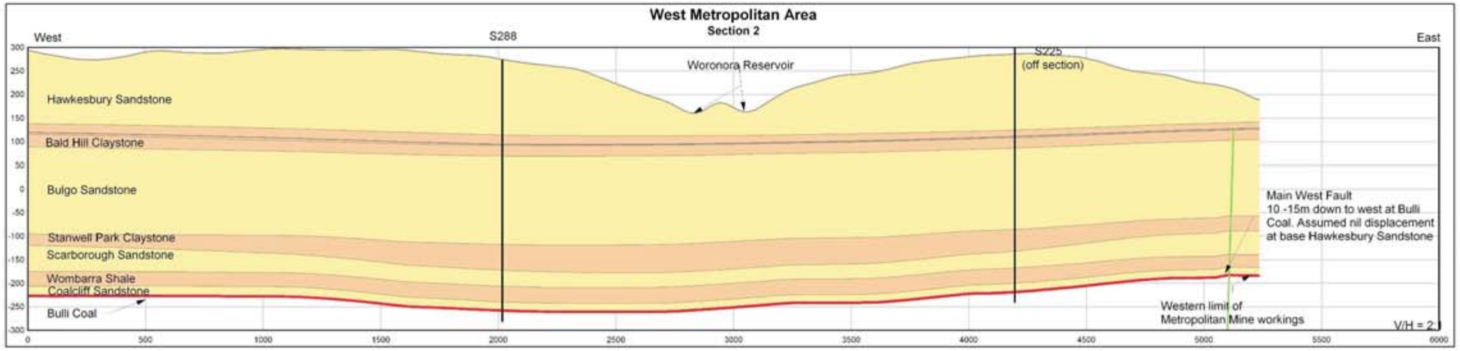
Bald Hill Claystone - consists of brownish-red coloured "chocolate shale", a physically weak but lithologically stable unit; nearly constant thickness over a large portion of the Southern Coalfield.

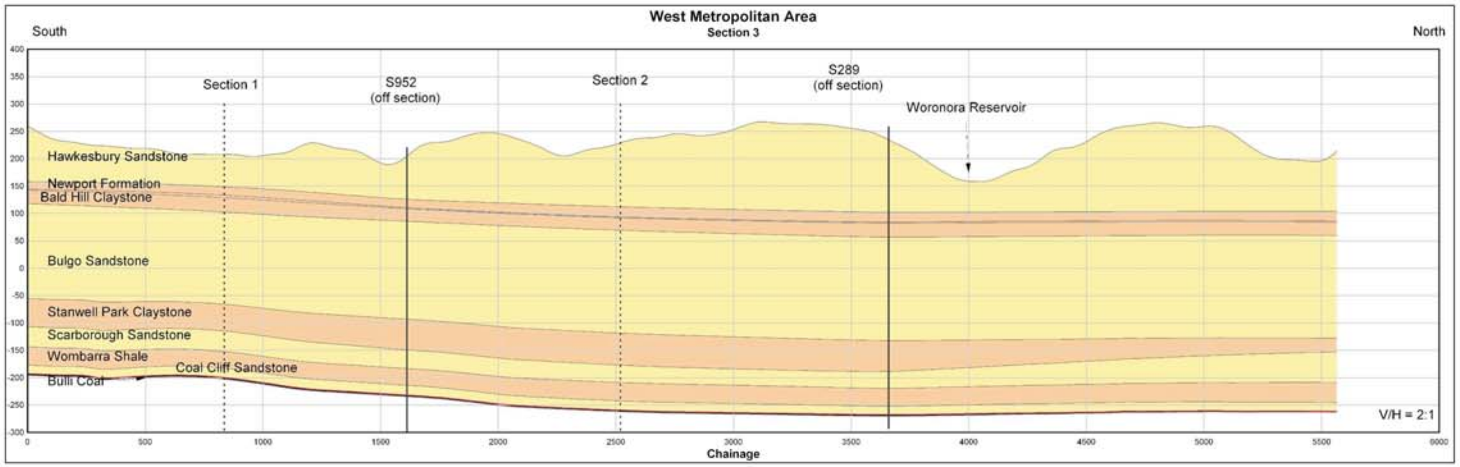
Bulgo Sandstone - consists of strong, thickly bedded, medium to coarse-grained lithic sandstone with occasional beds of conglomerate or shale; thickens northerly from 160 m to 195 m, averaging 175 m thick.

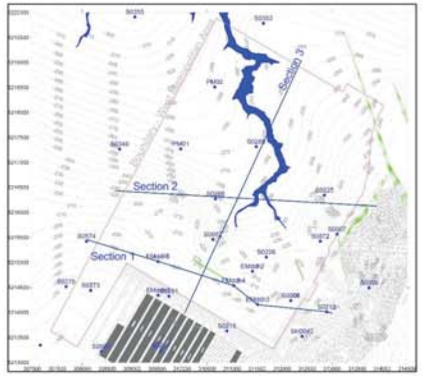
Stanwell Park Claystone - consists of greenish-grey mudstones and sandstones.

Scarborough Sandstone - consists of coarse sandstone and conglomerate interbedded with siltstone bands; transitional from the underlying Wombarra Claystone; average 24 m thickness over the Southern Coalfield.









Source: Geosensing Solutions (2008)

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FIGURE 4

Metropolitan Geological Cross Sections

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Wombarra Claystone - similar properties to the Stanwell Park Claystone.

Coal Cliff Sandstone - consists of basal shales and mudstones that are contiguous with the underlying Bulli Coal Seam.

Illawarra Coal Measures - consist of interbedded shales, mudstones, lithic sandstones and coals of which 10 named seams occur in the area.

Bulli Coal Seam - the uppermost coal unit in the Illawarra Coal Measures. It has been worked extensively in the northern portion of the Southern Coalfield, from outcrop mines on the coastal margins to inland mines; currently mined at Metropolitan Coal.

3.3 STRUCTURAL GEOLOGY

Geological structures that are known either to exist in underground workings or are inferred from current geological data that may extend into the Project area have been identified for further investigation through surface mapping (Figure 5). These include (Geosensing Solutions, 2008):

- Metropolitan Fault (also known as Pit Bottom Fault).
- Powell Fault.
- Main West Fault.
- Freeway Fault.
- Long Hole Fault.
- Madden Fault Zone.

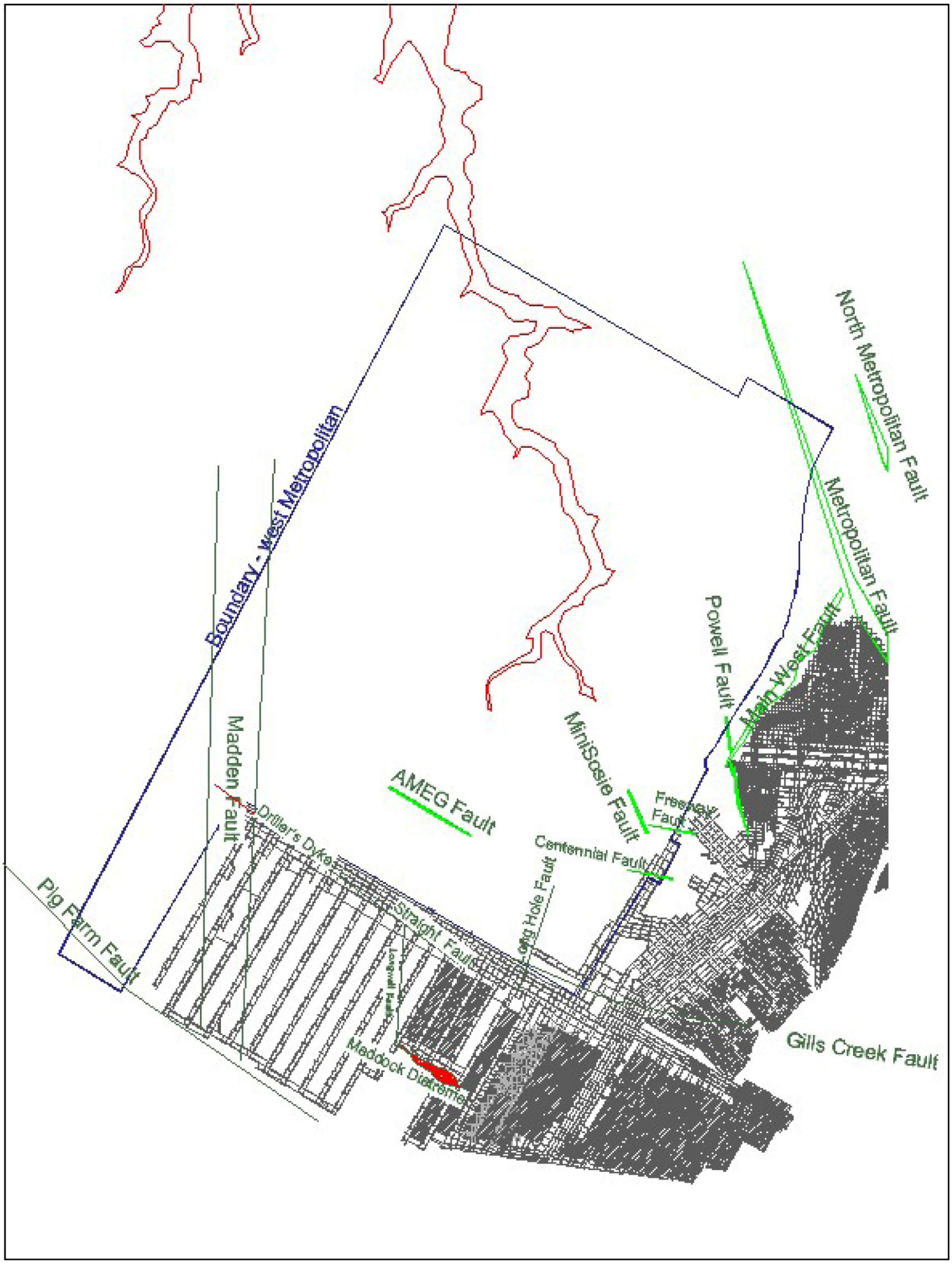
In addition to the known structures exposed in the underground workings, other structures are inferred from the review of existing data (Figure 5). These include (Geosensing Solutions, 2008):

- AMEG Fault.
- Mini Sosie Fault.

In general, individual structural features located on the floor of the Bulli Coal Seam have not been identified at surface despite focused searches over the years, nor have individual surface features been successfully projected and proven at the Bulli Coal Seam horizon.

Tertiary age igneous intrusions in the form of sills and dykes post date the sedimentary strata in the area. Igneous dykes are present as generally thin (less than 1 m) altered clays at outcrop. No igneous sills are known in the strata over the coal measures (Geosensing Solutions, 2008).

No diatremes have been identified in the Project area (Geosensing Solutions, 2008).



Source: Geosensing Solutions (2008).

Figure 5 Known Faults

3.4 SURFACE WATER

3.4.1 Overview

The Project Underground Mining Area is situated on the Woronora Plateau within the Woronora Reservoir and Hacking River catchments.

The Woronora Reservoir is a public water supply dam which supplies water to consumers within the Sutherland Shire Council area. A large portion of the Project Underground Mining Area is located within the Woronora Special Area, which is approximately 75 square kilometres (km^2) in area and includes all the land draining to the Woronora Reservoir (Figure 1). Part of the Project Underground Mining Area is located within the Dams Safety Committee Notification Area for the Woronora Reservoir (Figure 1).

The Project Underground Mining Area includes the Waratah Rivulet catchment and tributaries that flow directly to the Woronora Reservoir, as well as the upper reaches of the Woronora Reservoir (Figure 6). The headwaters of Cawleys Creek and Wilsons Creek, which drain in an easterly direction away from Woronora Reservoir into the Hacking River are also situated within the north-eastern corner of the Project Underground Mining Area. An overview of the watercourses is provided below.

The Waratah Rivulet is some 9 kilometres (km) in length from its headwaters to the full supply level of the Woronora Reservoir. The Waratah Rivulet flows through a relatively steep valley and has been subject to previous underground mining (Figure 6). The stream channel in Waratah Rivulet in the Project Underground Mining Area is characterised by a gently meandering, relatively shallow, wide channel with a sandstone bed. The channel contains a series of in-stream pools that have formed in local depressions in the bedrock and behind rock bars. There are also reaches that are covered in large boulders (Gilbert and Associates, 2008). A number of tributaries flow into the Waratah Rivulet (Figure 6). The tributaries are situated within moderately steep incised gullies and contain numerous small in-stream pools.

A number of tributaries in the Project Underground Mining Area flow direct to the Woronora Reservoir including the Eastern Tributary, Honeysuckle Creek and other tributaries with headwater upland swamps (Figure 6). The Eastern Tributary is situated in a moderately steep incised valley with numerous in-stream pools, while Honeysuckle Creek has a medium sized catchment and a relatively large upland swamp in its headwaters. A number of small tributary catchments that drain direct to Woronora Reservoir contain headwater upland swamps.

As described above, a portion of the Project Underground Mining Area is overlain by the headwaters of Cawley's and Wilson's Creeks which drain in an easterly direction away from Woronora Reservoir and into the Hacking River.

The Woronora Reservoir inundation area is characterised by alluvial deposition in the reservoir bed.

The Woronora River is a tributary of the Woronora Reservoir (Figure 6). The Woronora River is situated to the west of the Project Underground Mining Area and is unaffected by longwall mining activities.

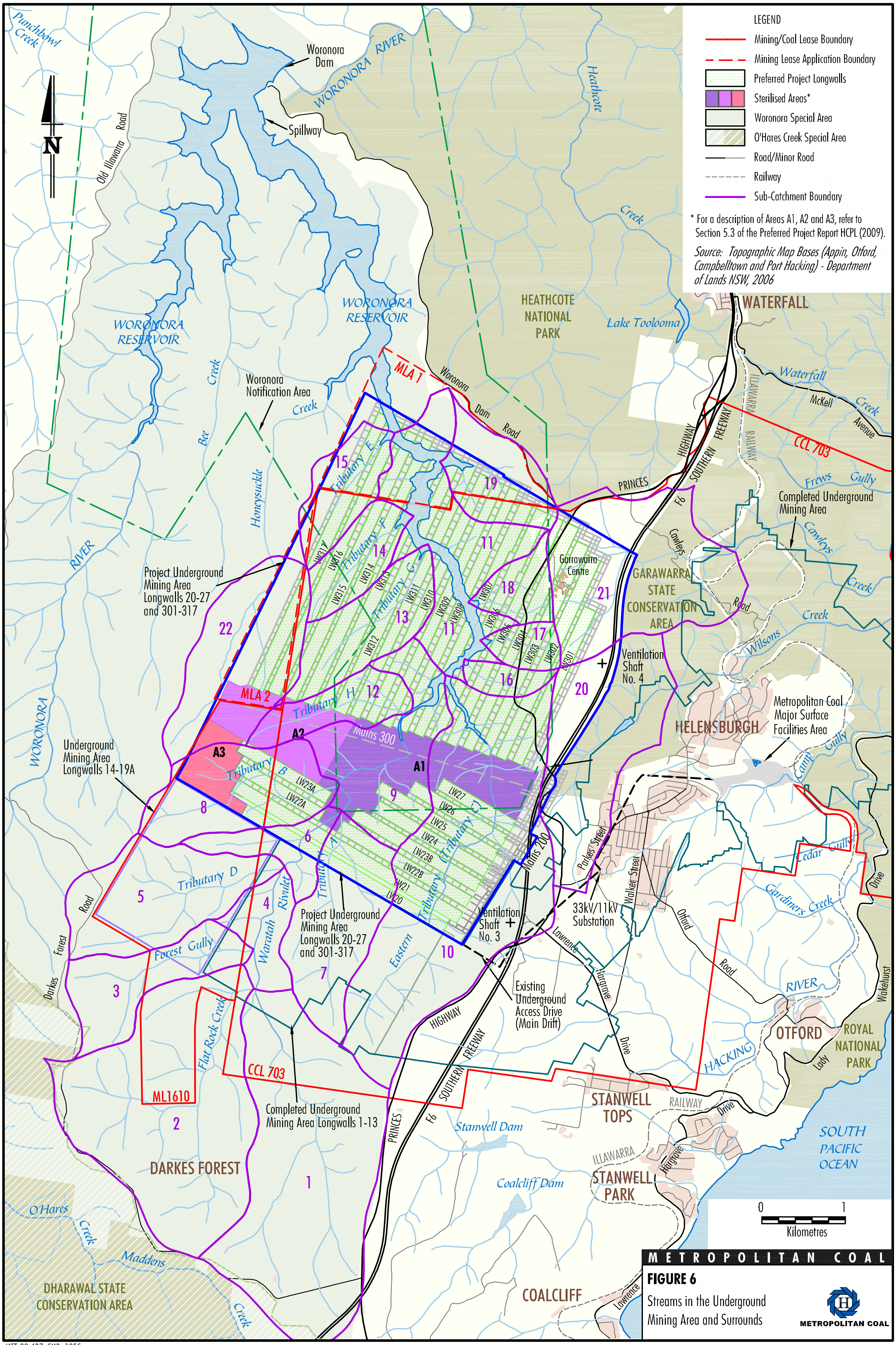


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FIGURE 6

Streams in the Underground Mining Area and Surrounds

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3.4.2 Sub-Catchments

For descriptive purposes the Project Underground Mining Area has been subdivided into 22 sub-catchments as shown Figure 6. The catchment subdivision provides a convenient means of describing the main features and their distribution relative to the longwall panel layout. The subdivision was based on internal watersheds bounding large tributaries and portions of tributaries that have either large drainage networks, or that drain a large proportion (10 percent [%] or more) of the total catchment, or that contain particular features. The key attributes of these sub-catchments are summarised in Table 3.

3.4.3 Stream Features

As a component of the Metropolitan Coal Longwalls 20-22 Water Management Plan, Mine Subsidence Engineering Consultants (MSEC) has compiled a comprehensive survey and photographic record of Waratah Rivulet (from Flat Rock Crossing to the Woronora Reservoir full supply level), Eastern Tributary (from the east-west headings to the Woronora Reservoir full supply level), Tributary A (from its headwaters to its confluence with Waratah Rivulet) and Tributary B (from its headwaters to its confluence with Waratah Rivulet). The following aspects were noted at each site:

- pool dimensions (i.e. width, length and depth);
- characteristics and dimensions of the retaining rock bar;
- characteristics of the water flow (channels, etc.);
- presence of small waterfalls;
- the location, approximate dimensions and orientations of surface cracks;
- the nature and extent of iron staining;
- any gas releases;
- presence of underflow; and
- photographs of the above.

Detailed mapping and photographs of the Waratah Rivulet, Eastern Tributary, Tributary A and Tributary B is provided in Appendices 1 to 4 of the Metropolitan Coal Longwalls 20-22 Water Management Plan, respectively.

No gas releases had previously been observed along the Waratah Rivulet, Eastern Tributary or other tributaries over the Metropolitan Coal lease, either before or during mining. For the purposes of this CMP, it is assumed that the baseline extent of gas release within 600 m of Longwalls 20-22 secondary extraction is nil.

Gas releases have however since been recorded downstream of Flat Rock Crossing and are described in the Metropolitan Coal Annual Reviews. Gas releases are monitored in accordance with the monitoring program outlined in Section 5.2.

Table 3
Summary of Mine Area Catchments and Sub-Catchments

Sub-Catchment Number	Local Catchment/ Sub-Catchment	Location	Past Mining Activities	Relevant Longwalls LW20-317	Catchment Area (ha)[1]	Stream Order	Average stream gradient (m/km)	Stream Length (km)
1	Upper Waratah Rivulet	Headwaters down to confluence with Flat Rock Creek	Old bord and pillar workings	-	578	3	26	3.9
2	Flat Rock Creek	Headwaters to confluence with upper Waratah Rivulet	Old bord and pillar workings	-	546	3	38	3.64
3*	Forest Gully	Left bank tributary of Waratah Rivulet	Un-mined in western extremity; old bord and pillar workings in southern extremity; Longwalls 11, 12, 13, 14 and 15	-	158	2	59	2.36
4*	Waratah Rivulet from Flat Rock Creek to Tributary D confluence		Longwalls 9, 10, 11, 12, 13 and 14	-	76	4	6	1.64
5*	Tributary D	Left bank tributary of Waratah Rivulet	Upper sections outside mine area; mid sections Longwall 18; lower sections Longwalls 13, 14, 15, 16 and 17	-	234	3	51	2.76
6*	Waratah Rivulet Tributary D to Tributary A		Gate Road and Longwalls 11, 12, 14, 15 and 16; includes Flat Rock Crossing	Longwalls 20, 21 and 22	91	4	20	1.02
7	Tributary A	Right bank tributary of Waratah Rivulet	Longwalls 5, 6, 7, 8, 9 and 10	Longwalls 20, 21 and 22	205	2	43	2.78
8*	Tributary B	Left bank tributary of Waratah Rivulet	Longwalls 17 and 18	Longwalls 20, 21, 22 and 23	201	3	61	2.8
9	Waratah Rivulet, and Tributary A to Waratah Rivulet confluence		None	Longwalls 22 to 27 and Longwalls 301 to 308	215	4	12	2.6
10	Eastern Tributary (Tributary C)	Major right bank tributary	Longwalls 1, 2, 3 and 4	Longwalls 22 to 27 and Longwalls 301 to 308	670	3	26	5.4
11	Woronora Reservoir, downstream of Eastern Tributary (Tributary C)		None	Longwalls 308 to 312	269	N/A	N/A	3.7

Table 3 (Continued)
Summary of Mine Area Catchments and Sub-Catchments

Sub-Catchment Number	Local Catchment/ Sub-Catchment	Location	Past Mining Activities	Relevant Longwalls LW20-317	Catchment Area (ha[1])	Stream Order	Average stream gradient (m/km)	Stream Length (km)
12	Left bank upland swamp tributary 1, Tributary H	Small left bank tributary draining direct to Woronora Reservoir	None	Longwalls 310 to 312	90	2	77	1.96
13	Left bank upland swamp tributary 2, Tributary G	Small left bank tributary draining direct to Woronora Reservoir	None	Longwalls 311 to 315	155	2	62	2.1
14	Left bank upland swamp tributary 3, Tributary F	Small left bank tributary draining direct to Woronora Reservoir	None	Longwalls 315 to 317	93	1	65	1.84
15	Left bank upland swamp tributary 4, Tributary E	Small left bank tributary draining directly to Woronora Reservoir	None	Longwalls 318 to 317	102	2	69	1.3
16	Right bank upland swamp tributary 1	Small right bank tributary draining directly to Woronora Reservoir	None	Longwalls 301 to 308	35	1	122	0.82
17	Right bank upland swamp tributary 2	Small right bank tributary draining directly to Woronora Reservoir	None	Longwalls 302 to 308	42	1	144	0.9
18	Right bank upland swamp tributary 3	Small right bank tributary draining directly to Woronora Reservoir	None	Longwalls 306 to 309	64	1	133	0.98
19	Right bank upland swamp tributary 4	Small right bank tributary draining directly to Woronora Reservoir	None	Parts of Longwalls 310 to 312 in southern extremity of catchment	122	3	63	1.12
20	Upper Wilson's Creek	Upper reaches of easterly flowing tributary of the Hacking River	None	Longwalls 301 to 303	288	3	52	3.1
21	Upper Cawley's Creek	Upper reaches of easterly flowing tributary of the Hacking River	None	Longwalls 301 to 305	353	3	51	2.92
22	Upper Honeysuckle Creek	Upper reaches of tributary which flows into Woronora Reservoir	None	Western ends of Longwalls 22 to 24; Longwalls 317 to 317	266	2	28	2.82

* Sub-catchments within the Current Underground Mining Area
[1] ha = hectares

Detailed mapping and photographic records of Tributaries E to H (catchments 11, 12, 13, 14 and 15) (Figure 6) will be conducted as a component of future Water Management Plans contained within respective Extraction Plans. Baseline recording will be conducted a minimum of two years prior to secondary extraction occurring within 400 m of the relevant stream. According to the provisional extraction schedule (Table 1), Tributary H would be mapped a minimum of two years prior to the completion of Longwall 306 (prior to the end of 2019). Baseline data collection for Tributaries E, F and G would therefore be initially flagged under requirements of 'Future Extraction Plans' in the Longwalls 301-306 Water Management Plan, and then provided as baseline data in the Longwalls 307-315 Water Management Plan.

3.4.4 Surface Water Flow

Surface water flow data is available for the SCA gauging station on Waratah Rivulet (GS2132102, 20.2 km^2 catchment area) and the SCA gauging station on the Woronora River (GS2132101, 12.4 km^2 catchment area) (Table 4 and Figure 7). The SCA gauging stations were established in February 2007, however the Woronora River gauging station contains periods of missing data. The Waratah Rivulet station is located downstream of longwall mining, while the Woronora River catchment has not been subject to longwall mining activities[1]. The locations of the Waratah Rivulet (GS2132102) and Woronora River (GS2132101) gauging stations are shown on Figure 7.

Table 4
Gauging Station Locations and Recording Periods

Station Number	Watercourse	Catchment Area (km^2)	Period of Record
SCA-owned (GS2132102)	Waratah Rivulet, upstream of the Woronora Reservoir full supply level	20.2	February 2007 to present
SCA-owned (GS2132101)	Woronora River, upstream of the Woronora Reservoir full supply level	12.4	February 2007 to present
OEH (GS213002)	O'Hares Creek at Darkes Forest	16	1924 to 1930
OEH (GS213200)	O'Hares Creek at Wedderburn	73	1978 to present

Surface water flow data is also available from the Office of Environment and Heritage (OEH) gauging stations on O'Hares Creek: an upstream gauging station at Darkes Forest (GS213002) and a downstream gauging station near the town of Wedderburn (GS213200) (Table 4). The O'Hares Creek catchment is located immediately south and west of the Woronora Dam catchment. Longwall mining occurred in the catchment of GS213200 in 1986 to 1987 and 1990 to 1999.

Two Metropolitan Coal-owned gauging stations are located on the Waratah Rivulet: GS300016 situated upstream of Flat Rock Crossing and GS300017 situated downstream of Flat Rock Crossing. Stream flows at these gauging stations may have been impacted by mine subsidence.

Additional gauging stations will be installed on the Eastern Tributary and Honeysuckle Creek (Figure 7). The gauging stations will be designed to accurately record high and low flows. The gauging stations will provide baseline data for the development of catchment models that will be used during the mining of Longwalls 23-27 (as described in Section 4).

[1] The headwaters of the Woronora River are proposed to be mined by BHP Billiton Illawarra Coal Bulli Seam Operations. On current mine planning (and subject to mine economics and detailed mine design), it is understood that mining within the catchment of the Woronora River is not proposed in the next 20 years (Heritage Computing, 2009a).

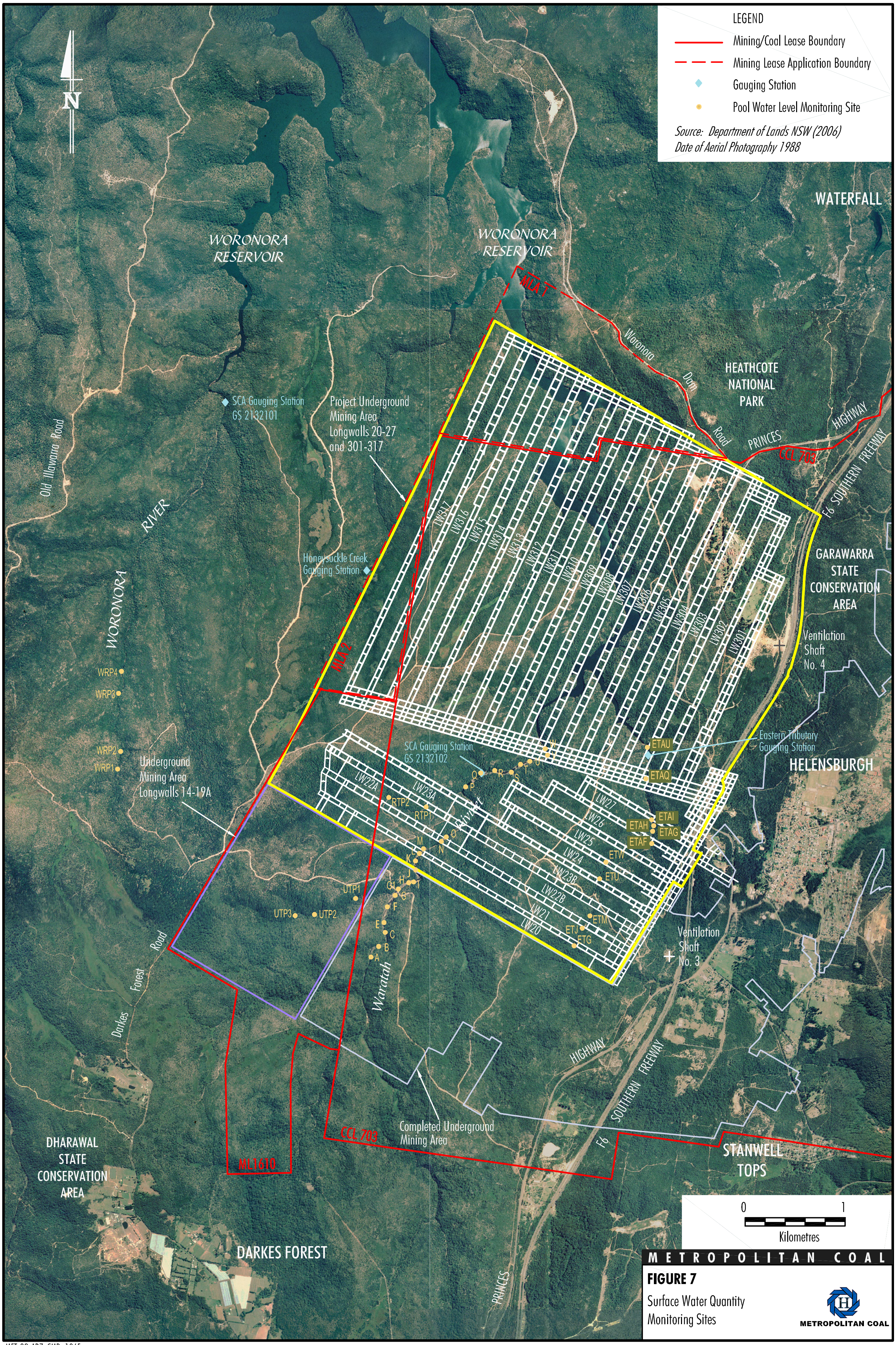

FIGURE 7
Surface Water Quantity Monitoring Sites

MET-08-AD7 CMP_106E

Figure 8 shows concurrent streamflow data from the SCA-owned gauging stations on Waratah Rivulet and Woronora River and the OEH-owned gauging station on O'Hares Creek at Wedderburn at the time of CMP development. Streamflow is expressed on a per unit catchment area basis (in millimetres [mm]) to allow direct comparison of flow magnitudes without having to adjust for contributing catchment area. Flows are plotted on a logarithmic scale to emphasise the lower flow range. Flow duration curves for each station for the period since February 2007 to June 2009 are shown on Figure 9.

