DENDROBIUM
AREA 3B

AUGUST 2020




AREA 3B

WATERCOURSE IMPACT, MONITORING, MANAGEMENT AND CONTINGENCY PLAN

Rev 1.9

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Review History

Revision	Description of Changes	Date	Approved
A	New Document-DRAFT	August 2012	GB
B	Updated with comments from agencies – post submission	October 2012	GB
C	Updated with comments from agencies – post submission	November 2012	GB
1	Updated to address SMP Conditions of Approval 6 February 2013	May 2013	GB
1.1	Updated to address Agency Feedback May 2013	November 2013	GB
1.2	Updated to address Agency Feedback December 2013 – March 2014	June 2014	GB
1.3	Updated to address DPE Feedback October 2014	December 2014	GB
1.4	Updated to address DPE Feedback May 2015	May 2015	GB
1.5	Updated to address Longwalls 14 – 18 requirements	October 2015	GB
1.6	Update to address Longwall 14 – 15 Conditions	October 2017	GB
1.7	Update to address Longwall 16 Conditions and IEP (2018)	March 2019	GB
1.8	Update to address Longwall 17 Conditions and revised flow TARPs	February 2020	GB
1.9	Updated to address Longwall 18 SMP Application	August 2020	GB

Persons involved in the development of this document include:

Name	Title	Company
Josh Carlon	Coordinator Environment	Illawarra Metallurgical Coal
Cody Brady	Principal Approvals	Illawarra Metallurgical Coal
Gary Brassington	Manager Approvals	Illawarra Metallurgical Coal

1 INTRODUCTION

1.1 Project Background

Illawarra Metallurgical Coal (IMC) operates underground coal mining operations at Dendrobium Mine, located in the Southern Coalfield of New South Wales (NSW). Longwalls from the Wongawilli Seam are currently being extracted from Area 3B.

IMC was granted Development Consent by the NSW Minister for Planning for the Dendrobium Project on 20 November 2001. In 2007 IMC proposed to modify its underground coal mining operations and the NSW Department of Planning advised that the application for the modified Area 3 required a modification to the original consent. The application followed the process of s75W of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and required the submission of a comprehensive Environmental Assessment (Cardno 2007). The Environmental Assessment (EA) described the environmental consequences likely from cracking and diversion of surface water as a result of the proposed mining. These impacts included diversion of flow, lowering of aquifers, changes to habitat for threatened species as well as other impacts and environmental consequences.

On 8 December 2008, the Minister for Planning approved a modification to DA_60-03-2001 for Dendrobium Underground Coal Mine and associated surface facilities and infrastructure under Section 75W of the EP&A Act.

On 4 October 2012 IMC submitted a Subsidence Management Plan (SMP) for approval from the Director Generals (now Secretaries) of the Department of Planning and Infrastructure (which became the Department of Planning and Environment [DPE]) and Trade and Investment (T&I). The SMP incorporates the Watercourse Impact, Monitoring, Management and Contingency Plan (WIMMCP). The SMP was approved by the Secretary T&I 5 February 2013 and the Secretary DPE 6 February 2013.

On 4 March 2016, IMC submitted a SMP, for Longwalls 14 – 19, for approval from the Secretary of the DPE. Conditional approval, for Longwalls 14 and 15, was granted by the DPE on 16 December 2016. The then Schedule 3, Condition 7 of the approval, stated the requirement for additional approval of the Secretary for Longwalls 16 to 18.

On 25 October 2017, the DPE requested a standalone application for Longwall 16 for approval consideration. IMC submitted the Longwall 16 SMP application to the DPE on 14 November 2017. The DPE established the Independent Expert Panel (IEP), on 26 February 2018, to provide informed expert advice on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a particular focus on risks to the quantity of water in the Catchment. The Longwall 16 SMP was approved by the Secretary of the DPE on 30 May 2018.

