South32 - Illawarra Coal

DENDROBIUM MINE

End of Panel Surface Water and Shallow Groundwater Assessment: Longwall 12 (Area 3B)

HGEO Pty Ltd
Date: May 2017
Project number: J21427
Report: D17260

DOCUMENT REGISTER

Revision	Description	Date	Comments
A	1st Draft	03/05/2017	
B	Final	19/05/2017	
C			

FILE

C:\OneDrive\HGEO\Projects\Dendrobium\04_Projects\03_EOP_Reports\EOP_LW12_Hydrology\D17260_S32_EOP_LW11_SW_Hydrology_V6.docx

QUALITY CONTROL

Process	Staff	Signature	Date
Authors	Will Minchin Stuart Brown		
Approved	Stuart Brown		19/05/2017

COPYRIGHT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

This report summarises the observed, measured and estimated effects on hydrological features resulting from the extraction of Dendrobium Longwall 12.

Longwall 12 is the fourth panel to be extracted from Dendrobium Area 3B. Extraction began on 22 January 2016 and was completed on 31 January 2017.

The Illawarra Coal Environmental Field Team (ICEFT) conducts monitoring and inspections on landscape features including watercourses and swamps within Dendrobium Area 3B. This monitoring is conducted in accordance with the:

- Dendrobium Area 3B Subsidence Management Plan (SMP);
- Dendrobium Area 3B Watercourse Impact, Monitoring, Management and Contingency Plan (WIMMCP) (October 2015);
- Dendrobium Subsidence, Landscape Monitoring and Management Plan (November 2012); and
- Dendrobium Area 3B Swamp, Impact, Monitoring, Management and Contingency Plan (SIMMCP) (October 2015).

The WIMMCP, SIMMCP and Landscape Trigger Action Response Plans (TARPs) form the basis of the impact assessments in this report.

A total of **24** new surface fractures were identified by the ICEFT within the zone of influence of Longwall 12 (within 400 m of the longwall footprint), of which **4** were in streambeds (LA4 [3] and WC21 [1]).

This assessment has identified that mining-related effects on the flow regime have occurred in tributaries to Donalds Castle Creek (DCS2, DC13S1) – see Table 1. There is a discernible loss of flows along the watercourse LA4, which is a tributary of Lake Avon. However, the apparent change in flow did not exceed a TARP trigger level. The Dendrobium Area 3B mine plan was modified to reduce the potential for impacts to Wongawilli Creek. No impacts have been identified in Wongawilli Creek as a result of Longwall 12 extraction.

Six swamps located above Area 3B longwalls are now at or above TARP Level 1 based on the observed groundwater level responses. These are Swamps 01a, 01b, 03, 05, 08 and 10. These swamps are among those listed in earlier assessment as having the potential to be affected by subsidence.

Table 1. Summary of Surface Water TARPs – Longwall 12

CATCHMENT	CATCHMENT YIELD TARP ASSESSMENT			SURFACE WATER QUALITY TARP ASSESSMENT		
	SITE	TARP TRIGGER	REDUCTION IN TOTAL DISCHARGE*	SITE	TARP TRIGGER	COMMENT
Donalds Castle Creek	DCS2	**Level 3**	-28%	DC_Pool 22	N/A	
	DC13S1	**Level 3**	-22%	DC13_Pool 2b	N/A	
	DCU	**not triggered**		Donalds Castle Ck (FR6)	**Level 2**	Dissolved Oxygen (DO) sags identified on two occasions; No other adverse trends
Wongawilli Creek	WC15S1	**not triggered**		WC15_Pool 9	N/A	
	WC21S1	**not triggered**		WC21_Pool 5	N/A*	
	WWL	**not triggered**		Wongawilli Ck (FR6)	**Level 1**	DO and EC TARP exceeded on two separate and non-consecutive occasions
Lake Avon tributaries	LA4S1	**not triggered**		LA4_S1	**Level 2**	DO below TARP on two occasions; Anomalous dissolved metal concentrations in December 2016

* sometimes referred to as 'Catchment Yield' in previous End-of-Panel Surface Water Reports

FR6 = Fire Road 6. There are monitoring sites on both Wongawilli Creek and Donalds Castle Creek where they pass FR6.

1. Introduction

Illawarra Coal is required to submit regular reviews of the local hydrological data, including water quantity and quality, for watercourses and water bodies above and adjacent to Dendrobium Mine. These studies contribute to an assessment of the chemical and ecological impacts of longwall mining on surface water catchment areas, being tributaries of Lake Cordeaux and Lake Avon, and upland swamps in the Wongawilli Creek, Donalds Castle Creek and Sandy Creek catchments.

This report reviews available hydrographic and water quality data obtained for the Wongawilli Creek catchment, Upper Donalds Castle Creek catchment, and the Lake Avon sub-catchments LA4 and LA5 up to the completion of Longwall 12.

Surface water monitoring has been undertaken by IC since 2003. Field parameter measurements and sampling for more detailed laboratory chemical analyses were collected by the ICEFT. Hydrographic gauging stations and piezometers were also installed and monitored.

1.1 Reporting Objectives

This End of Panel report has been prepared to satisfy Condition 3-9 of the Approval for Dendrobium Mine (DA 60-03-2001). The objectives are to provide an End-of-Panel report:

- of all subsidence effects (both individual and cumulative) for the panel and comparing subsidence effects with predictions;
- describing in detail all subsidence impacts (both individual and cumulative) for the panel;
- discussing the environmental consequences for watercourses, swamps, water yield, water quality, aquatic ecology, terrestrial ecology, groundwater, cliffs and steep slopes; and
- comparing subsidence impacts and environmental consequences with predictions.

1.2 Longwall 12

Extraction of Longwall 12 commenced on 22 January 2016 and was completed on 31 January 2017. Longwall 12 is the fourth panel to be extracted in Area 3B, with an extracted length of 2591 m, a void width of 305 m (including first workings) and a cutting height of between 3.7 and 3.95 m.

2. Surface Water and Groundwater Management

This section outlines the network of monitoring infrastructure and sites operated by Illawarra Coal at and around the Dendrobium Mine. Further details of monitoring sites and procedures are outlined in the Dendrobium Area 3B Watercourse Impact Monitoring Management and Contingency Plan (South32, 2015a).

2.1 Surface Water Monitoring

Monitoring includes a selection of sites downstream and within the mining area, as well as sites located away from the mining area as a comparison. Pools within streams are monitored monthly before and following mining and weekly (when site access available) during active subsidence and in response to any observed impacts.

Figure 1 presents Longwall 12 in relation to the locations of surface water *flow* monitoring sites in Areas 3B and 3A. The surface water catchments used in the modelling of surface runoff are also shown.

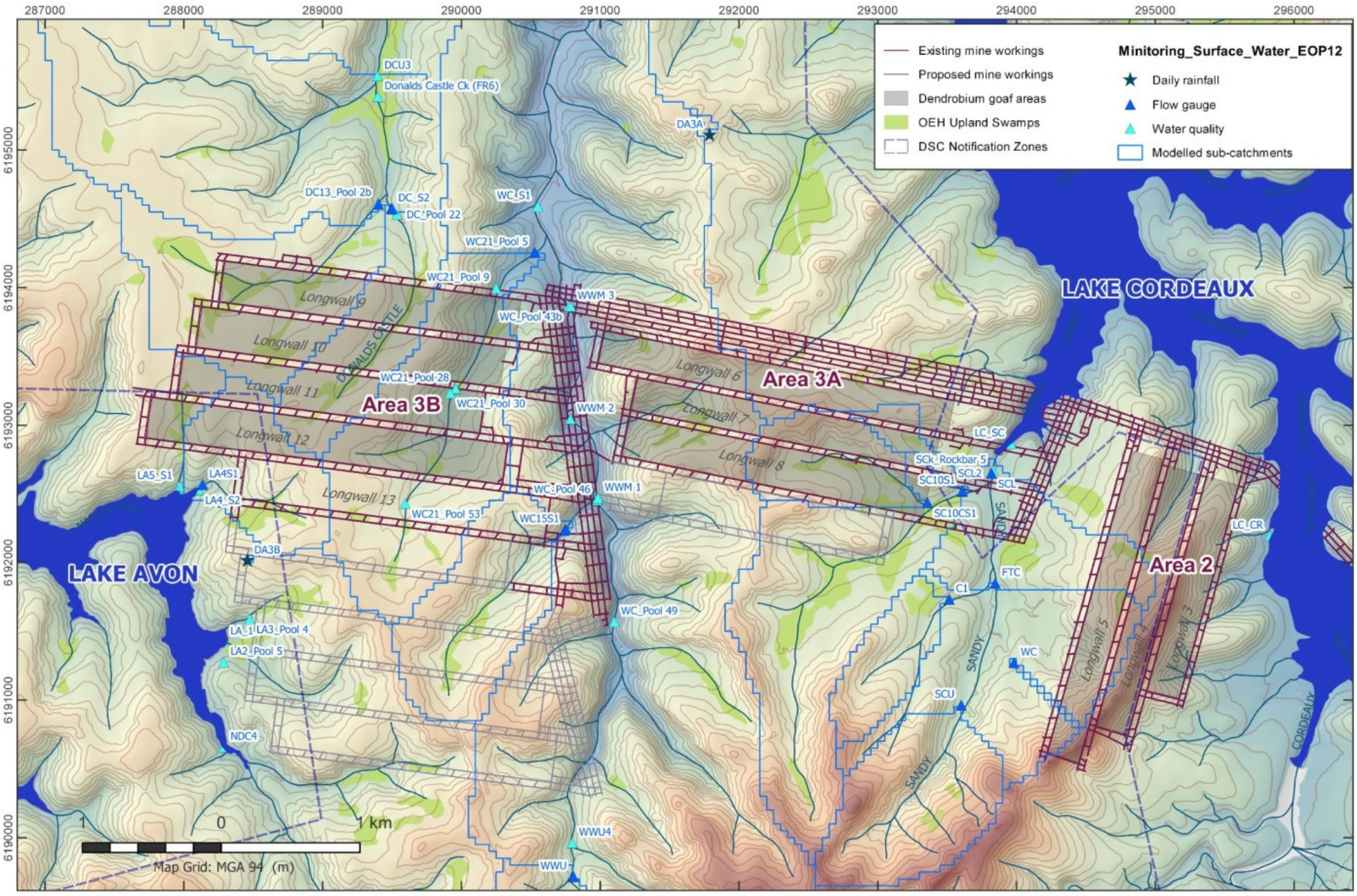


Figure 1. Monitoring sites – surface water flow and chemistry

A summary of these monitoring sites is presented in Table 2, ordered by mine area, catchment (watercourse) and then by approximate downstream order.

Table 2. Surface Water Flow Monitoring Sites

MINE AREA	LOGGER ID	SITE NAME	WATERCOURSE	EAST (MGA94)	NORTH (MGA94)	Catchment Area (km2)
Area 3B	300067	DC13S1	DC13 (Donalds Castle Creek tributary)	289397	6194613	1.64
Area 3B	300068	DCS2	Donalds Castle Creek	289496	6194574	1.08
Area 3B	300023	DCU	Donalds Castle Creek	289396	6195538	6.22
Area 3B	300071	WC15S1	WC15 (Wongawilli Creek tributary)	290743	6192232	1.19
Area 3B	300069	WC21S1	WC21	290555	6194270	2.43
Area 3B	300024	WWU	Wongawilli Creek	290814	6189769	3.21
Area 3B	300022	WWL	Wongawilli Creek	290979	6197544	20.08
Area 3B	300070	LA4S1	LA4 (Lake Avon tributary)	288138	6192567	0.82
Area 3A	300021	WC	SC6	293981	6191271	0.28
Area 3A	300026	C1	SC7	293515	6191732	0.78
Area 3A	300020	FTC	SC8	293846	6191848	0.69
Area 3A	300019	SC10CS1	SC10C	293358	6192433	0.82
Area 3A	300018	SC10S1	SC10	293609	6192519	2.77
Area 3A	300025	SCU	Sandy Creek	293602	6190964	1.25
Area 3A	300059	SCL2	Sandy Creek	293819	6192648	7.03

The monitoring of water quality parameters provides a means of detecting and assessing the effects of streambed fracturing or induction of ferruginous springs. Monitoring includes measurement of field parameters such as pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Oxygen Reduction Potential (ORP) and laboratory tested analytes (DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si). Water quality monitoring sites are shown in Figure 1.

2.2 Shallow Groundwater Monitoring

Figure 2 shows Longwall 12 in relation to the locations of shallow groundwater monitoring sites in Areas 3B and 3A. Typically, these sites are piezometers approximately 1 - 3 m deep that monitor groundwater levels within the swamp deposits located around the Dendrobium area.

Figure 2 also shows swamp areas: broadly mapped by NSW Office of Environment and Heritage (OEH) and refined through site-scale mapping for Illawarra Coal carried out by Biosis. Note that the TARP assessment relates only to those piezometers that are located within swamp sub-communities mapped as Banksia Thicket, Sedgeland-heath complex and Tea Tree Thicket; being listed as Costal Upland Swamp Endangered Ecological Community (EEC). Piezometers located within fringing Eucalypt Woodland are excluded from the TARP assessment as per the advice from OEH (dated 17/01/2014).

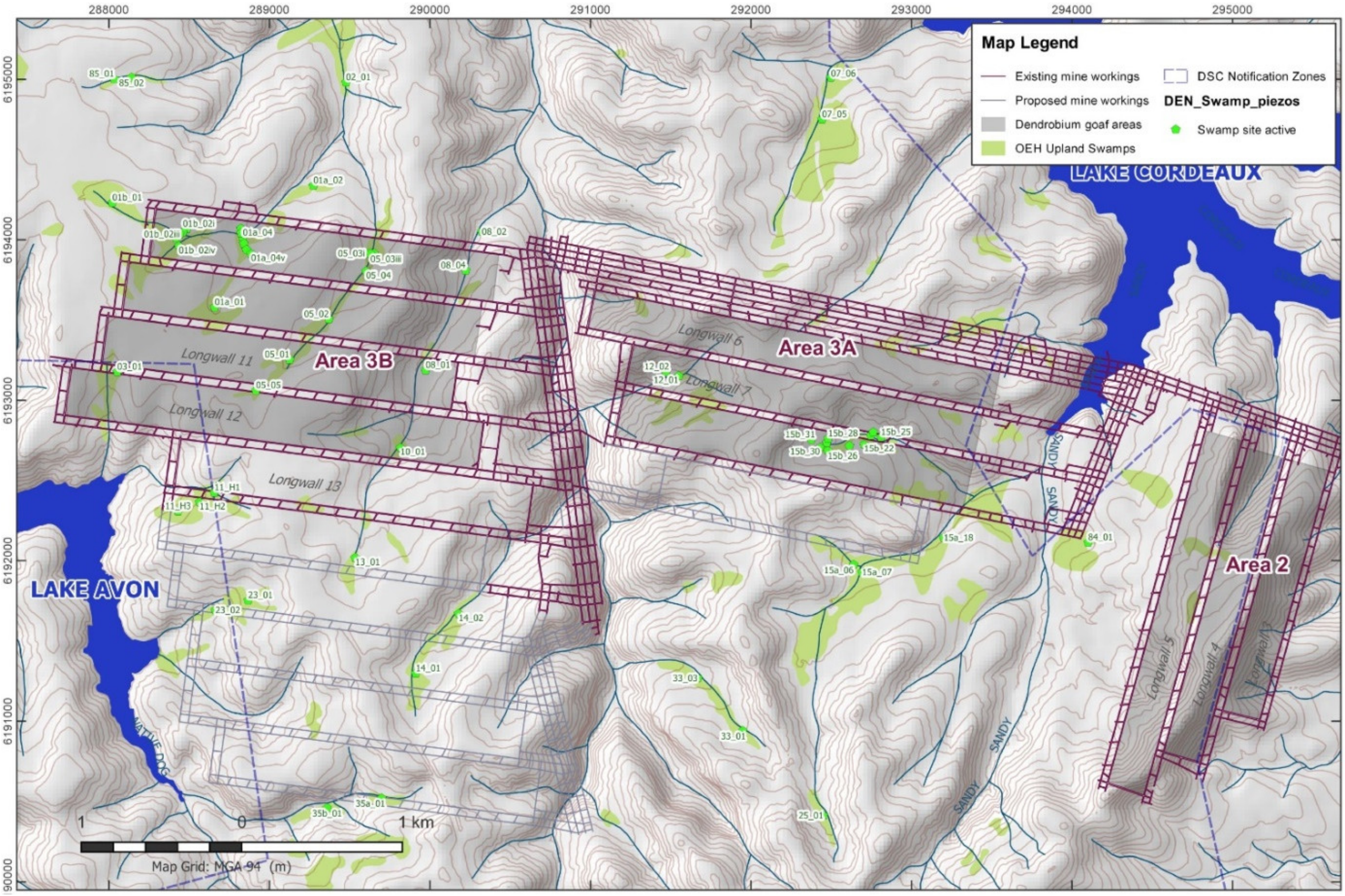


Figure 2. Monitoring Sites – 'Shallow' Groundwater (within swamps)

A summary of the shallow groundwater monitoring sites is presented in Table 3.