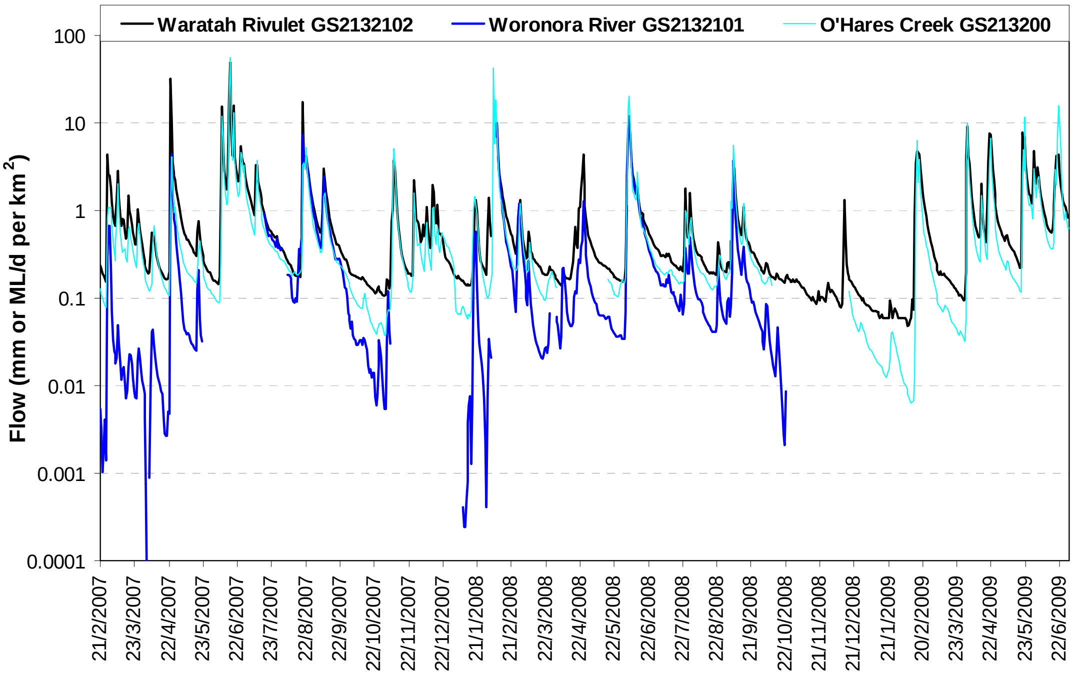

Figure 8 Recorded Streamflow Hydrographs – Waratah Rivulet, Woronora River and O'Hares Creek at Wedderburn

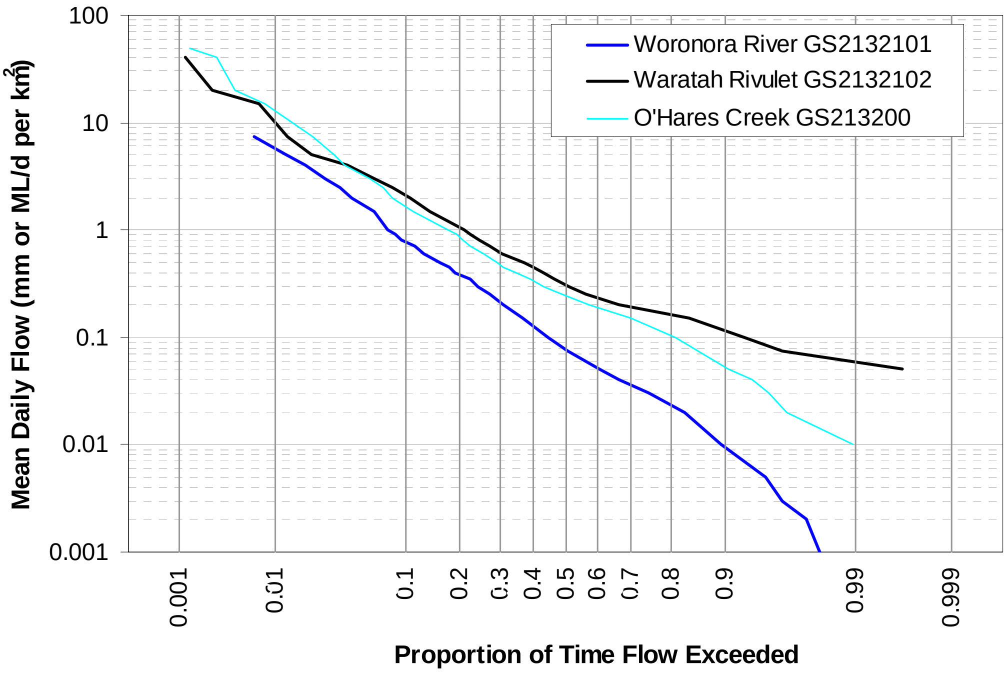

Figure 9 Flow Duration Curves – Waratah Rivulet, Woronora River and O'Hares Creek at Wedderburn

Of the three streams, Waratah Rivulet yielded the highest flow per unit catchment area in medium and low flows, with strong low flow persistence (lowest recorded flow 0.047 mm/day). O'Hares Creek (at Wedderburn) yielded similar flows, with slightly greater high flows, but notably steeper flow recession and lower magnitude low flows. The Woronora River recorded the lowest flows per unit catchment, with the steepest flow recessions.

The streamflow model used in the Metropolitan Coal Project Environmental Assessment (EA) Surface Water Assessment (Gilbert and Associates, 2008) has been re-calibrated using the updated Waratah Rivulet and O'Hares Creek gauging station data[2] using the nationally recognised Australian Water Balance Model (AWBM) (Boughton, 2004). The streamflow model and the calibration and validation program are discussed in Section 4.3.

3.4.5 Pool Water Levels

Pool water level data is available for a number of sites on the Waratah Rivulet, Eastern Tributary, Tributary B, Tributary D and the Woronora River (Table 5).

Table 5
Pool Water Level Monitoring Sites
(Manual and Continuous Water Level Data)

Site Number	Watercourse	Commencement Date
Pool A	Waratah Rivulet	29/9/2005
Pool B	Waratah Rivulet	29/9/2005
Pool C	Waratah Rivulet	29/9/2005
Pool E	Waratah Rivulet	29/9/2005
Pool F	Waratah Rivulet	29/9/2005
Pool G	Waratah Rivulet	29/9/2005
Pool G1	Waratah Rivulet	13/10/2005
Pool H	Waratah Rivulet	12/10/2005
Pool I	Waratah Rivulet	12/10/2005
Pool J	Waratah Rivulet	1/7/2010
Pool K	Waratah Rivulet	1/7/2010
Pool L	Waratah Rivulet	11/12/2008
Pool M	Waratah Rivulet	11/12/2008
Pool N	Waratah Rivulet	11/12/2008
Pool O	Waratah Rivulet	11/12/2008
Pool P	Waratah Rivulet	11/12/2008
Pool Q	Waratah Rivulet	20/1/2010
Pool R	Waratah Rivulet	11/12/2008
Pool S	Waratah Rivulet	11/12/2008
Pool T	Waratah Rivulet	20/1/2010
Pool U	Waratah Rivulet	20/1/2010
Pool V	Waratah Rivulet	20/1/2010
Pool W	Waratah Rivulet	20/1/2010
Pool ETG	Eastern Tributary	16/2/2011

2 Insufficient data was available at the time of CMP development to enable AWBM calibration of the SCA's Woronora River gauging station. Any subsequent AWBM calibration of the SCA's Woronora River gauging station will be reported in the Metropolitan Coal Annual Reviews.

Table 5 (Continued)
Pool Water Level Monitoring Sites
(Manual and Continuous Water Level Data)

Site Number	Watercourse	Commencement Date
Pool ETJ	Eastern Tributary	29/3/2011
Pool ETM	Eastern Tributary	11/12/2008
Pool ETU	Eastern Tributary	18/5/2010
Pool ETW	Eastern Tributary	18/5/2010
Pool ETAF	Eastern Tributary	18/5/2010
Pool ETAG	Eastern Tributary	18/5/2010
Pool RTP1	Tributary B	7/3/2007
Pool RTP2	Tributary B	7/3/2007
Pool UTP1	Tributary D	7/3/2007
Pool UTP2	Tributary D	7/3/2007
Pool UTP3	Tributary D	7/3/2007
Pool WRP1	Woronora River (Control Site)	11/12/2008

The following additional pools have also been instrumented with water level sensors and data loggers: Pools ETAH, ETAI, ETAQ and ETAU on the Eastern Tributary.

The locations of the pools are shown on Figure 7. Pools and rock bars along the Waratah Rivulet, Eastern Tributary, Tributary A and Tributary B are shown on the detailed mapping and photographs provided in the Metropolitan Coal Longwalls 20-22 Water Management Plan.

Additional pool water level sensors and data loggers will be established at select pools along Tributaries E to H based on the results of the baseline survey and photographic mapping described in Section 3.4.3. The pool water level monitoring equipment will be installed a minimum of two years prior to secondary extraction within 400 m of the relevant stream. For example, in the case of Tributary H, pool water level monitoring equipment will be installed a minimum of two years prior to completion of Longwall 306 (prior to the end of 2019). The baseline data collection for Tributaries E, F and G would therefore be initially flagged under requirements of 'Future Extraction Plans' in the Longwalls 301-306 Water Management Plan, and then provided as baseline data in the Longwalls 307- 315 Water Management Plan.

Inspection of other tributaries (sub-catchments on the eastern side of the Woronora Reservoir) indicates the drainage channels are small ephemeral streams.

3.4.6 Stream Water Quality

Water quality data has been collected at a large number of sites on the Waratah Rivulet and other streams. Water quality sites are summarised in Table 6 and shown on Figure 10.

Table 6
Stream Water Quality Monitoring Sites

Site Number	Watercourse	Commencement Date
WRWQ 1	Waratah Rivulet	27/9/2006
WRWQ 2	Waratah Rivulet	27/9/2006
WRWQ 3	Waratah Rivulet	27/9/2006
WRWQ 4 (Pool B)	Waratah Rivulet	27/9/2006
WRWQ 5	Waratah Rivulet	27/9/2006
WRWQ 6 (Pool F)	Waratah Rivulet	27/9/2006
WRWQ 7 (Pool H)	Waratah Rivulet	27/9/2006
WRWQ 8	Waratah Rivulet	27/9/2006
WRWQ 9 (Pool Q)	Waratah Rivulet	27/9/2006
WRWQ J	Waratah Rivulet	27/1/2010
WRWQ K	Waratah Rivulet	27/1/2010
WRWQ L	Waratah Rivulet	11/12/2008
WRWQ M	Waratah Rivulet	11/12/2008
WRWQ N	Waratah Rivulet	11/12/2008
WRWQ O	Waratah Rivulet	11/12/2008
WRWQ P	Waratah Rivulet	11/12/2008
WRWQ R	Waratah Rivulet	11/12/2008
WRWQ S	Waratah Rivulet	11/12/2008
WRWQ T	Waratah Rivulet	10/2/2010
WRWQ U	Waratah Rivulet	10/2/2010
WRWQ V	Waratah Rivulet	10/2/2010
WRWQ W	Waratah Rivulet	10/2/2010
UTWQ 1	Waratah Rivulet	3/8/2006
UTWQ 2	Tributary D	3/8/2006
UTWQ 3	Tributary D	3/8/2006
UTWQ 4	Tributary D	3/8/2006
UTWQ 5	Tributary D	3/8/2006
FGWQ 1	Forest Gully	1/8/2006
FGWQ 2	Forest Gully	1/8/2006
FGWQ 3	Forest Gully	1/8/2006
FGWQ 4	Forest Gully	1/8/2006
FGWQ 5	Forest Gully	1/8/2006
RTWQ 1	Tributary B	3/8/2006
RTWQ 2	Tributary B	3/8/2006
RTWQ 3	Tributary B	3/8/2006
ETWQ F	Eastern Tributary	17/2/2010
ETWQ J	Eastern Tributary	17/2/2010
ETWQ N	Eastern Tributary	7/9/2007
ETWQ U	Eastern Tributary	28/1/2010
ETWQ W	Eastern Tributary	28/1/2010
ETWQ AF	Eastern Tributary	28/1/2010
ETWQ AG	Eastern Tributary	28/1/2010
ETWQ AH	Eastern Tributary	28/1/2010
ETWQ AI	Eastern Tributary	28/1/2010
ETWQ AK	Eastern Tributary	28/1/2010
ETWQ AQ	Eastern Tributary	28/1/2010
ETWQ AU	Eastern Tributary	28/1/2010

Table 6 (Continued)
Stream Water Quality Monitoring Sites

Site Number	Watercourse	Commencement Date
FEWQ 1	Far Eastern Tributary	7/9/2007
BCWQ 1	Bee Creek	7/9/2007
HCWQ 1	Honeysuckle Creek	7/9/2007
WOWQ 1	Woronora River (Control Site)	7/9/2007
WOWQ 2	Woronora River (Control Site)	17/1/2008
WOWQ 3	Woronora River (Control Site)	11/12/2008
WOWQ 4	Woronora River (Control Site)	28/1/2010
WOWQ 5	Woronora River (Control Site)	28/1/2010
WOWQ 6	Woronora River (Control Site)	28/1/2010

Note: Water quality sampling sites WRWQ J to WRWQ W are taken from Pools J to W on the Waratah Rivulet and water quality sampling sites ETWQ F to ETWQ AU are taken from Pools ETF to ETAU on the Eastern Tributary, respectively.

A statistical summary of the key water quality parameters of particular relevance to expected subsidence effects (i.e. iron, manganese, aluminium and electrical conductivity) is provided in Table 7 for selected sites on the Waratah Rivulet, Eastern Tributary, Far-Eastern Tributary, Woronora River, Bee Creek and Honeysuckle Creek at the time of CMP development.

The historical pattern of water quality at these sites is illustrated on Figures 11 to 14 at the time of CMP development.

Additional water quality sites will be established at each pool selected for installation of automated water level sensors and data loggers. The water quality sampling program will commence when the pool water level monitoring equipment is established as described in Section 3.4.5 (i.e. a minimum of two years prior to secondary extraction occurring within 400 m of the relevant stream). In the case of Tributary H, this will occur prior to completion of Longwall 306 (prior to the end of 2019).

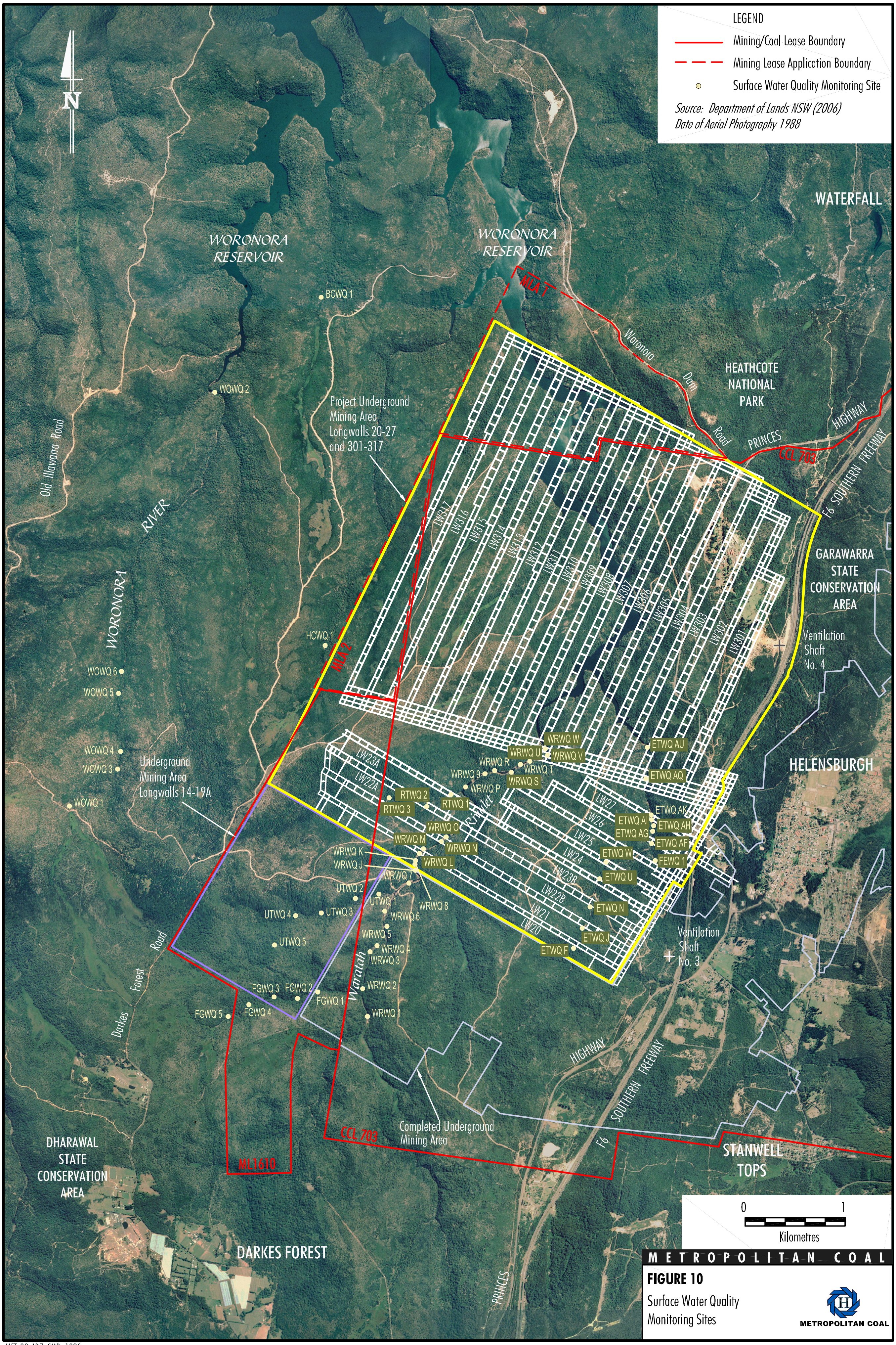

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FIGURE 10

Surface Water Quality Monitoring Sites

METROPOLITAN COAL

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Table 7
Statistical Summary of Water Quality Data

Site	Number of Samples	Iron (mg/L[1])				Manganese (mg/L)				Aluminium (mg/L)				Electrical Conductivity (µS/cm[2])			
		Min	Max	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max	Mean	Std. Dev
WRWQ 1	42	0.17	1.30	0.65	0.32	0.02	0.25	0.11	0.07	<0.001	0.18	0.03	0.04	110	880	200	116.2
WRWQ 8	42	0.02	0.92	0.26	0.18	0.02	0.50	0.18	0.10	<0.001	0.15	0.02	0.03	120	350	198	51.3
WRWQ 9	42	0.03	0.39	0.18	0.10	0.01	0.07	0.04	0.02	<0.001	0.15	0.03	0.03	120	340	199	52.7
ETWQ N	33	0.03	0.97	0.28	0.17	0.02	0.29	0.08	0.05	<0.001	0.12	0.03	0.02	110	299	177	39.5
FEWQ 1	33	0.07	0.68	0.27	0.15	0.003	0.12	0.02	0.02	0.03	0.16	0.07	0.03	150	250	197	25.2
WOWQ 1	33	<0.001	3.10	0.24	0.55	<0.001	0.09	0.02	0.02	0.10	0.26	0.18	0.04	96	180	136	18.3
WOWQ 2	32	0.05	1.30	0.19	0.24	0.01	0.10	0.03	0.02	<0.001	0.11	0.05	0.03	120	210	157	20.4
BCWQ 1	32	0.01	0.96	0.15	0.06	0.01	0.24	0.03	0.06	0.31	0.84	0.53	0.11	105	240	154	29.2
HCWQ 1	31	0.01	1.60	0.22	0.35	<0.001	0.05	0.01	0.01	0.18	0.63	0.46	0.09	91	198	122	20.3

[1] mg/L = milligrams/litre.

[2] µS/cm = microSiemens per centimetre.

Note: Data analysis consistent with the following period of record for each site:

WRQW 1 (27/9/2006 – 3/12/2009), WRWQ 8 (27/9/2006 – 3/12/2009), WRWQ 9 (27/9/2006 – 3/12/2009)

ETWQ N (7/9/2007 – 1/12/2009), FEWQ 1 (7/9/2007 – 1/12/2009)

WOWQ 1 (7/9/2007 – 1/12/2009), WOWQ 2 (7/9/2007 – 1/12/2009)

BCWQ 1 (7/9/2007 – 1/12/2009), HCWQ 1 (7/9/2007 – 1/12/2009)

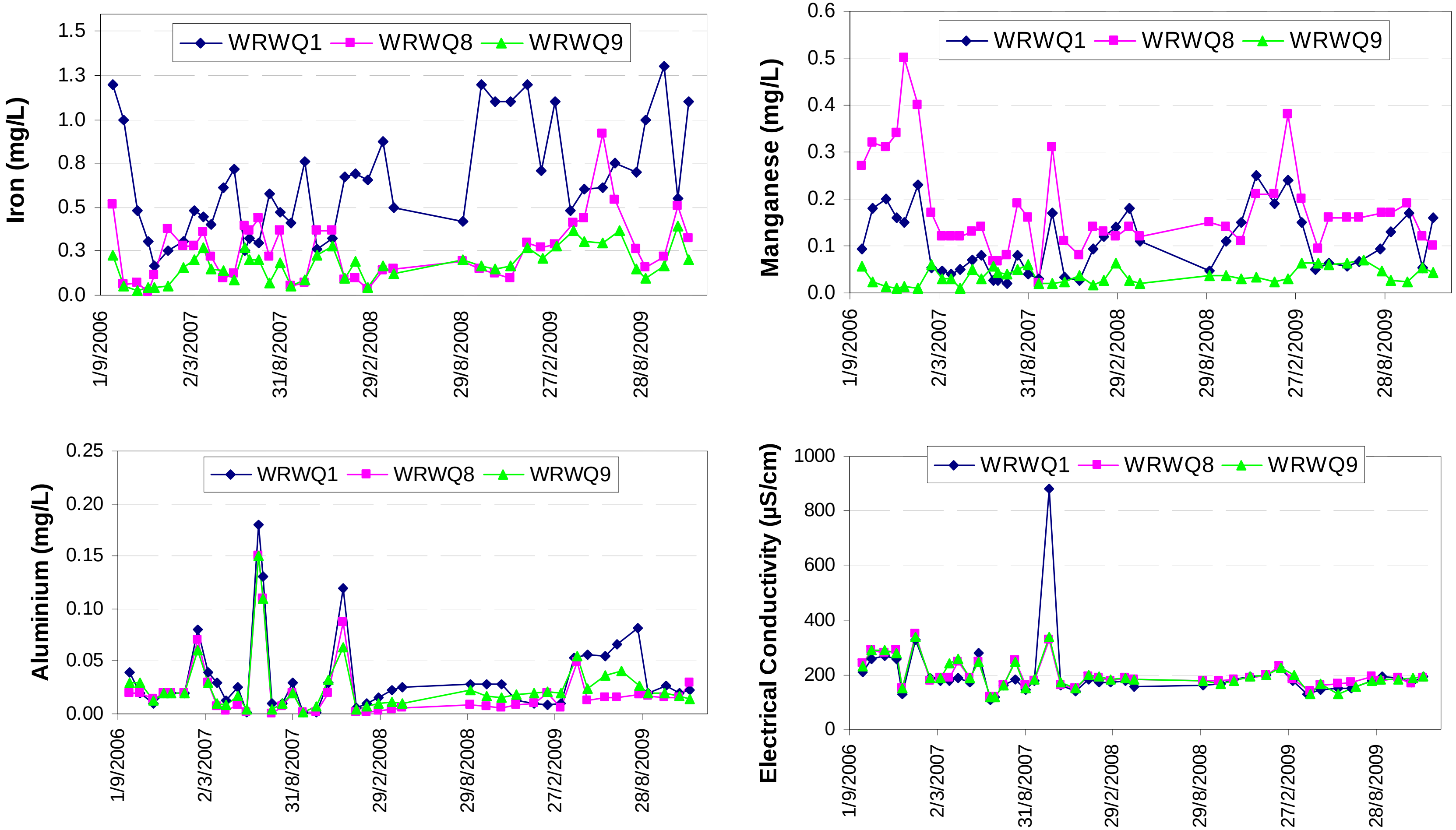

Figure 11 Water Quality Time Series – Waratah Rivulet Monitoring Sites

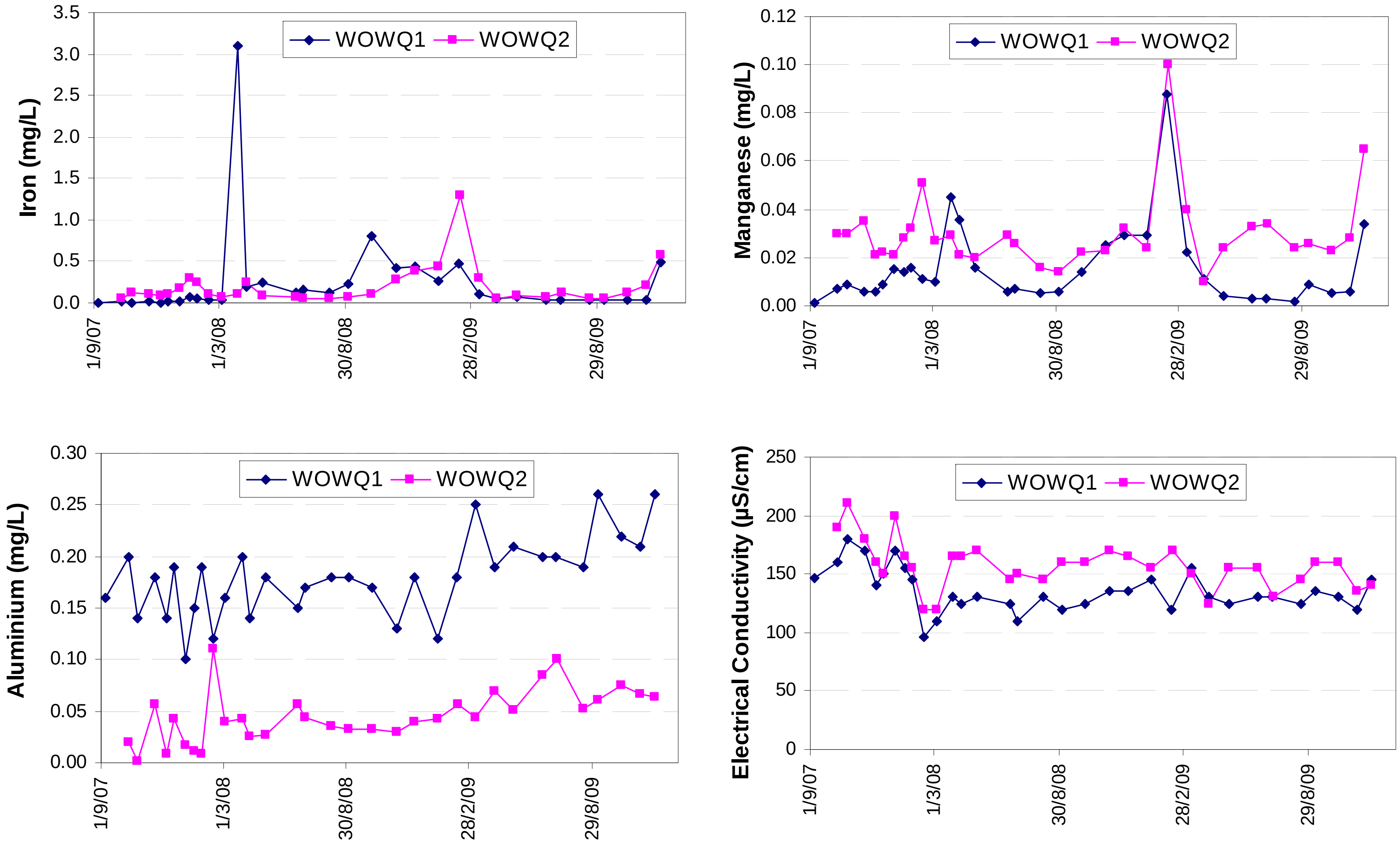

Figure 12 Water Quality Time Series – Woronora River Monitoring Sites

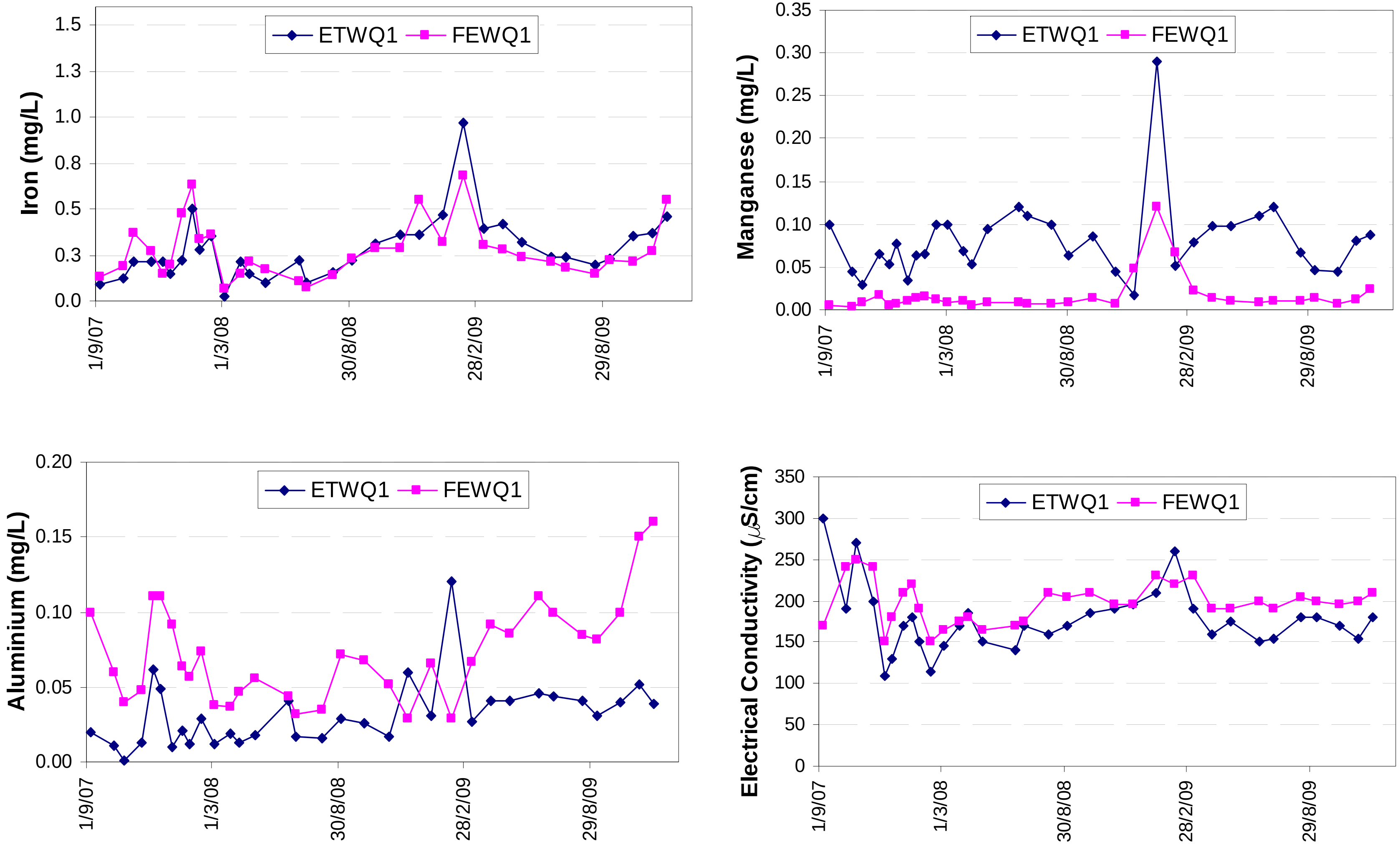

Figure 13 Water Quality Time Series – Eastern and Far Eastern Tributary Monitoring Sites