The then Schedule 3 Condition 7 of the Longwall 16 SMP Approval states the requirement of approval by the Secretary of DPE prior to gateroad development for, or the extraction of, Longwalls 17 to 18.

On 25 March 2019, IMC submitted a SMP application to Department of Planning, Industry and Environment (DPIE) for Longwall 17, for approval from the Secretary. The Longwall 17 SMP was approved by the Secretary of DPIE on 11 July 2019.

1.2 Scope

The WIMMCP has been prepared to comply with the Dendrobium Development Consent and the SMP Approval in respect to surface water management within Dendrobium Area 3B.

The Dendrobium Development Consent requires a WIMMCP subject to Schedule 3, Condition 4 as provided below.

> 4. Prior to carrying out any underground mining operations that could cause subsidence in either Area 3A, Area 3B or Area 3C, the Applicant shall prepare a Watercourse Impact Monitoring, Management and Contingency Plan to the satisfaction of the Secretary. Each such Plan must:
>
> (a) demonstrate how the subsidence impact limits in conditions 1 - 3 are to be met;
>
> (b) include a monitoring program and reporting mechanisms to enable close and ongoing review by the Department and DPI of the subsidence effects and impacts (individual and cumulative) on Wongawilli Creek, Sandy Creek and Sandy Creek Waterfall;
>
> (c) include a general monitoring and reporting program addressing surface water levels, water flows, water quality, surface slope and gradient, erodibility, aquatic flora and fauna (including Macquarie Perch, any other threatened aquatic species and their habitats) and ecosystem function;

(d) include a management plan for avoiding, minimising, mitigating and remediating impacts on watercourses, which includes a tabular contingency plan (based on the Trigger Action Response Plan structure) focusing on measures for remediating both predicted and unpredicted impacts; (e) address third and higher order streams individually but address first and second order streams collectively; (f) be prepared in consultation with DECC, WaterNSW and DPI; (g) incorporate means of updating the plan based on experience gained as mining progresses; (h) be approved prior to the carrying out of any underground mining operations that could cause subsidence impacts on watercourses in the relevant Area; and (i) be implemented to the satisfaction of the Secretary.

The SMP Area for the WIMMCP is defined in accordance with Mine Subsidence Engineering Consultants (MSEC] 2020), as the surface area that is likely to be affected by the mining of Longwall 18 in Dendrobium Area 3B. The extent of the Longwall 18 SMP Area has been calculated by combining the areas bounded by the following limits:

- A 35 degree angle of draw from the extents of Longwall 18;
- The predicted limit of vertical subsidence, taken as the 20 mm subsidence contour resulting from the extraction of Longwall 18;
- The natural features within 600 m of the extent of the longwall mining area, in accordance with Condition 8(d) of the Dendrobium Development Consent; and
- Features which are expected to experience either far-field horizontal movements, or valley related movements, and which could be sensitive to these movements.

The watercourses located outside the extent of longwall mining, which could experience far-field or valley related movements, and could be sensitive to these movements, have been identified and included in the assessments provided in this report. The WIMMCP also provides updated monitoring, management and contingency for the Area 3B mining domain. The location of the watercourses in respect of Dendrobium Area 3B is shown in **Figure 1-1**.

This WIMMCP addresses:

- Impact assessment and how the subsidence impact limits specified in the approval will be met;
- Monitoring and reporting;
- Trigger levels that initiate the implementation of management or remedial measures (including contingency measures);
- Implementation of remedial measures should mining induced degradation to the watercourses be observed or measured (including contingency measures); and
- Access to watercourses and rehabilitation of access routes to watercourses.

The WIMMCP does not provide detailed reporting of monitoring data. These requirements are fulfilled by the EA (Cardno 2007), Area 3B SMP (Cardno 2012), End of Panel (EoP) Reports, Annual Environmental Management Reports (AEMRs) and other reports.