Table 3. Summary of Swamp Monitoring

Swamp	Site type	Number of piezometers		Undermined by longwalls	Comment
		Total	TARP (Within Coastal Upland Swamp EEC		
01a	Impact	9	6	LW9, LW10	Limited baseline data for 5 piezometers
01b	Impact	7	6	LW9	Limited baseline data for 5 piezometers
02	Reference	1	n/a	No	900 m from LW9
03	Impact	1	1	Pillar 11/12	3_01 Undermined by LW12 on 2/4/2016
05	Impact	9	6	LW9 to LW12	LW12 passed piezometer 5_05 within 400 m on 24/5/2016.
07	Reference	2	n/a	No	1.2 km from LW6
08	Impact	6	0	LW9, LW10 LW11	Limited baseline data for 1 piezometer, insufficient recent data for 1 piezometer
10	Impact	1	1	LW12	Piezometer 10_01 undermined by LW12 on 15/11/2016

Swamp	Site type	Number of piezometers		Undermined by longwalls	Comment
		Total	TARP (Within Coastal Upland Swamp EEC		
11	Impact	3	3	LW13, LW14	Yet to be mined under
13	Impact	1	1	LW14	Yet to be mined under
14	Impact	2	2	LW15, LW16	Yet to be mined under
15a	Impact	16	7	LW8, LW19	Limited baseline data for 1 piezometer, yet to be mined under
15b	Impact	23	10	LW7, LW8	
22	Reference	2	n/a	No ; Elouera Colliery	Limited baseline data
23	Impact	2	2	LW15, LW16	Yet to be mined under
25	Reference	1	n/a	No	1.4 km from LW5
33	Reference	2	n/a	No	1 km from LW16
84	Reference	1	n/a	No	500 m from LW5
85	Reference	2	n/a	No	900 m from LW9
86	Reference	2	n/a	No	3 km from LW9
87	Reference	2	n/a	No ; Avon Colliery	Limited baseline data
88	Reference	2	n/a	No ; Huntley Colliery	Limited baseline data
Notes:	Blue shading are reference swamps; Pink shading are those swamps directly mined under by Longwall 12				

2.3 Soil moisture monitoring

Soil moisture profiles are monitored at most swamps, with sensor arrays typically positioned near shallow piezometers (where possible). Where possible the monitoring arrays are numbered according to the corresponding piezometer (if present) with an 'S' prefix. At most locations, five sensors are installed at 20 cm depth intervals to a total depth of 1 m.

Soil moisture is measured using Sentek sensors which monitor changes in the dielectric constant within a cylinder of soil extending to a radial distance of 10 cm from the access tube. Soil moisture is reported as mm water per 100 mm soil depth (or volumetric % water) at each monitored depth (Sentek 2017). The most recent installations are equipped with automated data loggers set to record moisture levels every hour (S5_S01, S05_S08, S11_S01, S14_S01, S87_S02). The remaining installations are recorded manually during scheduled site visits.

2.4 Weather conditions during the assessment period

Weather observations at Area 3B for the reporting period and the previous two years are summarized in Figure 3. Rainfall data are from the 'DA3A' rainfall station at Area 3A which has the most complete record for the reporting period, and solar exposure is for the Cordeaux Quarters station (BOM site 68211), plotted as a proxy for potential evaporation.

The average annual rainfall for Areas 3A and 3B is 1150 mm (2003 – 2017). Rainfall over the 12 months leading up to the end of Longwall 12 was significantly below average at 801 mm (and 973 mm for the 2016 calendar year). Conditions were particularly dry in the last 6 months of Longwall 12, and exacerbated by elevated summer temperatures. A very large rainfall event occurred over three days between 3/6/2016 and 5/6/2016 during which 310 mm fell on the catchments.

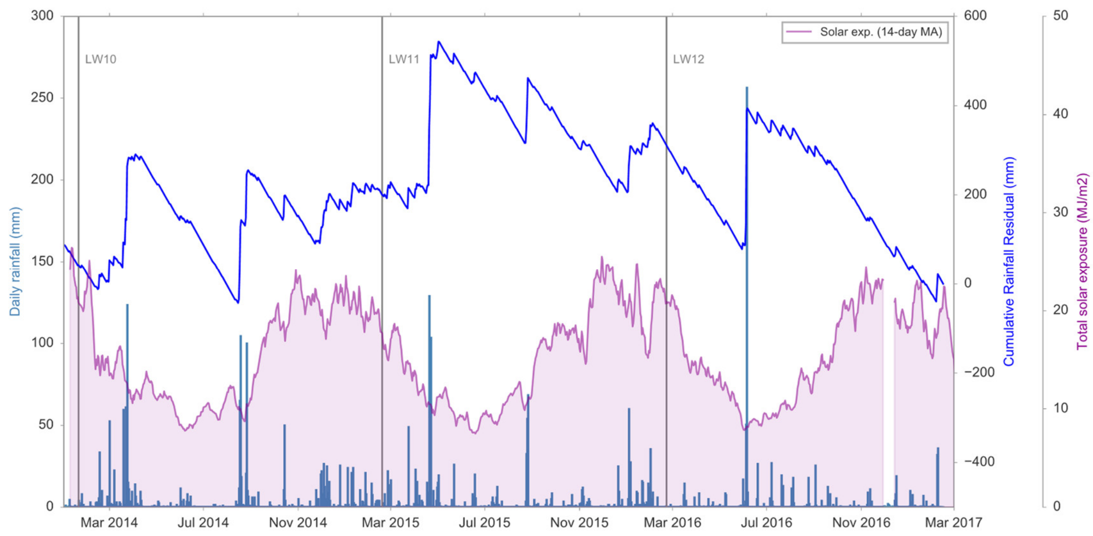


Figure 3. Daily rainfall and solar exposure at Area 3 for the reporting period

3. Longwall subsidence effects

Figure 4 presents the total subsidence predicted by MSEC (2015) above Area 3B longwalls. This shows that Wongawilli Creek is outside the main area of subsidence (above the mains), although its tributaries WC21 and WC15 lie directly across the area of predicted maximum subsidence (from recent or future longwalls). The upper reaches of Donalds Castle Creek, its tributary DC13 as well as Lake Avon tributary LA4 lie across some or all of Longwalls 9-13, although are slightly westward of the area with the greatest predicted subsidence.

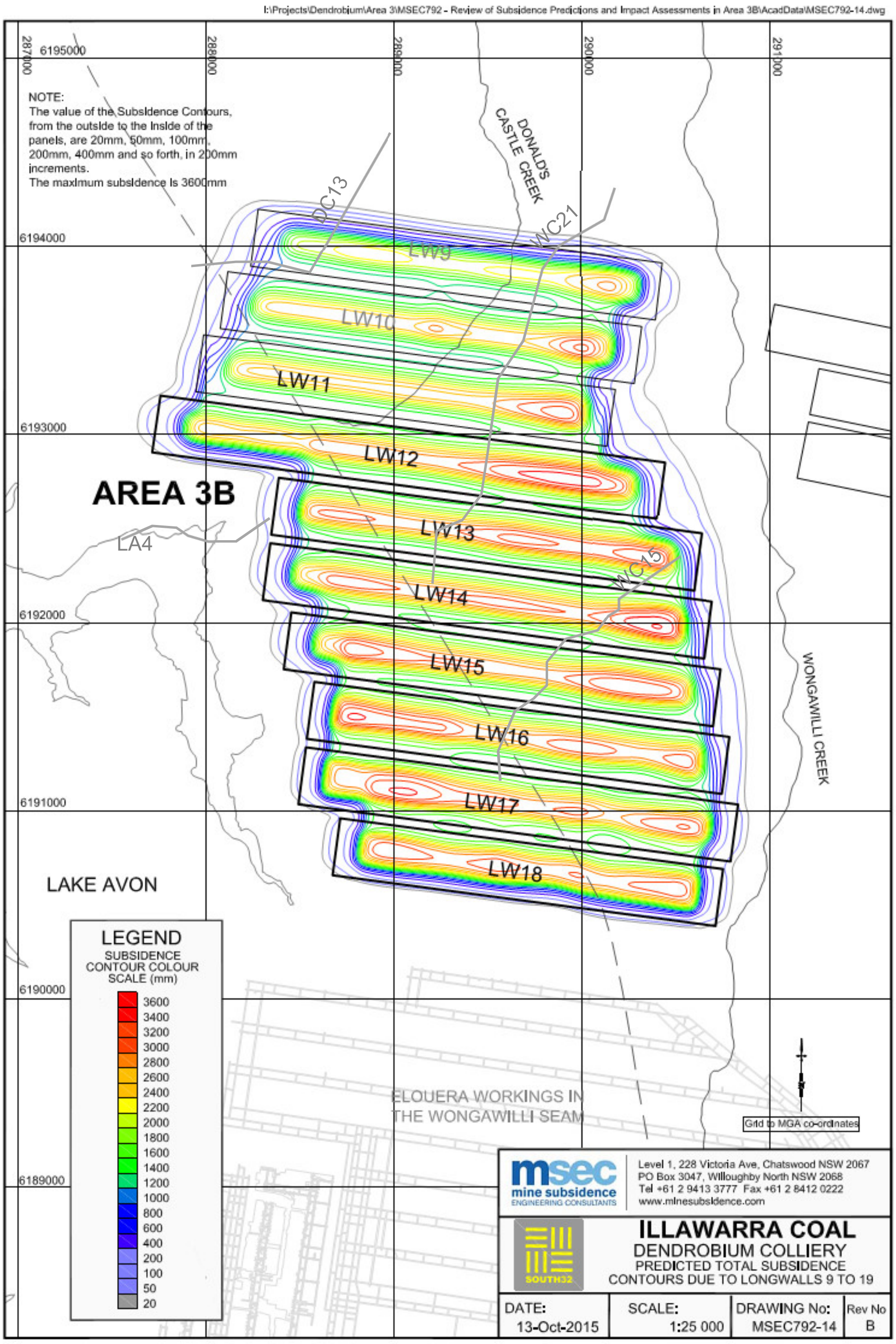


Figure 4. Predicted Subsidence above Area 3B (from MSEC, 2015)

Surface watercourses and catchments undermined by Longwall 12 are listed in Table 4.

Table 4. Surface water features undermined by Longwall 12

Catchment / location	Approximate date	Monitoring locations (level and chemistry)	
		Upstream	Downstream
LA5 (upper reaches)	26/03/2016	-	LA5 S1
LA4 (upper reaches)	16/07/2016	-	LA4 S1, LA4 S2
Donalds Castle Creek (headwaters)	02/07/2016	-	DC S2, DC Pool 22
WC21	03/09/2016 to 26/11/2016	WC21 Pool 53	WC21 Pool 30, 5

Observed subsidence impacts on the landscape, including surface fracturing and iron staining are monitored by the ICEFT and reported separately in the End of Panel Landscape Report (South32 2017). A total of **24** new surface fractures were noted within the zone of influence of Longwall 12 (within 400 m of the longwall footprint), of which **4** were in stream beds (Table 5).

Table 5. Reported subsidence impacts to stream beds

Site ID	Report Dates	Description	Tarp Level
DA3B_LW12_005	4/05/2016, 6/07/2016	Rock fracturing and uplift in watercourse LA4 rockbed.	2
DA3B_LW12_008	23/05/2016, 6/07/2016	Fracturing and uplift to rockbar in tributary LA4B at the basal step of Swamp 4.	2
DA3B_LW12_010	26/05/2016	Rock fracturing to sandstone channel on tributary LA4B. Flow diversion evident.	2
DA3B_LW12_019	9/11/2016	Hairline fracture and associated uplift to step between WC21_Pool 49 and 48. No water loss is expected.	1

4. Assessment of Surface Water Quality Effects

Trigger values for water quality field parameters are defined in Attachment 1 of the Watercourse Impact Monitoring Management and Contingency Plan (South32 2015a). Trigger thresholds (TARPs) have been defined for three locations downstream of the mining area for which there is adequate high quality baseline information (Wongawilli Creek (at Fire Road 6 [FR6]) and Donalds Castle Creek (at FR6) and Lake Avon (tributary site LA4_S1). The TARPs are based on the field parameters pH, EC and DO and defined by the value three standard deviations (SD) from the baseline mean (mean plus 3SD for EC and mean minus 3SD for pH and Dissolved Oxygen). TARP levels are defined as follows:

- Level 1: One exceedance during the monitoring period
- Level 2: Two exceedances during the monitoring period
- Level 3: Three exceedances during the monitoring period
- Exceeding prediction: Mining results in two consecutive exceedances during the monitoring period

During the 12 month reporting period between the start of Longwall 12 (22/01/2016) and one month after the end of Longwall 12 (31/02/2017), monitoring was carried out at 112 sites. Sites were monitored on an approximately weekly basis (45 monitoring events) for TARP sites and approximately monthly for other sites.

TARP triggers for the monitoring period are summarised in Table 6.

Table 6. Summary of Water Quality TARPs for the monitoring period

DATE	CATCHMENT / LOCATION	PARAMETER	VALUE	TARP	TRIGGER LEVEL
23/02/2016	Donalds Castle Ck (FR6)	DO	37.5	40.1	2
08/09/2016	Donalds Castle Ck (FR6)	DO	39.2	40.1	
23/02/2016	Wongawilli Ck (FR6)	DO	31	50.5	1
25/01/2017	Wongawilli Ck (FR6)	SpC	189	154.1	1
03/05/2016	LA4_S1	DO	60	69.5	2
20/05/2016	LA4_S1	DO	64.4	69.5	

Assessment of surface water quality effects is presented by catchment (watercourse) in the following subsections. Key figures are included in the text here, while a selection of plots (hydrographs) is available for all sites in **Appendix A**.

4.1 Donalds Castle Creek Catchment

Time series plots of key field parameters measured at Donalds Castle Creek at FR6 are shown in Figure 5, Figure 6 and Figure 7.