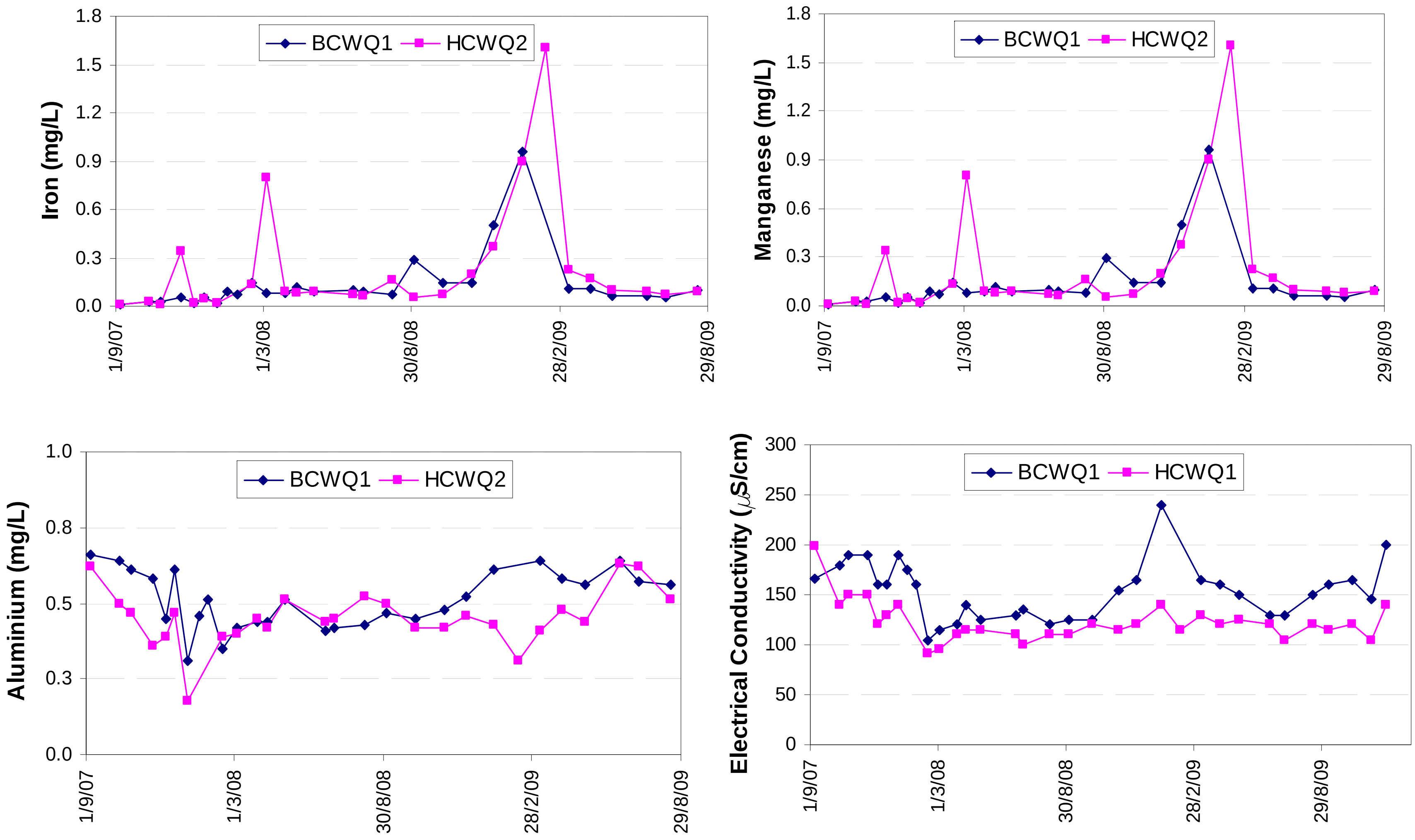

Figure 14 Water Quality Time Series – Bee Creek and Honeysuckle Creek Monitoring Sites

3.4.7 Woronora Reservoir Water Quality

The SCA has an extensive water quality database for the Woronora Reservoir. Recorded iron concentrations in Woronora Reservoir (at site 'Dam Wall 1') have not increased in the period since longwall mining commenced (1995) and in particular they have not been affected by the pulses observed in some upstream reaches in 2006 (Figure 15). Similar trends are evident with manganese concentrations in Woronora Reservoir which have not increased in the period since longwall mining commenced. Whilst the available data on manganese commences much more recently than iron (1986 compared to 1939) the trends in manganese concentrations over the period that data is available mirror the trends in iron concentration (Figure 16).

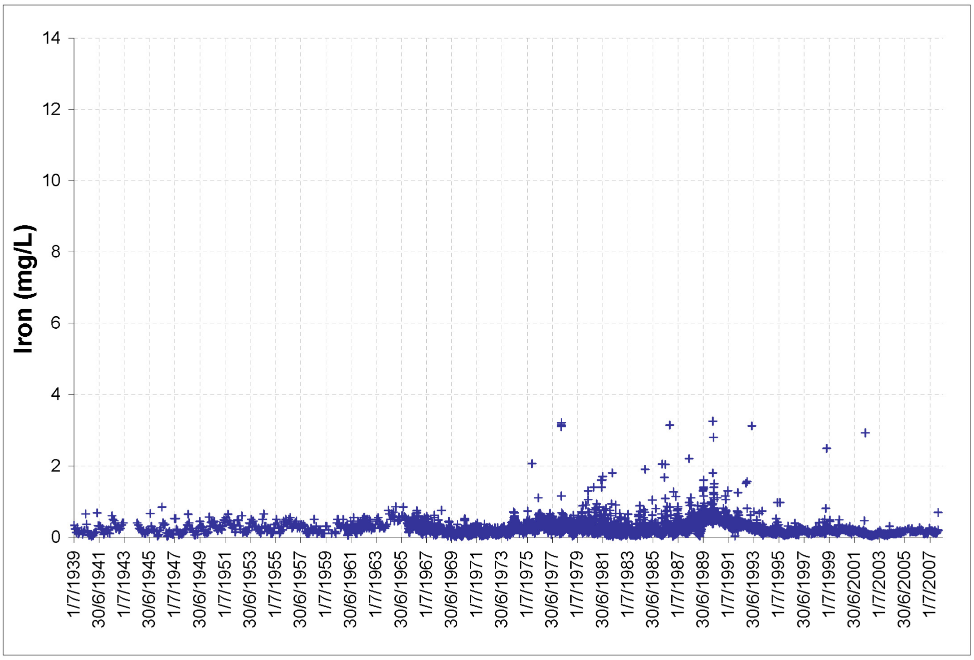

Figure 15 Baseline Iron Concentrations in Woronora Reservoir

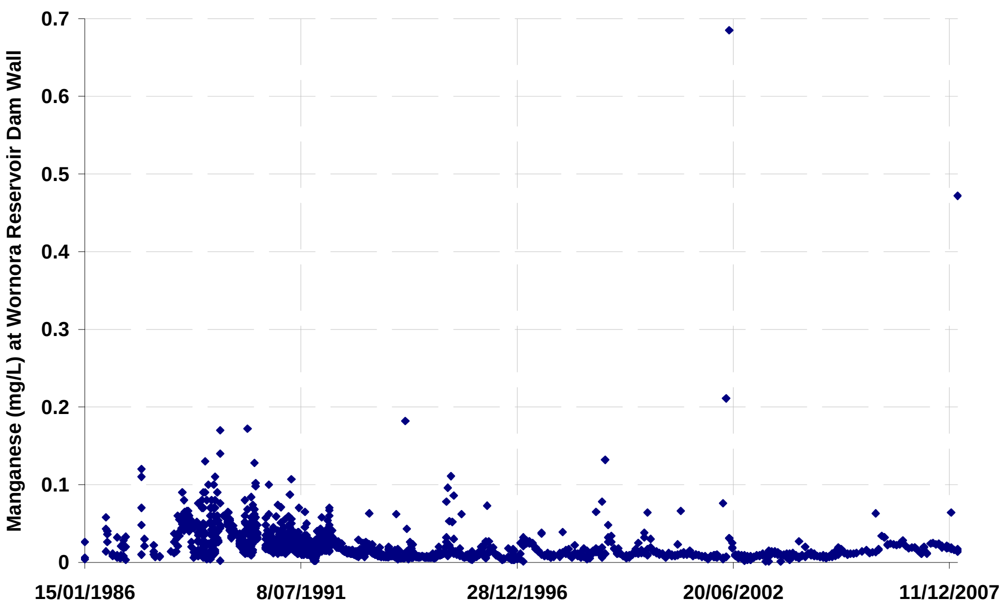

Figure 16 Baseline Manganese Concentrations in Woronora Reservoir

3.5 GROUNDWATER

3.5.1 Hydrogeology

Apart from coal seam aquifers at depths in excess of 400 m, the recognised aquifers in the stratigraphic sequence at Metropolitan Coal are the Hawkesbury Sandstone and the sandstones of the Narrabeen Group. Whilst of very low permeability, the Hawkesbury Sandstone has the relatively higher permeability compared to other units and is therefore capable of higher groundwater yields.

The Hawkesbury Sandstone outcrops over the area in the form of the Woronora Plateau and is subject to weathering processes. Secondary porosity in the form of fractures dominates over primary porosity. Due to alternation of sheet and massive facies, groundwater flow is primarily horizontal with minor vertical leakage. Surface water fed perched water tables (i.e. hydraulically disconnected from the regional aquifer) can be expected adjacent to cliff faces and within upland swamps.

Vertical hydraulic continuity with the underlying Narrabeen Group aquifer is interrupted by a major aquitard, the Bald Hill Claystone which has a consistent thickness across the Project area. This unit will retard vertical groundwater flow downwards from the Hawkesbury Sandstone.

The base of the Narrabeen Group, at the top of the Bulli Seam, is marked by the Wombarra Claystone. This unit is an aquitard that will limit vertical flow into mine workings. The Coal Cliff Sandstone lies between the two where it is developed.

The only recognised economic aquifer in the area is the Hawkesbury Sandstone. The water quality in the Hawkesbury Sandstone is of generally good quality beneath the Woronora Plateau and the Illawarra Plateau, but it deteriorates rapidly towards the northern limits of the Southern Coalfield. In the vicinity of Metropolitan Coal, the salinity is generally in the range 100 to 3,000 mg/L.

Metropolitan Coal lies within the Hawkesbury Sandstone – South-East groundwater flow system (GFS) as defined by Grey and Ross (2003). This GFS tracks the Metropolitan Water Supply Catchment Area that includes the Nepean, Avon, Cordeaux, Cataract and Woronora Reservoirs. Very little groundwater development has been permitted due to its status as a protected area. Only 82 bores are registered throughout the whole area of the GFS for stock and domestic use with total entitlements of 55 megalitres per year (ML/year). This contrasts with a sustainable yield estimate of 58,000 ML/year (Grey and Ross, 2003). There are no high yield bores (>6 litres per second [L/s]) identified within the GFS.

In the NSW Office of Water *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2010* which was on public exhibition until 30 July 2010, Metropolitan Coal lies within the Sydney Basin Central Groundwater Source. The groundwater source area is bounded by the Hawkesbury River to the north, the Nepean River to the west and south, and the Pacific Ocean to the east (excluding the Botany Sands Groundwater Source).

The Hawkesbury Sandstone is in general a low-yield aquifer of good quality. It is well developed for commercial production in the Mangrove Mountain area north of Sydney and partially developed in the Blue Mountains west of Sydney. It has been the subject of investigations by the SCA in the Southern Highlands at Kangaloon-Robertson and at Leonay-Wallacia for an emergency water supply for Sydney during prolonged droughts. High yields (~30 L/s) have been found in both areas where the sandstone is heavily fractured. The Hawkesbury Sandstone in the Southern Coalfield would be expected to be as productive as the Mangrove Mountain and Blue Mountains aquifers, but water supply protection prevents its development.

The Narrabeen Group is a much poorer aquifer than the Hawkesbury Sandstone, and there is no known use of the aquifer in the Southern Coalfield. The low permeability of the Narrabeen Group lithologies is substantiated by the common experience of “dry mines” in the Southern Coalfield.

Although geological structures are known to exist in underground workings or are inferred to extend into the approved mining area, there is no evidence of structural control on groundwater levels or flow directions. In general, individual structural features located on the floor of the Bulli Coal Seam have not been identified at surface despite focused searches over the years, nor have individual surface features been successfully projected and proven at the Bulli Coal Seam horizon.

3.5.2 Swamp Groundwater Levels

Groundwater level data for upland swamps includes piezometers at sites SWAMP1, SWAMP2 and SWAMP3, and paired piezometers at site SWAMP4 and SWGW1 (Table 8 and Figure 17).

As a component of the Metropolitan Coal Longwalls 20-22 Biodiversity Management Plan, groundwater level data for upland swamps will include (Table 8 and Figure 17):

- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and one sandstone piezometer to a depth of approximately 10 m), located in Swamp 25 (S25) overlying Longwalls 20-22.
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and one sandstone piezometer to a depth of approximately 10 m), located in control Swamp 101 (S101).
- One sandstone piezometer to a depth of approximately 10 m located on the upland swamp/fire road boundary between Swamps 16 and 17 (S16/S17) overlying Longwalls 20-22[3].
- Multiple piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and two sandstone piezometers to depths of approximately 4 and 10 m), located in Swamp 20 (S20) overlying Longwalls 20-22.
- Multiple piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and two sandstone piezometers to depths of approximately 4 and 10 m), located in control swamp Woronora River 1.

Consistent with the Longwalls 20-22 Biodiversity Management Plan planning for Longwalls 23-27, groundwater monitoring data will also be obtained for upland swamps overlying Longwalls 23-27 and surrounds, namely Swamp 28 (S28), Swamp 30 (S30), Swamp 33 (S33), Swamp 35 (S35), Bee Creek Swamp (SBC), Swamp 137a (S137a) and Swamp 137b (S137b) (Figure 17).

[3] Note, one sandstone piezometer (to a depth of approximately 10 m) has been installed in Swamp 16 (S16) and one sandstone piezometer (to a depth of approximately 10 m) has been installed in Swamp 17 (S17).

Table 8
Swamp Groundwater Level Monitoring Sites

Site Number	Swamp	Easting	Northing	RL (mAHD)	Depth (m)	Lithology	Commencement Date
SWAMP1	S14	308625	6215963	295.6	To point of refusal (3.12)	Hawkesbury Sandstone	7 February 2007
SWAMP2	Bee Creek	308755	6218787	245.3	To point of refusal (1.46)	Hawkesbury Sandstone	4 April 2007
SWAMP3	S92	310063	6216007	294.7	To point of refusal (4.33)	Hawkesbury Sandstone	7 February 2007
SWAMP4	S06	307891	6214219	344.1	1.02	Hawkesbury Sandstone	12 March 2009
SWGW1	S06	307893	6214226	343.7	~20	Hawkesbury Sandstone	12 March 2009
S25	S25	311161	6214040	273.1	0.9	Hawkesbury Sandstone	31 August 2010
		311161	6214040	272.9	10		
S101	S101	308651	6216582	293.4	0.9	Hawkesbury Sandstone	31 August 2010
		308651	6216582	293.4	10		
S16	S16	309702	6214791	251.2	10	Hawkesbury Sandstone	30 August 2010
S17	S17	309599	6214931	240.6	10	Hawkesbury Sandstone	1 September 2010
S20	S20	310431	6214413	219.3	0.9	Hawkesbury Sandstone	1 September 2010
		310429	6214403	219.1	4		
		310428	6214401	219.1	10		
WRSWAMP1	Woronora River 1	306454	6214914	321.1	0.9	Hawkesbury Sandstone	2 September 2010
		306452	6214913	321.1	4		
		306451	6214912	321.1	10		

RL = Relative Level AHD = Australian Height Datum

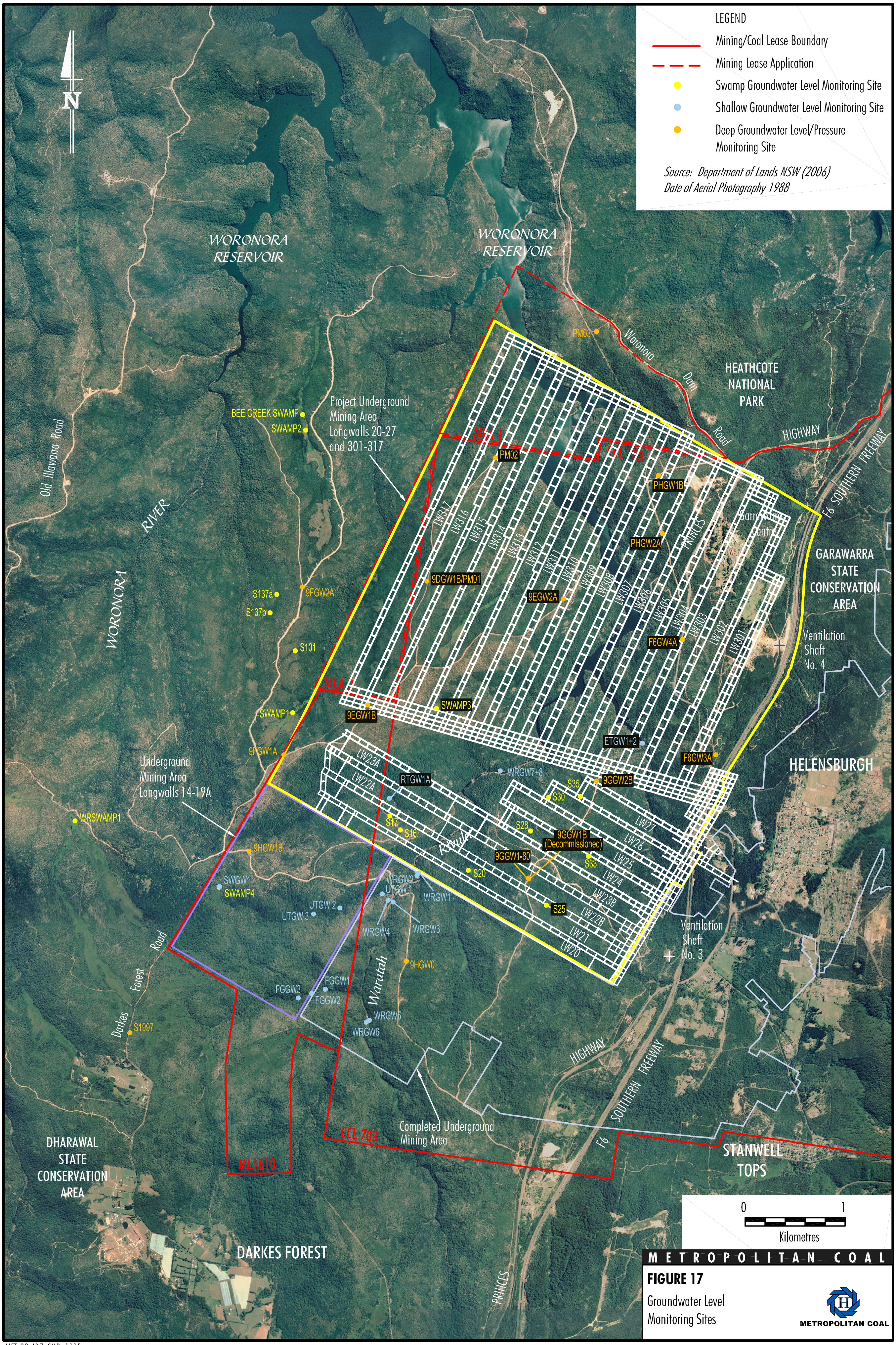

FIGURE 17
Groundwater Level Monitoring Sites

MET-08-AD7 CMP_111F

Figure 18 shows that the perched groundwater levels at SWAMP1 (S14), SWAMP2 (Bee Creek) and SWAMP3 (S92) sites have a highly dynamic behaviour that is characterised by an immediate response to rainfall events, followed by fairly rapid recessions as water is lost by evaporation and evapotranspiration. The depth to water ranges from about 0.3 m to 2.6 m across the three sites. The monitored sites are far from current mining, and there is no evidence of any change in behaviour due to mining.

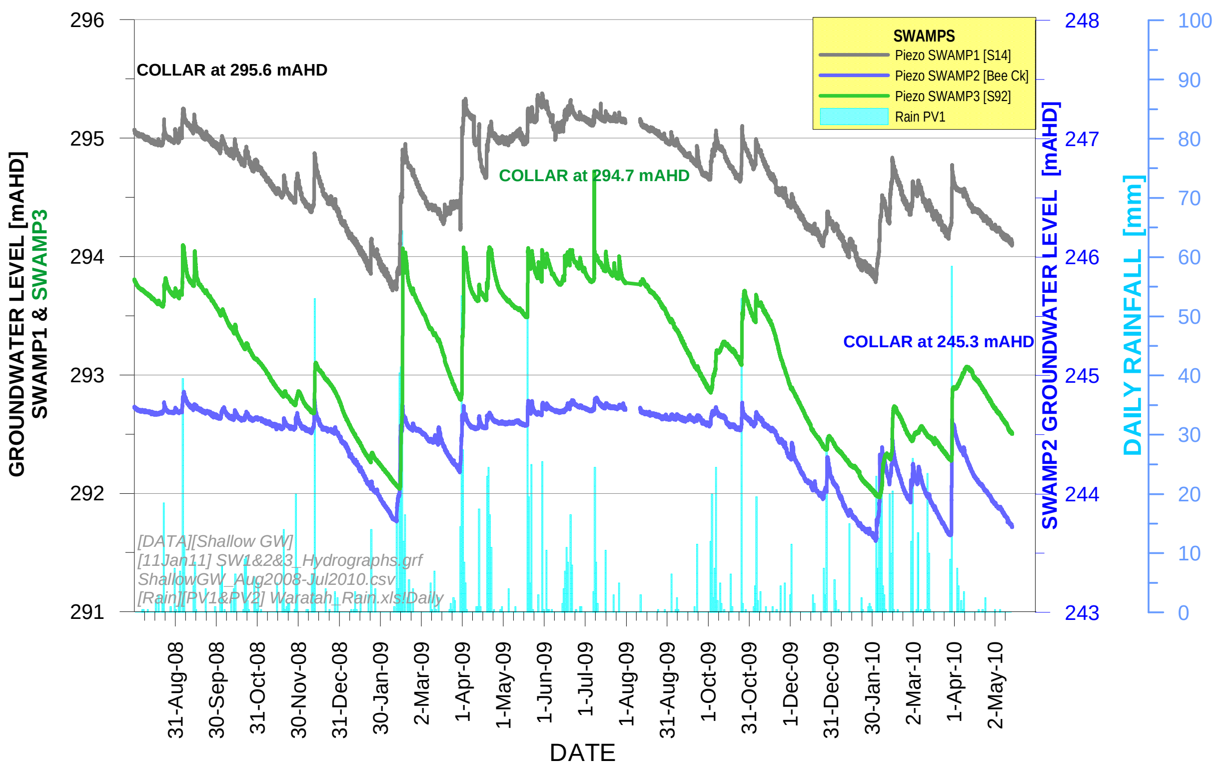

Figure 18 Perched Groundwater Hydrographs in Upland Swamps

The groundwater levels in the paired piezometers at site SWAMP4 and site SWGW1 are shown on Figure 19. Figure 19 indicates that the groundwater levels at SWAMP4 are perched and hydraulically isolated from the regional sandstone aquifer (measured by site SWGW1). SWAMP4 is considered to be characteristic of headwater upland swamps in that they typically obtain most of their moisture from direct rainfall infiltration. The water tables at this swamp (S06) are greater than 3 m apart. There is a strong correlation between swamp and sandstone water level fluctuations which suggests either direct leakage from the swamp to the underlying sandstone, and/or direct rain recharge to adjacent sandstone with lateral groundwater flow to the sandstone beneath the swamp.

The depth to water is typically about 1 m in the swamps at sites SWAMP1 to SWAMP4 and about 4 m in the sandstone beneath the swamp (at site SWGW1).

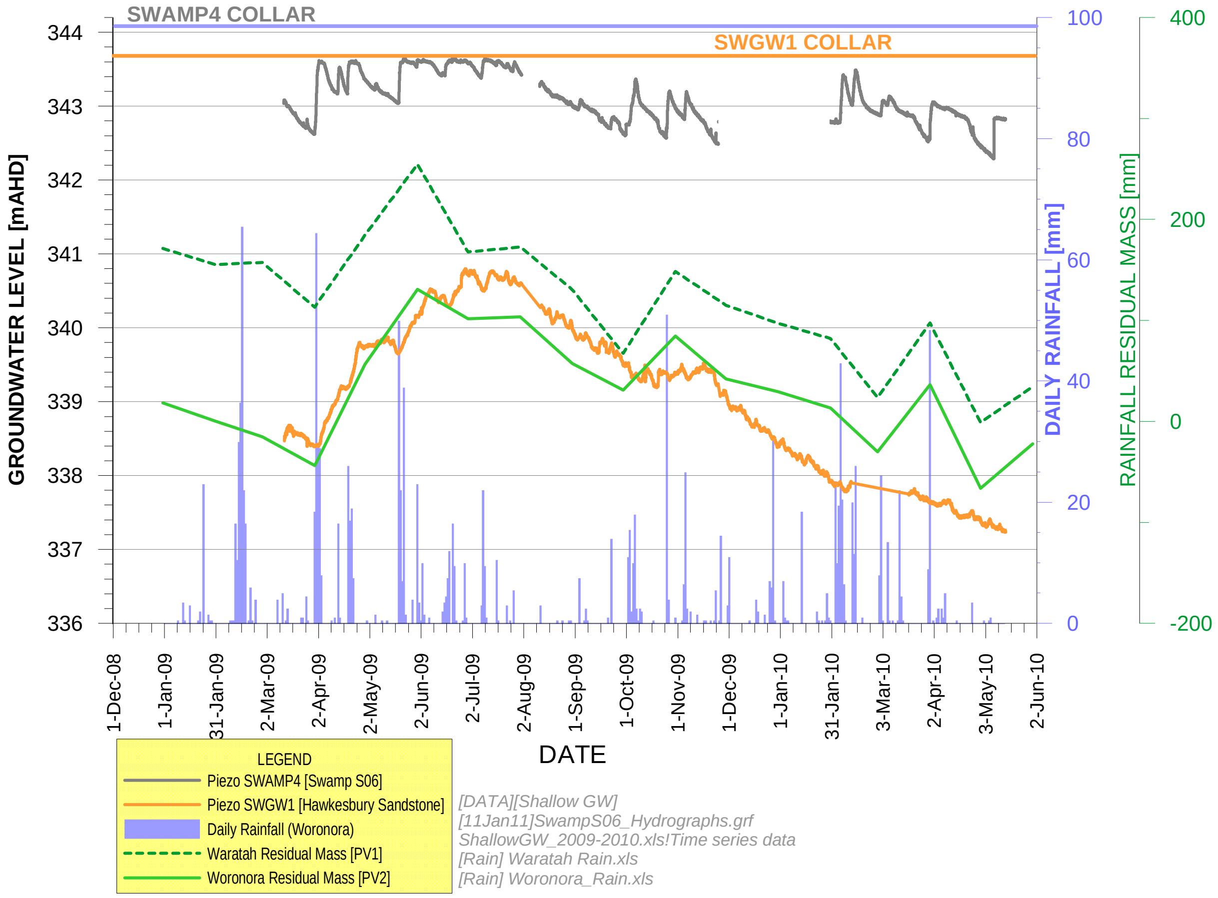

Figure 19 Separation of Water Tables at Upland Swamp S06

Additional swamp groundwater level monitoring sites will be established as a component of future Extraction Plan(s) and revisions to the Biodiversity Management Plan, and as informed by the environmental assessment that will be conducted for Swamps 76, 77 and 92 in accordance with Project Approval Condition 4 of Schedule 3.