1.3 Objectives

The objectives of this WIMMCP are to identify at risk watercourse features and characteristics within the Dendrobium 3B Study Area (**Figure 1-1**) and to monitor and manage potential impacts and/or environmental consequences of the proposed workings on watercourses. The WIMMCP is to comply with the Area 3B SMP Approval, including Schedule 3, Condition 13 Performance Measures for Area 3B. The WIMMCP also provides updated monitoring, management and contingency for the Area 3B mining domain.

1.4 Consultation

The WIMMCP has been developed by IMC, in consultation with:

- DPIE;
- Biodiversity and Conservation Division within the Department (BCD);

- The Department of Mining, Exploration and Geosciences (MEG); and
- WaterNSW.

The WIMMCP and other relevant documentation are available on the IMC website (Condition 11 Schedule 8: DA 60-03-2001).

1.4.1 SMP and WIMMCP Consultation

A number of submissions were made in relation to the Area 3B SMP and the WIMMCP, including detailed submissions from BCD (8 December 2017), WaterNSW (13 December 2017) and Dams Safety NSW (formerly Dam Safety Committee) (14 December 2017). IMC provided detailed responses to the submissions dated 16 March 2018 and 13 April 2018.

1.4.2 2013 SMP Condition 11 WIMMCP Revision

The Secretary of DPE approved the Dendrobium Area 3B SMP 6 February 2013. The then Condition 11 of this approval requires the WIMMCP be reviewed to the satisfaction of the Secretary by 31 May 2013. The WIMMCP was redrafted to take into account feedback during SMP consultation as well as the conditions and performance measures included in the Area 3B SMP Approval. The revised WIMMCP was provided to DPE, OEH, NoW, WaterNSW and T&I 10 May 2013. The WIMMCP (Rev 1.4) was approved by the Secretary 10 August 2015.

1.4.3 Agency Workshop May 2013

The Wollongong Office of T&I hosted a joint agency workshop with IMC to discuss the WIMMCP. The workshop was held 27 May 2013 with the following agencies attending DPIE, BCD, WaterNSW and the then T&I.

Following the workshop the agencies provided submissions:

- Minutes of the workshop 5 June 2013;
- DPE 4 June 2013;
- WaterNSW 13 June 2013; and
- OEH 14 June 2013.

This WIMMCP has been revised on the basis of the agreed outcomes from the workshop and taking the above submissions into account.

1.4.4 Agency Workshop December 2013

The Wollongong Office of T&I hosted a second joint Agency workshop with IMC to discuss the WIMMCP. The workshop was held 16 December 2013 with the following agencies attending DPIE, BCD, WaterNSW and the then T&I.

Following the workshop the Agencies provided submissions:

- T&I 10 January 2014;
- OEH 17 January 2014; and
- WaterNSW 7 February 2014.

The WIMMCP has been revised on the basis of the agreed outcomes from the workshop and taking the above submissions into account.

1.4.5 2013 SMP Condition 11 WIMMCP Revision

The Secretary of DPE approved the Dendrobium Area 3B SMP for Longwalls 9 – 13 on 6 February 2013. The then Condition 11 of this approval requires the WIMMCP be reviewed to the satisfaction of the Secretary prior to 31 May 2013.