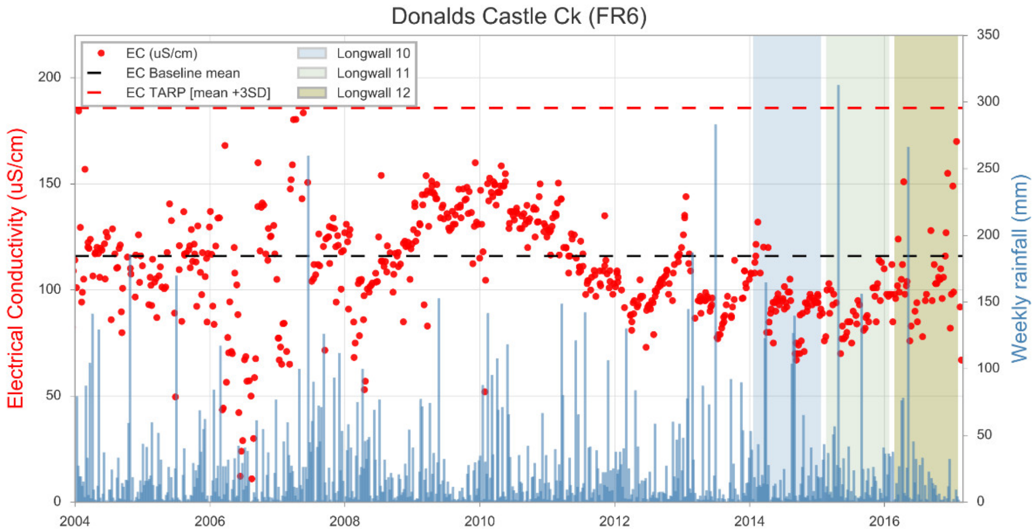


Figure 5. Field measured Electrical Conductivity (EC) at Donalds Castle Creek (FR6)

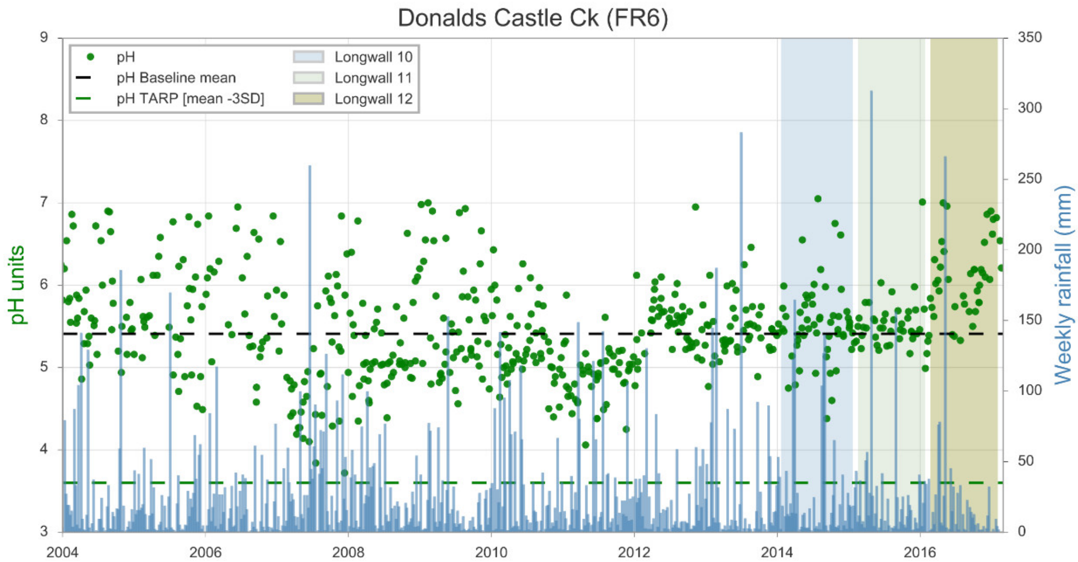


Figure 6. Field measured pH at Donald's Castle Creek (FR6)

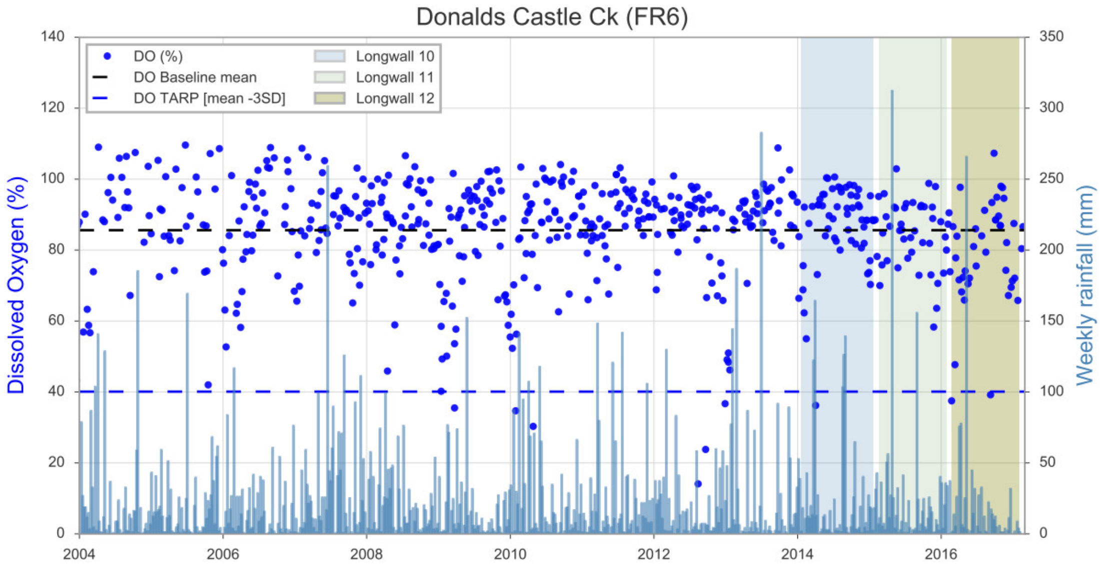


Figure 7. Field measured pH at Donald's Castle Creek (FR6)

At the Donalds Castle Creek site (at FR6), the TARP for DO was triggered on two non-consecutive instances, representing a Level 2 Trigger. Given that the TARP trigger levels are based on a statistical measure of baseline variability it is expected that the threshold would be exceeded from time to time without significance.

A rising trend in EC is evident at this site and most other sites and is likely related to the effects of evaporation of isolated pools during the very low rainfall conditions of late 2016 to February 2016. Similar increasing EC trends have occurred in response to prolonged dry conditions in the past. The key field parameters showed no other adverse trends during the monitoring period and the records are considered to show no water quality impacts from mining.

4.2 Wongawilli Creek Catchment

Plots of key field parameters from Wongawilli Creek at FR6 are shown in Figure 8, Figure 9 and Figure 10.

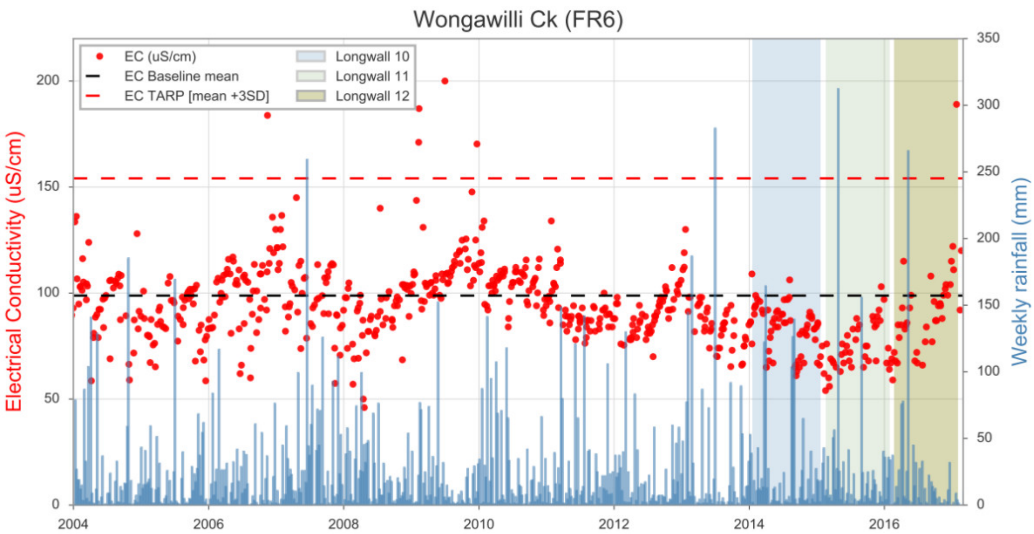


Figure 8. Field measured Electrical Conductivity (EC) at Wongawilli Creek (FR6)

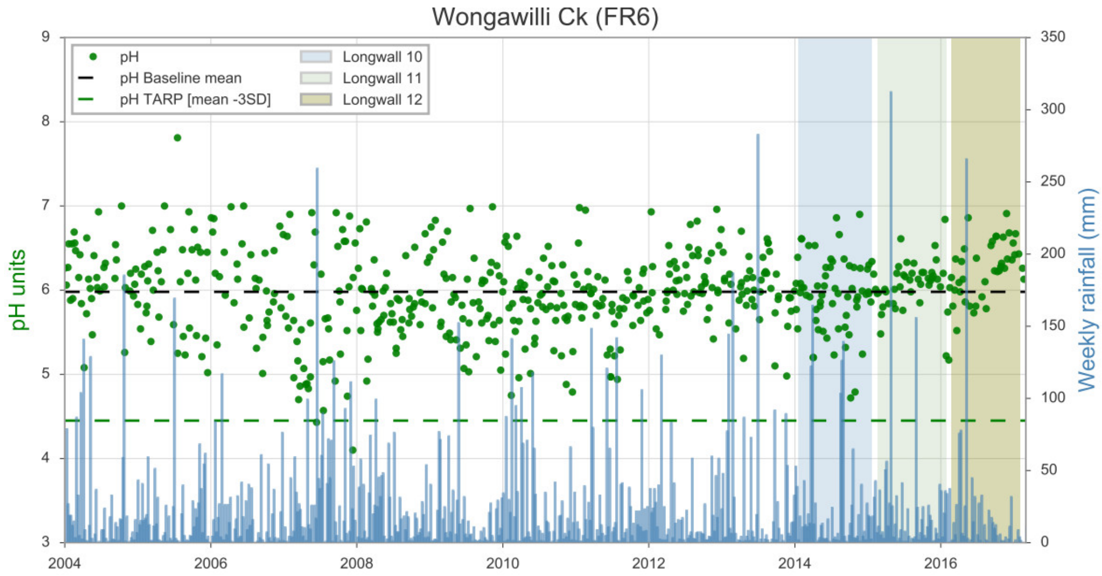


Figure 9. Field measured pH at Wongawilli Creek (FR6)

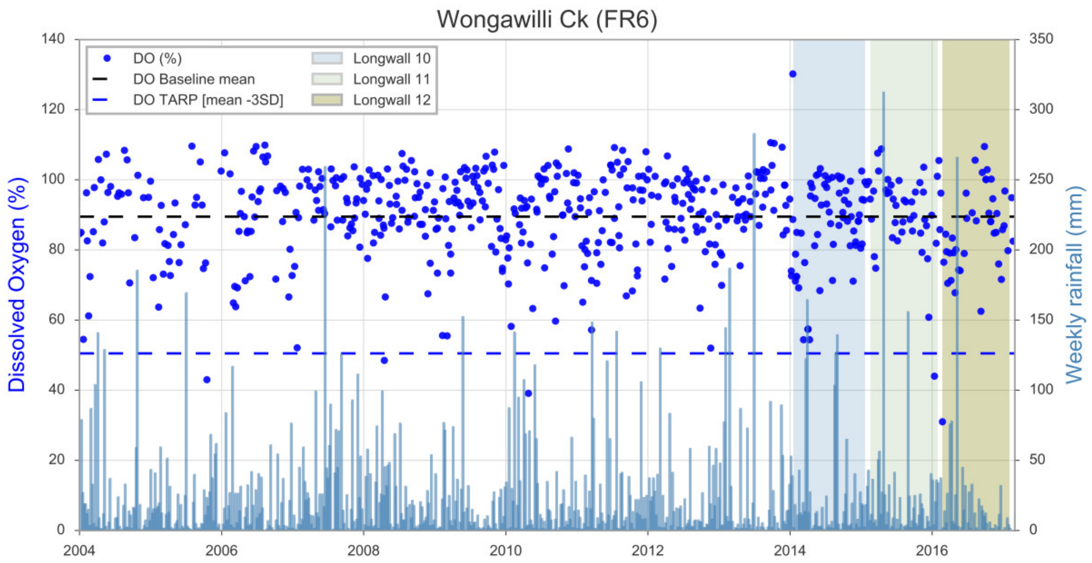


Figure 10. Field measured pH at Wongawilli Creek (FR6)

At the Wongawilli Creek site (at FR6), the TARP level for EC was triggered on one occasion and the DO trigger level was exceeded on a separate occasion. This represents a Level 1 trigger for both EC and DO.

As with the Donalds Castle Creek site, elevated and apparently increasing EC values in late 2016 to February 2016 are likely due to evaporation during that dry period. No other adverse trends are apparent during the monitoring period and the records are considered to show no water quality impacts from mining at this location.

Subcatchment WC21

The DA3B Longwall 12 End of Panel Landscape Report (South32 2017) identifies surface cracking at one location in WC21 within the zone of influence for Longwall 12. The fractures are consistent with a Level 1 impact being less than 100 mm in width and 10 m in length with no observable loss of surface water or erosion. Water quality data for catchment WC21 monitored at locations upstream (WC21_Pool 53) and downstream of Longwall 11 (Pool 30 and Pool 5) are discussed below.

Monitoring location WC21_Pool 5 is located downstream (to the north) of mining Area 3B. The EC of water at this location was elevated above the baseline P95 during Longwall 12 on 9 occasions (Figure 12). As noted above, elevated EC was observed at many other locations and is likely related to the unusually low rainfall conditions rather than mining impacts. Water pH remained within the P5-95 range for pre-Longwall 12 data.

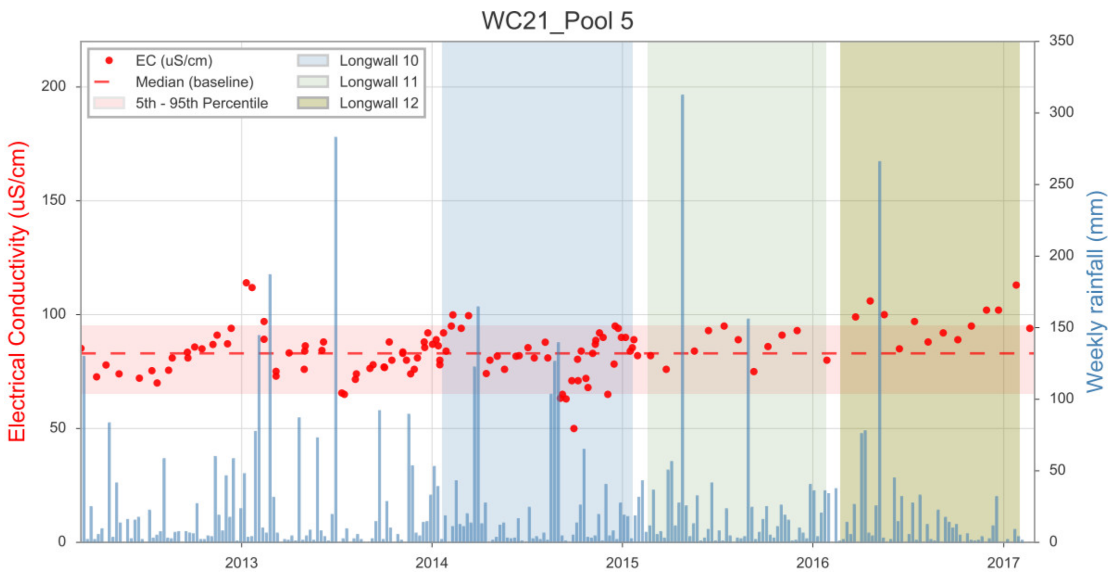


Figure 11. Field measured EC and pH at WC21 Pool 5, downstream of Area 3B

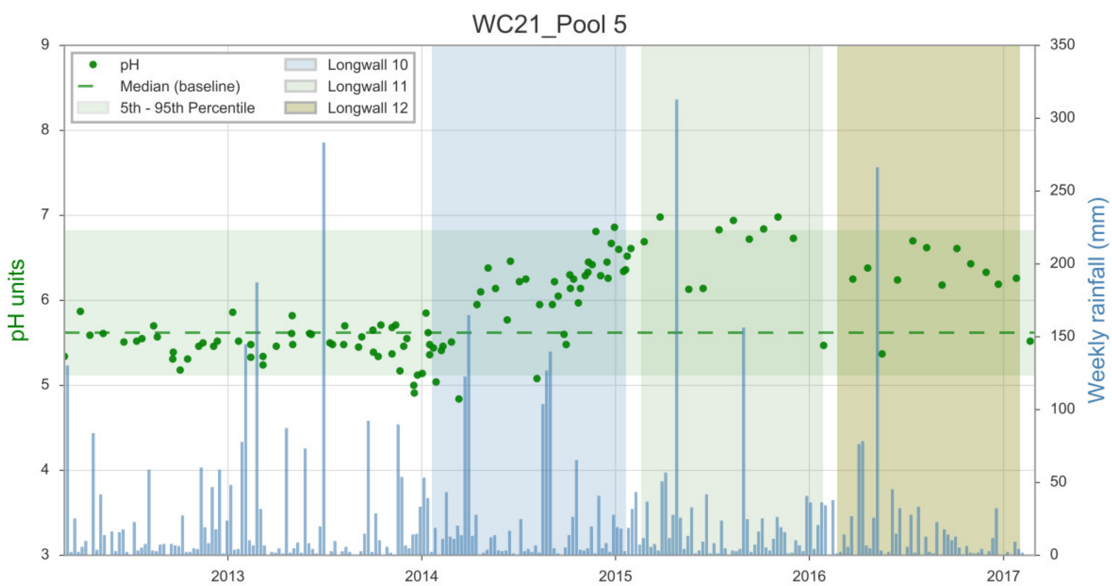


Figure 12. Field measured EC and pH at WC21 Pool 5, downstream of Area 3B

Dissolved iron at WC21 Pool 5 increased to ~1 mg/L on three consecutive occasions in the first half of Longwall 12 (before WC21 was undermined). A similar transient increase in dissolved iron concentration was seen during Longwall 11 and 10. Data are sparse and inconclusive at Pool 30, the closest downstream site to Longwall 12 (Figure 14); whereas iron concentrations remained low in Pool 53, upstream of Longwall 12.