As described in the Metropolitan Coal Longwalls 20-22 Biodiversity Management Plan, baseline data will be obtained for the Longwalls 23-27 Extraction Plan prior to the extraction of Longwall 21. The timing for the baseline data in relation to the next Extraction Plan (Longwalls 23-27) is to ensure that baseline data for the next upland swamps are collected before extraction occurs within 600 m of these features.

3.5.3 Shallow Groundwater Levels

Shallow groundwater level data is available at a number of sites, as summarised in Table 9. The piezometer locations are shown on Figure 17.

Table 9
Shallow Groundwater Level Monitoring Sites

Site Number	Location	Easting	Northing	RL (mAHD)	Depth (m)	Lithology	Commencement Date
SWGW1	Swamp S06	307893	6214226	343.7	~20	Hawkesbury Sandstone	12 March 2009
WRGW1	Waratah Rivulet	309886	6214360	207.8	~20	Hawkesbury Sandstone	16 February 2007
WRGW2	Waratah Rivulet	309868	6214335	207.9	~20	Hawkesbury Sandstone	16 February 2007
WRGW3	Waratah Rivulet	309629	6214072	215.0	~20	Hawkesbury Sandstone	16 February 2007
WRGW4	Waratah Rivulet	309579	6214090	217.8	~20	Hawkesbury Sandstone	16 February 2007
WRGW5	Waratah Rivulet	309393	6212890	225.4	~20	Hawkesbury Sandstone	4 April 2007
WRGW6	Waratah Rivulet	309361	6212871	226.1	~20	Hawkesbury Sandstone	4 April 2007
WRGW7	Waratah Rivulet	310717	6215382	184.2	~20	Hawkesbury Sandstone	1 September 2010
WRGW8	Waratah Rivulet	310717	6215382	184.3	~20	Hawkesbury Sandstone	1 September 2010
RTGW1A	Tributary B	309594	6215106	222.0	~19.5	Hawkesbury Sandstone	23 August 2007
FGGW1	Forest Gully	308951	6213200	232.4	~20	Hawkesbury Sandstone	8 March 2007
FGGW2	Forest Gully	308816	6213158	240.5	~20	Hawkesbury Sandstone	4 April 2007
FGGW3	Forest Gully	308682	6213113	250.4	~20	Hawkesbury Sandstone	4 April 2007
UTGW1	Tributary D	309520	6214151	218.2	~20	Hawkesbury Sandstone	16 February 2007
UTGW2	Tributary D	309097	6214012	237.6	~20	Hawkesbury Sandstone	7 March 2007
UTGW3	Tributary D	308833	6213951	247.2	~20	Hawkesbury Sandstone	7 March 2007
ETGW1	Eastern Tributary	312129	6215644	172.6	~20	Hawkesbury Sandstone	1 September 2010
ETGW2	Eastern Tributary	312129	6215644	172.1	~20	Hawkesbury Sandstone	1 September 2010

Table 10 indicates the median and mean depth to water at the shallow groundwater bores on Waratah Rivulet, Tributary D, Forest Gully and at site SWGW1 (below Swamp S06) (from 1 August 2008 to 14 May 2010). The depth to water at the Waratah Rivulet bores is typically 3.1 m with a standard deviation of 1.4 m (Table 10). (Depths are measured from top of casing [typically about 0.5 m above ground level].) The depth to water at the Tributary D bores is typically 1.9 m with a standard deviation of 0.3 m and the depth to water at the Forest Gully bores is typically about 4 m with a standard deviation of 2.8 m (Table 10). The depth to water is typically about 4.7 m (±0.6 m) in the sandstone beneath Swamp S06 (at site SWGW1).

Table 10
Shallow Piezometer Depths to Groundwater in Sandstone

Sites	Location	Median (m)	Mean (m)	Standard Deviation (m)
WRGW1-WRGW6	Waratah Rivulet	3.3	3.1	1.4
UTGW1-UTGW3	Tributary D	1.8	1.9	0.3
FGGW1-FGGW3	Forest Gully	3.9	4.7	2.8
SWGW1	Below Swamp S06	4.7	4.7	0.6

Figures 20 to 22 show the shallow groundwater levels in sandstone at monitoring sites on the Waratah Rivulet, Tributary D and Forest Gully, respectively.

The Waratah Rivulet piezometers show the same dynamic responses to stream flow interaction and rainfall, with upgradient sites (WRGW5 and WRGW6) having the greater response amplitude. There is no indication of reduction in water levels due to mining.

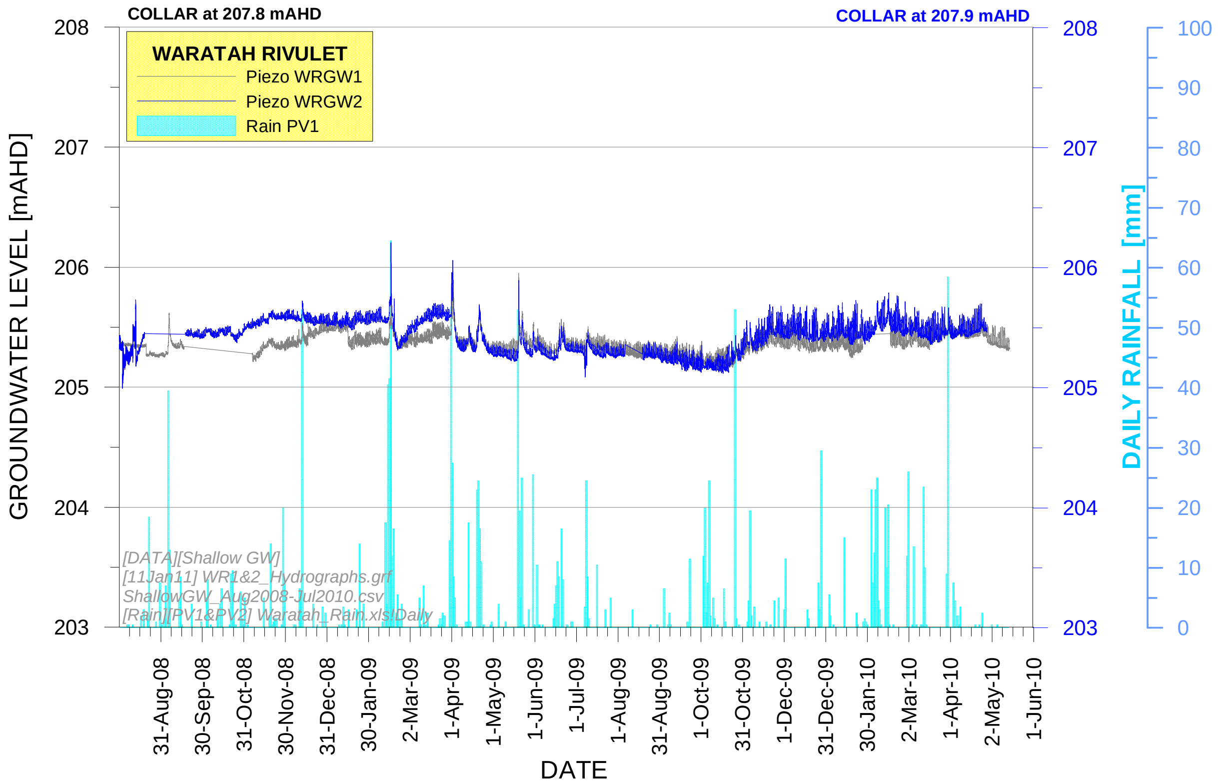

Figure 20a Shallow Groundwater Hydrographs along Waratah Rivulet at WRGW1 and WRGW2

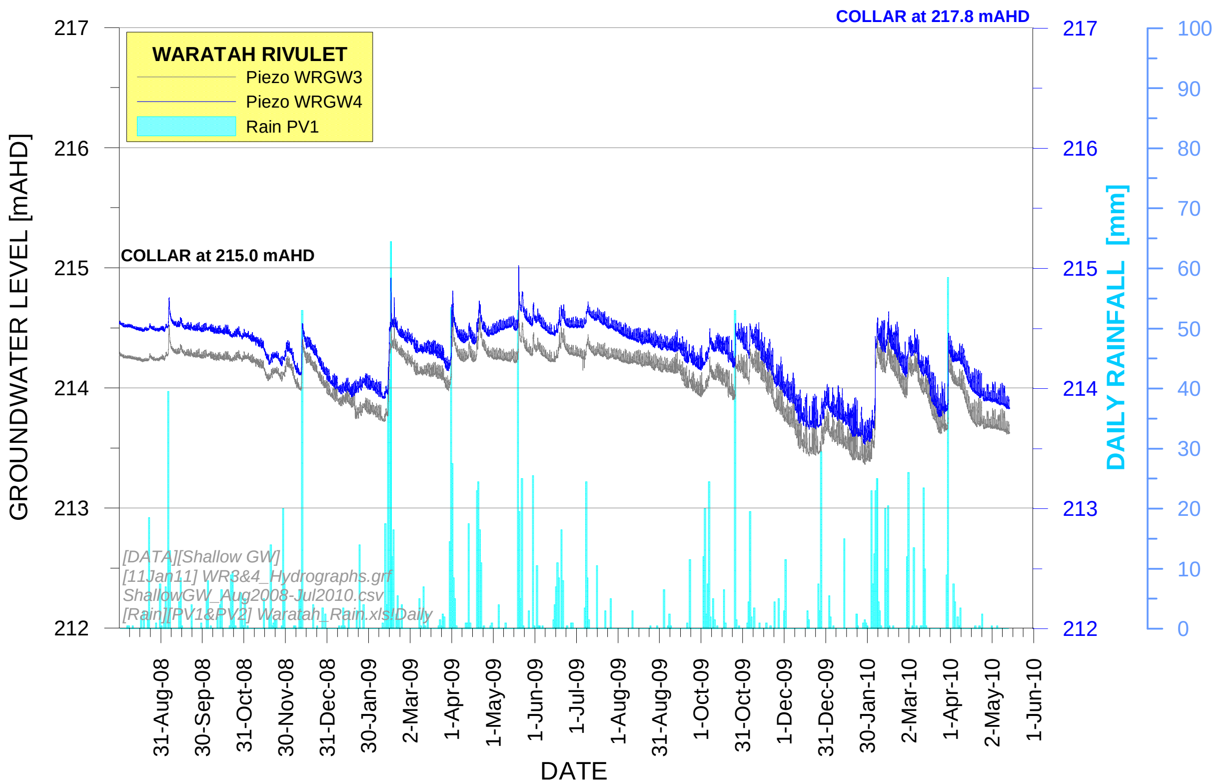

Figure 20b Shallow Groundwater Hydrographs along Waratah Rivulet at WRGW3 and WRGW4

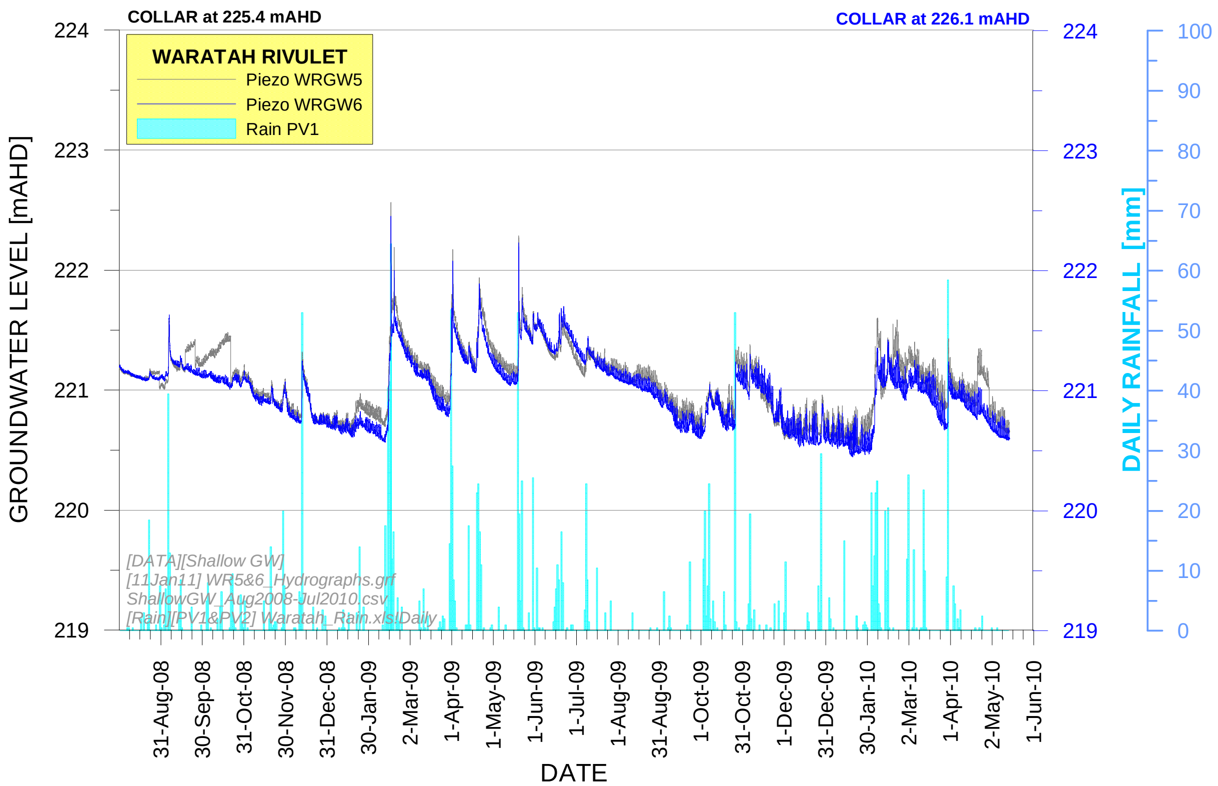

Figure 20c Shallow Groundwater Hydrographs along Waratah Rivulet at WRGW5 and WRGW6

The groundwater responses along Tributary D (Figure 21) are compared with water levels monitored in two pools. Comparison with Pool UTP1 shows that the piezometers follow the same dynamics as the pool, but the groundwater fluctuations are muted in amplitude. At the upstream site, piezometer UTGW3 and Pool UTP2 are within 11 m lateral distance of each other. At times, the pool and groundwater levels are almost identical (Figure 21c); at other times there is a difference of about 0.2 m, usually with groundwater level higher than the pool level.

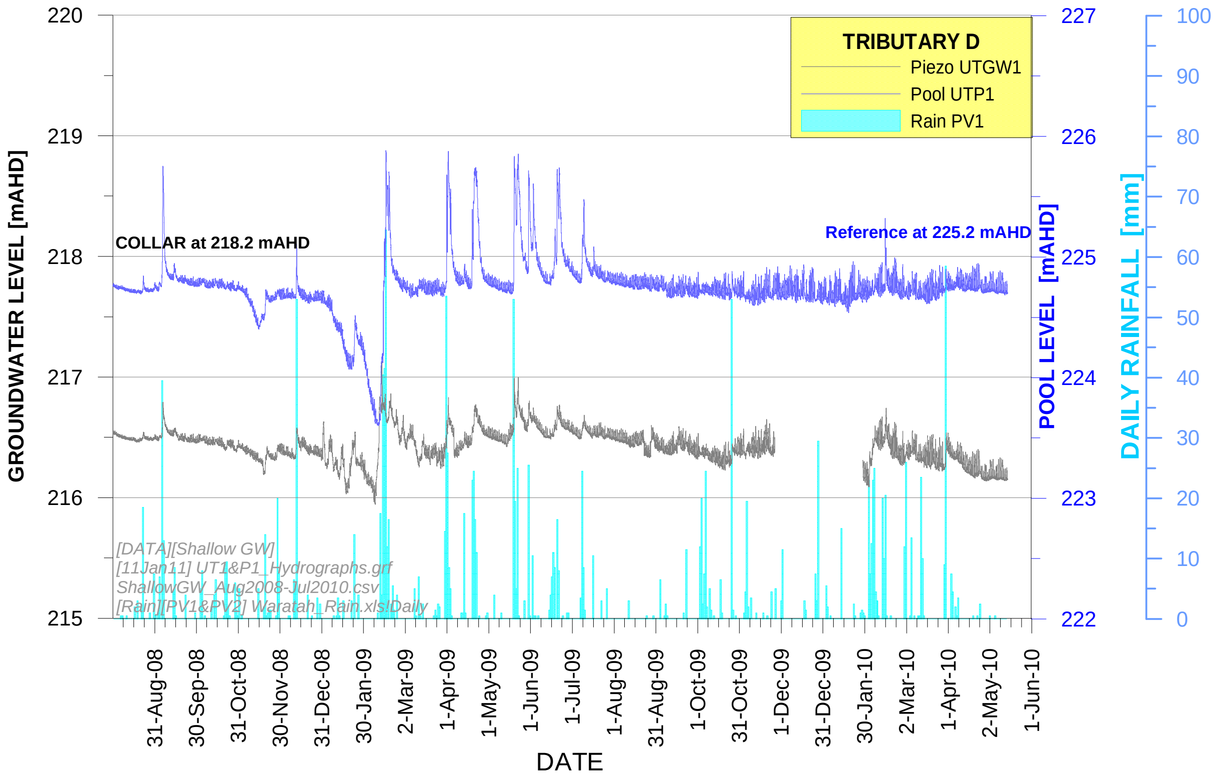

Figure 21a Shallow Groundwater Hydrographs along Tributary D at UTGW1 and UTP1

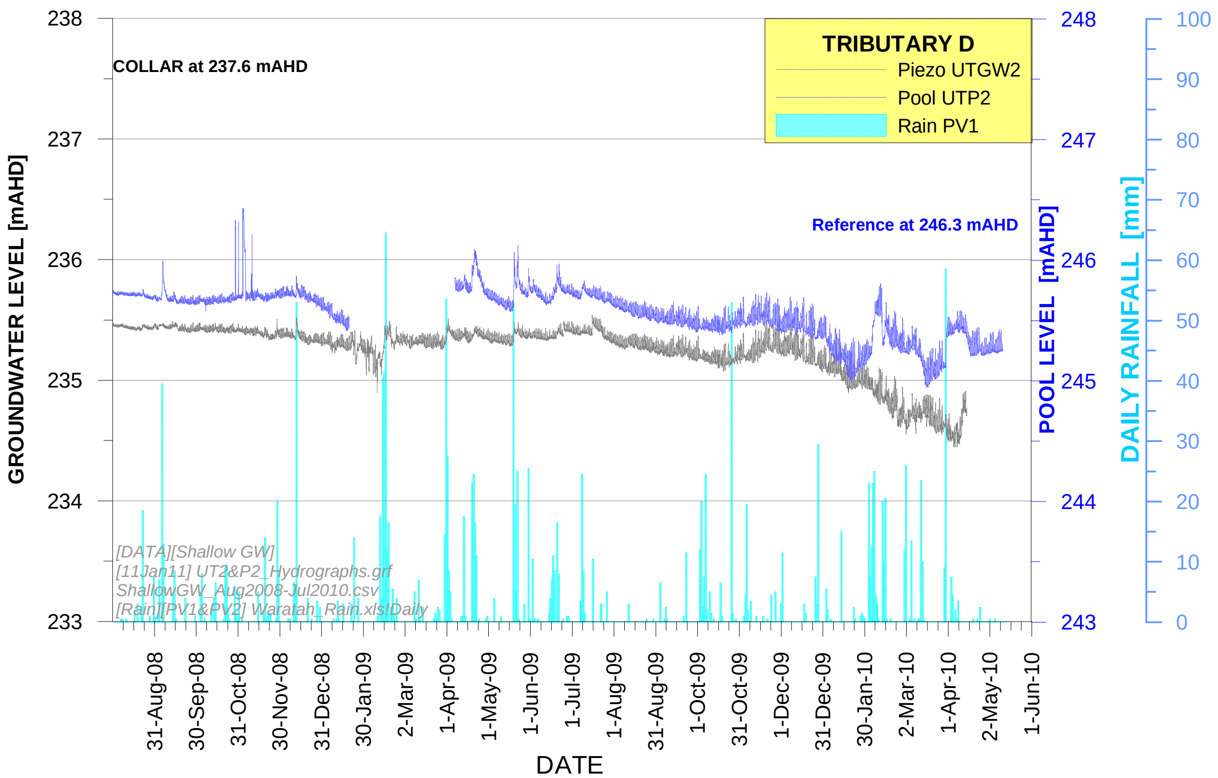

Figure 21b Shallow Groundwater Hydrographs along Tributary D at UTGW2 and UTP2

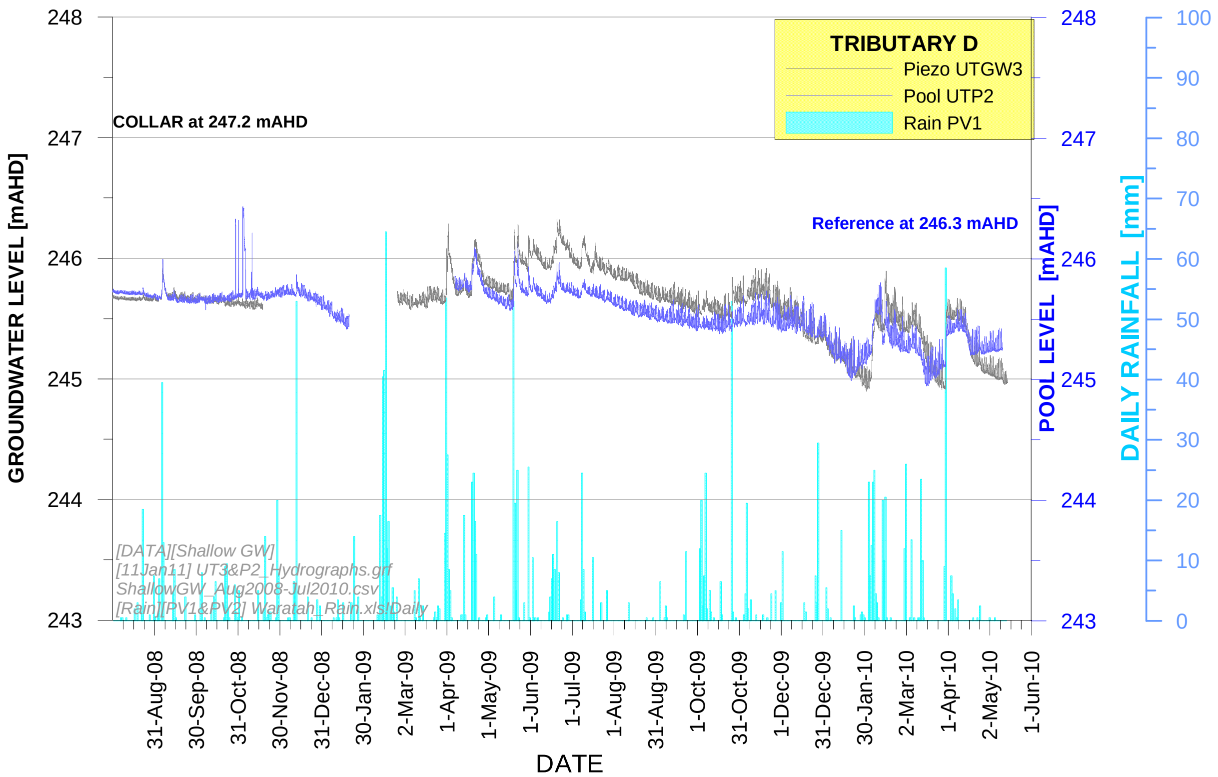

Figure 21c Shallow Groundwater Hydrographs along Tributary D at UTGW3 and UTP2

Along Forest Gully the monitoring sites are located above completed Longwalls 13 and 14. The groundwater levels at the upstream and middle sites (Figure 22b) have low-amplitude dynamics and similar temporal patterns. However, the response at FGGW1 (over Longwall 13) (Figure 22a) is atypical, with sudden rises of about 6 m followed by month-long recessions.

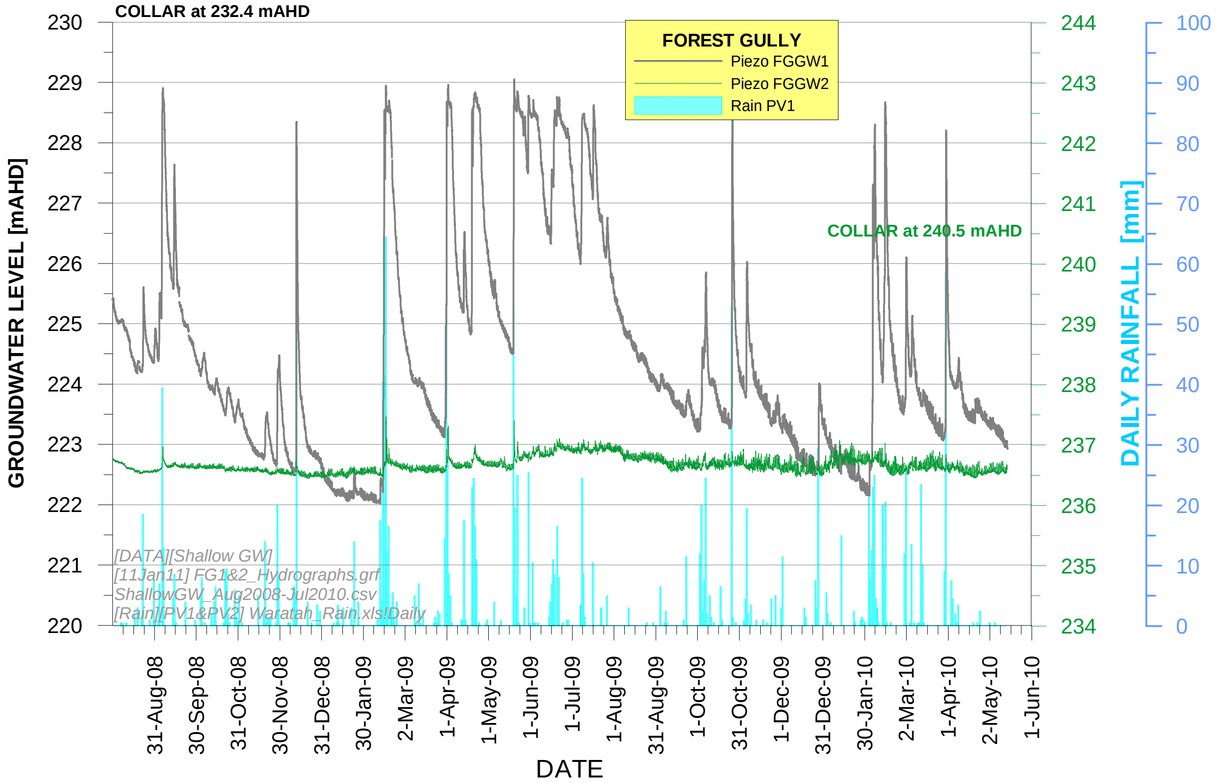

Figure 22a Shallow Groundwater Hydrographs along Forest Gully at FGGW1 and FGGW2

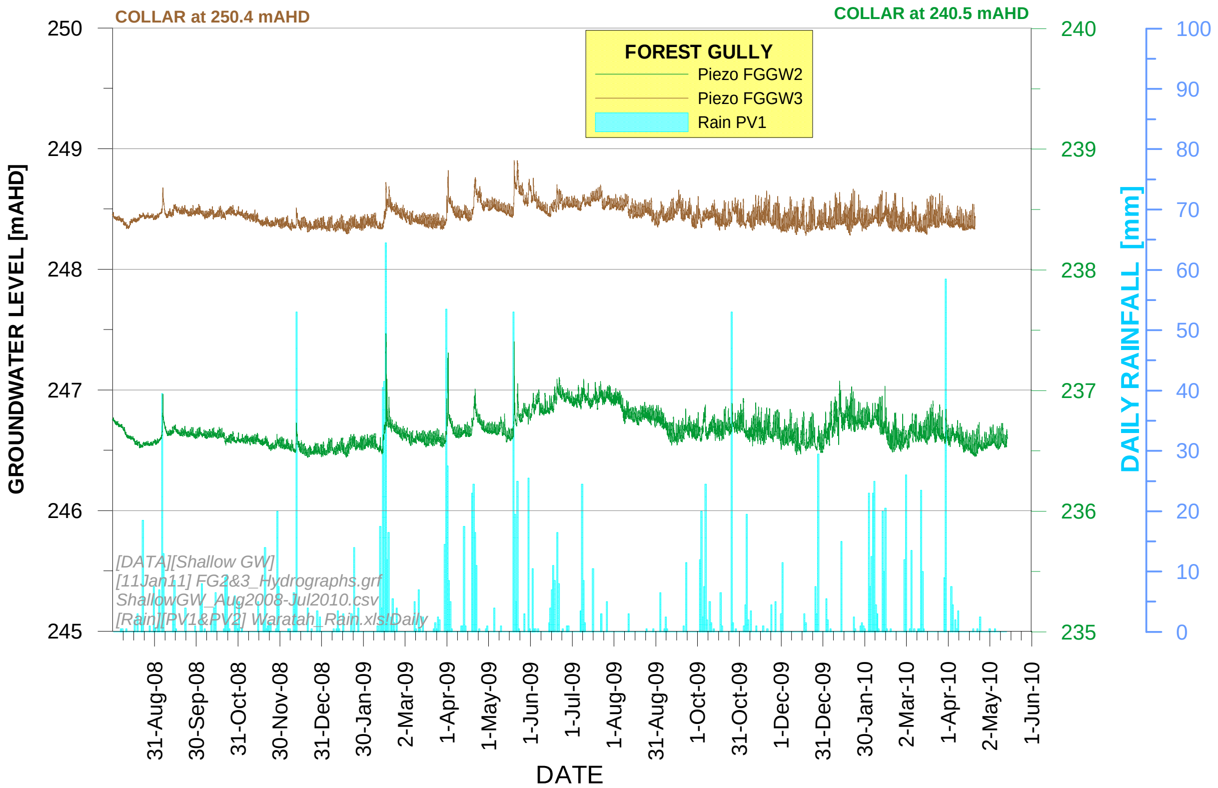

Figure 22b Shallow Groundwater Hydrographs along Forest Gully at FGGW2 and FGGW3

Additional shallow groundwater bores will be established at other locations if required in advance of future Extraction Plans. Additional bores are not anticipated prior to completion of Longwall 308 (in approximately 2022).