1.4.6 2016 SMP Condition 14 WIMMCP Revision

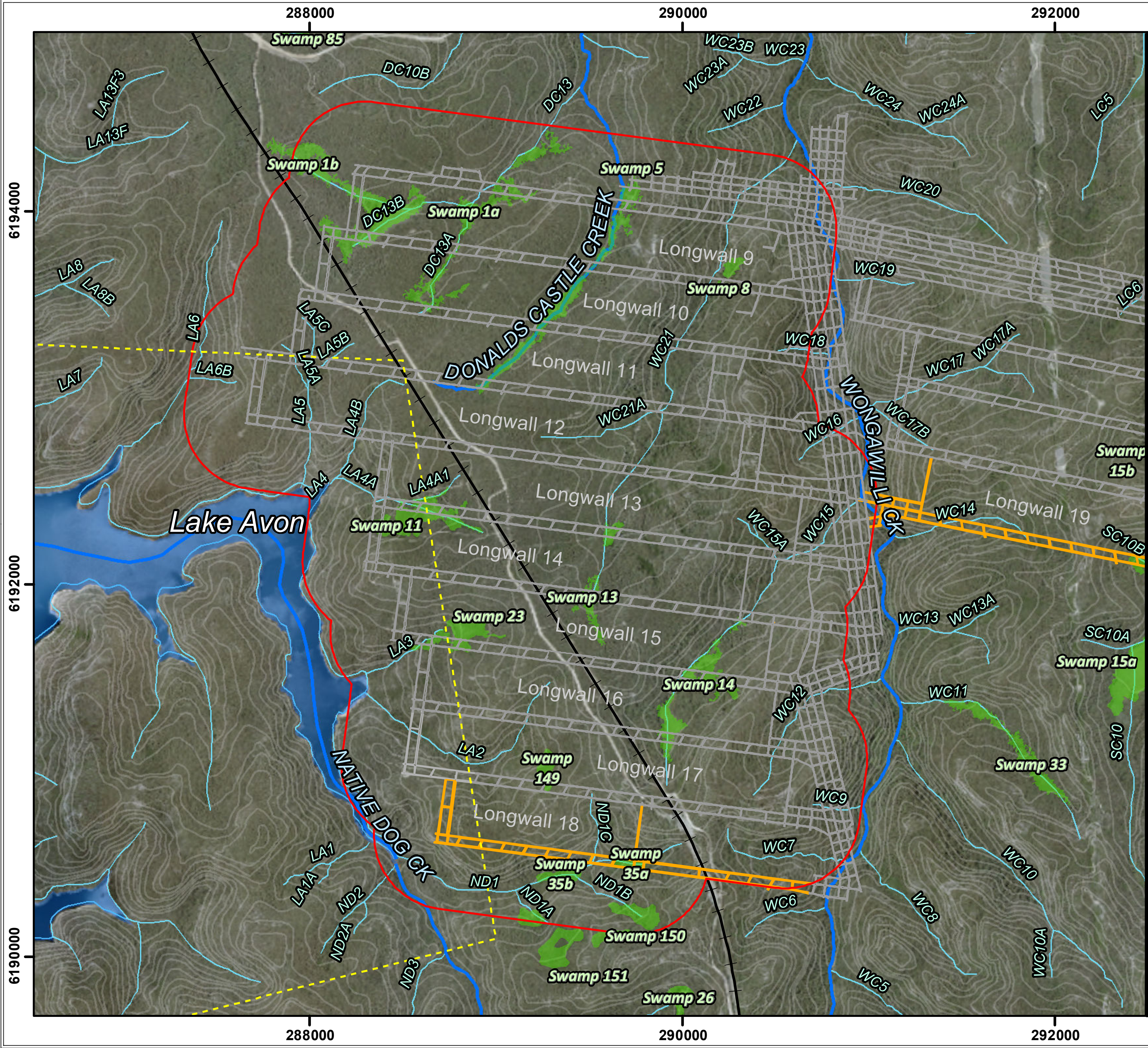
The Secretary of DPE approved the Dendrobium Area 3B SMP for Longwalls 14 – 15 on 16 December 2016. The then Condition 14 of this approval requires the WIMMCP be reviewed to the satisfaction of the Secretary prior to the extraction of Longwall 14.

1.4.7 2018 SMP Condition 11 WIMMCP Revision

The Secretary of DPE approved the Dendrobium Area 3B SMP for Longwall 16 on 30 May 2018. The then Condition 11 of this approval requires the WIMMCP be reviewed to the satisfaction of the Secretary prior to the extraction of Longwall 15.