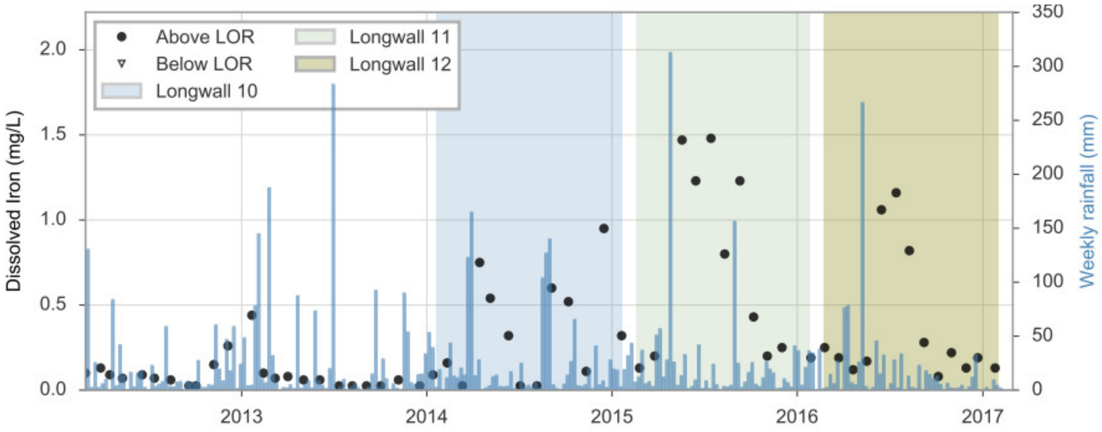


Figure 13. Dissolved iron in WC21 Pool 5, downstream of Area 3B

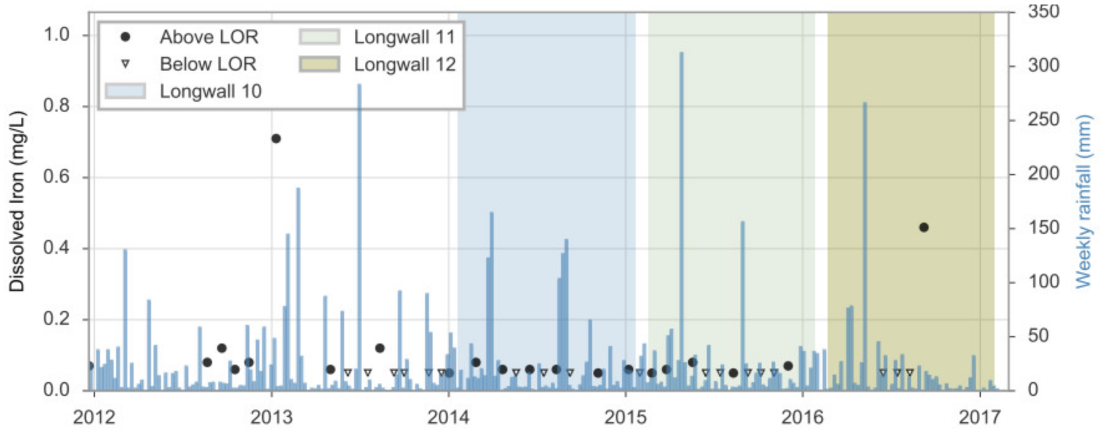


Figure 14. Dissolved iron in WC21 Pool 30, downstream of Longwall 12

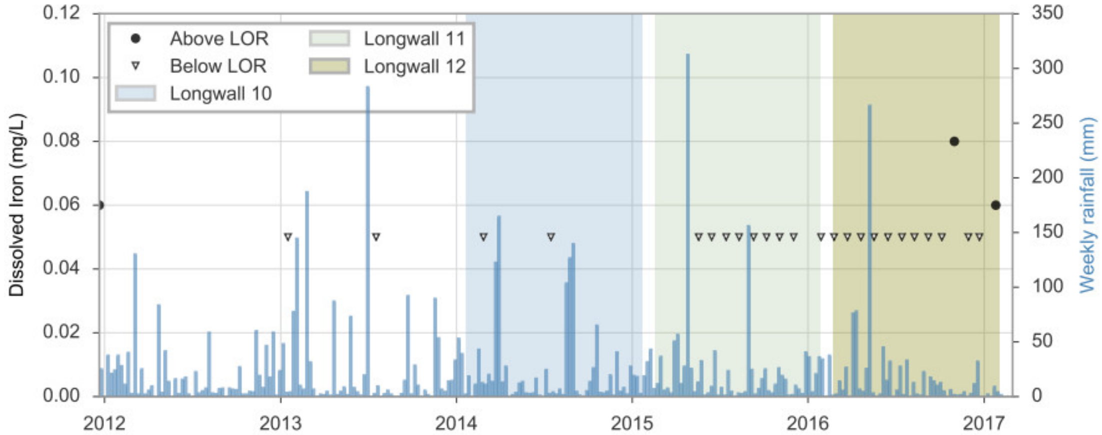


Figure 15. Dissolved iron in WC21 Pool 53, upstream of Longwall 11

In summary, assessment of water quality at WC21 Pool 5 indicates anomalous trends in EC and dissolved iron during Longwall 12 (and the previous 2 longwalls). There are no similar or clear trends at locations immediately downstream of Longwall 12, nor at locations upstream of Longwall 12 and these trends are considered minor. The concentration of dissolved iron in Pool 5 declined to normal baseline levels after May 2016, approximately the time the tributary was mined under by Longwall 12. The effect seen at WC21_Pool 5 was not evident in Wongawilli Creek at site WC_S1 which is located approximately 500 m downstream of the confluence between WC21 and Wongawilli Creek.

4.3 Lake Avon

The DA3B Longwall 12 End of Panel Landscape Report (South32 2017) identifies surface fracturing at three locations along the LA4_S1 tributary within the zone of influence for Longwall 12. The fractures are consistent with a Level 2 impact being greater than 100 mm in width or 10 m in length with observable loss of surface water or erosion.

Time series plots of key field parameters measured at LA4_S1 near Lake Avon are shown in Figure 16, Figure 17 and Figure 18.

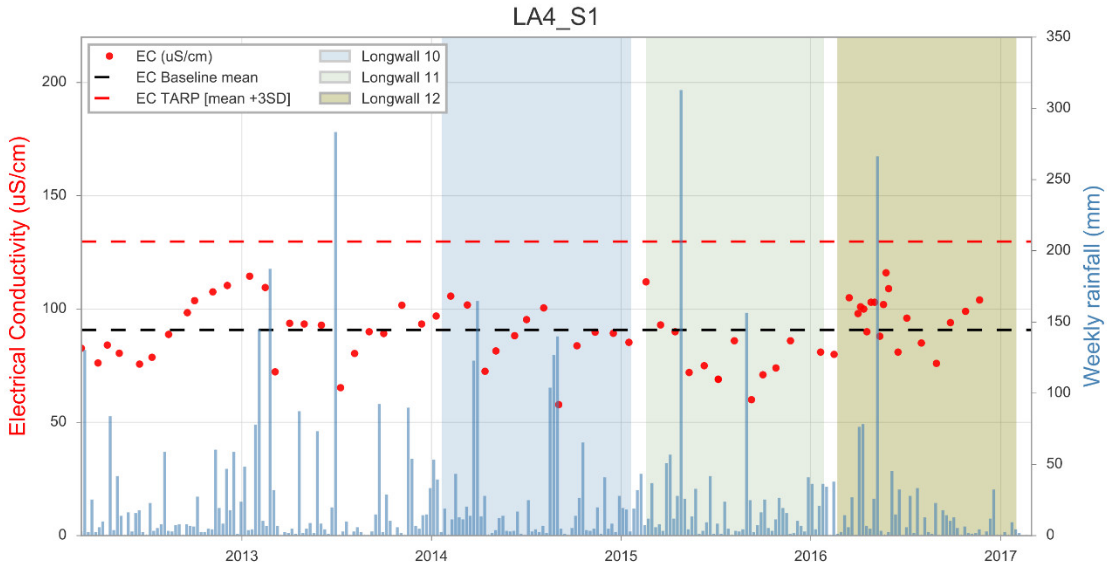


Figure 16. Field measured Electrical Conductivity (EC) at Lake Avon tributary (LA4_S1)

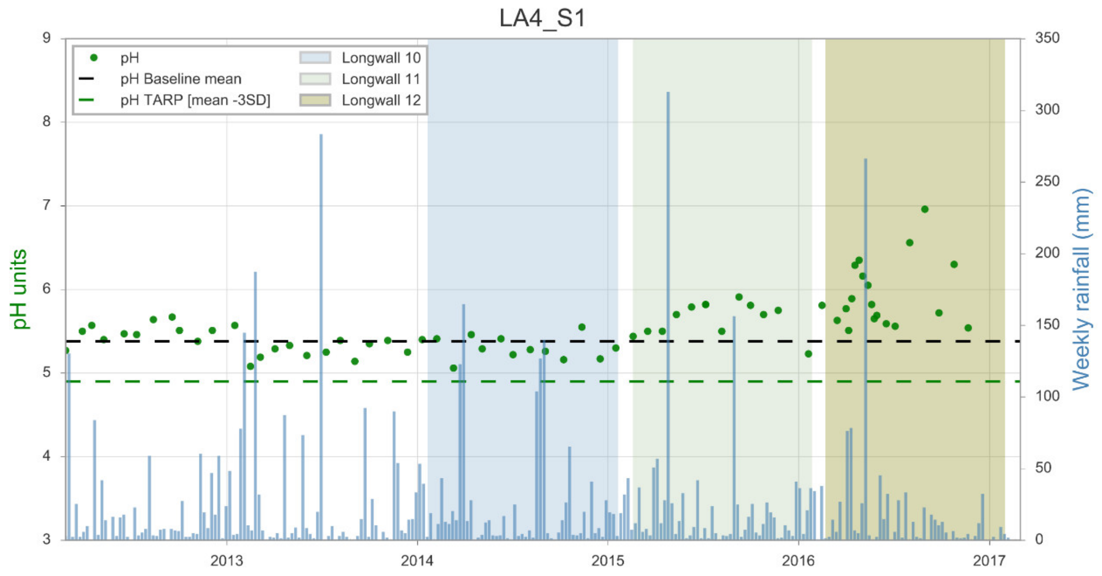


Figure 17. Field measured pH at Lake Avon tributary (LA4_S1)

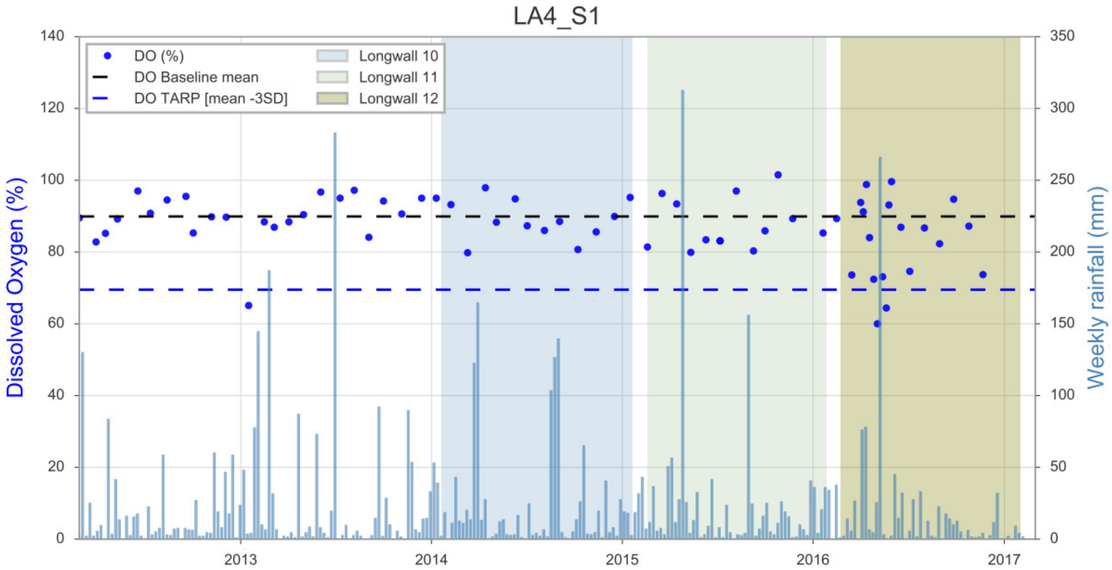


Figure 18. Field measured DO at Lake Avon tributary (LA4_S1)

At LA4_S1, the TARP for DO was triggered on two non-consecutive occasions (Figure 18). There was a mild increase in pH during Longwall 12 (following on from an increase during Longwall 11), peaking at 6.96 in August 2016. While anomalous compared with baseline data it is neither a TARP trigger nor a pH level of concern. The increase in pH was not accompanied by systematic changes in dissolved metal concentrations during the same period, although anomalously high concentrations of dissolved iron, manganese and aluminium are noted in the sample collected from this site on 22/12/2016 (Figure 19). Monitoring data for the site should be reviewed within the next six months to determine if the anomalous result is repeated.

A Level 2 TARP trigger requires review of the monitoring frequency. In this case, the current weekly frequency is considered appropriate for continued monitoring at this site.