3.5.4 Deep Groundwater Levels/Pressures

Deep groundwater level/pressure data is available from five multi-level piezometers, namely, sites 9EGW1B, 9GGW1B, 9HGW1B, PM02 and 9HGW0 (Table 11 and Figure 17). Groundwater level/pressure data is also available at site S1997, courtesy of BHP Billiton Illawarra Coal (Table 11 and Figure 17). Additional bores have been drilled (e.g. 9FGW1A and 9GGW2B), but not all vibrating wire piezometers are reliable/stable at this stage.

The vertical hydraulic head profiles at multi-piezometer bores 9GGW1B, 9HGW1B, PM02, 9HGW0, S1997 and 9EGW1B are illustrated on Figures 23 to 28 on stratigraphic sections with piezometer offtakes and average potentiometric head levels. It should be noted that the potentiometric heads at all bores have been affected to some degree by previous mining at Metropolitan Coal and/or other nearby mines (e.g. North Cliff and Darkes Forest).

Bore 9GGW1B

Bore 9GGW1B shows strong depressurisation below the Bulgo Sandstone, with heads of zero to -10 mAHD in the Scarborough Sandstone and the Coal Cliff Sandstone (Figure 23). The heads in the Bulgo Sandstone are 80 to 160 mAHD.

This bore is about 500 m on the northern side of previous mining (prior to Longwall 20), and is in line with Longwalls 6 and 7 which were mined in 2000-2001. Hence, pressures at depth have equilibrated (Heritage Computing, 2009b). No substantial changes would be expected until Longwall 20 mining and development headings approach the site.

Table 11
Deep Groundwater Level Monitoring Sites

Site Number	Location	Easting	Northing	Collar (mAHD)	Depth (m)	Elevation (mAHD)	Lithology	Commencement Date
9GGW1B[1]	Fire Trail 9G	310986	6214305	287.9	45.0	242.9	Hawkesbury Sandstone	14 March 2009
					59.5	228.4	Hawkesbury Sandstone	
					124.0	163.9	Hawkesbury Sandstone	
					159.0	128.9	Bald Hill Claystone	
					179.0	108.9	Bulgo Sandstone	
					345.1	-57.2	Bulgo Sandstone	
					385.1	-97.2	Bulgo Sandstone	
					404.1	-116.2	Stanwell Park Claystone	
					416.0	-128.2	Scarborough Sandstone	
					476.7	-188.8	Coal Cliff Sandstone	

[1] Multi-level piezometer site 9GGW1B was decommissioned in late 2013.

Table 11 (Continued)
Deep Groundwater Level Monitoring Sites

Site Number	Location	Easting	Northing	Collar (mAHD)	Depth (m)	Elevation (mAHD)	Lithology	Commencement Date
9HGW1B	Fire Trail 9H	308189	6214580	351.2	52.0	299.2	Hawkesbury Sandstone	12 November 2008
					81.5	269.7	Hawkesbury Sandstone	
					158.0	193.2	Hawkesbury Sandstone	
					174.6	176.6	Newport Formation	
					205.4	145.8	Bald Hill Claystone	
					225.4	125.8	Bulgo Sandstone	
					303.0	48.2	Bulgo Sandstone	
					385.6	-34.4	Bulgo Sandstone	
PM02	Fire Trail 9D	310650	6218509	267.4	35.0	232.35	Hawkesbury Sandstone	23 December 2007
					100.0	167.35	Hawkesbury Sandstone	
					220.0	47.35	Bald Hill Claystone	
					250.0	17.35	Bulgo Sandstone	
					400.0	-132.65	Bulgo Sandstone	
					435.0	-167.65	Stanwell Park Claystone	
					475.0	-207.65	Scarborough Sandstone	
					495.0	-227.65	Scarborough Sandstone	
9HGW0	Longwall 10 Goaf Hole	309762	6213480	274.5	35.0	239.5	Hawkesbury Sandstone	12 April 2007
					70.0	204.5	Hawkesbury Sandstone	
					110.0	164.5	Hawkesbury Sandstone	
					135.0	139.5	Bald Hill Claystone	
					165.0	109.5	Bulgo Sandstone	
					205.0	69.5	Bulgo Sandstone	
					250.0	24.5	Bulgo Sandstone	
					300.0	-25.5	Bulgo Sandstone	

Table 11 (Continued)
Deep Groundwater Level Monitoring Sites

Site Number	Location	Easting	Northing	Collar (mAHD)	Depth (m)	Elevation (mAHD)	Lithology	Commencement Date
9EGW1B	Fire Trail 9E	309483	6216090	309.0	52.0	257.0	Hawkesbury Sandstone	1 November 2009
					91.0	218.0	Hawkesbury Sandstone	
					170.0	139.0	Hawkesbury Sandstone	
					213.0	96.0	Bald Hill Claystone	
					233.0	76.0	Bulgo Sandstone	
					403.0	-94.0	Bulgo Sandstone	
					424.0	-115.0	Stanwell Park Claystone	
					450.0	-141.0	Scarborough Sandstone	
					488.0	-179.0	Scarborough Sandstone	
					541.5	-232.5	Coal Cliff Sandstone	
S1997*	North Cliff	306997	6212765	370.2	24.0	346.2	Hawkesbury Sandstone	10 June 2009
					68.5	301.7	Hawkesbury Sandstone	
					132.0	238.2	Hawkesbury Sandstone	
					218.0	152.2	Bulgo Sandstone	
					292.5	77.7	Bulgo Sandstone	
					372.0	-1.83	Bulgo Sandstone	
					429.0	-58.8	Scarborough Sandstone	
					441.5	-71.3	Scarborough Sandstone	
					454.0	-83.3	Scarborough Sandstone	
					504.5	-134.3	Coal Cliff Sandstone	
					511.6	-141.4	Bulli Coal Seam	

* Data courtesy of BHP Billiton Illawarra Coal.

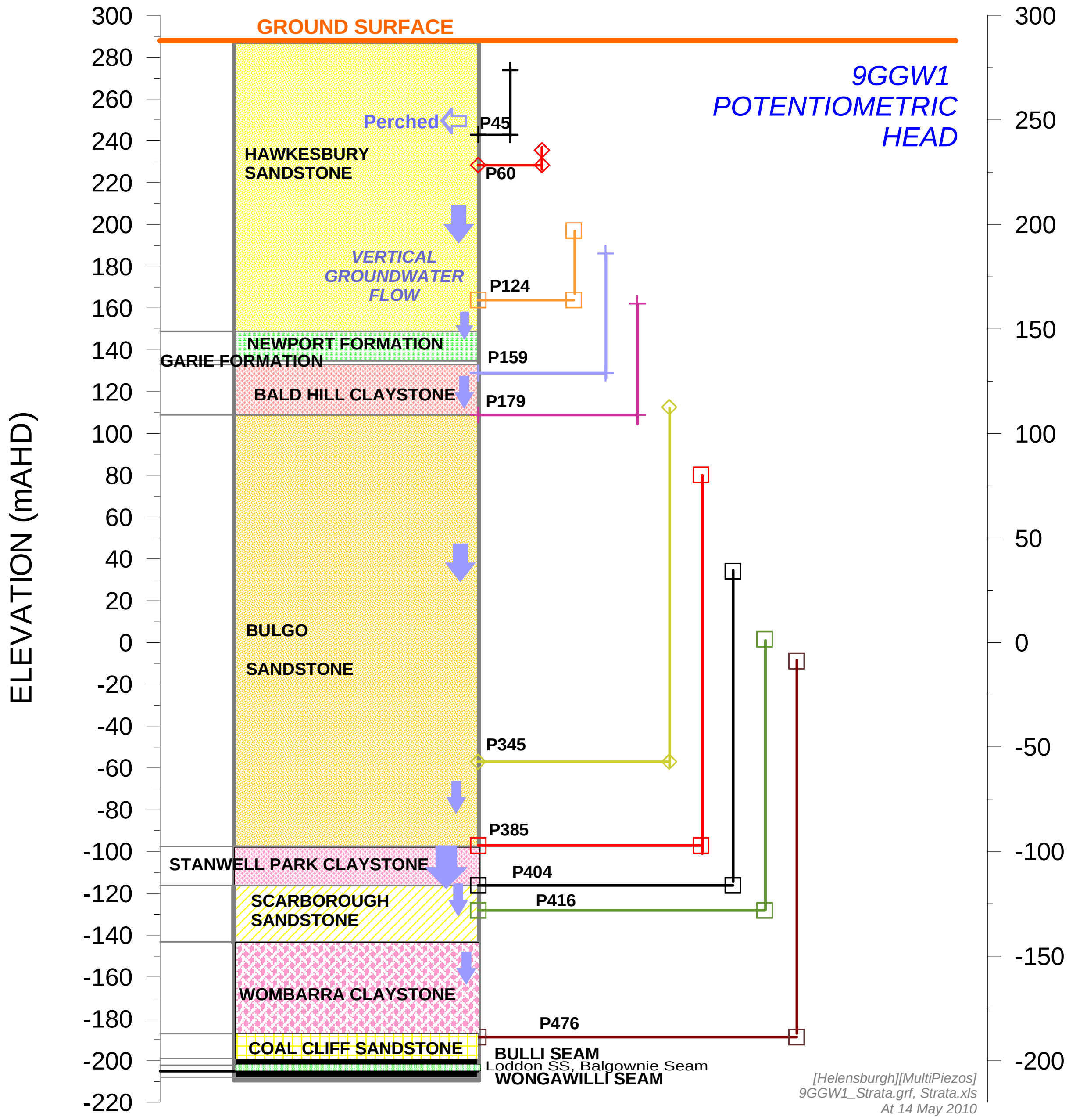

Figure 23 Vertical Groundwater Flow Directions, Relative Piezometer Elevations and Potentiometric Heads at Bore 9GGW1B [at 14 May 2010]

Bore 9HGW1B

Bore 9HGW1B terminated in a “mushy” Stanwell Park Claystone. Hence, no head information is available in deeper lithologies (Scarborough Sandstone and the Coal Cliff Sandstone). The Lower Bulgo Sandstone is the deepest monitored lithology (Figure 24). The head there is about 215 mAHD (compared with 80 mAHD at 9GGW1B). The difference is due more to topography than mining influence. The potentiometric level at 9HGW1B is 135 m below ground level (compared with 205 m at 9GGW1B, where some mining effect can be expected).

The heads at 9HGW1B would be expected to remain stable now that Longwall 18 mining is completed. Some prior depressurisation of deeper unmonitored formations would have occurred during the mining of Longwall 18.

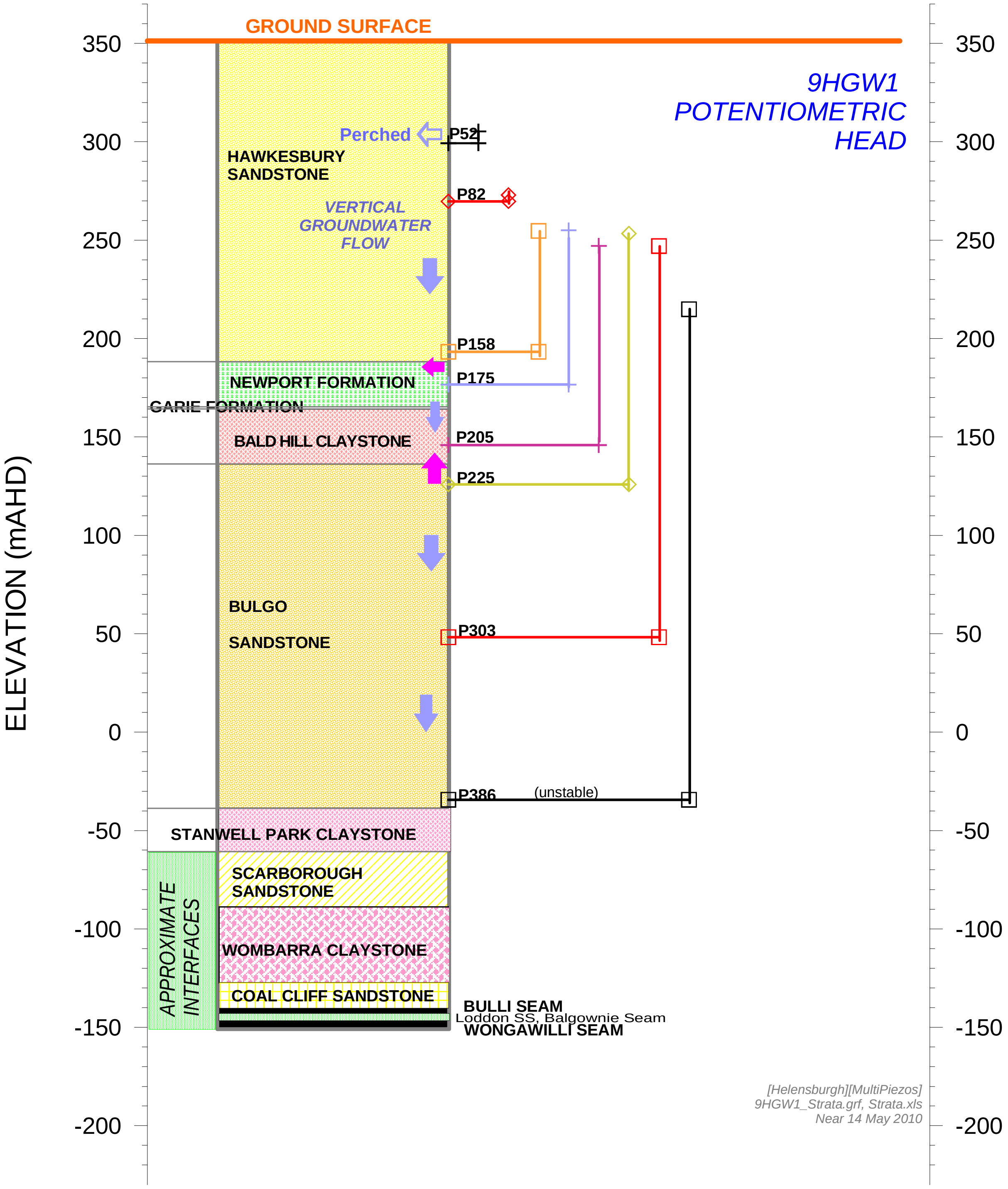

Figure 24 Vertical Groundwater Flow Directions, Relative Piezometer Elevations and Potentiometric Heads at Bore 9HGW1B [at 14 May 2010]

Bore PM02

As bore PM02 is 4 km north-northeast of current mining, it would not be expected to show any dramatic response to mining but could show a slight slow decline in heads as the groundwater “cone of depression” extends radially away from the area of mining.

Figure 25 indicates that all potentiometric heads are high and within 30 m of the level of the Woronora Reservoir. As there is no difference in head between the Lower Bulgo Sandstone and the Lower Scarborough Sandstone, it is inferred that there is no substantial change in vertical hydraulic gradient (at depth) due to mining. For comparison with other bores, the head in the Lower Bulgo Sandstone is about 140 mAHD (compared with 80 mAHD at 9GGW1B and 215 mAHD at 9HGW1B). The potentiometric level at PM02 is 120 m below ground level (compared with 135 m at 9HGW1B, and 205 m at 9GGW1B where some mining effect can be expected). Time-series graphs show that there is no decline in or above the Upper Bulgo Sandstone, but there is a gradual decline at greater depths (Heritage Computing, 2009b).

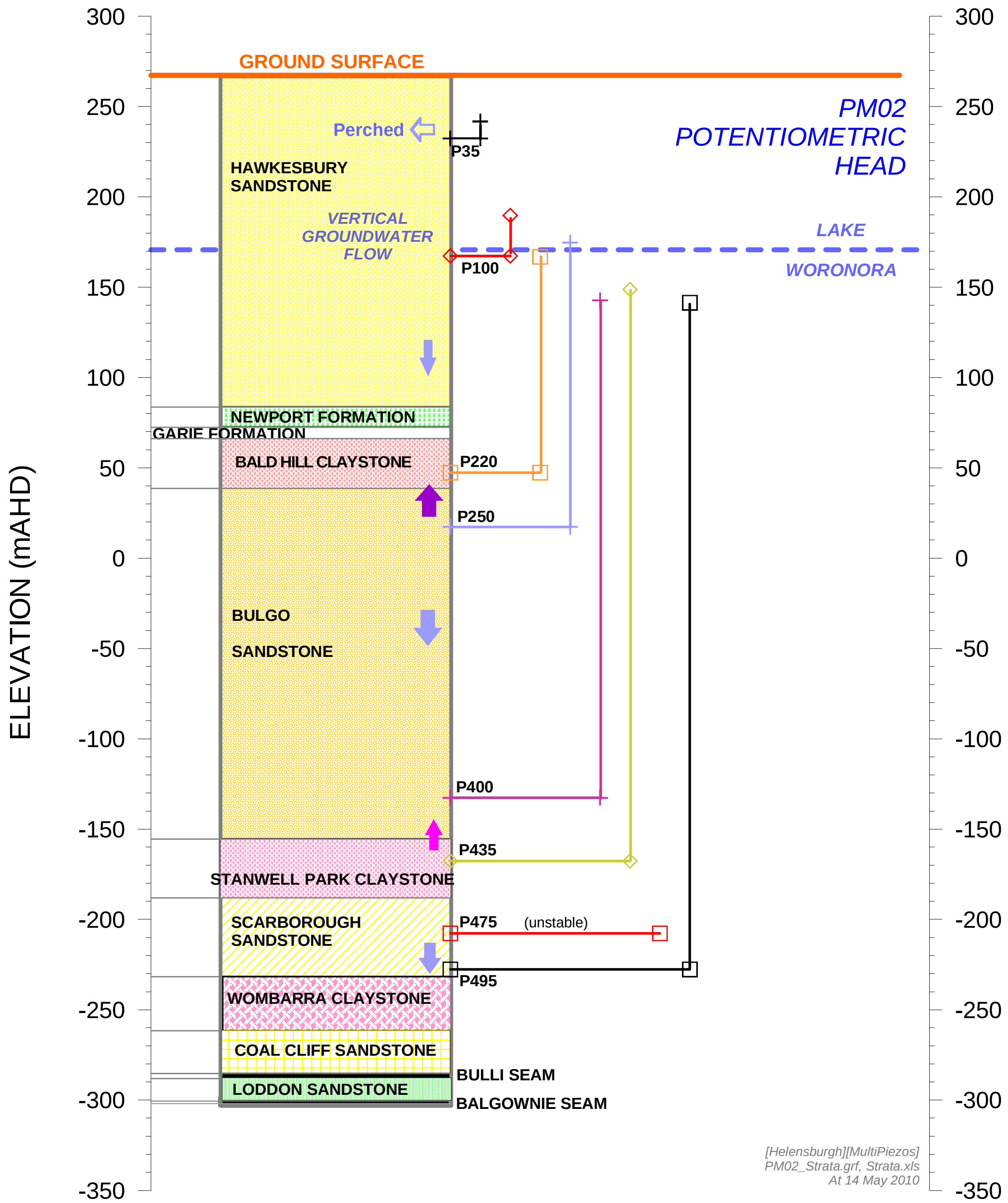

Figure 25 Vertical Groundwater Flow Directions, Relative Piezometer Elevations and Potentiometric Heads at Bore PM02 [at 14 May 2010]

Bore 9HGW0 (Longwall 10 Goaf Hole)

Bore 9HGW0 is a multi-level piezometer hole drilled over the Longwall 10 goaf. Hence, no head information is available beneath the Bulgo Sandstone. Due to mining, there is a substantial hydraulic gradient across the thickness of the Bulgo Sandstone (Figure 26).

For comparison with other bores, the head in the Lower Bulgo Sandstone is about 140 mAHD (compared with 80 mAHD at 9GGW1B, 140 mAHD at PM02 and 215 mAHD at 9HGW1B). The potentiometric level at 9HGW0 is about 140 m below ground level (compared with 120 m at PM02, 135 m at 9HGW1B, and 205 m at 9GGW1B where some mining effect can be expected).

Very little change with time is observed in time-series plots (Heritage Computing, 2009b).

Bore S1997

Bore S1997 at North Cliff has 11 piezometers down to and including the Bulli Coal seam (Figure 27). This is the first bore close to Metropolitan Coal to monitor the head in the Bulli seam. It shows very little head difference from the Coal Cliff Sandstone, which is monitored routinely at other sites.

Considerable depressurisation has occurred at S1997 due to Darkes Forest historical mining and North Cliff development headings. The vertical gradient is almost linear, except for a probably erroneous head in the Mid Scarborough Sandstone.

For comparison with other bores, the head in the Lower Bulgo Sandstone is about 150 mAHD, similar to the head (140 mAHD) at PM02 and 9HGW0 (compared with 80 mAHD at 9GGW1B and 215 mAHD at 9HGW1B). The potentiometric level at S1997 is 215 m below ground level (compared with 120 m at PM02, 135 m at 9HGW1B, 140 m at 9HGW0 and 205 m at 9GGW1B where some mining effect can be expected). This confirms a significant mining effect, due mostly to Darkes Forest old workings.

Bore 9EGW1B

Bore 9EGW1B is about 1.1 km due north of the western end of Longwall 20. There is a mild natural decline in potentiometric head with depth through the stratigraphic section, with evidence of slight depressurisation of the Coal Cliff Sandstone (Figure 28).

The head in the Lower Bulgo Sandstone is about 210 mAHD (compared with 80 mAHD at 9GGW1B, 140 mAHD at PM02 and 9HGW0, 150 mAHD at S1997 and 215 mAHD at 9HGW1B). The potentiometric level at 9EGW1 is 100 m below ground level (compared with 120 m at PM02, 135 m at 9HGW1B, 140 m at 9HGW0, 205 m at 9GGW1B and 215 m at S1997 [where mining effects have occurred, S1997]).

Additional deep groundwater bores to those described in Table 11 have been installed including bores 9GGW2B, 9FGW1A, 9DGW1B (PM01), PHGW1B, PHGW2A, PM03, 9EGW2A, F6GW3A, F6GW4A shown on Figure 17.

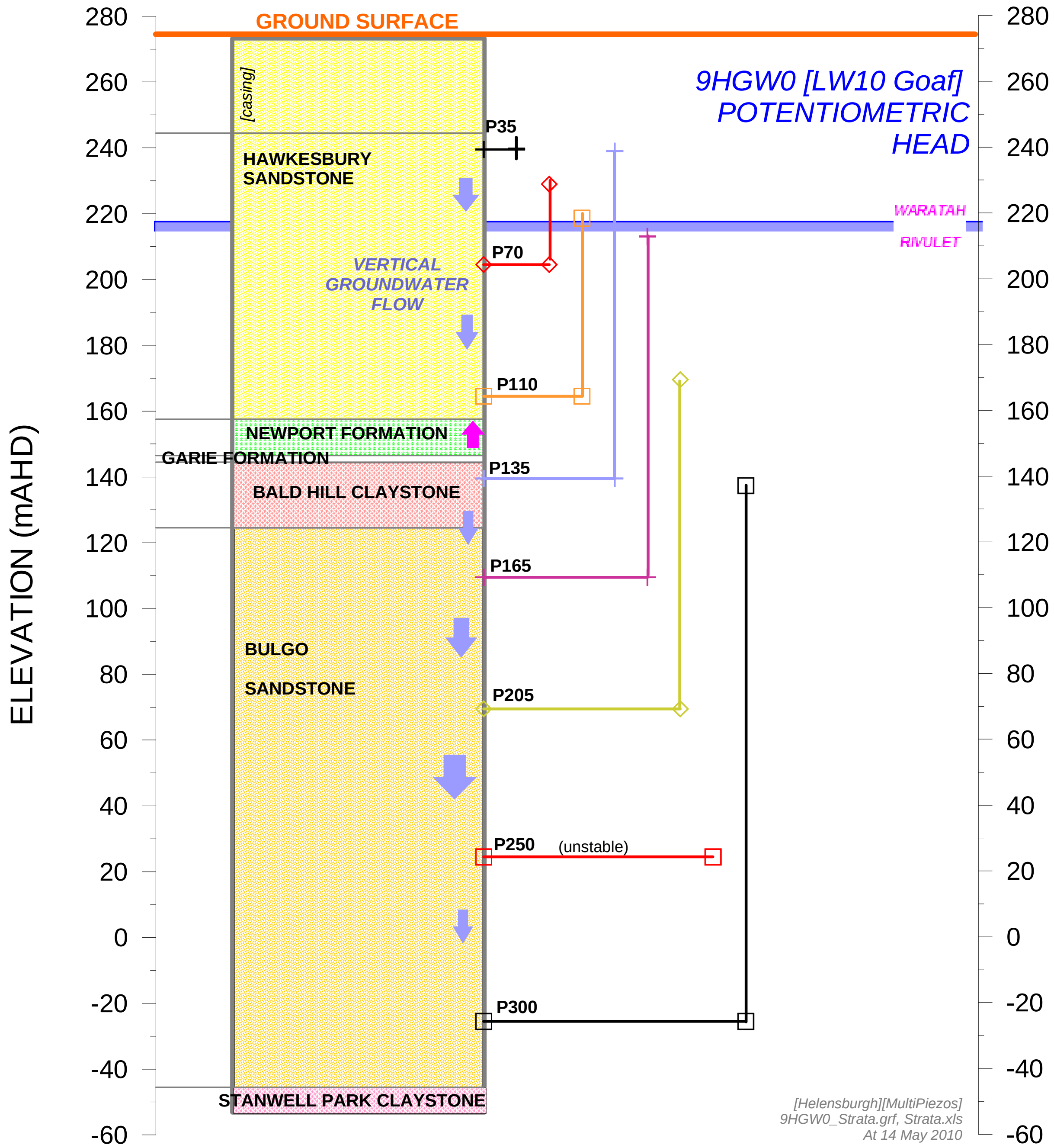

Figure 26 **Vertical Groundwater Flow Directions, Relative Piezometer Elevations and Potentiometric Heads at Bore 9HGW0 (Longwall 10 Goaf Hole) [at 14 May 2010]**