1.4.8 2019 SMP Schedule 4, Condition 5 WIMMCP Revision

The Secretary of DPIE approved the Dendrobium Area 3B SMP for Longwall 17 on 11 July 2019. Schedule 4, Condition 5 of this approval requires the WIMMCP to be reviewed in consultation with WaterNSW to the satisfaction of the Secretary, prior to the extraction of Longwall 16.



Watercourses & Swamps Above Dendrobium Mine Longwalls 9-18

DENDROBIUM AREA 3B SMP

Figure 1-1

- DSC Notification Areas
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Inactive Railway Corridor
- Swamps
- Creeks
- Tributaries
- 10m Contours

Date: August, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

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2 PLAN REQUIREMENTS

Extraction of coal from Longwall 18 will be undertaken in accordance with the conditions set out in the Dendrobium Development Consent and the requirements of the Area 3B SMP Approval as well as conditions attached to relevant mining leases.

Baseline studies have been completed within the Study Area and surrounds to record biophysical characteristics. Monitoring is conducted in the area potentially affected by subsidence from the Area 3B extraction. The baseline studies have identified monitoring sites in these areas based on the Before After Control Impact (BACI) design criteria.

The Area 3B monitoring and assessment programs will provide ongoing water-related monitoring of the streams and sub-catchments potentially affected by the mining of Dendrobium Area 3B and allow assessment of the magnitude of any developing trends in overland and subsurface flow and water quality effects resulting from mining. The Dendrobium Area 3B watercourse monitoring is summarised in **Appendix A**.

The Strahler stream classification system is commonly used to define the class of a watercourse and was used in the Southern Coalfield Inquiry (IEP, 2019a). Streams are classified based on the number of contributing tributaries, with headwater streams classed as first and second order streams and third and higher order streams being given the classification as ‘streams of significance’. The Southern Coalfield Inquiry recommends that assessments should focus on these higher order streams. Within Area 3B, Wongawilli Creek is classed as a third order stream and Donalds Castle Creek is classed as a second order stream. Other unnamed drainage lines within Area 3B are first or second order streams.

The baseline assessments on first, second and third order streams as well as associated features such as swamps are summarised in **Section 3.2** and is comprehensively described in the Dendrobium Area 3B SMP (Cardno 2012). The monitoring locations for watercourses within Dendrobium Area 3B will be reviewed as required and can be modified (with agreement) accordingly.

Should monitoring reveal impacts greater than what is authorised by the approval, modifications to the project and mitigation measures would be considered to minimise impacts.

2.1 Dendrobium Development Consent DA60-03-2001

The Dendrobium Underground Coal Mine (DA 60-03-2001) modification 8 was approved under Section 75W of the EP&A Act on 8 December 2008. **Table 1** lists the Conditions of Consent relevant to the WIMMCP and where the conditions are addressed.

Table 1 Dendrobium Modified DA-60-03-2001 Development Consent Conditions

Dendrobium Development Consent Condition	Relevant WIMMCP Section
Condition 2 – Schedule 3 The Applicant shall ensure that underground mining operations do not cause subsidence impacts at Sandy Creek and Wongawilli Creek other than “minor impacts” (such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality) to the satisfaction of the Secretary.	Sections 3, 4 and 5 (Sandy Creek not within the Study Area)
Condition 3 – Schedule 3 The Applicant shall ensure the development does not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek, to the satisfaction of the Secretary.	Sections 3, 4 and 5