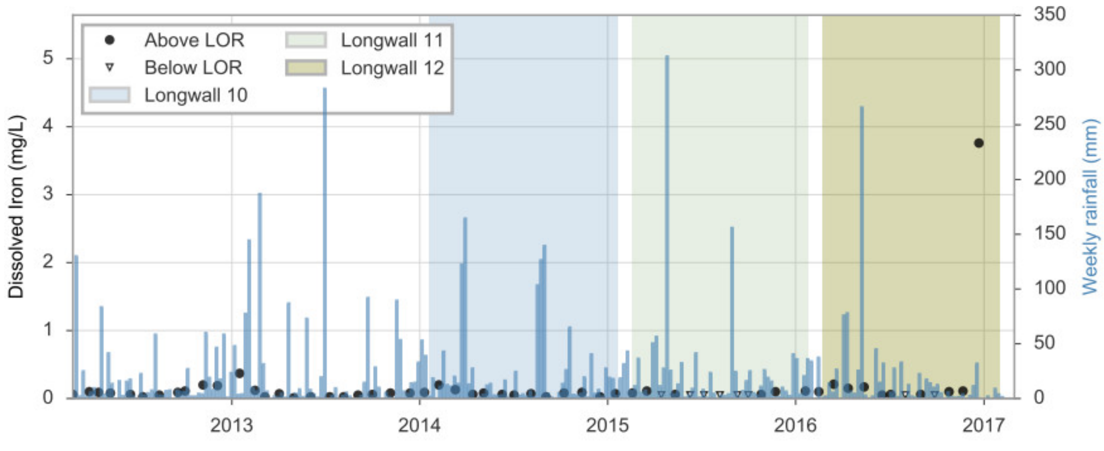


Figure 19. Dissolved iron concentration at Lake Avon tributary (LA4_S1)

5. Assessment of Surface Water Flow Effects

5.1 Assessment approach and criteria

The effects of mining subsidence on surface water hydrology is assessed by comparing observed stream flow characteristics for each monitored sub-catchment against predictions of streamflow from a calibrated rainfall-runoff model. The model is calibrated to baseline conditions using observed rainfall and stream flow such that predicted stream flow closely matches observed for the baseline period (pre-mining).

This approach, and trigger levels for action response (TARP triggers) are defined in Attachment 1 of the Watercourse Impact Monitoring Management and Contingency Plan (South32 2015a). TARP levels are defined in terms of the change in catchment runoff, as shown in Table 7.

Table 7. Performance criteria related to catchment water balance

TARP Level	Criteria	Response
1	A change in measured discharge (between pre- and post-mining) **6-12%** less than average annual precipitation	See WIMMCP for details
2	A change in measured discharge (between pre- and post-mining) **12-18%** less than average annual precipitation	
3	A change in measured discharge (between pre- and post-mining) **>18%** less than average annual precipitation	

These levels were developed by Ecoengineers (Ecoengineers 2015) and based on a water balance model called RUNOFF-2005 (Van de Griend et al. 2002). The Longwall 11 EoP report (HydroSimulations 2016) adopted a similar approach but used the Australian Water Balance Model (AWBM; Boughton 2004) implemented through eWater Source. Source is a national hydrological modelling platform developed and backed by the Australian Government (eWater 2017).

This assessment continues the AWBM approach and the use of the TARP criteria defined above. The TARP assessment is sensitive to the inputs, including the SILO-estimated actual evapotranspiration (ET) and the inclusion of flows above the maximum reliable flow. We have made comment on any change in flow regime based on comparison of modelled and observed flows (irrespective of the other components of the TARP, specifically Actual ET).

5.2 Modelling Assessment

The AWBM approach and adopted parameters are presented in Appendix C. More discussion on model set-up is presented in the previous End of Panel report (HydroSimulations 2016)

Data Sources

Rainfall and potential evaporation inputs were obtained from Dendrobium's Centroid rainfall station and from SILO 'Data Drill' for the location in which Dendrobium lies (DSITI 2011).

Catchment areas were calculated in GIS from LiDAR ground elevation data and compared against the catchment areas provided by Illawarra Coal. The GIS catchment area has been used in the AWBM models Figure 1.

Daily flow from each of the monitoring sites has been used to calibrate the respective Source catchment model. Some sites have flow data from late 2007, while others have data covering the last few years.

Site-by-Site Modelling and Assessment

The site-by-site assessment relies on calibrating the model to observed pre-mining flows and then reviewing whether flows have diverged from the model in the post-mining case. Differences in the pre- and -post-mining period are then highlighted and used to infer and quantify any effects that mining has had on the catchment. The critical behaviour that is investigated is whether the recession limbs on the observed flow hydrograph in the post-mining periods fall consistently below the modelled hydrograph. This behaviour would suggest a reduction in flow in that sub-catchment.

The figures presented for each modelled catchment are the same as the following list, and in order to make the assessment as concise as possible, only the key features of the four charts are listed for each catchment in this same format:

(A) is a correlation of observed and modelled flows, with the pre-mining calibration period presented as one series, and all the post-mining period presented as another. In some cases, a third series, also pre-mining, may also be used in order to check whether any inferred mining effects are transient (non-permanent).

(B) is a comparison of the calculated flow duration curve for observed and modelled flows for pre-mining (calibration) and post-mining periods, including the Longwall 11 sub-period.

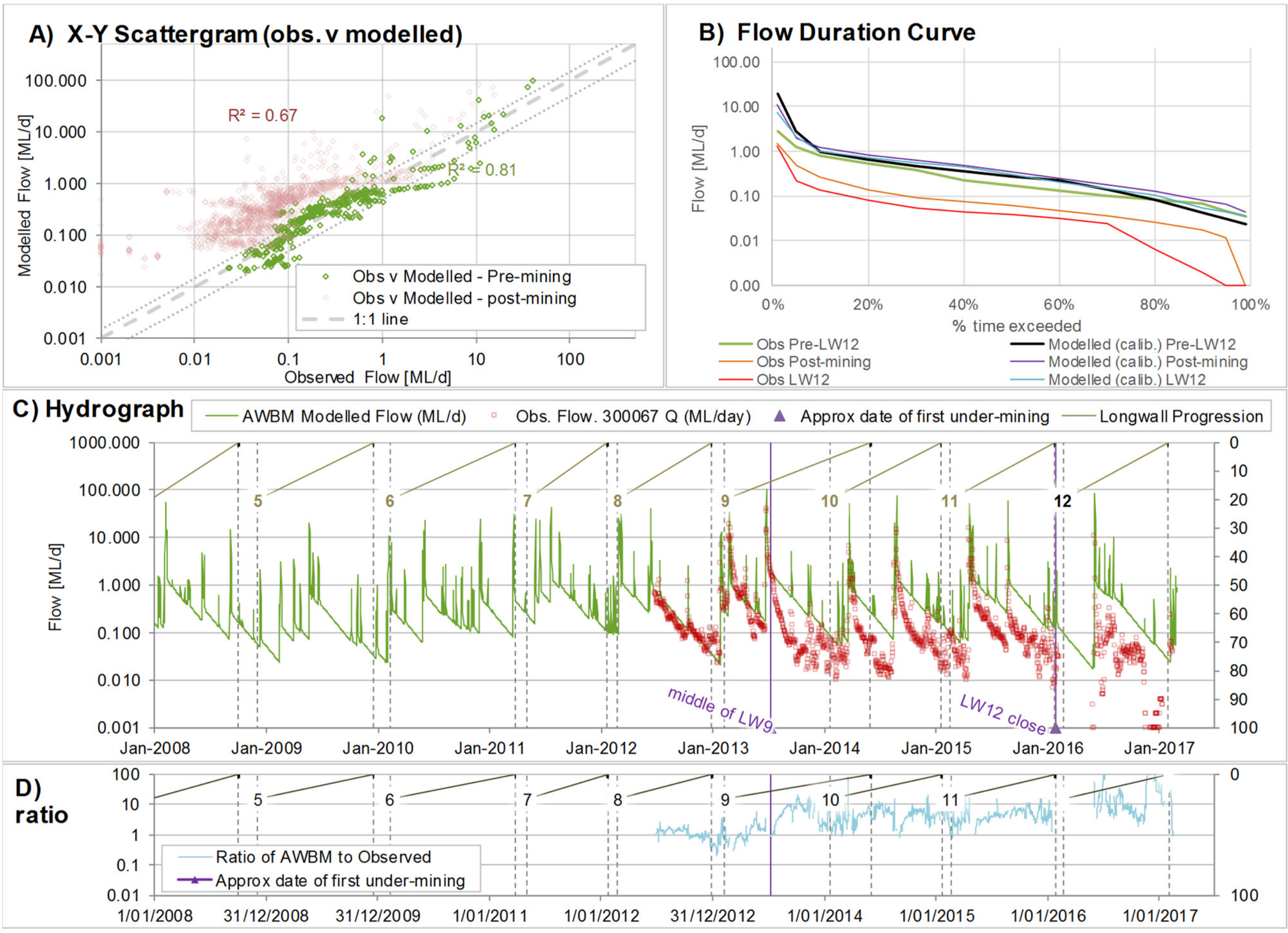
(C) presents a comparison of modelled and observed flow hydrographs, with longwall progression and mining dates for context. The hydrograph is on a log-scale to allow easier comparison of flows at the lower end of the scale.

(D) presents a ratio of the modelled and observed flows as a timeseries, in order to provide a graphical estimate of any effect of mining on catchment outflow.

Some further comments are that Chart A (the scattergram) shows R^2 (the “coefficient of determination”) as a measure of correlation. Previous End of Panel Assessments relied on the Nash-Sutcliffe coefficient to describe the fit between observed and modelled flows. While R^2 is presented here, it is a guide only – we have relied far more heavily on the visual comparison of the scattergram (Chart A), the flow duration curves (Chart B), and the hydrographs (Charts C and D), alongside a comparison of the mean modelled flow and mean observed flow in the pre-mining period, to judge calibration.

DC13S1 – tributary of Donalds Castle Creek

This tributary lies across the centre of several Area 3B panels. The catchment to DC13S1 was first mined under at the commencement of Longwall 9, and has been undermined by Longwall 10 and Longwall 11. Longwall 12 did not directly mine under this sub-catchment.



E:\WSHED\PROJ\DENDROBIUM\Model\SWModel\Source\OUTPUT\EoP12\[300067-DC13S1_Obs_v_AWBM_StatsV1.xlsx]AWBM_REPORT

Figure 20. Comparison of Observed and Simulated Flows – DC13S1

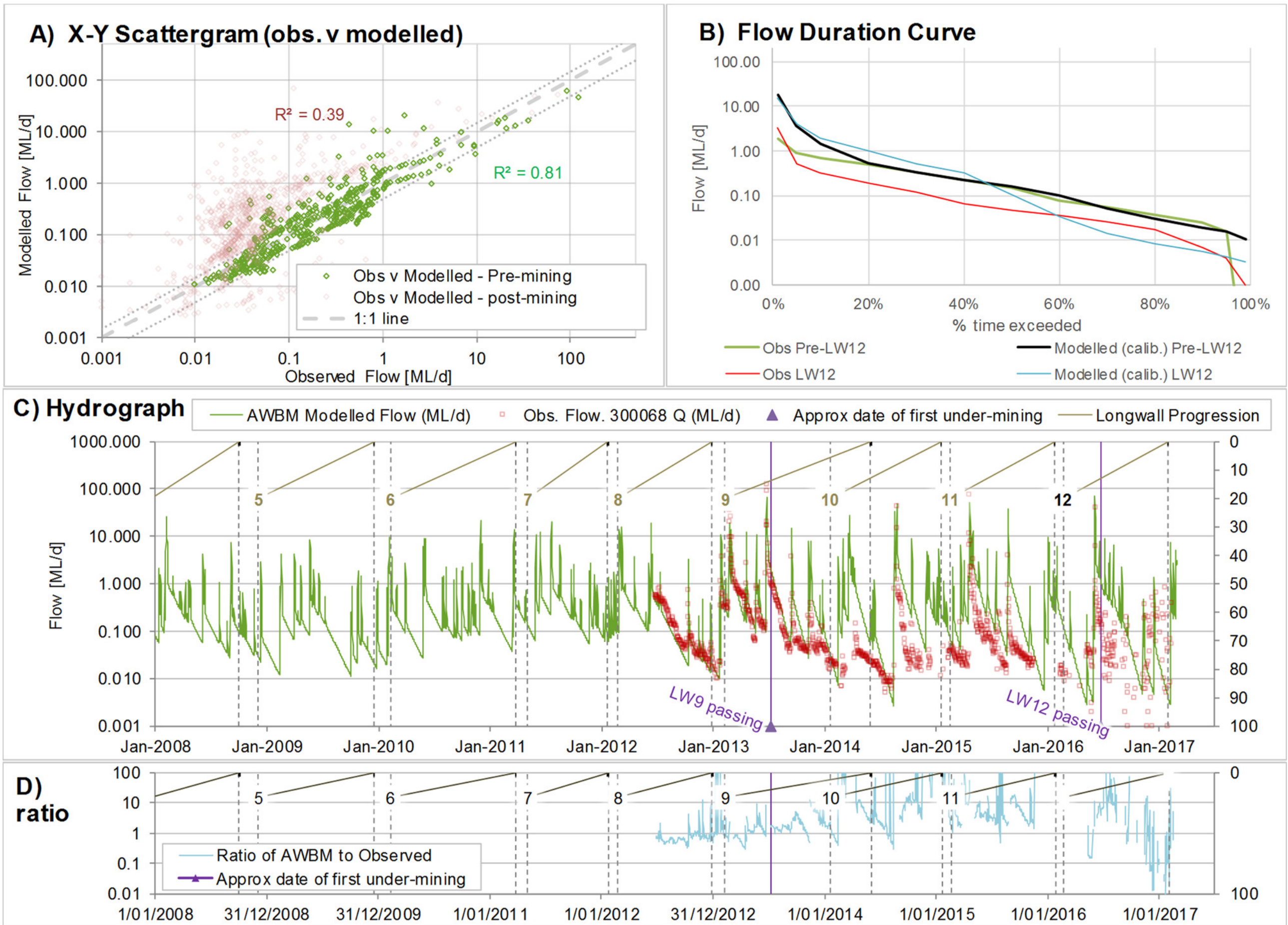
A	The scattergram shows that during the pre-mining period the model is a good fit to observed data, as shown by the graphical correlation to the 1:1 line and also the R^2. This fit declines significantly when the post-mining period is considered.
B	Confirms the good match between modelled and observed flows for the pre-mining period, and illustrates that the model over-estimates flow for the subsequent post-mining period, including throughout Longwall 12 (also a period of generally dry weather).
C	The hydrograph shows a very good match between observed flows up until July 2013 (mid-way through Longwall 9). The full range of flows is quite well matched, including the recessions. Initial undermining by Longwall 9 did not affect the fit, but the fit declines significantly midway through Longwall 9, and from then on the observed hydrograph remains consistently below that predicted by the model, except during the heaviest of rainfall events.
D	The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1, with deviation during short-term high flow events. The post-mining ratio oscillates around 4-10 to the end of Longwall 11, and then oscillates even more during Longwall 12.

Assessment: Stream flow characteristics and sub-catchment yield as measured at DC13S1 appear to have been affected as a result of undermining of the watercourse midway through Longwall 9. The effect continues through Longwalls 10-12. Following undermining, average flow has declined by about 75%, with cease-to-flow conditions occurring about 3% of the time after undermining 9.

Catchment discharge for Longwall 12:	**TARP LEVEL 3**	Water balance [Qsim + ETsim] is 22% below average Pobs.

DCS2 – Donalds Castle Creek

This creek lies across several Area 3B panels. The catchment to DCS2 was first mined under by Longwall 9 (in early July 2013), then by Longwall 10, 11, and again by Longwall 12 in mid-2016. Future longwalls will not directly mine under DCS2.



F:\HYDROSIM\DENDROBIUM\Model\SWModel\Source\OUTPUT\EoP12\[300068-DCS2_Obs_v_AWBM_StatsV1.xlsx]AWBM_REPORT

Figure 21. Comparison of Observed and Simulated Flows – DCS2

A The scattergram shows that during the pre-mining period the model is a good fit to observed data, as shown by the graphical correlation to the 1:1 line and also the R^2. This correlation declines significantly in the post-mining period.

B Confirms the good match between modelled and observed flows for the pre-mining period, and illustrates that the model over-estimates flow for the subsequent post-mining period, including after the passing of Longwall 12.