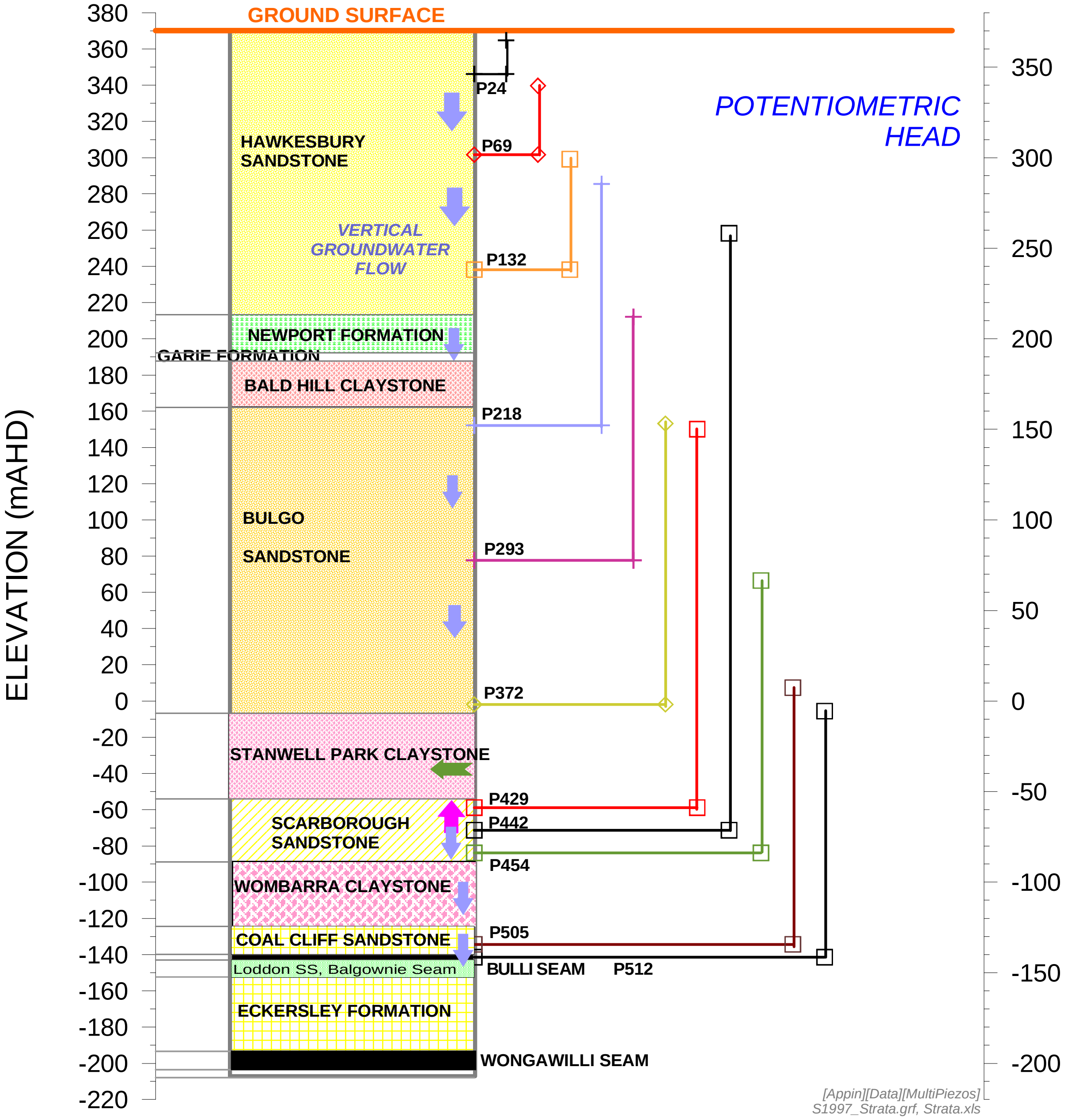

Figure 27 **Vertical Groundwater Flow Directions, Relative Piezometer Elevations and Initial Potentiometric Heads at Bore S1997 at North Cliff [Sampled 15 June 2009]**

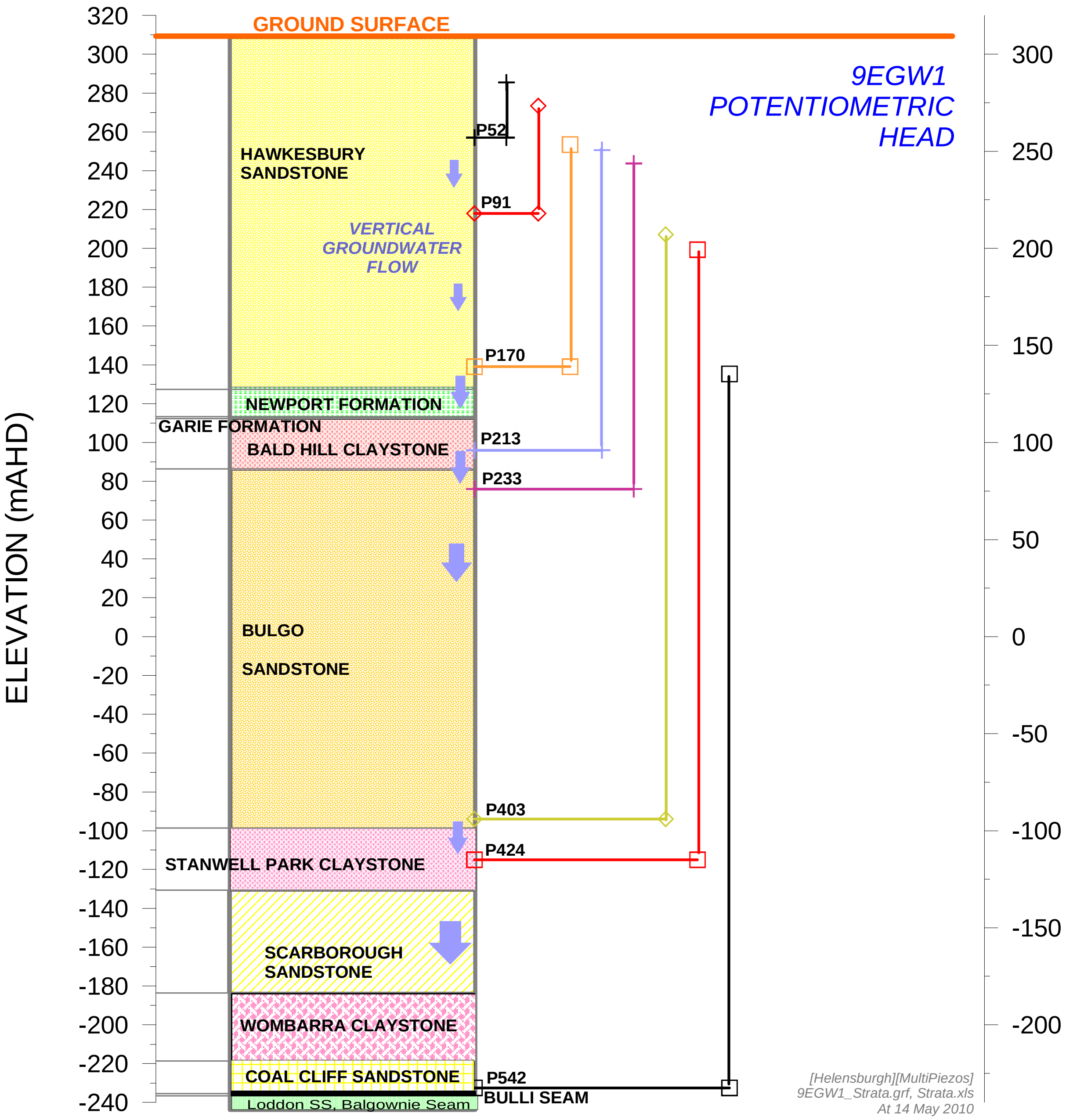

Figure 28 **Vertical Groundwater Flow Directions, Relative Piezometer Elevations and Potentiometric Heads at Bore 9EGW1B [at 14 May 2010]**

3.5.5 Mine Water Make

Mine water make (i.e. groundwater that has seeped into the mine through the strata) is calculated from the difference between total mine inflows (reticulated water into the mine and moisture in the downcast ventilation and the Run-of-Mine [ROM] 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).

Since May 2006, Metropolitan Coal has had no available additional underground water storage capacity. Using a conservative estimate of 10% for the ROM coal moisture content (which maximises the inferred water inflow calculation), the average daily 'water make' is 0.2 ML/day (Figure 29). Using what is considered to be a more realistic estimate of ROM coal moisture content of 7%, the average daily 'water make' is 0.07 ML/day.

Metropolitan Coal has installed a moisture scanning device on Main Drift Belt No. 1 near the mine's exit to measure the ROM coal moisture content. The device was commissioned in August 2010.

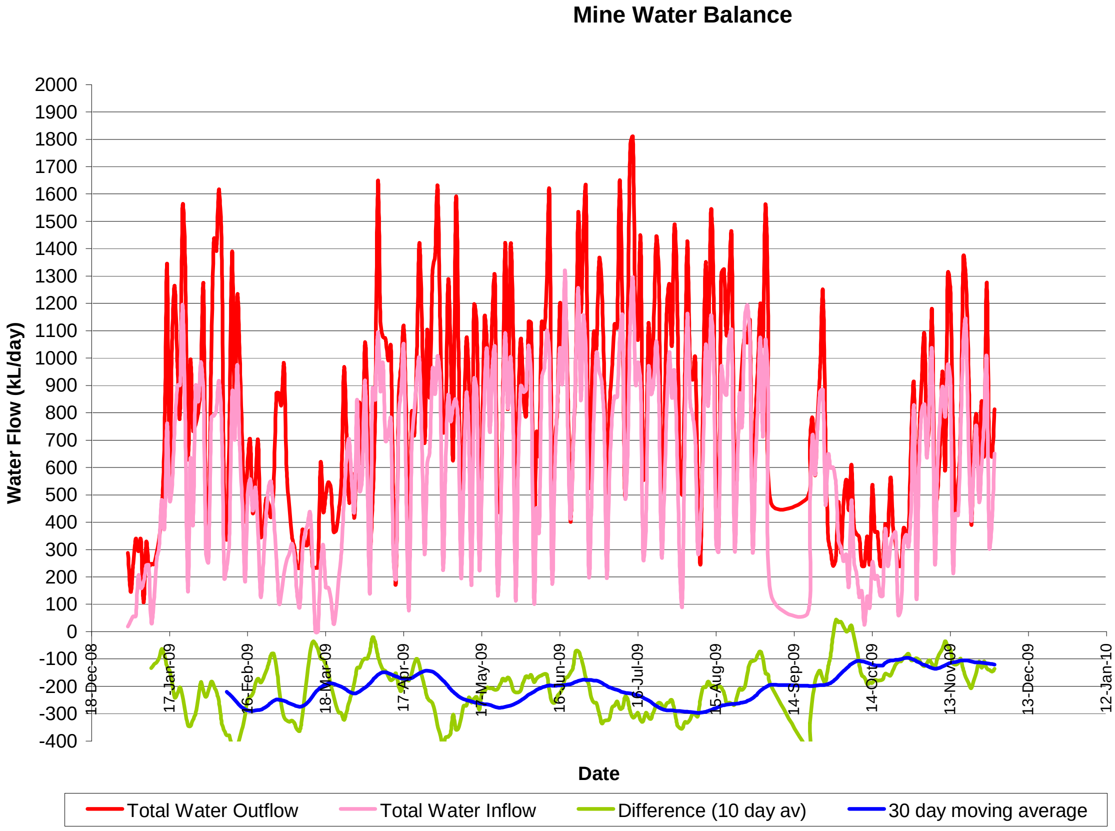

Figure 29 Mine Water Balance, January 2008 to November 2009

3.5.6 Groundwater Quality

Groundwater quality data is available from a number of sites with installed piezometers, as summarised in Table 12. The locations are shown on Figure 30.

Table 12
Groundwater Quality Monitoring Sites

Site Number	Location	Easting	Northing	RL (mAHD)	Commencement Date
SWGW1	Swamp S06	307893	6214226	343.7	12 March 2009
WRGW1	Waratah Rivulet	309886	6214360	207.8	16 February 2007
WRGW2	Waratah Rivulet	309868	6214335	207.9	16 February 2007
WRGW3	Waratah Rivulet	309629	6214072	215.0	16 February 2007
WRGW4	Waratah Rivulet	309579	6214090	217.8	16 February 2007
WRGW5	Waratah Rivulet	309393	6212890	225.4	4 April 2007
WRGW6	Waratah Rivulet	309361	6212871	226.1	4 April 2007
RTGW1A	Tributary B	309594	6215106	222.0	23 August 2007
UTGW 1	Tributary D	309521	6214152	218.2	16 February 2007
UTGW 2	Tributary D	309098	6214012	237.6	7 March 2007
UTGW 3	Tributary D	308834	6213952	247.2	7 March 2007
FGGW1	Forest Gully	308951	6213200	232.4	8 March 2007
FGGW2	Forest Gully	308816	6213158	240.5	4 April 2007
FGGW3	Forest Gully	308682	6213113	250.4	4 April 2007

The water quality data from shallow groundwater piezometers indicates the groundwater is fresh, as indicated by a median electrical conductivity of 230 µS/cm (Heritage Computing, 2008).

Additional groundwater quality sites will be established at sites WRGW7 and ETGW1 when the shallow piezometers are commissioned (Figure 30). It is anticipated that no further groundwater quality sites will be required prior to mining Longwall 308 (in approximately 2022).

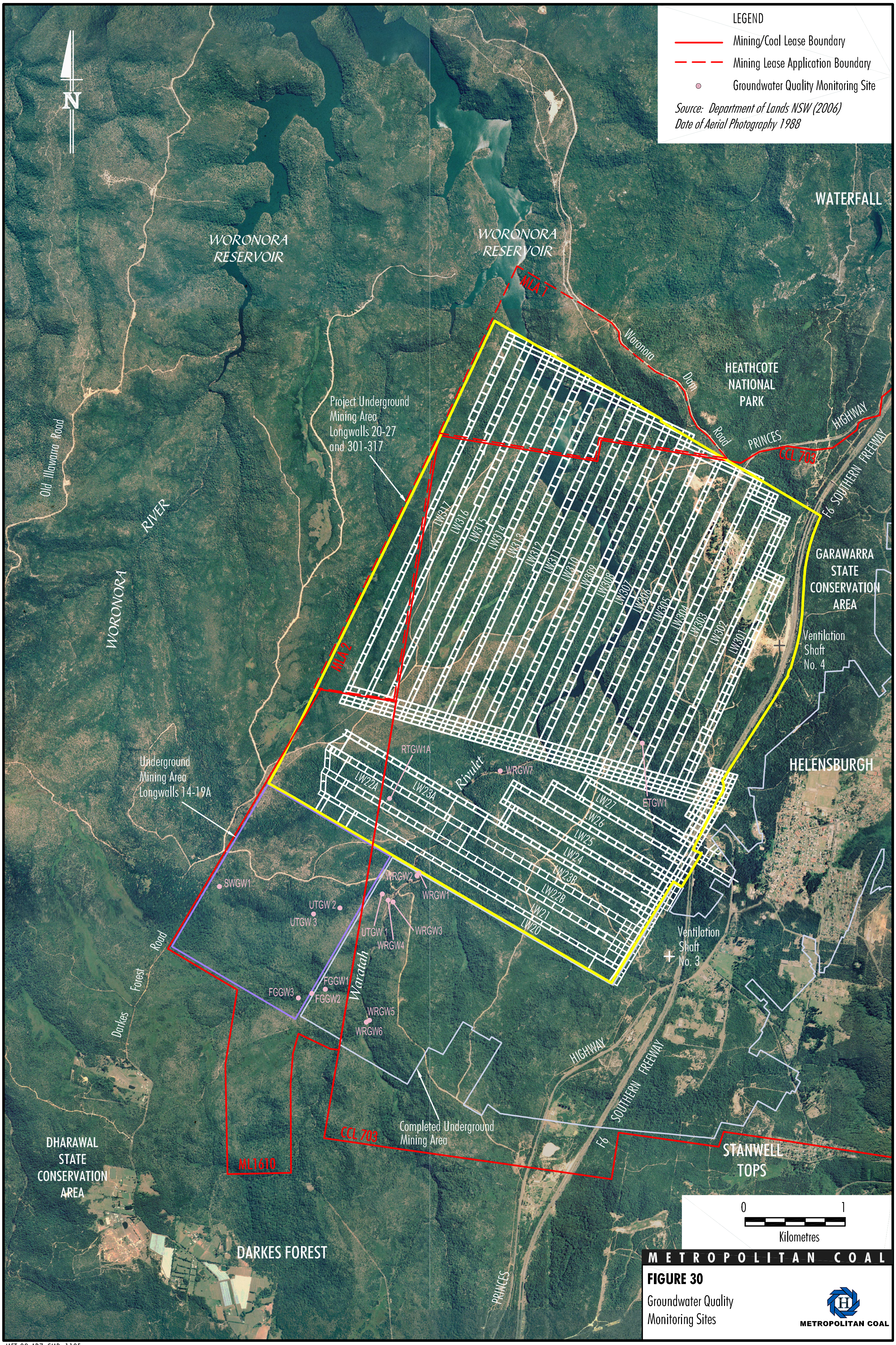

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FIGURE 30

Groundwater Quality Monitoring Sites

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4 SURFACE AND GROUNDWATER MODELS

4.1 INTRODUCTION

A conceptual hydrological model for Metropolitan Coal has been developed that describes the processes governing the movement of water. These processes are described in terms of:

- rainfall and interception storage;
- overland and open channel flow;
- infiltration and sub-surface flow (including interflow, and underflow);
- transmission loss;
- interflow and baseflow contribution to streamflow; and
- movement of water through the various groundwater systems comprising:
  - the perched groundwater system;
  - the shallow groundwater system; and
  - the deep groundwater system.

The conceptual hydrological model has also been used to consider the effects of longwall mining and subsidence on water movement processes including the effects of surface and near surface fracturing and changes to strata permeability. Changes to strata permeability include the deep fracture system about longwall extraction and the separate shallow fracture system associated with non-systematic surface subsidence movement (e.g. the valley closure mechanism).

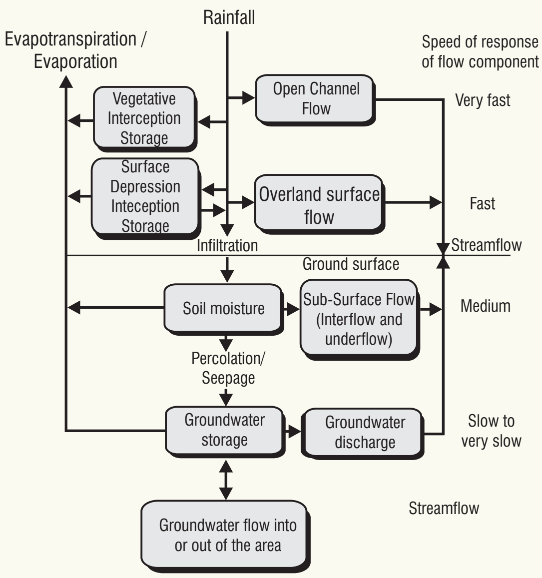
Numerical models have been developed to provide a quantitative understanding of the key hydrological behaviours. Numerical models have been developed in relation to catchment yield and groundwater behaviour. The models are described in the following sections, together with a description of model development, model calibration and validation/verification.

4.2 CONCEPTUAL MODEL

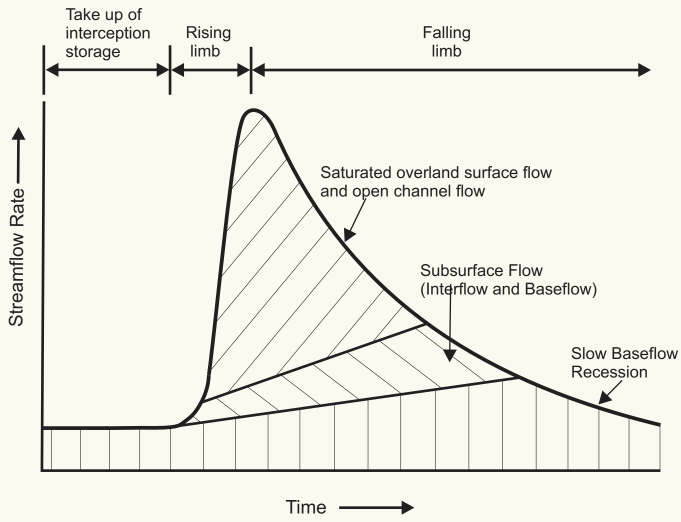
A schematic representation of the hydrological processes which make up the conceptual model is shown on Figure 31. The hydrological processes are described below.

4.2.1 Rainfall and Interception Storage

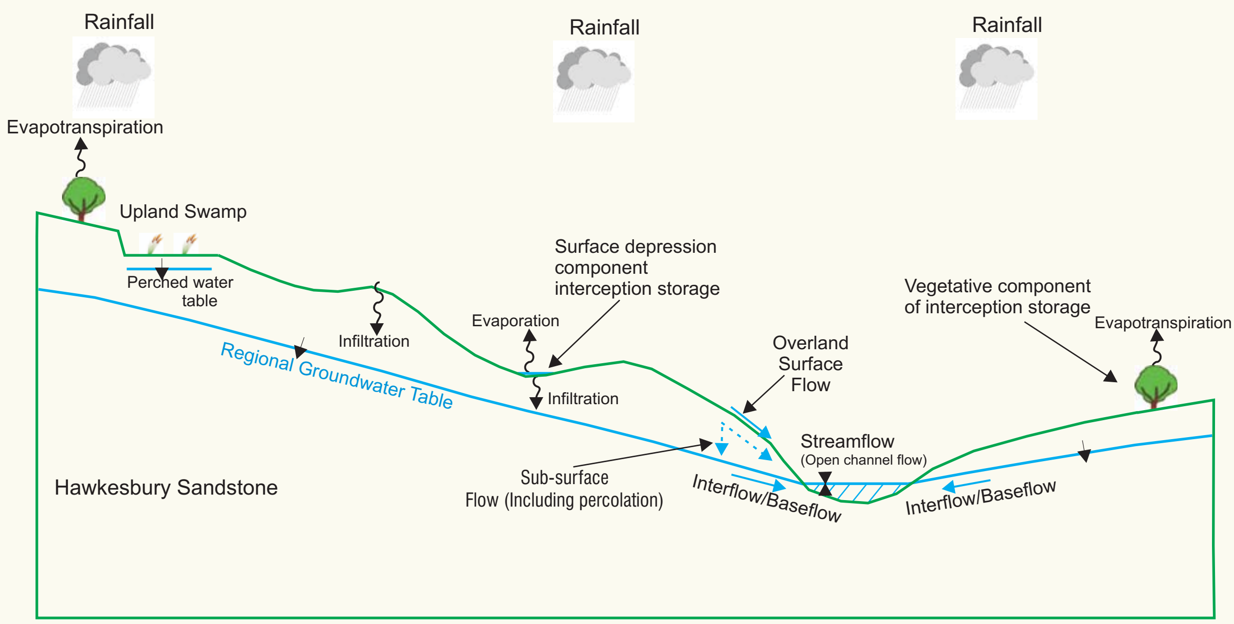
The initial retention of rainfall on the catchment surface is known as interception storage. The capacity of the interception store at the start of a rainfall event will depend on the moisture condition of the catchment. The capacity of the interception store would largely depend on the frequency and amount of previous rainfall and would vary with seasonal changes to vegetation and in response to the effects of drought and fire. Rainfall that is in excess of the capacity of the vegetative component of interception store will reach the ground surface where it will either be held in surface depressions, will infiltrate (seep) into the catchment soil mantle, or will runoff (i.e. result in overland surface flow). Rain that falls directly onto saturated areas of the catchment will add directly to overland surface flow. Rain that falls onto flowing streams will add directly to open channel flow and hence to surface runoff from the catchment. Open channel flow occurs via a defined network of formed drainage channels or watercourses. The movement of water in the open channel drainage network is the fastest pathway for water movement through the catchment.



Hydrological Conceptual / Model - Component Linkages



Water Flow Components of Streamflow



Schematic Representation of Conceptual Hydrological Model

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FIGURE 31

Conceptual Representation of Surface Hydrological Processes

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MET-08-AD7 CMP_003C

Water that is retained in the catchment's interception store (i.e. on the surface of vegetation and in surface depressions) will either evaporate or infiltrate (seep) into the catchment soil mantle.

4.2.2 Overland and Open Channel Flow

Once the capacity of the interception store to hold water has been exceeded, further rainfall will result in the movement of water as overland surface flow. Overland surface flow will typically occur from parts of the catchment that are saturated (i.e. areas where the groundwater table intersects the surface or where surface saturation occurs because water infiltration is slower than the rate at which rainfall intercepts the catchment surface). Overland flow from areas close to flowing streams will quickly reach the streams and add to the open channel flow in the surface drainage network. The majority of water that falls on the remainder of the catchment will also move to the open channel drainage network from areas that are relatively distant from the drainage network as sub-surface flow through the permeable shallow surface soil layers (as described in Section 4.2.3). The proportion of the catchment area which produces overland flow connecting to the surface drainage network will increase with increasing rainfall intensity and duration.

Open channel flow occurs in defined channels or watercourses which form in the valley floors of the catchment. Open channel flow is characterised by deep high velocity turbulent flow conditions. Open channel flow (or streamflow) flowing past a given point in a stream network comprises the accumulated surface drainage which has moved to that point via all the different water flow pathways in operation. Streamflow during a rainfall event will increase as more and more water draining off the catchment reaches the open channel drainage network. The shape of the rising limb of a recorded hydrograph at a given point on the open channel network will reflect the pattern of rainfall and the drainage characteristics of the catchment stream. The rising limb of hydrographs is typically steep and can contain multiple rises reflecting the effect of isolated rainfall bursts. The shape of the recessionary limb of a hydrograph reflects the drainage processes in a catchment during the drying cycle. They typically approximate declining exponential curves and are largely independent of the rainfall pattern which generated runoff. Consistent changes in the recessionary behaviour of a catchment are indicative of change in the catchment's drainage processes.

4.2.3 Infiltration and Sub-Surface Flow (including Interflow and Underflow)

A proportion of incident rainfall that is not held either on the surface of vegetation or in surface depressions, or that flows via saturated or relatively impermeable surfaces as overland surface flow will infiltrate the surface. A portion of overland surface flow which begins to flow over the surface during intense bursts of rainfall can also infiltrate the surface during less intense rainfall or as it traverses more permeable parts of the catchment surface.

Water that infiltrates the surface will move by gravity as sub-surface flow, both vertically and horizontally, through the near-surface unsaturated (vadose) zone[4] or through the saturated zone[5]. The vadose zone typically corresponds to the weathered zone above the groundwater table. It is tapped by the roots of vegetation and a large proportion of the water which infiltrates into this zone is transferred back to the atmosphere by evaporation from the catchment surface and transpiration from stomata on the leaves of vegetation.

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4 *Zone of vadose water*, is the typically moist but unsaturated subsurface zone between the land surface and the top of the *zone of saturation* (water table). Pore pressures in the vadose zone are maintained below atmospheric pressure.

5 *Zone of saturation* is that part of the sub-surface in which the interstices of porous and permeable rocks are saturated with water under pressure equal to or greater than atmospheric pressure.

The remainder of the water either moves downslope to emerge at the surface as drainage seeps (i.e. interflow[6]), or moves predominantly vertically downward though the underlying strata until it joins the underlying regional groundwater table as recharge.

In some streams a significant amount of water can also flow along the stream as underflow[7]. This commonly occurs in alluvial streams which have significant depths of permeable bed alluvium to convey water as sub-surface flow. Deposits of permeable bed alluvium are typically intermittent along the length of a stream, which means flows can emerge as streamflow and/or disappear as underflow. In the case of the Waratah Rivulet and other streams on the Woronora Plateau that contain a series of pools, rock bars, waterfalls and cascades, water has been observed to flow through fractures and fissures in the bedrock to emerge as open channel flow further downstream. This phenomenon is known as underflow. It is different from transmission loss (described in Section 4.2.4) in that it is not a loss of flow from the drainage network, but an alternative, sub-surface pathway for water flowing downstream. Underflow has been observed in several rock bars in Waratah Rivulet and its tributaries, both in reaches affected by mining and in other reaches not affected by mine subsidence. A more detailed description of the effects of mining on underflow is provided in Section 4.2.7 below.

There are likely to be many different pathways for water moving as saturated or unsaturated flow in the Waratah Rivulet catchment. The more significant pathways include:

- Saturated flow: areas of the catchment at lower elevations near drainage lines will saturate relatively quickly during rainfall and water will flow as both overland surface flow and as sub-surface flow. Saturated flow also occurs in higher elevation areas of the catchment where perched groundwater conditions occur.
- Unsaturated flow through the soil mantle. Water will move both upward and downward through the unsaturated soil profile. In homogenous soil deposits, the flows are predominantly vertically downward during and immediately following rainfall. These movements reverse to vertically upward flow during drying periods when sub-atmospheric or suction pressures in the soil lead to the upward movement of water and loss of water to the atmosphere through evaporation. Suction pressures and unsaturated hydraulic conductivities are highest in finer grained soils where pore spaces are smaller.
- Fracture flow above the regional groundwater table. The Waratah Rivulet catchment is underlain by a series of sub-horizontal bedded sandstone, siltstone and claystone layers that contain a network of natural vertical and sub-vertical fractures. The movement of water through these strata is dominated by fracture flow which is expected to occur as preferential flow through interlinked fractures. Whilst flow will follow the fracture path, it will tend to move downward. In places where a significant fracture network outcrops at the surface, water may emerge as a seep. This water may then flow over the surface and either re-infiltrate further downslope or flow into a drainage line by overland surface flow. During drying periods, seeps emerging at the surface are small and are lost to evaporation, as described in Section 4.2.4 below.

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6 *Interflow* is the component of sub-surface flow that directly enters a stream channel or other body of water without having occurred first as surface runoff.

7 *Underflow* is the down-valley movement of water in a near-surface alluvial aquifer that is hydraulically connected and directly related to the stream channel. It is the component of sub-surface flow that reappears as surface flow.

4.2.4 Transmission Loss

The loss of water from streamflow can occur as a result of evaporation (i.e. evaporation from the flowing surface) and as a result of seepage through the bed and banks of the stream. Together, these processes are referred to as transmission losses. Seepage losses will generally only occur in areas where the adjacent and underlying groundwater table is below the level of the bed of the surface drainage.

4.2.5 Baseflow Contribution to Streamflow

Baseflow is stream discharge derived from groundwater sources (as differentiated from surface runoff). It includes a range of different sub-surface pathways including shallow flow through the vadose zone, the movement of shallow flow from the zone which becomes saturated during a storm event close to the drainage network, and the discharge of water into the stream network from the regional groundwater system. Baseflow can be distinguished from surface flow by its relatively slow movement via sub-surface pathways compared to the rapid movement of surface runoff which results in the rapid rise in flow during the rising limb of the hydrograph. Baseflow is responsible for the persistence of flow following rainfall. The yield of a catchment can be partitioned into its baseflow and surface flow components. The contribution that baseflow makes to overall flow can be quantified by the baseflow index which is the overall ratio of baseflow to total flow averaged over all flows. The contributions that surface runoff, interflow and baseflow make to the overall flow in a catchment are shown schematically on a typical hydrograph on Figure 31.