Dendrobium Development Consent Condition		Relevant WIMMCP Section
Condition 4 – Schedule 3 Prior to carrying out any underground mining operations that could cause subsidence in either Area 3A, Area 3B or Area 3C, the Applicant shall prepare a Watercourse Impact Monitoring, Management and Contingency Plan to the satisfaction of the Secretary. Each such Plan must:		
(a)	demonstrate how the subsidence impact limits in conditions 1 - 3 are to be met;	Sections 3, 4 and 5
(b)	include a monitoring program and reporting mechanisms to enable close and ongoing review by the Department and DPI of the subsidence effects and impacts (individual and cumulative) on Wongawilli Creek, Sandy Creek and Sandy Creek Waterfall;	Section 3 and **Appendix A**
(c)	include a general monitoring and reporting program addressing surface water levels, water flows, water quality, surface slope and gradient, erodibility, aquatic flora and fauna (including Macquarie Perch, any other threatened aquatic species and their habitats) and ecosystem function;	Section 3 and **Appendix A**
(d)	include a management plan for avoiding, minimising, mitigating and remediating impacts on watercourses; include a tabular contingency plan (based on the Trigger Action Response Plan structure) which focuses on measures for remediating both predicted and unpredicted impacts on watercourses;	Section 6 and **Appendix A**
(e)	address third and higher order streams individually but address first and second order streams collectively;	Sections 3 and 5
(f)	be prepared in consultation with DECC, WaterNSW and DPI;	Section 1.4
(g)	incorporate means of updating the plan based on experience gained as mining progresses;	Section 7
(h)	be approved prior to the carrying out of any underground mining operations that could cause subsidence impacts on watercourses in the relevant Area; and	Section 1.4
(i)	be implemented to the satisfaction of the Secretary.	

2.2 Dendrobium Area 3B SMP Approval

The Dendrobium Mine Area 3B SMP Approval was granted July 2019. Schedule 4 Condition 5 requires the WIMMCP to be revised as provided below.

Watercourse Impact Monitoring, Management and Contingency Plan Condition 5 – Schedule 4 Prior to the extraction of Longwall 16, the Applicant must review the Watercourse Impact Monitoring, Management and Contingency Plan for Area 3B prepared under condition 4 of Schedule 3 of the development consent (DA 60-03-2001) to provide for achievement of the performance measures listed in Table 1 in consultation with WaterNSW, to the satisfaction of the Secretary. The revised plan must include: (a) a program of long-term groundwater monitoring, to be developed in consultation with WaterNSW, to monitor groundwater levels at specific locations and depths until post-mining groundwater levels have stabilised; (b) flow gauges with sufficient low flow accuracy in watercourses LA2, LA3 and WC12; and (c) a monitoring and management strategy for waterfall WCWF54, which considers adaptive management of mining to avoid impacts to the waterfall.

The Dendrobium Mine Area 3B SMP performance measures for watercourses are outlined below.

Performance Measures for Area 3B

Condition 13 – Schedule 3

The Applicant must ensure that the development does not cause any exceedance of the performance measures in Table 1, to the satisfaction of the Secretary.

Waterfall WC-WF54

- Negligible environmental consequences including:
  - no rock fall occurs at the waterfall or from its overhang;
  - no impacts on the structural integrity of the waterfall, its overhang and its pool;
  - negligible cracking in Wongawilli Creek within 30 m of the waterfall; and
  - negligible diversion of water from the lip of the waterfall.

Wongawilli Creek and Donalds Castle Creek

- Minor environmental consequences including:
  - minor fracturing, gas release and iron staining; and
  - minor impacts on water flows, water levels and water quality.

Water Storages

- Negligible environmental consequences including:
  - negligible reduction in the quality or quantity of surface water inflows to the reservoir;
  - negligible reduction in the quality or quantity of groundwater inflows to the reservoir; and
  - negligible leakage from the reservoir to underground mine workings.

2.3 Leases and Licences

The following licences and permits may be applicable to IMC's operations in Dendrobium Area 3B:

- Dendrobium Mining Lease as shown in **Table 2**;
- Environmental Protection Licence 3241 which applies to the Dendrobium Mine. A copy of the licence can be accessed at the EPA website via the following link http://www.environment.nsw.gov.au/poeo;
- Dendrobium Mining Operations Plan FY 2016 to FY 2022;
- Relevant Occupational Health and Safety approvals; and
- Any additional leases, licences or approvals resulting from the Dendrobium Development Consent.