C The hydrograph shows a very good match between observed flows up until July 2013. Some of the peak flows are not well matched (the model tends to overestimate), but the recession is very well matched. After the initial undermining by Longwall 9, the observed hydrograph remains consistently below that predicted by the model, except during the heaviest of rainfall events.

D The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1, with deviation during short-term high flow events. The post-mining ratio oscillates after that, generally at around 6-10 through to the middle of Longwall 12. Later in Longwall 12 the ratio declines, due in part to dry weather, but also due to mining effects.

Assessment: Evidence that undermining by Longwall 9 affected the sub-catchment yield, and this continues through Longwalls 10-11; as well as during Longwall 12. The effects at site occur across the range of flows, other than peak flows.

Catchment discharge for Longwall 12:	**TARP LEVEL 3**	Water balance [Qsim + ETsim] is 28% below average Pobs.

DCU – Donalds Castle Creek

This catchment incorporates DC13 and DCS2 . and was therefore mined under at the commencement of Longwall 9, and again by Longwalls10-12. However, about 60% of the catchment to DCU lies downstream of Longwall 9 is therefore not directly mined under.

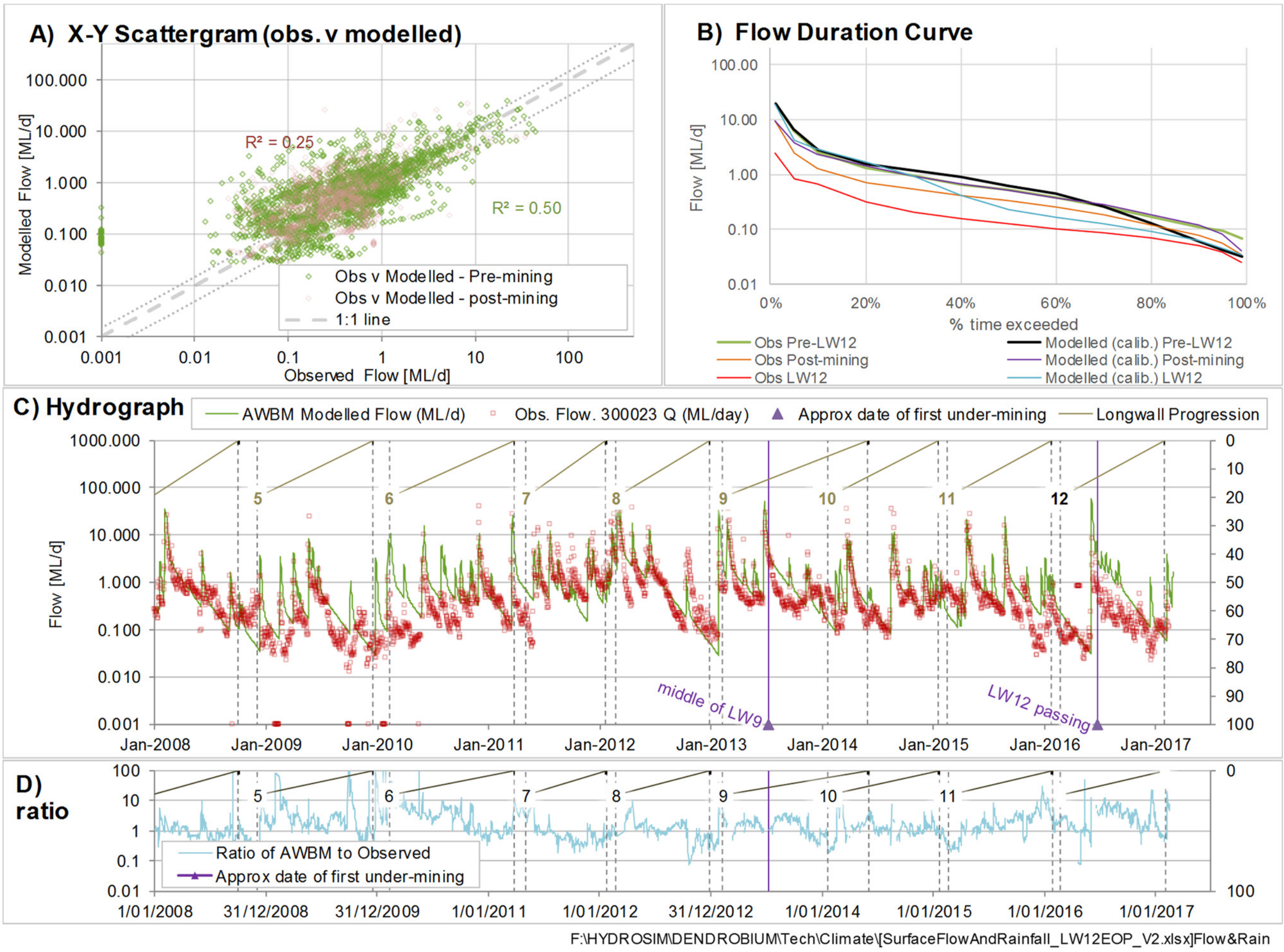


Figure 22. Comparison of Observed and Simulated Flows – DCU

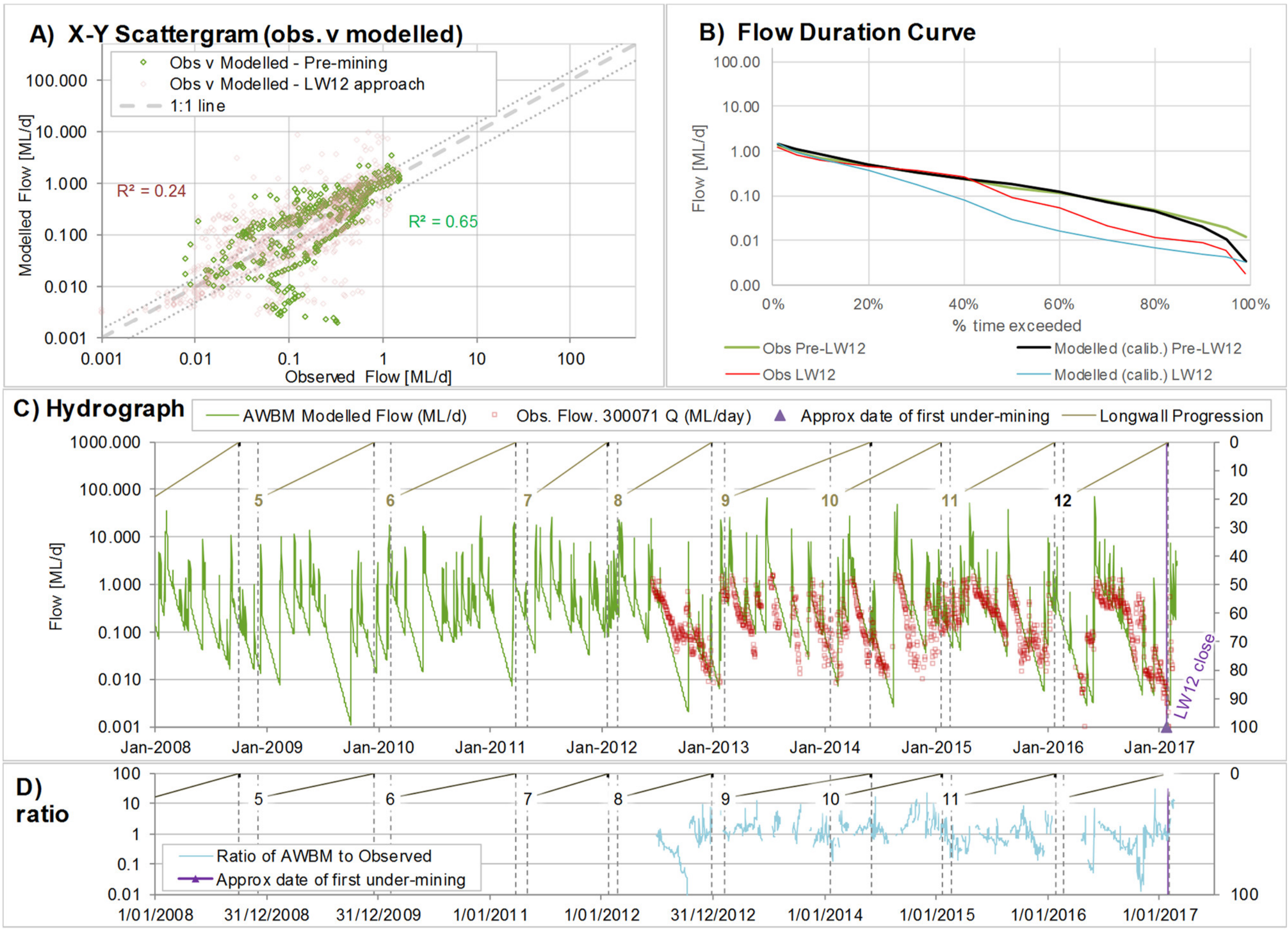
A	The scattergram shows that during the pre-mining period the model is a reasonable fit to observed data, as shown by the graphical correlation to the 1:1 line and also the R^2. The fit is less in the post-mining period.
B	Confirms the reasonable match between modelled and observed flows for the pre-mining period, and illustrates that the model tends to overpredict flows for the subsequent post-mining period including throughout Longwall 12. Low flows are well matched.
C	The hydrograph shows a good match between observed flows up until Feb-2013, and the match is the same after that time. Generally, the flow recessions are well matched, but some are not, e.g. late 2011 – pre-mining and Jan/Feb-2015 - post-mining. The hydrograph suggests that there may be a deviation between modelled and observed flow in late 2015 and in mid-2016, however this looks somewhat similar to the periods early-2010 and mid-2012. Data for the March/April-2017 is not yet available (sites are inaccessible after wet weather).
D	The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1 (i.e. a good match between observed and modelled). The post-mining ratio also oscillates around 1, the exceptions being at the end of Longwall 11 and mid-Longwall 12. However, ratios in those periods are similar to those calculated during the pre-mining period (e.g. during Longwalls 5, 6).

Assessment: There is a suggestion that flow has declined late in LW11 and again in mid-LW12; however, this may just be the response to weather patterns during mid/late 2015 and 2016, as the recession in early 2016 is well-matched. No cease-to-flow events have been recorded in 2015-17, even though these were recorded in the pre-mining period (2009-10).

Catchment discharge for Longwall 12:	**TARP – NOT TRIGGERED**	Water balance [Qsim + ETsim] is within 6% of average Pobs (-5%).

WC15S1 – Wongawilli Creek tributary

This tributary to Wongawilli Creek lies above Longwalls 13-17 of Area 3B, with its confluence with Wongawilli Creek above the eastern end of Longwall 13. This catchment has not yet been directly mined under, although Longwall 12 came within 100 m of the catchment.



F:\HYDROSIM\DENDROBIUM\Reports\HGE001\[300071-WC15S1_Obs_v_AWBM_StatsV1.xlsx]AWBM_REPORT

Figure 23. Comparison of Observed and Simulated Flows – WC15S1

A The scattergram shows that during the pre-mining period the model is a good fit to observed data, as shown by the graphical correlation to the 1:1 line and also the R^2. There is no second series as there has been no direct undermining of this catchment.

B This chart confirms the good match between modelled and observed flows for the pre-mining period, with the main weakness being the lower end of the flow duration curve. The modelled sequence is below the observed record for the period of Longwall 12, suggestive of no mining effect (unsurprising given the lack of direct undermining).

C The hydrograph shows the fit is somewhat mixed. The key points are that while the very low flows are typically underestimated by the model, the rate of recession is represented well.

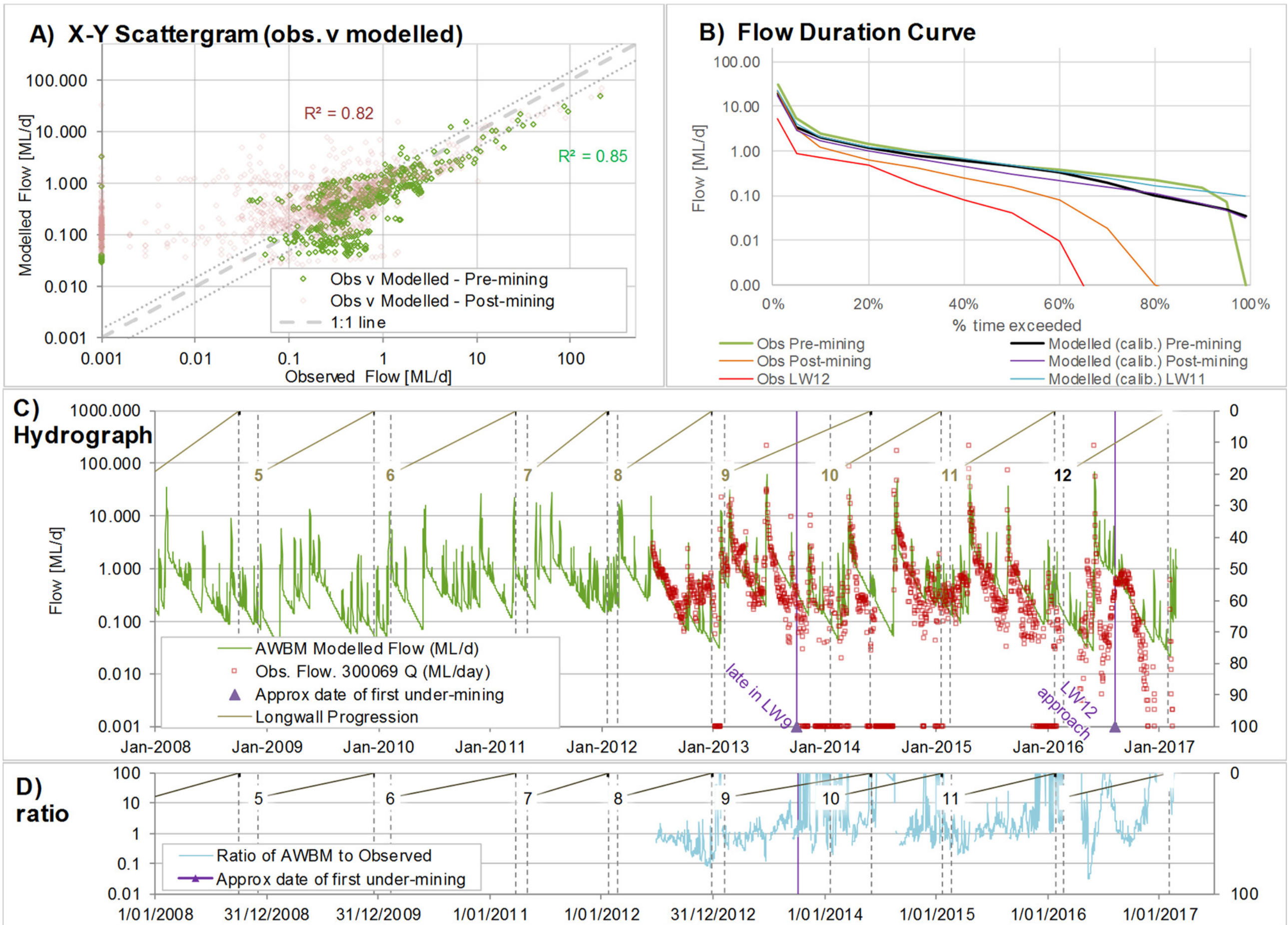
D The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1, with deviation during some periods, but returning to the baseline value of 1. The short-lived decline in this ratio during November 2017 (during Longwall 12) is similar to that in mid-2012 (pre-mining).

Assessment: No evidence that mining has affected flows in this sub-catchment yield, including during Longwall 12., noting that the period of Longwall 12 was marked by generally dry conditions, with the exception of the ~300 mm rain event in June-2016.

Catchment discharge for Longwall 12:	**TARP - NOT TRIGGERED**	Water balance [Qsim + ETsim] is within +1% of average Pobs.