4.2.6 Groundwater System

A conceptual model of the hydrogeological regime was developed by Heritage Computing (2008) based on a review of hydrogeological data. These included:

- Southern Coalfield geology mapping;
- surrounding and regional geological logs;
- relevant data from the Department of Water and Energy (now NSW Office of Water) register on the Natural Resources Atlas (http://test.nratlas. nsw.gov.au);
- geological and hydrogeological assessments undertaken for Metropolitan Coal and other Southern Coalfield mine operations;
- SCA's hydrogeological investigations and assessments undertaken for the Upper Nepean (Kangaloon) Borefield Project; and
- piezometric monitoring and geological information from the Longwall 10 Goaf Hole and PM02 Hole at Metropolitan Coal.

The surface water and groundwater (baseflow) interaction mechanisms (described in Sections 4.2.1 to 4.2.5) have also been considered.

Conceptually, there are three distinct groundwater systems:

- deep groundwater system;
- shallow groundwater system; and
- perched groundwater system, associated with swamps and shallow sandstone.

A perched water table occurs in headwater swamps and near-surface sandstone. It is hydraulically distinct from the underlying regional sandstone water table in the shallow groundwater system. There is hydraulic connection between the shallow and deep groundwater systems, but mining-induced reductions in pressure in the deep aquifer system are moderated by substantial claystone aquitards in the Narrabeen Group. The three groundwater systems are illustrated in the conceptual model of the region shown on Figure 32.

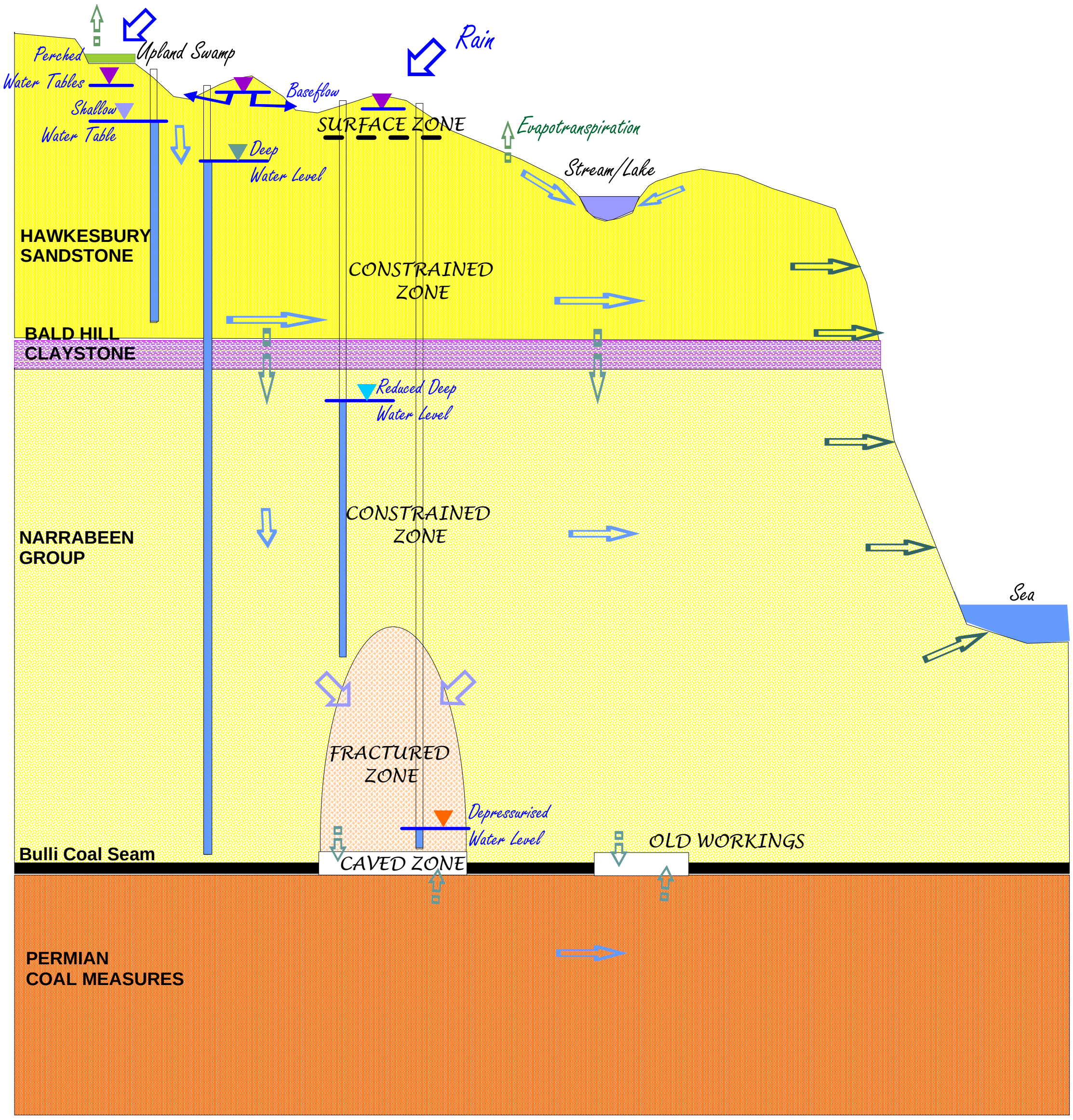

Figure 32 Conceptual Groundwater Model

Following from the surface hydrological processes described in Sections 4.2.1 to 4.2.5, recharge to the groundwater system is from rainfall and from lateral groundwater flow (i.e. from groundwater movement outside the limits of the groundwater system being considered). Although groundwater levels are sustained by rainfall infiltration, they are controlled by ground surface topography and surface water levels. A local groundwater mound develops beneath the sandstone hills with ultimate discharge to incised streams and water bodies.

During short events of high surface flow, streams can lose water to the sandstone aquifers that host the streams (i.e. transmission loss, described in Section 4.2.4), but during recession the sandstone will discharge water slowly back into the stream from bank storage (i.e. baseflow, described in Section 4.2.5). Groundwater also discharges naturally to cliff faces and ultimately to the sea. In places where mining has occurred, groundwater discharge is expected to occur to the mined seam from above and below in proportion to local permeabilities. The local permeabilities are influenced by strata behaviour about longwall extraction.

Immediately above a mined coal seam, rocks will collapse into the void to form a caved zone and cause changes to aquifer permeability and porosity. As the mining proceeds, a fractured zone will develop above the caved zone and aquifer properties will change with time. The overlying rocks in the fractured zone will have a higher vertical permeability. Depending on the width of the longwall panels and the depth of mining, and an alternation of thick sandstone/claystone lithologies, there will be a constrained zone in the overburden that acts as a bridge. This will isolate shallow and deep aquifers. At the substantial depths of cover at Metropolitan Coal, there will not be connective cracking from the ground surface to the mined seam. Groundwater pressures will reduce towards atmospheric pressure at the base of the fractured zone.

A stream bed with an exposed rock base can experience cracking in response to subsidence to a depth of approximately 10 to 20 m. There will be no permanent loss of shallow water to a deep mine because there will be no continuity of fractures from the surface to the mine. There will be diversion of a portion of surface water flows through the rock fractures beneath the stream bed, which will move as underflow through the aquifer immediately beneath the stream, with emergence further downstream.

Topographic relief will drive vertical groundwater flow near the ground surface, but at depth the alternation of aquifers and aquitards will promote horizontal groundwater flow at the base of permeable units. Along the escarpment to the east of Metropolitan Coal, water will appear as seeps in cliff faces at the junction of formations with contrasting permeability.

4.2.7 Subsidence Impacts and the Conceptual Hydrological Model

Figure 32 includes characterisation of sub-surface strata movement about longwall extraction in terms of fracture development. These include:

- A *Caved Zone,* which comprises loose blocks of rock detached from the roof and occupying the cavity formed by mining. This zone can contain large voids.
- A *Fractured Zone,* which comprises *in situ* material lying immediately above the caved zone which has sagged downwards and consequently experienced significant bending, fracturing, joint opening and bed separation. This zone has a lower section where the induced fractures are connected, and an upper section where fracturing is disconnected. At Metropolitan Coal the height of the connective fractured zone has been measured to be within the range 0.8 to 1.2 times the longwall width.
- A *Constrained Zone,* which comprises confined rock strata above and adjacent to the fractured zone. Some shear along bedding can be present as well as discontinuous vertical cracks, but not to the extent that significantly impacts on vertical permeability. Some zones of increased horizontal permeability may occur in the constrained zone. Weak or soft beds (such as clays) would typically experience plastic deformation.
- A *Surface Zone*, which comprises unconfined (in a vertical sense) strata at the ground surface in which mining induced tensile and compressive strains, together with non-systematic ground movements (e.g. valley closure), may occur.

The effects of subsidence movements in the Waratah Rivulet catchment associated with past longwall mining are described in detail in Gilbert and Associates (2008). Subsidence can result in fracturing of the surface and sub-surface strata and increases and decreases in the opening aperture of the existing fracture system. Subsidence movements also result in phenomena known as valley closure and upsidence that cause fracture networks beneath the valley floor and upward dilation and buckling type fracturing of the bedrock. This produces a high capacity pathway for underflow where the surface buckling fractures join with the sub-surface fracture network which approximately parallels the stream bed.

The fracture network caused by upsidence and valley closure is limited to valley floors above the mining zone. As a consequence, flow in the fracture network is forced back to the surface beyond the mining zone. Observation bores along the banks of Waratah Rivulet have recorded significant declines in groundwater level as valley closure and upsidence movements occur at that point. This reflects the creation of a high capacity fracture network which acts as a sub-surface drain for low flows.

4.3 SURFACE WATER

4.3.1 Numerical Catchment Yield Model

A numerical catchment model for the Waratah Rivulet and control catchment(s) has been developed using the nationally recognised Australian Water Balance Model (AWBM) (Boughton, 2004). The AWBM is a catchment-scale water balance model that estimates streamflow from rainfall and evaporation.

The structure of the AWBM model is shown on Figure 33. Key parameters in the AWBM are:

- Surface storage capacity (C1, C2 and C3): the capacity (in mm) of the three surface storage components of the model – once the model surface storages are filled, they spill to generate either runoff or baseflow recharge. This may be thought of as similar to catchment interception capacity which is the amount of rainfall required to saturate a catchment before runoff occurs.
- Surface storage areas (A1, A2 and A3): the proportions of the total catchment area represented by the three surface stores.
- Baseflow Index (BFI): the proportion of rainfall excess from the model surface stores that recharges the baseflow store. Baseflow is derived from slow drainage of groundwater and dominates the flow hydrograph during periods of no rainfall.
- Recession Constant (K): the rate at which baseflow diminishes in the absence of rainfall.

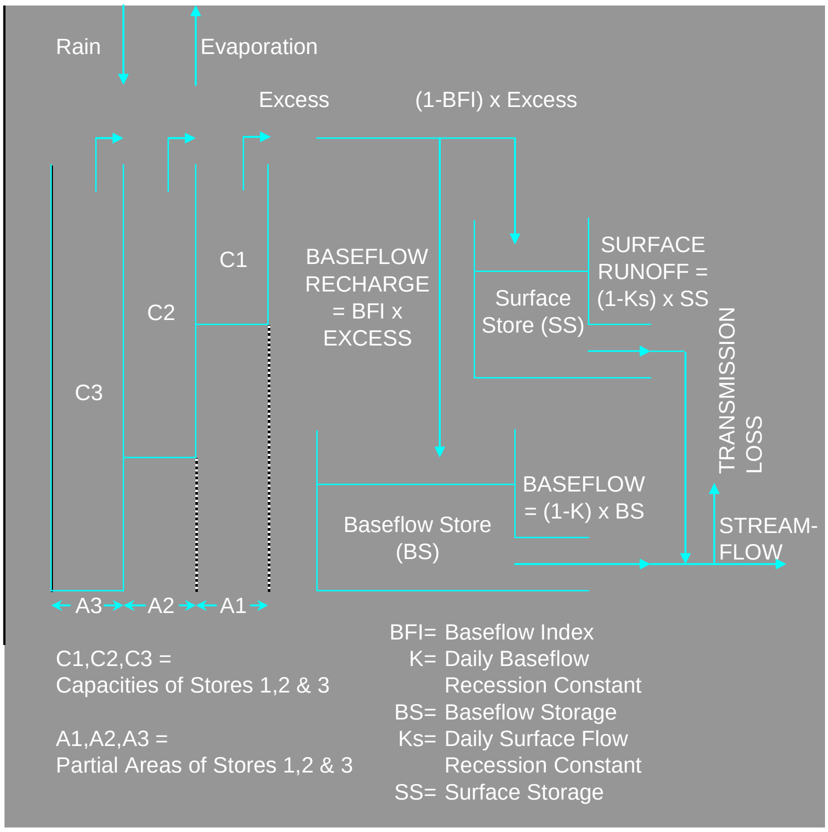

Figure 33 AWBM Model Structure and Parameter Definition

The model comprises three surface storages and a groundwater storage. Rainfall is applied to each surface store and evaporation losses simulated by withdrawal from each surface store. Each surface store has a defined capacity (C1, C2 and C3 in mm) which are model parameters. The surface stores also have defined areas (A1, A2 and A3) which are model parameters being the proportion of the catchment that each storage represents. Once the surface storages are filled by rainfall they spill to generate runoff and baseflow recharge – to the groundwater store. The simulated dynamic water balance of the surface stores in response to applied rainfall and evaporation represent the processes of rainfall interception, infiltration, overland and open channel flow.

The groundwater store does not have a defined capacity. It is recharged during periods when runoff is generated from the surface stores. The proportion of rainfall excess that recharges the baseflow store is determined by a model parameter known as the Baseflow Index (BFI). Water stored in the groundwater store drains at a rate defined by another parameter known as the recession constant (K). The rate of baseflow contribution is numerically set to (1-K) times the volume of water held in the baseflow store. In the absence of recharge events it has the effect of exponentially depleting the baseflow store. Water draining from the groundwater store reports to the simulated catchment runoff as the baseflow. The simulated dynamic water balance of the groundwater store in response to recharge events from the surface storages represents the processes of infiltration and groundwater recharge, and groundwater discharge by interflow and baseflow processes.

Variants of the AWBM can be set up to simulate losses to deep groundwater systems which do not report as runoff at the catchment outlet, transmission losses from streamflow, streamflow attenuation and lag processes due to surface storage effects and the incorporation of an additional groundwater store to simulate more complex baseflow behaviour.

The AWBM is calibrated against recorded rainfall, evaporation and streamflow data by adjusting the model parameters to obtain a close fit between simulated and observed flows. Calibration can be undertaken using both automated numerical optimisation methods and/or by manual methods. Use of both automated and manual methods can overcome issues associated with periods of suspect or erroneous data. Model validation is the process whereby the predictive performance of a calibrated model is assessed by comparing simulated with observed flows not used in the calibration process. Validation, in the conventional hydrological modeling meaning of the word, requires a significantly longer period of observed flows than that required for calibration alone and has not been undertaken for the Waratah Rivulet or other Project area catchments to date. Given the limitations on the period of data it is proposed to undertake model verification rather than validation, where verification is a process where by additional analysis and model sensitivity analyses are undertaken to demonstrate the reasonableness and robustness of model performance given all of the available information.

The AWBM models of Waratah Rivulet and the O'Hares Creek catchments used in the Metropolitan Coal Project EA studies (Gilbert and Associates, 2008) have been re-calibrated using updated Waratah Rivulet and O'Hares Creek gauging station data.

Table 13 shows the calibrated values of these parameters for the OEH gauging stations on O'Hares Creek at Darkes Forest and Wedderburn, and the SCA-owned gauging stations on the Waratah Rivulet and Woronora River.

Table 13
Comparison of Calibrated AWBM Parameters

Gauging Station	AWBM Parameters							
	C1 (mm)	C2 (mm)	C3 (mm)	A1	A2	A3	BFI	K
GS213002 O'Hares Creek at Darkes Forest	5	270	530	0.068	0.366	0.565	0.11	0.98
GS213200 O'Hares Creek at Wedderburn	4	150	400	0.164	0.633	0.203	0.21	0.97
GS2132102 Waratah Rivulet	5	130	880	0.10	0.56	0.34	0.30	0.979
GS2132101 Woronora River	4	150	400	0.164	0.633	0.203	0.21	0.97

The data in Table 13 indicates:

- Overall the calibrated model parameter values are quite similar and reflect the nature of the catchments.
- The C2 and C3 values are quite high when compared with other Australian catchments, which is consistent with the dense vegetation coverage of the catchments.
- The BFI values are quite low (less than 0.35) and reflect the generally fast-draining nature of the steep, sandstone catchments. Baseflow is however an important component of the catchment hydrology in sustaining flows through dry periods – the GS213200 data indicates that O'Hares Creek at Wedderburn has never ceased to flow in its recorded period (since 1978).
- Figures 34 and 35 show a plot of recorded data at the Waratah Rivulet gauging station and AWBM generated flows – derived from catchment rainfall and regional evaporation data both as flow hydrographs and flow duration curves. Both figures show that the model gives a good fit to the observed data.

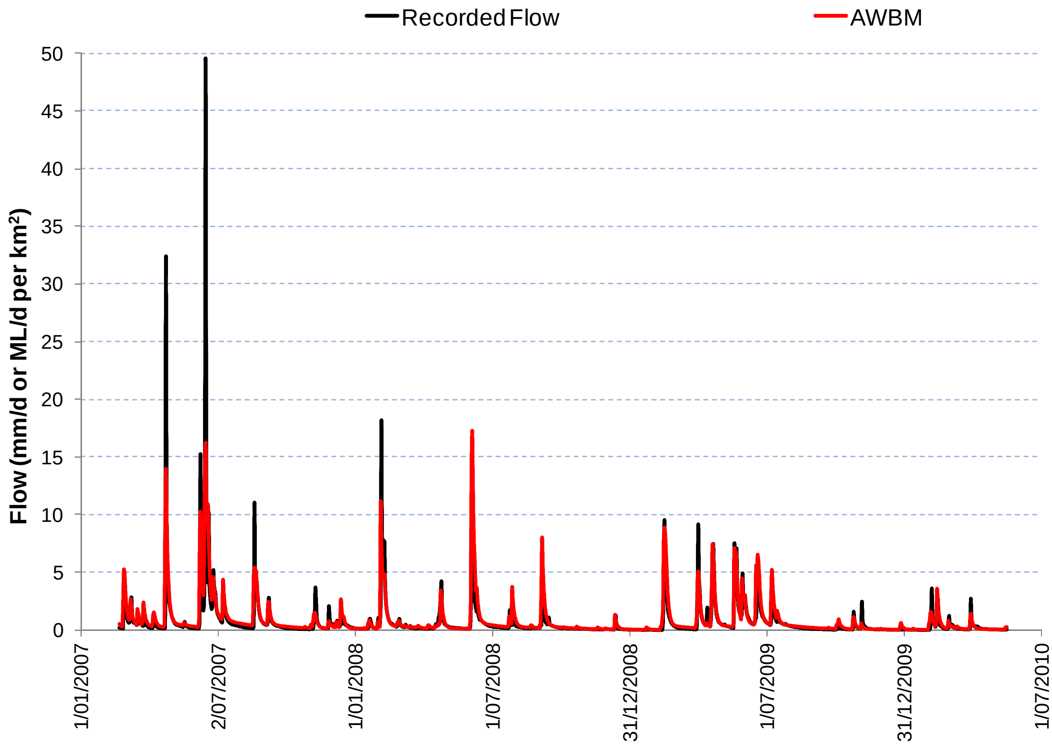

Figure 34 Recorded and Modelled Streamflow Hydrographs – GS2132102 Waratah Rivulet

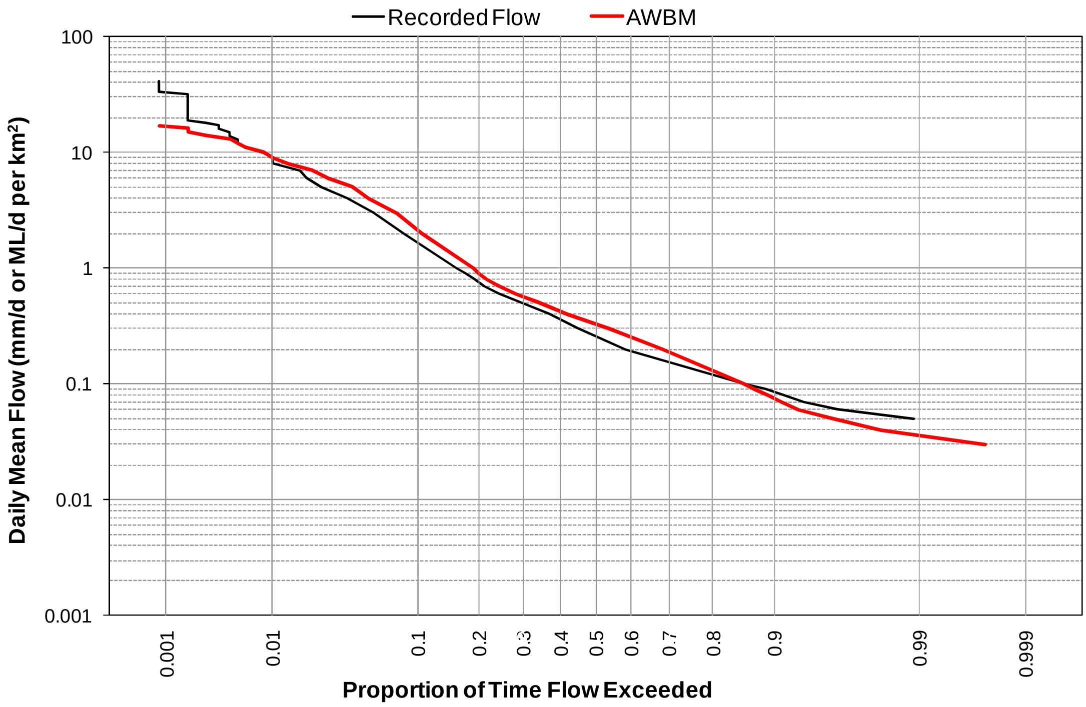

Figure 35 Recorded and Modelled Flow Duration Curves - GS2132102 Waratah Rivulet

4.3.2 Catchment Yield Model Development, Calibration and Verification Program

Catchment models have been developed and calibrated for Waratah Rivulet at the SCA's gauging station (GS 2132102), Woronora River at the SCA's gauging station (GS 2132101) and the O'Hares Creek catchment above the Wedderburn gauging station (GS 213200). These models will be progressively updated using the latest monitoring data, and ongoing (periodic) calibration and verification checks will be undertaken using the methods described below.

Re-calibration and verification of both the mine area catchment model (Waratah Rivulet) and the control catchment(s) (O'Hares Creek and Woronora River) will be conducted.

Re-calibration of these models will be undertaken using the available monitoring data. The proposed calibration and verification program involves the following components:

- Metropolitan Coal uses rating curve and manual gauging information provided by the SCA for the Waratah Rivulet and Woronora River gauging stations. Metropolitan Coal will request details of any updates to the flow rating curves, new gaugings conducted to date and revised flow data under their Data Licence Agreement with the SCA. Re-calibration of the models will occur upon receipt of revised rating curves and updated flow data.
- Data checking and correction or removal of erroneous data. Based on the upgrade and data review described above, it is proposed to review the flow data sets for missing data, errors and inconsistencies. The detection of errors in data is undertaken by checking for volumetric and temporal consistency in rainfall and runoff data sets and internal consistency between data observed at different sites in the region. Flow and rainfall data sets are also examined for signs of erroneous (non natural) responses such as increasing flow during dry periods and constant flow data over significant periods or fluctuation in flow data that are unrelated to rainfall, all of which can be signs of faulty instrumentation. In some instances missing or erroneous data can be in-filled or corrected where information from other sites (rainfall for example) can be imported and translated to site of missing data. In other instances systematic errors can be adjusted/ corrected where the magnitude of the error can be determined over the period of error. This might be the case where a gauging station has recorded a constant flow due to instrument malfunction during a dry period where there is a high probability that the flow in the catchment would have been declining exponentially over this period in accordance with its "normal" recessionary behaviour and in accordance with recessionary behaviour observed at other local catchments or other gauging stations or water level data recorded in pools upstream. In these circumstances the erroneous flow record could be corrected by replacing it with synthetic data derived from an analysis of baseflow recessionary behaviour in the catchment.
- The model re-calibration process will initially be completed with independent expert review (once the updated flow rating curves and revised flow data have been obtained) to confirm the quality of the model and its calibration. Whilst not currently contemplated it is possible that the re-calibration process might lead to the need to refine the model structure to more closely match low flow recessionary behaviour for example. This might involve the use of model variants with several baseflow stores.
- The re-calibrated model will be verified by testing the model sensitivity for changes of parameter values and by testing the uniqueness of the model calibration – and its goodness of fit to different components and periods of the flow record. An independent review of the results of this process would be commissioned.

Catchment models will be developed for the Eastern Tributary and Honeysuckle Creek gauging stations once a suitable period of data has been collected (which will be dependent on climatic conditions and flow variability).

4.4 GROUNDWATER

4.4.1 Groundwater Model Development Program

The area has been simulated with MODFLOW-SURFACT software (an advanced version of MODFLOW that is distributed commercially by Hydrogeologic, Inc. [Virginia, USA]). It is able to simulate variably saturated flow and can handle desaturation and resaturation of multiple aquifers. This is pertinent to the depressurisation that occurs in the caved zone and fractured zone above mined coal panels, and to possible dewatering of the uppermost model layer(s).

A three-dimensional numerical model of groundwater flow had been developed for Metropolitan Coal and its surroundings to allow evaluation of near-field mine dewatering requirements and far-field environmental effects (Heritage Computing, 2008; Heritage Computing, 2009c). The model extent was 18 km from west to east and 14 km from south to north, with uniform 100 m cell size (140 rows, 180 columns). The model consisted of 327,600 cells. To handle the observed vertical changes in groundwater head within a given formation, and expected goaf fracturing, the numerical model had 13 model layers. That included subdivision of Hawkesbury Sandstone into three layers, and subdivision of Bulgo Sandstone and Scarborough Sandstone into two layers each.

To account for uncertainty in the height of the fractured zone and the permeability characterisation of the fractured zone, two transient models were developed (Heritage Computing, 2009b). These models were identical except for the permeabilities adopted in the fractured zones above the longwall panels and in the host zones for layers 10-13:

> *“High-inflow model": Fractured zone expands up to Layer 7 (roof of Stanwell Park Claystone). The permeability of these fractured zones varies from 6.4E-05 m/day to 6.5E-02 m/day. Host vertical (Kz) and horizontal (Kx) hydraulic conductivities above the Bulli seam (Layer 12) to Layer 7 are higher than the "Low-inflow model".*
>
> *“Low-inflow model": Fractured zone expands up to Layer 8 (roof of upper Scarborough Sandstone, floor of Stanwell Park Claystone). Fractured zone permeabilities are the same for all fractured layers, 2.0E-06 m/day.*

The high-inflow model had the better performance against head targets, but the low-inflow model gave better agreement with mine inflow records.

A revision of the upper part of the model (Hawkesbury Sandstone layers) was undertaken in 2012 (Akhter and Merrick, 2012) to re-calibrate the model for the water levels and vertical head differences measured in the Hawkesbury Sandstone. The revised model follows the same conceptualisation (Figure 32) and has the same extent as the previous one, but the new model has two additional model layers. Initially, a sub-model of the upper four layers was extracted from the original 13-layer model. This sub-model divided the Hawkesbury Sandstone into five layers instead of three. A layer for the Bald Hill Claystone was included at the base. The upper six layer interface elevations were customized to align with the vibrating wire piezometer (VWP) positions. The top layer (Superficial Aquifer) thickness was increased to allow the layer to remain wet in order to avoid numerical instabilities from dry cells.

Re-calibration of this six-layer sub-model was conducted in steady-state mode using groundwater level and vertical head difference targets at all bores with nested piezometers in the Hawkesbury Sandstone.

After steady-state re-calibration was completed, the full model was expanded from 13 to 15 layers to achieve better replication of vertical gradients through the Hawkesbury Sandstone. The re-calibrated hydraulic conductivity (Kx, Kz) property values for Hawkesbury Sandstone and the Bald Hill Claystone were transferred to the full model. Vertical and horizontal hydraulic conductivities below layer 6 (Bald Hill Claystone) remained unchanged.

Table 14 presents the final horizontal and vertical permeabilities for both the "high-inflow model" and the "low-inflow model", after re-calibration of the upper six layers. These models serve as alternative base models. The models are identical except for the permeabilities adopted in Scarborough Sandstone to Coal Cliff Sandstone (Layer 10 to Layer 13) and fractured zones. The "high-inflow model" fractured zones are extended up to the roof of Stanwell Park Claystone (Layer 9), roof height about 115 m above Bulli Coal Seam. For the "low-inflow model", fractured zones are extended up to the roof of the upper Scarborough Sandstone (Layer 10), roof height about 92 m above Bulli Coal Seam. Higher fractured permeabilities are considered in the "high-inflow model".

Table 14
Calibrated Horizontal and Vertical Hydraulic Conductivities [m/day]

	High-Inflow Model*			Low-Inflow Model^		
	Host Kx	**Host Kz**	**Fracture Kz**	**Host Kx**	**Host Kz**	**Fracture Kz**
1. Superficial Aquifer	1	0.1		1	0.1	
2. Upper Hawkesbury Sandstone	0.046	6.98E-04		0.046	6.98E-04	
3. Mid-Upper Hawkesbury Sandstone	0.001	4.9E-05		0.001	4.9E-05	
4. Mid- Lower Hawkesbury Sandstone	1.64E-03	2.21E-05		1.64E-03	2.21E-05	
5. Lower Hawkesbury Sandstone	2.49E-03	1E-04		2.49E-03	1E-04	
6. Bald Hill Claystone	7.45E-05	2.07E-05		7.45E-05	2.07E-05	
7. Upper Bulgo Sandstone	2.5E-02	2.0E-03		2.5E-02	2.0E-03	
8. Lower Bulgo Sandstone	6.6E-05	1.0E-05		6.6E-05	1.0E-05	
9. Stanwell Park Claystone	2.9E-04	6.0E-05	8.1E-05	2.9E-04	6.0E-05	
10. Upper Scarborough Sandstone	9.0E-04	8.8E-03	0.052	1.0E-05	1.0E-06	2.0E-06
11. Lower Scarborough Sandstone	3.3E-03	5.2E-03	0.065	1.0E-05	1.0E-06	2.0E-06
12. Wombarra Claystone	2.7E-04	3.6E-06	6.4E-05	2.7E-04	1.0E-06	2.0E-06
13. Coal Cliff Sandstone	2.3E-04	1.1E-03	5.9e-03	1.0E-05	1.0E-06	2.0E-06
14. Bulli Coal Seam	0.016	0.034		0.016	0.034	
15. Loddon Sandstone	1.0E-05	2.0E-06		1.0E-05	2.0E-06	

* Drain conductance 10 square metres per day (m^2/day).
^ Drain conductance 1 m^2/day.