WC21S1 - Wongawilli Creek tributary

The WC21 tributary to Wongawilli Creek flows above Longwalls 9-15, entering Wongawilli Creek just north of Longwall 9. This catchment was therefore mined under late in Longwall 9, has since been undermined by Longwall 10-12, and it is planned to be mined under by future Longwalls13-15.



F:\HYDROSIM\DENDROBIUM\Model\SWModel\Source\OUTPUT\EoP12\[300069-WC21S1_Obs_v_AWBM_StatsV1.xlsx]AWBM_REPORT

Figure 24. Comparison of Observed and Simulated Flows – WC21S1

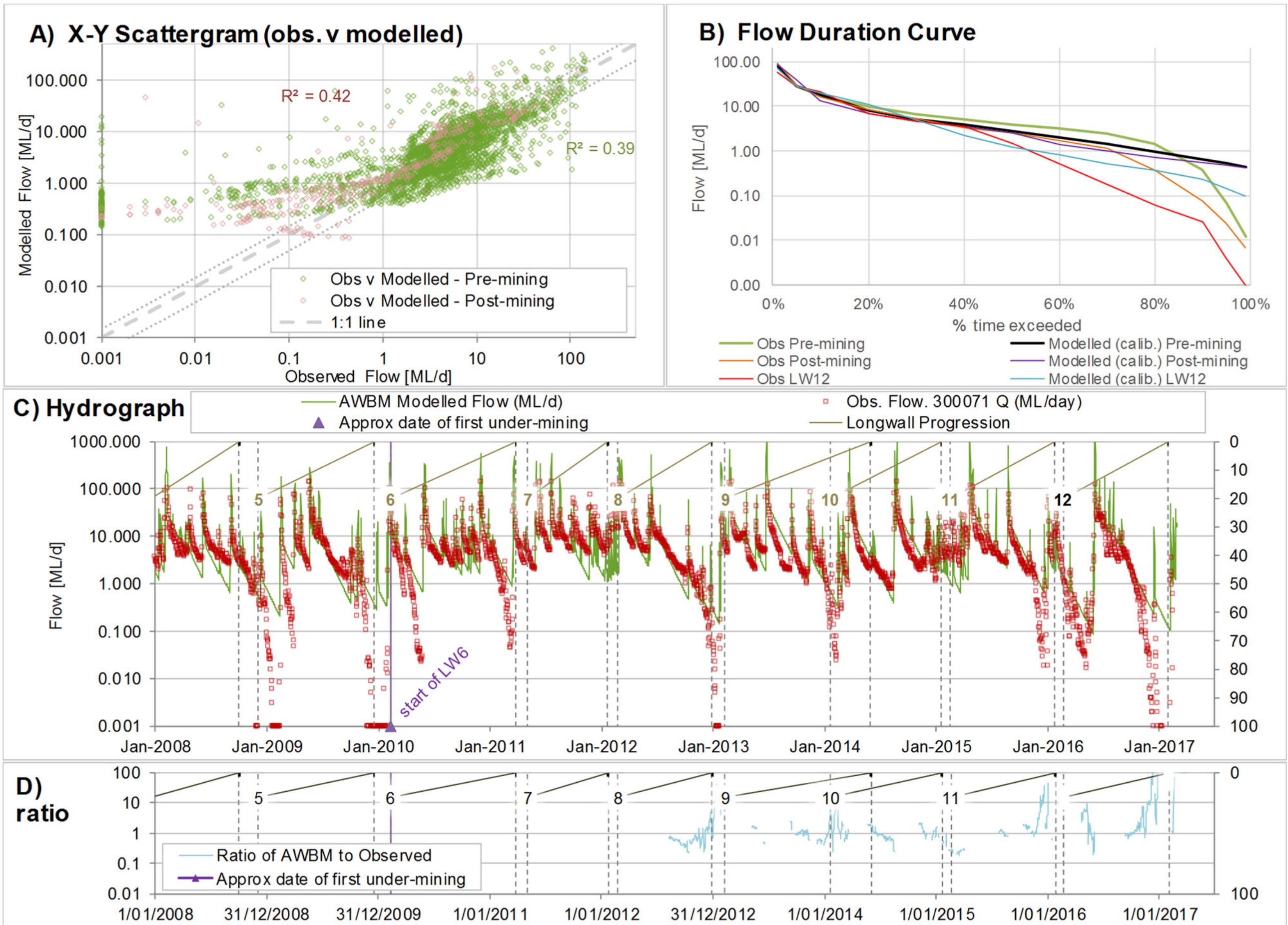
A	The scattergram shows that during the pre-mining period the model is a good fit to observed data, as shown by the graphical correlation to the 1:1 line and also the R^2. This correlation declines somewhat in the post-mining period.
B	Confirms the good match between modelled and observed flows for the pre-mining period, and illustrates that the observed flows have been below predicted flow for the subsequent post-mining period, including throughout Longwall 12.
C	The hydrograph shows a good match between observed flows up until August-October 2013. After the initial undermining by Longwall 9, the observed recession limbs are consistently below that predicted by the model. During July-Oct 2017 the observed hydrograph appears to show a response (increase in flow and subsequent decline without any corresponding rainfall pattern) that is suggestive of compression of strata as Longwall 12 approached.
D	The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1, with deviation during short-term high flow events. The post-mining ratio oscillates around 2-5 through to the end of Longwall 11, and has oscillated to a large degree during Longwall 12.

Assessment: The evidence is that recent undermining by Longwall 10 and 11, and now Longwall 12 has affected sub-catchment yield. This is supported by field observation of the creek being dry upstream of the gauge. Since undermining occurred and during Longwall 12 the creek at the gauging station has been dry about 20 and 30% of the time, respectively.

Catchment discharge for Longwall 12:	**TARP - NOT TRIGGERED**	Water balance [Qsim + ETsim] is within 2% below average Pobs. This is inconsistent with the review of modelled and observed flows (above).

WWL – Wongawilli Creek (lower)

Wongawilli Creek lies between Areas 3A and 3B and the main stream is not directly mined under, although some tributaries have been or will be mined under by panels in those areas, including during Longwall 12.



F:\HYDROSIM\DENDROBIUM\Model\SWModel\Source\OUTPUT\EoP12\[300022-WWL_Obs_v_AWBM_StatsV1.xlsx]AWBM_REPORT

Figure 25. Comparison of Observed and Simulated Flows – WWL

A	This shows that during the pre-mining period the model is a reasonable fit to observed data, with the key weakness being the model's over-estimation of very low flows. This fit is essentially the same (even marginally better) in the post-mining period.
B	Confirms the reasonable match between modelled and observed flows for the pre-mining period, and illustrates that the model still predicts the range of flows reasonably well for the subsequent post-mining period. Observed flows during Longwall 12 are well simulated above 1 ML/d, but below this the match is not good. This is likely due to the dry conditions prevalent during Longwall 12, rather than mining (see discussion of charts C and D, below).
C	The hydrograph shows a reasonable match between observed flows up until Feb-2010 (the start of Longwall 6), and the match is the same after that time. Generally, the flow recessions are reasonably matched, but some are over-estimated and some under-estimated in both the pre-mining and post-mining periods. There is no discernible systematic change in behaviour. The overestimation of low flows during late 2016 (Longwall 12) is similar to that in early 2009 and early 2010 (pre-mining).
D	The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1 (i.e. a good match between observed and modelled). The post-mining ratio also oscillates around 1. The exceptions are the periods of very low (observed) flows, where the model typically over-estimates flows, however this occurs in both pre- and post-mining periods.

Assessment: There is no evidence that undermining has reduced sub-catchment flow / yield.

Catchment discharge for Longwall 11:	**TARP – NOT TRIGGERED**	Water balance [Qsim + ETsim] is within 6% of average Pobs. (-3%)

LA4S1 – Lake Avon tributary

This un-named tributary to Lake Avon lies above the western parts of Longwalls 11-14 in Area 3B. It was directly mined under by Longwall 12 (and 11), and is planned to be mined under by future Longwalls 13 and 14.

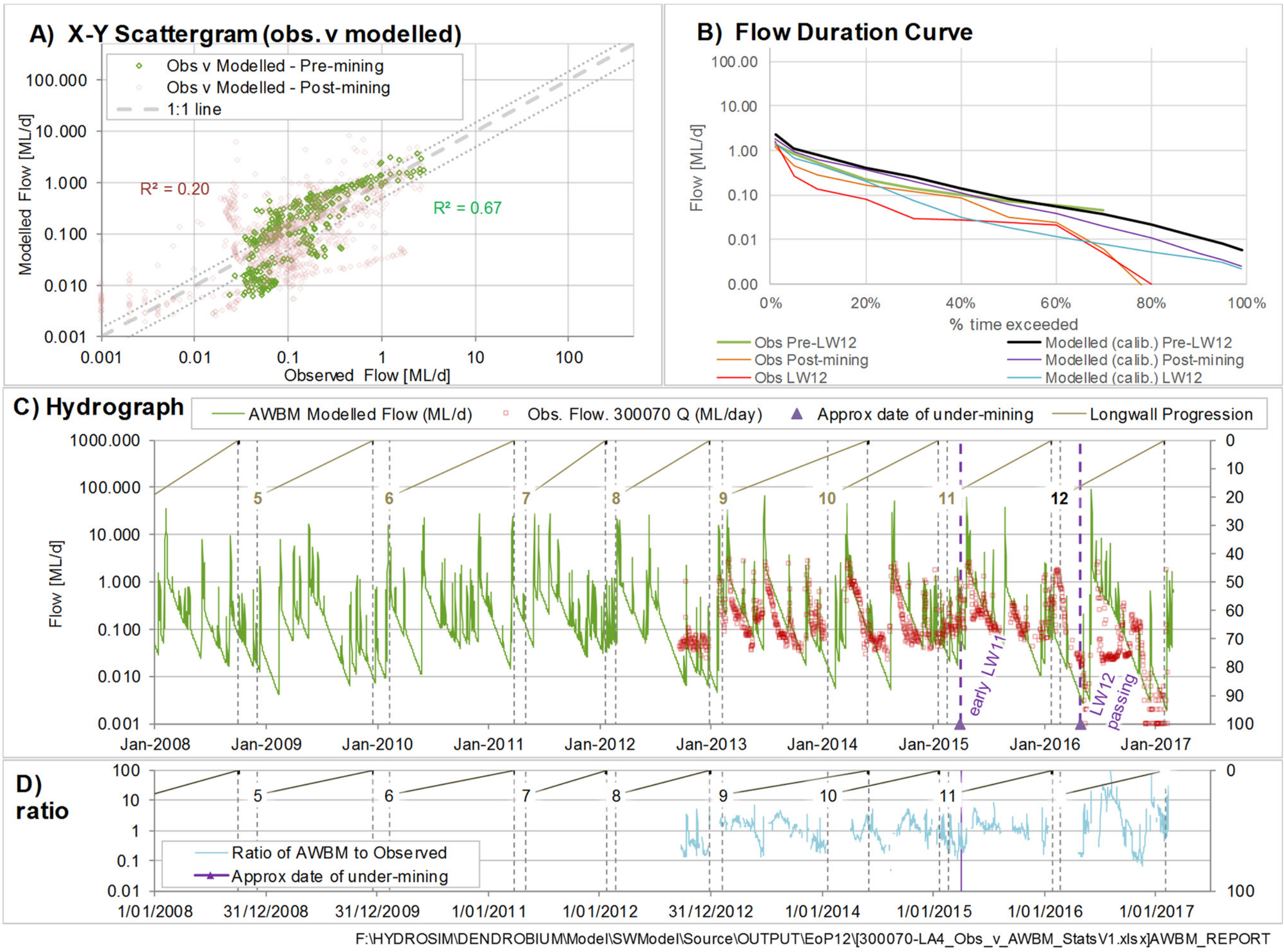


Figure 26. Comparison of Observed and Simulated Flows – LA4

A	The scattergram shows that during the pre-mining period the model is a reasonable fit to observed data, as shown by the graphical correlation to the 1:1 line and also the R^2. This correlation has declined in the post-mining period.
B	Confirms the reasonable match between modelled and observed flows for the pre-mining period, and illustrates that the model over-estimates flows for the subsequent post-mining period, including throughout Longwall 12.
C	The hydrograph shows a reasonable match between observed flows up until early Longwall 11, and the match is similar throughout Longwall 11. However, after the passing of Longwall 12, the model overestimates flows during two main periods: June-Sept-2016 and again during Dec-2016-Jan-2017. Observed flows during summer 2016-17 are lower than previously recorded.
D	The pre-mining ratio of modelled to observed flows shows the ratio hovers at about 1 (i.e. a good match between observed and modelled). The post-mining ratio also hovers around 1 during Longwall 11, but oscillates significantly after Longwall 12 has passed.
Assessment:	Longwall 12 has affected flows in LA4, resulting in a 20% decline in average flow (accounting for the drier than average conditions occurring during Longwall 12) and cease-to-flow conditions occurring about 20% of the time.

Catchment discharge for Longwall 11:	**TARP – NOT TRIGGERED**	Water balance [Qsim + ETsim] is <1% below average Pobs. This is inconsistent with the review of modelled and observed flows (above).

6. Assessment of Shallow Groundwater Effects

6.1 Shallow groundwater levels

Trigger values for subsidence-induced decreases in groundwater levels at surface and near surface monitoring sites at Area 3B swamps have been established within the most recent SIMMCP (South32 2015b). Shallow groundwater level has been identified as an indicator of potential changes in ecosystem functionality of the swamps. TARPS are defined as follows:

Table 8. Performance criteria related to shallow groundwater levels at swamp monitoring sites

TARP Level	Criteria	Response
1	Groundwater **level** lower than baseline level at **any** monitoring site within a swamp (in comparison to reference swamps); and/or; **Rate** of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at **any** monitoring site (measured as average mm/ day during the recession curve).	Increased intensity and frequency of vegetation monitoring and/or further investigations of subsidence impacts on bedrock base and rockbars
2	Groundwater **level** lower than baseline level at **50%** of monitoring sites (within 400 m of mining) within a swamp (in comparison to reference swamps); and/or **Rate** of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at **50%** of monitoring sites (within 400 m of mining) within the swamp.	
3	Groundwater **level** lower than baseline level at **>80%** of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps); and/or **Rate** of groundwater level reduction exceeds rate of groundwater level reduction during baseline period at **>80%** of monitoring sites (within 400 m of mining) within the swamp.	

Groundwater level hydrographs for each shallow piezometer are presented in **Appendix C**. The hydrograph is plotted together with ground elevation and the elevation of the piezometer base, longwall timing, rainfall trend ("rainfall CRM"), and the dates that longwalls pass under (if relevant) a piezometer. Assessment of mining effects is based on these hydrographs.

A summary of the hydrograph responses at Area 3B swamps is included in Table 9 for Impact Sites and

Table 10 for Reference Sites. In accordance with the definition of the TARPs, the sites included for the assessment against the triggers are only those within 400 m of mining *and* within the mapped swamp areas.