The south-eastern corner of the model crosses the Illawarra Escarpment and reaches the sea. This allows the inclusion of a significant natural boundary condition at regional scale. The Scarborough Sandstone, normally model layers 10 and 11 to the west of the escarpment, outcrops at the coast where it occupies layers 1-11 in the model. Sea level heads are specified in model layer 1. The model includes neighbouring old workings at Darkes Forest and Helensburgh, and first workings at North Cliff. The main streams in the area are established as “river” cells in model layer 1, to allow water exchange in either direction between the stream and the aquifer. The river conductances are set at 5 to 50 m^2/day. Minor drainage lines are established as “drain” cells in model layer 1, allowing groundwater to discharge to the drainage lines as baseflow. The drain conductances are set at 2.5 m^2/day.

Rainfall infiltration has been imposed uniformly over the model extent as a fraction of the long-term 1894 to 2006 Darkes Forest median monthly rain (74 mm/month). The infiltration rate is set at 5%.

Initial model calibration was based on: (1) matching vertical head profile data at the first two multi-level piezometer holes (9HGW0 [the Longwall 10 goaf hole] and PM02); (2) indicative mine inflows; and (3) spatial replication of shallow groundwater levels. The revised calibration focused on shallow water levels and hydraulic gradients through the Hawkesbury Sandstone. At this time, model calibration has been limited to steady-state. As more time-series data become available, transient calibration can be undertaken.

With the current data set, there is uncertainty as to the parameterisation of the fractured zone, which is assumed to extend from the Bulli Coal Seam (model layer 14) to the top of the Stanwell Park Claystone (model layer 9). The height of the fractured zone is about 120 m in the model. This accords with the termination of the Longwall 10 goaf hole at 130 m above the coal seam.

For the time being, there are two active model variants called the “high-inflow model” and the “low-inflow model”. These models are identical except for the permeabilities adopted in the fractured zone and the drain conductance for the longwall panels (Table 14).

The high-inflow model has the better performance against heads targets (7% RMS), compared with 8.3 % RMS for the low-inflow model. The low-inflow model has the better performance against mine inflow (0.11 ML/day), compared with 0.38 ML/day for the high-inflow model.

The model permeabilities will be refined through a process of validation and re-calibration (Section 4.4.2) as mining proceeds and the monitoring program provides more data, and by adherence to magnitudes determined by core laboratory measurement and *in situ* packer testing. The expectation is that, in time, the two model variants will converge to a single model. At present, the permeability in each host formation is uniform spatially. Some spatial variability in the model can be expected as the model evolves.

The numerical model was designed to simulate the propagation of depressurisation effects throughout the entire aquifer system. It does not simulate the effects of near-surface tensile cracking due to subsidence of the land surface. However, this can be addressed to some degree by enhancing the horizontal and vertical permeabilities of model layer 1 directly above longwall panels, with a corresponding increase in rainfall infiltration.

The model was also designed to replicate the saturated part of the groundwater system close to the land surface. It does not simulate the occurrence of near-surface perched water tables which occur in upland swamps and shallow outcropping sandstone. Due to the observed isolation between perched and regional water tables, the expectation is that there will be no effect on baseflow derived from perched aquifers. Upland swamps can be assessed to some extent in a regional model by a "river" cell device. This can show potential mining-induced increases in leakage or reductions in baseflow for swamps that are in communication with the water table, but for the most common disconnected systems there can be no impact unless the fracturing increases the swamp floor conductance.

4.4.2 Model Development, Calibration and Validation Program

The groundwater model(s) will continue to be refined as new data become available. The development program includes:

- development of a local area model for transient calibration of swamp characteristics at Swamp S06 using swamp water levels (at SWAMP4) and shallow sandstone water levels (at SWGW1);
- transient calibration of dynamic rainfall infiltration and stream interaction by use of shallow time-series groundwater levels;
- experimental mesh refinement in the mining area to match the scale of chain pillars, to allow an investigation of the role that pillars play in ameliorating environmental impacts;
- transient calibration of formation hydraulic and storage properties by use of time-series groundwater heads measured in multi-piezometer bores;
- incorporation of near-surface tensile cracking by enhancing the horizontal and vertical permeabilities of model layer 1 directly above longwall panels, with a corresponding increase in rainfall infiltration; and
- incorporation of upland swamps.

The model will be validated progressively as new multi-level piezometric data become available from the monitoring program. This process commenced in 2009 (Heritage Computing, 2009b) and has been undertaken at six-monthly intervals since then. Although the deep groundwater portion of the model was calibrated against only two multi-piezometer bores, verification has been checked against an additional 10 bores installed since that time. Overall, the agreement between measured and predicted vertical head profiles at these "blind" sites has been very good.

Re-calibration of the model can also address alternative representations of the fractured zone. At present, enhanced vertical permeabilities are multiples of the unfractured host values. An alternative approach is to abandon any link to host values, and to apply a ramp function of monotonically decreasing vertical permeability over the height of the fractured zone. Another alternative approach is to aggregate the 1 m scale permeabilities predicted by the geotechnical modeling of Strata Control Technologies.

At present, horizontal permeabilities are not enhanced in the fractured zone of the model or in the overlying constrained zone. This enhancement process (primarily due to bed separation) requires investigation.

In addition, the formation below the Bulli Coal Seam is expected to undergo some fracturing. Accommodation of this feature would require splitting the bottom model layer into three layers, with only the uppermost of the three layers undergoing fracturing.

5 PROGRAM TO MONITOR AND ASSESS IMPACTS ON THE QUANTITY AND QUALITY OF SURFACE AND GROUNDWATER RESOURCES

This section describes the catchment wide monitoring program to monitor and assess impacts on the quantity and quality of surface and groundwater resources.

The program will be reviewed in association with the Annual Review that will be conducted in accordance with Condition 3, Schedule 7 of the Project Approval. This will include consideration of changes to the monitoring locations, parameters and frequencies based on the data obtained in the previous period and the planned future mining activities. As described in Section 2, any revisions to the CMP will be made to the satisfaction of the Director-General of the DP&E.

5.1 METEOROLOGY

Rainfall intensity data will be monitored using six pluviometers at the following locations (Figure 3):

- Waratah Rivulet catchment (sites PV1, PV6 and 'Reverces' [Bureau of Meteorology Station 568069]);
- Woronora River catchment (site PV2);
- Honeysuckle Creek catchment (site PV5);
- Eastern Tributary catchment (site PV7); and
- O'Hares Creek catchment (Bureau of Meteorology Station 68024).

This data will be supplemented by climate data from nearby Bureau of Meteorology stations or SCA-owned monitoring equipment, as required.

A pan evaporimeter at site PV1 (Figure 3) has been established to monitor evaporation in the Waratah Rivulet catchment.

It is anticipated that the meteorology sites listed above will remain over the life of the Project. At this stage (subject to the review process described in Section 2), no additional meteorological monitoring equipment is anticipated to be required. The meteorology data will input to the catchment model described in Section 4.3.1.

5.2 STREAM FEATURES

As described in Section 3.4.3, MSEC has compiled a comprehensive survey and photographic record of Waratah Rivulet (from Flat Rock Crossing to the Woronora Reservoir full supply level), Eastern Tributary (from the east-west headings to the Woronora Reservoir full supply level), Tributary A (from its headwaters to its confluence with Waratah Rivulet) and Tributary B (from its headwaters to its confluence with Waratah Rivulet) as a component of the Metropolitan Coal Longwalls 20-22 Water Management Plan.

Visual inspection and photographic surveys will be conducted:

- along the Waratah Rivulet from Flat Rock Crossing to the full supply level;
- along the Eastern Tributary within the 35 degree (°) angle of draw of Longwalls 20-22 to the full supply level;

- along Tributary A within the 35° angle of draw of Longwalls 20-22 and Longwalls 23-27; and
- along Tributary B within the 35° angle of draw of Longwalls 20-22 and Longwalls 23-27.

Consistent with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, visual and photographic surveys of the Waratah Rivulet and Eastern Tributary will be conducted monthly until subsidence is less than 20 mm/month, and thereafter within three months of the completion of each longwall. Visual inspections of Tributary A and Tributary B will be conducted within three months of the completion of each longwall.

The visual and photographic surveys will record:

- the location, approximate dimensions (length, width and depth), and orientation of surface cracks (specifically whether cracks are developed perpendicular to the stream flow or are controlled by rock joints or other factors etc.);
- the nature of iron staining (e.g. whether isolated or across the entire streambed);
- the extent of iron staining (e.g. the length of stream affected);
- a description of gas release (e.g. isolated bubbles or continuous stream, and type of gas [methane or carbon dioxide]);
- the nature of scouring, for example the depth of scouring, type of soil exposed, any obvious vegetation impact, potential for severe erosion etc.;
- water discoloration or opacity if present;
- natural underflow if evident (i.e. evidence of surface flows either entering or exiting the sub-surface domain via surface cracks in the streambed);
- rock bar characteristics such as extent of cracking, seepage, underflow;
- whether any actions are required (e.g. implementation of management measures, incident notification, implementation of appropriate safety controls, review of public safety, etc.); and
- any other relevant information.

Global Positioning System (GPS) coordinates will be recorded where appropriate (e.g. of particular observations and associated photographs).

In the event gas releases are identified, monitoring will be conducted weekly to determine the extent of the gas releases, gas concentration (analysis for carbon dioxide and methane content) and any observable environmental effects (e.g. impacts to riparian vegetation or fish kills).

The monthly visual and photographic surveys will record the above parameters by exception (i.e. where they differ to the baseline visual and photographic record). The visual and photographic surveys conducted within three months of the completion of each longwall will provide a detailed photographic record in a similar manner to that provided in Appendices 1 to 4 of the Metropolitan Coal Longwalls 20-22 Water Management Plan.

As described in Section 3.4.3, visual and photographic surveys of Tributaries E to H will be included in the relevant future Extraction Plan(s) for stream reaches that are located within, and downstream of, the 35° angle of draw of the relevant longwall extraction mining area. The baseline surveys will occur prior to mining within 400 m of the relevant stream reach. Inspection of other tributaries (sub-catchments on the eastern side of the Woronora Reservoir) indicates the drainage channels are small ephemeral streams.

5.3 SURFACE WATER

5.3.1 Surface Water Flow

Surface water flow monitoring will include continuous flow monitoring at (Figure 7):

- the existing SCA-owned gauging station on the Waratah Rivulet, close to the inundation limits of the Woronora Reservoir (GS2132102);
- the existing SCA-owned gauging station on the Woronora River, close to the inundation limits of the Woronora Reservoir (GS2132101) (control site);
- the existing Metropolitan Coal-owned gauging station on the Eastern Tributary, close to the inundation limits of the Woronora Reservoir;
- the existing Metropolitan Coal-owned gauging station on Honeysuckle Creek (control site); and
- the existing OEH gauging station on O'Hares Creek at Wedderburn (GS213200) (control site).

Data from the SCA-owned gauging stations will continue to be downloaded monthly by the SCA and provided to Metropolitan Coal in accordance with an existing data exchange agreement.

At the Waratah Rivulet gauging station (Pool Q), a subsidence survey line will monitor conventional and non-conventional subsidence magnitudes at this location. If monitoring identifies subsidence effects at this location, Metropolitan Coal will consult with the SCA and conduct a review of the hydrological performance of the gauging station including analysis of the rating curve and separately an analysis of the recession model. If this analysis shows the hydrological performance of the gauging station has been compromised and cannot be rectified, an additional gauging station will be installed at an appropriate location further downstream.

Metropolitan Coal will identify a suitable gauging station site downstream of the existing SCA owned gauging station on Waratah Rivulet, develop design plans and seek approval for its construction through the Construction Management Plan, in consultation with the SCA. With the approval in place, Metropolitan Coal will be able to immediately commence construction of the gauging station site should the hydrological performance of the SCA owned gauging station become compromised.

Metropolitan Coal will continue to source flow data for the O'Hares Creek gauging station at Wedderburn from the OEH.

The gauging station data will input to the catchment models described in Section 4.3.1.

In accordance with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, the calibrated catchment model for the Waratah Rivulet will be used to assess the quantity of water resources reaching the Woronora Reservoir. Measured and predicted flows will be compared using the calibrated catchment model developed for the Waratah Rivulet and control catchment(s). The methodology provides a means to test for a change in flow behaviour in Waratah Rivulet and in nearby, hydrologically similar, control streams (O'Hares Creek and Woronora River) before and after the commencement of Longwall 20 secondary extraction.

An analysis of catchment yield will be conducted on a six monthly basis and will include:

- Comparison of measured flows with modelled (predicted) flows, using the calibrated catchment model developed for the Waratah Rivulet catchment prior to Longwall 20 secondary extraction.
- Comparison of the Waratah Rivulet catchment model predicted flows with the control catchment(s) (i.e. O'Hares Creek and Woronora River).

Details of assessment against performance indicators and subsidence impact performance measures are provided in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

5.3.2 Pool Water Levels

The water level in Pools B, C, E, G, G1, H and I on Waratah Rivulet will be manually monitored daily (Figure 7).

Pool water levels will be monitored using a continuous water level sensor and logger in (Figure 7):

- Pools A, F, J, K, L, M, N, O, P, Q, R, S, T, U, V and W on Waratah Rivulet;
- Pools ETG, ETJ, ETM, ETU, ETW, ETAF, ETAG, ETAH, ETAI, ETAQ and ETAU on the Eastern Tributary;
- Pools RTP1 and RTP2 on Tributary B; and
- control Pools WRP1, WRP2, WRP3 and WRP4 on the Woronora River.

Data from these devices will be downloaded monthly.

Pools P, Q, R, S, T, U, V and W on Waratah Rivulet are situated downstream of maingate 23, approximately 390 m, 600 m, 740 m, 980 m, 1,080 m, 1,350 m and 1,460 m downstream of the Longwall 22 maingate, respectively. In accordance with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, Pool P will be visually inspected on a weekly basis when mining of Longwalls 20-27 is within 400 m of this pool. Pools Q, R, S, T, U, V and W on Waratah Rivulet will be subject to weekly visual inspections when mining of Longwalls 23-27 is within 400 m of these pools.

Pools ETAF to ETAU on the Eastern Tributary are situated downstream of maingate 26. Pool ETAF is situated approximately 925 m downstream of maingate Longwall 22. In accordance with the Metropolitan Coal Longwalls 23-27 Water Management Plan, pools ETAF to ETAQ on the Eastern Tributary will be subject to weekly visual inspections when mining of Longwalls 23-27 is within 400 m of these pools.

All pools between Pools ETG and ETAQ on the Eastern Tributary will be inspected monthly when mining of Longwalls 23-27 is within 400 m of the Eastern Tributary and until subsidence reduces to less than 20 mm/month. Pool ETAU is situated more than 400 m downstream of Longwall 27, however will be inspected monthly when mining is within 400 m of the Eastern Tributary during the extraction of Longwall 27.

Details of assessment against performance indicators and subsidence impact performance measures in relation to pools on Waratah Rivulet and the Eastern Tributary are provided in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

The Metropolitan Coal Rehabilitation Management Plan, Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan describe how stream remediation activities will be triggered at relevant pools on the Waratah Rivulet (between the downstream edge of Flat Rock Swamp and the full supply level of the Woronora Reservoir) and the Eastern Tributary (between the maingate of Longwall 26 and the full supply level of the Woronora Reservoir).

Additional pools may be selected for monitoring as a component of the baseline data considerations for future Extraction Plans. All streams within, or downstream of, the 35° angle of draw of the relevant Extraction Plan will be assessed and if required, additional automated pool monitors will be installed a minimum of two years prior to mining within 400 m of the relevant stream reach.

5.3.3 Stream Water Quality

Surface water quality sampling will be conducted at the following sites (Figure 10):

- sites WRWQ 2, WRWQ 6, WRWQ 8 and WRWQ 9 on the Waratah Rivulet;
- sites WRWQ M, WRWQ N, WRWQ P, WRWQ R, WRWQ T and WRWQ W on the Waratah Rivulet;
- site RTWQ 1 on Tributary B;
- site UTWQ 1 on Tributary D;
- sites ETWQ F, ETWQ J, ETWQ N, ETWQ U, ETWQ W, ETWQ AF, ETWQ AH, ETWQ AQ and ETWQ AU on the Eastern Tributary;
- site FEWQ 1 on the Far Eastern Tributary;
- site HCWQ 1 on Honeysuckle Creek;
- site BCWQ 1 along Bee Creek; and
- control sites WOWQ 1 and WOWQ 2 on the Woronora River.

Water quality will be sampled monthly. Water quality parameters will include electrical conductivity (EC), pH, redox potential (Eh), dissolved oxygen (DO), turbidity, calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), sulphate (SO_4), bicarbonate (HCO_3), total nitrogen (Ntot), total phosphorous (Ptot), nitrate (NO_3), barium (Ba), strontium (Sr), manganese (Mn), iron (Fe), zinc (Zn), cobalt (Co) and aluminium (Al). Samples collected for metal analysis will be field filtered.

Unfiltered water quality samples will also be collected at the following sites and analysed for total iron:

- sites WRWQ 2, WRWQ 6, WRWQ 8 and WRWQ 9 on the Waratah Rivulet;
- sites WRWQ M, WRWQ N and WRWQ P on the Waratah Rivulet;
- sites ETWQ F, ETWQ J, ETWQ N and ETWQ AF on the Eastern Tributary; and
- control site WOWQ2 on the Woronora River.

In accordance with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, water quality data (iron, manganese and aluminium) from sites WRWQ9 and ETWQ2 collected post-mining of Longwall 20 will be analysed against baseline monitoring data collected at both sites and against water quality data collected from site WOWQ2 on the Woronora River. The results will be assessed against the performance indicator and subsidence impact performance measure in relation to the quality of water resources reaching the Woronora Reservoir, as detailed in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

Additional water quality sites will be established at each pool selected for installation of automated water level sensors and data loggers. The water quality sampling program will commence when the pool water level monitoring equipment is established as described in Section 3.4.5 (i.e. a minimum of two years prior to secondary extraction occurring within 400 m of the relevant stream). In the case of Tributary H, this will occur prior to completion of Longwall 306 (prior to the end of 2019).

5.3.4 Woronora and Nepean Reservoir Water Quality

As a component of the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, Metropolitan Coal will source water quality data for the Woronora Reservoir (site DW01, measurements taken from 0 to 9 m below the water surface level) from the SCA in accordance with a data exchange agreement.

Metropolitan Coal will also source water quality data for the Nepean Reservoir and Cataract Reservoir from the SCA in accordance with a data exchange agreement.

In accordance with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, water quality data (iron, manganese and aluminium) collected from site DW01 (Woronora Reservoir) following the commencement of Longwall 20 will be analysed against monitoring data collected at site DW01 prior to the commencement of Longwall 20 and against water quality data collected from the Nepean Reservoir. The analyses will be conducted following the receipt of data from the SCA. The results will be assessed against the performance indicator and subsidence impact performance measure relating to Woronora Reservoir water quality, as detailed in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

5.4 GROUNDWATER

Metropolitan Coal will provide a groundwater impact verification in the Annual Review including an interpretation of multi-aquifer drawdown for the relevant monitoring piezometers.

5.4.1 Swamp Groundwater Levels

Monitoring of upland swamp groundwater levels will be conducted in accordance with the Metropolitan Coal Longwalls 20-22 Biodiversity Management Plan and Metropolitan Coal Longwalls 23-27 Biodiversity Management Plan. An overview of the monitoring programs is provided below.

Groundwater monitoring of upland swamps will involve the use, where practicable, of paired piezometers, one in the swamp substrate and one sandstone piezometer. Where a swamp substrate piezometer has not been practicable to install due to the depth of the swamp sediments, deeper piezometers have been installed in the shallow sandstone.

As a component of the Metropolitan Coal Longwalls 20-22 Biodiversity Management Plan, monitoring of groundwater level data in upland swamps includes (Figure 17):

- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and one sandstone piezometer to a depth of approximately 10 m), located in Swamp 25 overlying Longwalls 20-22.
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and one sandstone piezometer to a depth of approximately 10 m), located in control Swamp 101.
- One sandstone piezometer to a depth of approximately 10 m in valley side Swamp 16 (S16).
- One sandstone piezometer to a depth of approximately 10 m in valley side Swamp 17 (S17).
- Multiple piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and two sandstone piezometers to depths of approximately 4 and 10 m), located in Swamp 20 overlying Longwalls 20-22.
- Multiple piezometers (i.e. one swamp substrate piezometer to a depth of approximately 0.9 m and two sandstone piezometers to depths of approximately 4 and 10 m), located in control swamp Woronora River 1 (WRSWAMP1).

As a component of the Metropolitan Coal Longwalls 23-27 Biodiversity Management Plan, monitoring of groundwater level data in upland swamps includes (Figure 17):

- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in Swamp 28 (S28) overlying Longwalls 23-27.
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in Swamp 30 (S30) overlying Longwalls 23-27.
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in Swamp 33 (S33) overlying Longwalls 23-27.
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in Swamp 35 (S35) overlying Longwalls 23-27.
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in control Swamp 137 (at Site 137a).
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in control Swamp 137 (at Site 137b).
- Paired piezometers (i.e. one swamp substrate piezometer to a depth of approximately 1 m and one sandstone piezometer to a depth of approximately 10 m), located in control swamp Bee Creek Swamp.

Consistent with the Metropolitan Coal Longwalls 20-22 Biodiversity Management Plan and Metropolitan Coal Longwalls 23-27 Biodiversity Management Plan, data will be downloaded monthly and analysis will be conducted on a six monthly basis. The results will be assessed against the performance indicator and subsidence impact performance measure described in relation to upland swamp groundwater monitoring in the Metropolitan Coal Longwalls 20-22 Biodiversity Management Plan and Metropolitan Coal Longwalls 23-27 Biodiversity Management Plan.

As described in the Metropolitan Coal Longwalls 23-27 Biodiversity Management Plan, baseline data will be obtained for the Longwalls 301-303 Extraction Plan prior to the extraction of Longwall27. The timing for the baseline data in relation to the next Extraction Plan (Longwalls 301-303) is to ensure that baseline data for the next upland swamps are collected before extraction occurs within 600 m of these features.

Swamps 76, 77 and 92

Additional swamp groundwater level monitoring sites will be established as a component of future Extraction Plan(s) and revisions to the Biodiversity Management Plan, and as informed by the environmental assessment that will be conducted for Swamps 76, 77 and 92 in accordance with Condition 4, Schedule 3 of the Project Approval.

Condition 4 of Schedule 3 states:

> *The proponent shall not undermine Swamps 76, 77 and 92 without the written approval of the Director-General. In seeking this approval, the proponent shall submit the following information with the relevant Extraction Plan (see Condition 6 below):*
>
> *a) a comprehensive environmental assessment of the:*
> - *potential subsidence impacts and environmental consequences of the proposed Extraction Plan;*
> - *potential risks of adverse environmental consequences; and*
> - *options for managing these risks;*
>
> *b) a description of the proposed performance measures and indicators for these swamps; and*
>
> *c) a description of the measures that would be implemented to manage the potential environmental consequences of the Extraction Plan on these swamps (to be included in the Biodiversity Management Plan – see Condition 6(f) below), and comply with the proposed performance measures and indicators.*

5.4.2 Shallow Groundwater Levels

Continuous water level monitoring sites of shallow groundwater will be conducted at (Figure 17):

- sites WRGW1, WRGW2, WRGW7 and WRGW8 along Waratah Rivulet;
- site RTGW1A on Tributary B; and
- sites ETGW1 and ETGW2 along the Eastern Tributary.

These shallow (20 m) boreholes will contain a piezometer at the base of each hole. Data will be downloaded monthly and analysis will be conducted on a six monthly basis.

In accordance with Condition 3, Schedule 7 of the Project Approval, Metropolitan Coal will conduct an Annual Review of the environmental performance of the Project by the end of March each year for the past calendar year. The Annual Review will include a comprehensive review of monitoring results.

5.4.3 Deep Groundwater Levels/Pressures

Continuous groundwater level/pressure monitoring will be conducted at (Figure 17):

- site 9HGW0 (Longwall 10 Goaf Hole);
- site 9EGW1B;
- site 9FGW1A;

- site 9GGW1-80;
- site 9GGW2B
- site 9HGW1B;
- site PM02;
- site PM01;
- site PM03;
- site 9EGW2A;
- site PHGW1B;
- site PHGW2A;
- site F6GW3A; and
- site F6GW4A.

Data from the piezometers will be downloaded monthly. The measured vertical hydraulic head profiles for these bores (with the exception of bore 9GGW1-80 which is a single level standpipe) will be compared against the predicted vertical hydraulic head profiles for each bore on a six monthly basis.

In accordance with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, groundwater pressures monitored at site 9FGW1A (adjacent to Longwall 20) and/or site 9GGW2B will be compared to the predicted vertical head profiles. The results will be assessed against the performance indicator and subsidence impact performance measure relating to connective cracking, as detailed in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

In addition, shallow groundwater levels at site 9GGW2B (to the south of Woronora Reservoir) and site PM02 (to the west of Woronora Reservoir) will be compared to the measured water levels in the Woronora Reservoir. The results will be assessed against the performance indicator and subsidence impact performance measure relating to leakage from the Woronora Reservoir, as detailed in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

Three new groundwater monitoring sites will be installed during 2014 to monitor deep groundwater levels in the vicinity of the 300 series longwall panels as described in the Metropolitan Coal Longwalls 23-27 Water Management Plan.

5.4.4 Mine Water Make

Metropolitan Coal has developed an In-rush Hazard Management Plan required by clause 28(b)(iii) of the *Coal Mines Health and Safety Regulation, 2006* to manage the potential risk of in-rush from:

- water lodgement in external (from adjacent mines) workings;
- water stored in existing Metropolitan workings;
- mining under surface water bodies; and
- intersection with boreholes or gas drainage holes.

In addition to shift inspections conducted by statutory officials that report on any abnormal conditions at the working face and in outbye areas, Metropolitan Coal conducts statutory weekly inspections of development workings to identify water accumulations. A weekly audit of the statutory inspections is conducted by the shift undermanager. In the event the statutory inspection identifies the potential for in-rush, an investigation is conducted by the Senior Mine Supervisor on that shift and reported to the Mine Manager.

Monitoring of the mine water balance will comprise:

- Metered water reticulated into the mine (recorded continuously and downloaded monthly).
- Metered water reticulated out of the mine (recorded continuously and downloaded monthly).
- Manual measurement of moisture content into and out of the mine through the mine ventilation system using a digital psychrometer. The frequency of readings will be as follows:
  - every hour over a 9 hour period on two occasions during a 12 month period;
  - daily (week day) except public holidays or other circumstances (access, fan maintenance etc) that prevent readings to be taken; and
  - once per week as a minimum.
- Measurement of the *in situ* moisture content of the coal during channel sampling for coal quality.
- Measurement of the moisture content of ROM coal conveyed out of the mine at the drift portal using an automated moisture scanner. A fully automated data acquisition system records and stores the data.

The inferred water make (i.e. groundwater that has seeped into the mine through the strata) will be calculated from the difference between total mine inflows (reticulated water into the mine, moisture in the downcast ventilation, and the *in situ* coal moisture content) and total mine outflows (reticulated water out of the mine, moisture in the exhaust ventilation, and moisture in the ROM 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 20 day average will be used to provide a more reliable estimate of water make.

In accordance with the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan, statutory visual inspections and the mine water balance will be used to assess the potential for connective cracking between the surface and the mine. The monitoring components will 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 metered moisture content of ROM coal).

The monitoring results will be assessed against the performance indicator and subsidence impact performance measure relating to connective cracking, as detailed in the Metropolitan Coal Longwalls 20-22 Water Management Plan and Metropolitan Coal Longwalls 23-27 Water Management Plan.

Metropolitan Coal will report in the Annual Review on the total volume of groundwater taken as inflows to the underground mine as a component of the underground water balance. In addition, the following volumes of surface water will be measured: water taken by means of the weir on Camp Gully, water discharged into Camp Gully and Sydney Water usage. Other meters will measure usage on site (e.g. stockpile sprays and recycled water).

5.4.5 Groundwater Quality

Shallow groundwater quality sampling will be conducted at the following sites (Figure 30):

- sites WRGW1, WRGW2 and WRGW7 along the Waratah Rivulet;
- site RTGW1A adjacent to Tributary B; and
- site ETGW1 along the Eastern Tributary.

Groundwater quality will be sampled monthly. Water quality parameters will include EC, pH, Eh, Ca, Mg, Na, K, Cl, SO_4, HCO_3, Ba, Sr, Mn, Fe, Zn, Co and Al. The samples collected for the analysis of metals will be field filtered.

In accordance with Condition 3, Schedule 7 of the Project Approval, Metropolitan Coal will conduct an Annual Review of the environmental performance of the Project by the end of March each year for the past calendar year. The Annual Review will include a comprehensive review of the monitoring results.

6 REFERENCES

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