Table 9. Summary of shallow groundwater level TARP status at *Impact Sites*

SWAMP	TARP SITES	RELEVANT LONGWALLS	PIEZOMETERS WITH AN OBSERVED RESPONSE			OBSERVED BEHAVIOUR	COMMENT	TARP LEVEL
			YES	UNCLEAR	NO			
01a^	6	LW9, LW10	01, 04, 04i, 04ii, 04iii, 04iv, 04v		02	Groundwater levels lower than baseline and recession rate greater than baseline at greater than 50% to 90% of monitoring sites	Limited baseline data for five piezometers.	Level 3^
01b^	5	LW9	02, 02iii	02ii, 02iv	01	Groundwater levels lower than baseline and recession rate greater than baseline at greater than 50% of monitoring sites.	Limited baseline data for five piezometers	Level 2^
03	1	Pillar 11/12	01			Possible increase in recession rate and apparently reduced response to rainfall after LW11 passed and LW12 undermined.	Unclear whether swamp has been further impacted by LW12 due to lack of rainfall in 2016	Level 3
05	6	LW9, LW10, LW11	01, 02, 03, 03ii, 04	05		Groundwater levels lower than baseline and recession rate greater than baseline at >80% of monitoring sites	Unclear if piezometer 5_05 impacted by either LW11 or 12 due to limited baseline.	Level 3
08	0	LW9, LW10 LW11	*01, 04*		*02*	Groundwater levels lower than baseline and recession rate greater than baseline at a number of piezometers, not within swamp boundary.	Outside swamp boundary (Not subject to TARP)	n/a
10	1	LW12	01			Sharp decline in groundwater levels below base of the piezometer after LW12. Level and rate of decline anomalous compared with baseline.	Mined under by LW12	Level 3
11	3	LW13, LW14			H1, H2, H3	A sharp decline in shallow groundwater levels in March 2017 similar response to previous dry periods.	Yet to be mined under	n/a
13	1	LW14			01	Decline in shallow groundwater levels from late 2016; Similar response to previous dry periods.	Yet to be mined under	n/a
14	2	LW15, LW16			01, 02	n/a	Yet to be mined under. (no data since Sept 2015*)	n/a
23	2	LW15, LW16			01, 02	n/a	Yet to be mined under. (no data since August 2015*)	n/a
35a	1	LW18			01	n/a	Yet to be mined under	n/a
35b	1	LW18			01	n/a	Yet to be mined under	n/a

Note: " i " in site name (e.g. 04i) indicates installation during Longwall 9 extraction. These piezometers are of limited use diagnostically due to a lack of observations establishing baseline conditions (observations prior to mining). * at these swamps which are located away from active or recent mining areas the data has been logged (recorded) at the piezometer, but not collected since that time. ^ the *Longwall 12 End of Panel Landscape Assessment* assessed Swamps 01a+0b1 as a single entity, in which case the TARP Level would be L2. Either approach could be considered appropriate.

Table 10. Summary of shallow groundwater level trends at *Reference Sites*.

SWAMP	NUMBER OF PIEZO-METERS	PIEZOMETERS	PROXIMITY TO LONGWALLS	OBSERVED EFFECTS	COMMENT
02	1	01	900 m from LW9	n/a	900 m from LW9
07	2	01, 0	1.2 km from LW6	n/a	1.2 km from LW6
15a	3	06, 07	0.5 km south of LW8, 130 m south of LW19	n/a	0.5 km from LW8
22	2	01, 02	Elouera Colliery	n/a	Limited baseline data
25	1	01	1.4 km from LW5	n/a	1.4 km from LW5
33	2	01, 03	1 km from LW16	n/a	1 km from LW16
84	1	01	500 m from LW5	n/a	500 m from LW5
85	2	01, 02	900 m from LW9	n/a	900 m from LW9
86	2	01, 02	3 km from LW9	n/a	3 km from LW9
87	2	01, 02	Avon Colliery	n/a	Limited baseline data
88	2	2	Huntley Colliery	n/a	Limited baseline data

6.2 Soil moisture

Significant changes in soil moisture characteristics compared with baseline monitoring is identified as an indicator of potential changes in ecosystem functionality of the swamps. Performance criteria and response actions (TARP) related to soil moisture at swamp monitoring sites are listed in the most recent SIMMCP (South32 2015b), and reproduced in Table 11.

Table 11. Performance criteria related to soil moisture at swamp monitoring sites

TARP Level	Criteria	Response
1	Soil moisture level lower than baseline level at **any** monitoring sites (within 400 m of mining) within a swamp (in comparison to reference swamps).	Increased intensity and frequency of vegetation monitoring and/or further investigations of subsidence impacts on bedrock base and rockbars
2	Soil moisture level lower than baseline level at **50%** of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps).	
3	Soil moisture level lower than baseline level at **>80%** of monitoring sites (within 400m of mining) within a swamp (in comparison to reference swamps).	

The TARP has been assessed by comparing the average moisture content of the soil profile during the longwall assessment period against that of the baseline period. If the average soil moisture level drops below the minimum level recorded during the baseline period, a TARP is triggered. The TARP level increases according to the proportion of monitoring sites that exceed this criterion at each swamp within the area of mine influence (Table 11). This is the approach used by the ICEFT for regular impact reporting. The baseline period is the period of monitoring before the site is first undermined or passed within 400 m.

Soil moisture hydrographs for all active monitoring locations are presented in Appendix D. Assessment of soil moisture hydrographs for locations within Areas 3A and 3B zone of influence (< 400 m) are presented in Table 12.

Soil moisture sites at Swamps 05 and 08 were mined under by Longwall 12, and two of the three Swamp 11 sites (S01 and S02) were within 400 m of Longwall 12. Sites from Swamp 8 are not within mapped swamp boundaries and therefore not subject to the TARP. Hydrographs show that average soil moisture has fallen below baseline levels in all sites that have been mined under or are within 400 m of the longwall. However, it should be noted that baseline data for those sites is less than 2 years and may not be representative of normal variability over the long term. In addition, the latter part of Longwall 12 was characterised by unusually dry summer conditions during which soil moisture at reference sites and sites yet to be mined under also fell below the limited baseline range (e.g. Swamps 11 and 13).

Soil moisture monitoring at Swamps 05 and 11 technically represent Level 3 TARP triggers. However, comparison with reference swamp sites suggests that the unusually dry weather conditions were a significant factor in observed soil moisture trends at impact sites. Given the uncertainty in detecting impacts at these sites, it is recommended that monitoring at the current frequency continue.

Table 12. Assessment of soil moisture hydrographs in Areas 3A and 3B

Swamp	Longwall	Sensors and TARP triggers			Comment	TARP Level
		Not triggered	Triggered	Not within mine influence		
05	LW9 – LW12		S05_S05, S05_S01, S05_S02, S05_S08		S05_S05 undermined by LW12. Three sites show SM decline below baseline after LW passes; baseline <2 y)	3
08	LW12	S08_S05			S08_S05 undermined by LW12. Soil moisture falls below baseline after undermining. *Not within mapped swamp boundary*.	n/a
11	LW13, LW14		S11_S01, S11_S02,	S11_S05	Soil moisture at all sensors dropped below baseline despite not having been mined under	3
13	LW14			S13_S01, S13_S02, S13_S03	Soil moisture at all sensors dropped below baseline despite not having been mined under	-
14	LW16			S14_S02, S14_S01	Soil moisture at all S01 dropped below baseline despite not having been mined under	-
15a	-			S15a_Piezo, S15a_S03, S15a_S01, S15a_S04, S15a_S06	Outside Area 3A Longwalls; Soil moisture in 3 sensors dropped below baseline due to dry conditions	-
23	LW15			S23_S01, S23_S02	Not yet mined under	-
35a	LW18			S35a_S01	Not yet mined under	-

Note: * Sites for which there are too few data points for a statistically valid assessment (<10)

7. Conclusions

7.1 Water Quality

Donalds Castle Creek

Measured levels of DO at Donalds Castle Creek (FR6) were below the TARP trigger level (baseline mean minus 3 standard deviations) on two non-consecutive occasions during Longwall 12. Although these represent a level 2 TARP, they are not considered to reflect significant water quality impacts from mining. No other adverse water quality trends were noted.

Wongawilli Creek

TARP trigger levels were met on two non-consecutive occasions at Wongawilli Creek (FR6), once for DO and once for EC. The elevated EC value is considered to reflect evaporative concentration in isolated pools due to the unusually dry conditions, rather than a mining impact.

Slightly anomalous trends in EC and dissolved iron are noted at WC21, Pool 5, during Longwall 12 (and the previous 2 longwalls). There are no similar or clear trends at locations immediately downstream of Longwall 12, nor at locations upstream of Longwall 12 and these trends are considered minor. The concentration of dissolved iron in Pool 5 declined to normal baseline levels after May 2016, approximately the time the watercourse was mined under by Longwall 12.

Lake Avon tributaries

Measured levels of DO at Lake Avon tributary site LA4_S1 were below the TARP trigger level on two non-consecutive occasions during Longwall 12. These represent a level 2 TARP. Anomalous trends in pH (increasing pH) are noted since the start of Longwall 11 (an effect seen also at WC21_Pool 5). However, there are no coincident trends in dissolved metals. One sample collected in December 2016 reported unusually high concentrations of dissolved iron, manganese and aluminium which should be reviewed in the next End of Panel report.

7.2 Effects on Flow and Catchment 'Yield'

The modelling assessment indicates that headwater catchments to WC21S1, DC13S1, DCS2, are affected by mining, as is the tributary LA4 of Lake Avon.

Effects are possible, but not definitive at Donalds Castle Upper (DCU). Effects are not observed in the downstream catchment at Wongawilli Creek Lower (WWL). This suggests that some or all flow lost in Wongawilli Creek headwater catchments is returned downgradient, but this assessment is not conclusive, as evapotranspiration (ET) might account for some fraction of that.

Modelling suggests that flows at the high range of flows in the mined under catchments are less affected than the lower, recession-limb flows.

Wongawilli Creek

Based on the modelling assessment there is a loss of sub-catchment yield in the main tributary catchments of Wongawilli Creek that overlie Area 3B (the catchment of WC21) through the period of most of Longwall 9, through Longwall 10 to Longwall 12. WC15 is yet to be mined under, and shows no discernible effects.

There is no observable significant decline in sub-catchment yield or flow through the next downstream gauging station WWL (i.e. below TARP Level 1).

Donalds Castle Creek

It is found that there is a loss of sub-catchment yield in the headwater catchments of Donalds Castle Creek (to DC13S1 and DCS2) through the period of most of Longwall 9, through Longwall 10 to Longwall 12. Both DCS2 and DC13S1 are at TARP Level 3.

The lengthy dry spells during the last two years make it difficult to confidently state whether there has or has not been an effect on recession flows or decline in catchment flow + ET at the downstream gauging station DCU. It remains below TARP Level 1, but mid-range flows were below the expected (modelled) flows, and this could be the result of upstream losses.

Tributaries to Lake Avon

There is now a discernible loss of flows along the watercourse LA4, which is a tributary of Lake Avon. The previously determined TARPs have not been triggered, however flow behavior during Longwall 12 was anomalous, including the occurrence of cease-to-flow conditions, indicative of a mining effect.

7.3 Swamps

It was expected that Swamps 01a, 01b, 03, 04, 05, 08, 10, 11, 13, 14, 23, 35a and 35b might be affected by mine subsidence due to mining in Area 3B (South32 2015b). The assessment of shallow groundwater levels indicates that TARPs have been triggered at the following swamps, most of which were found to have been triggered in earlier End of Panel assessments:

- Swamp 01a Level 3
- Swamp 01b Level 2
- Swamp 03 Level 3 (because the only piezometer is affected)
- Swamp 05 Level 3
- Swamp 08 Level 2
- Swamp 10 Level 3 (because the only piezometer is affected)

Soil moisture sites at Swamps 05 and 08 were mined under by Longwall 12. Hydrographs show that soil moisture has fallen below baseline levels in all the mined under sites. However, it should be noted that baseline data for those sites is less than 2 years and may not be representative of normal variability over the long term. In addition, the latter part of Longwall 12 was characterised by unusually dry summer conditions during which soil moisture at sites yet to be mined under also fell below the limited baseline range (e.g. Swamps 11 and 13).

8. References

Boughton W (2004) The Australian water balance model. Environ Model Softw 19:943–956. doi: doi:10.1016/j.envsoft.2003.10.007

Boughton W, Chiew F (2003) Calibration of the AWBM for use on ungauged catchments. Coorperative Research centrre for Catchment Hydrology, Monash University

DSITI (2011) SILO Climate Data Drill. https://www.longpaddock.qld.gov.au/silo/datadrill/. Accessed 2 May 2017

Ecoengineers (2015) End of Panel Surface and Shallow Groundwater Impacts Assessment – Dendrobium Area 3B Longwall 10.

eWater (2017) eWater Source - Australia's national hydrological modelling platform: Integrated Water Resources Management (IWRM) combined with water policy and governance capability. http://ewater.org.au/products/ewater-source/. Accessed 2 May 2017

HydroSimulations (2016) Dendrobium Mine End of Panel Surface and Shallow Groundwater Impact Assessment – Dendrobium Area 3B Longwall 11.

Sentek (2017) Soil Moisture Measuring, Soil Moisture Measurement – Sentek. http://www.sentek.com.au/products/soil-moisture-triscan-sensors.asp. Accessed 28 Apr 2017

South32 (2017) Dendrobium Longwall 12 end of panel landscape report. South32 Illawarra Coal

South32 (2015a) Dendrobium Area 3B Watercourse impact monitoring management and contingency plan. South32 Illawarra Coal

South32 (2015b) Dendrobium Area 3B Swamp impact monitoring management and contingency plan. South32 Illawarra Coal

Van de Griend A, De Vries J, Seyhan E (2002) Groundwater discharge from areas with a variable specific drainage resistance. J Hydrol 259:203–220. doi: DOI: 10.1016/S0022-1694(01)00583-2

Appendix A

Water Quality Plots (Key Parameters) for all Monitoring Sites

Appendix B

Parameters used for AWBM by modelled catchment

AWBM was first developed by W. Boughton in the early 1990s (Boughton and Chiew 2003; Boughton 2004). The model takes average rainfall and potential evaporation across a catchment as inputs on a daily timestep. The user provides parameters to describe the relative area and soil moisture storage capacity of three stores covering the catchment (Figure 27. AWBM Rainfall-runoff model flow diagram). Based on these inputs and parameters, surface runoff and baseflow are calculated and then released from the relevant storage using a linear decay (*Ksurf* or *Kbase*). These decayed flows are summed to estimate total catchment outflow on a daily basis.

Most of the parameters relate in part to the simulated connected groundwater system in the catchment. For this project, AWBM has been populated and run via the eWater 'Source' platform (eWater 2017).

Table 13. AWBM parameters for Dendrobium catchment models

SITE	A1	A2	A3	Kbase	Ksurf	BFI	C1	C2	C3
	area - fraction	area - fraction	area - fraction	fraction	fraction	fraction	mm	mm	mm
Donalds Castle Creek catchments									
DCS2	0.15	0.20	0.65	0.97	0.26	0.32	0.008	0.12	0.27
DC13	0.08	0.433	0.487	0.982	0.22	0.34	0.015	0.14	0.37
DCU	0.08	0.20	0.72	0.98	0.75	0.4	0.015	0.10	0.40
Wongawilli Creek catchments									
WC15	0.15	0.20	0.65	0.945	0.26	0.32	0.008	0.20	0.27
WC21	0.134	0.433	0.433	0.974	0.35	0.42	0.001	0.12	0.25
WWL	0.134	0.433	0.433	0.97	0.26	0.32	0.01	0.10	0.25
Lake Avon tributaries									
LA4	0.10	0.433	0.467	0.96	0.26	0.25	0.05	0.1	0.20

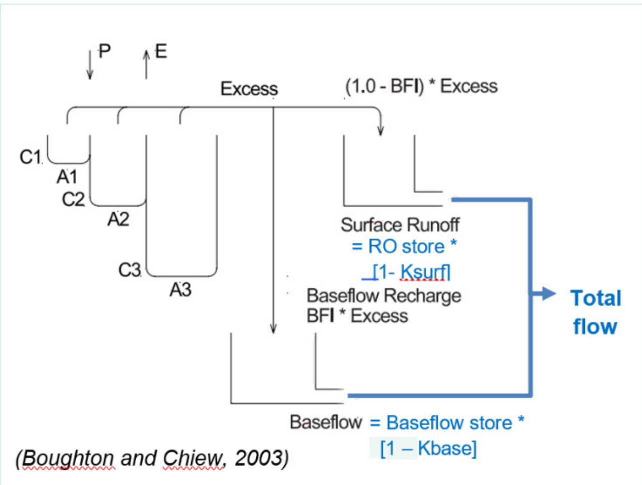


Figure 27. AWBM Rainfall-runoff model flow diagram

Appendix C

Shallow groundwater (swamp) hydrographs

Appendix D

Soil moisture hydrographs