Table 2 Dendrobium Leases

Mining Lease - Document Number	Issue Date	Expiry Date/ Anniversary Date
CCL 768	7 May 1998	7 September 2026

3 MONITORING

3.1 Subsidence Monitoring

Survey monitoring techniques will be employed at Upland Swamps and watercourses throughout the Study Area to measure subsidence movements. Additionally, regional 3D Global Navigation Satellite System (GNSS) marks will be placed at strategic positions throughout the Study Area to monitor absolute surface movements.

Pending site access and approval, survey monitoring lines will be established across watercourses and Upland Swamps within the 20 mm predicted subsidence contour. The monitoring lines will target controlling rockbars and steps. Additionally, survey monitoring lines have been installed across the Wongawilli Creek valley to measure closure (or opening) of the valley. Wongawilli Creek monitoring lines will be subject to site constraints

Watercourse and Upland Swamp monitoring lines will employ a series of marks along a transect at nominally 20 m intervals. If practical, Upland Swamp transects will be related to a GNSS control network to provide absolute 3D movements in addition to level, tilt and strain changes.

Nominal accuracy will be +/- 5 mm relative between marks and +/- 20 mm for horizontal and vertical accuracy if the swamp is related to a GNSS control network. Survey closure lines across the Wongawilli Creek valley will be measured for closure only; nominal accuracy will be +/- 5 mm.

Survey monitoring sites will be chosen for suitability and detailed in the Dendrobium Survey Monitoring Program, separate to the SMP. Baseline monitoring will be conducted prior to active subsidence.

3.2 Area 3B Watercourses

Extensive geomorphological mapping has been completed for Dendrobium Area 3, including the location of significant features in the watercourses (**Figure 1-1**). In line with recommendations of IEP (2019a) and the 2016 Catchment Audit (Alluvium Consulting Australia 2017a) the locations and timing of monitoring for ecological aspects, water quality and stream flow is integrated and uses a BACI design (**Table 3**). **Table 3** details watercourses to be monitored within Area 3B and 600 m of Longwall 18. Other watercourses throughout Area 3B will continued to be monitored in accordance with previous WIMMCPs where appropriate.

The eastern area is broadly sited on a plateau dissected by a number of relatively shallow sub-catchments draining either into Cordeaux River via Wongawilli Creek, Donalds Castle Creek or five un-named 1st and 2nd order streams draining directly to the southern end of Lake Avon.

The largest watercourse within Area 3B is Wongawilli Creek which is located between Areas 3A and 3B. The headwaters of Wongawilli Creek are located along a drainage divide separating runoff and shallow groundwater outflow from Native Dog Creek and Lake Avon to the west.

Donalds Castle Creek and its tributaries also drain the north-western part of Area 3B through a weakly incised plateau.

The south-western area drains directly to Lake Avon via five 1st and 2nd order streams designated as Native Dog Creek, ND1, LA2, LA3, LA4 and LA5.

The geomorphology of sub-catchments in Area 3B is typically characterised by upland plateau and a series of ‘benches’ comprised of catenary hill-slopes and swamps enclosed in roughly crescent-shaped cliff lines.

Wongawilli and Donalds Castle Creeks are permanent to perennial flowing streams with small base flows and increased flows for short periods of time during and after significant rain events.

Table 3 Summary of Watercourses to be Monitoired within Area 3B

Watercourse	Catchment	Monitoring
Sites within 600 m of Longwall 18		
Wongawilli*	Wongawilli	Water Quality, Observations, Photo, Water Level, Flow, Aquatic Ecology
WC15	Wongawilli	Water Quality, Observations, Photo, Water Level, Flow
WC12	Wongawilli	Water Quality, Observations, Photo, Water Level, Flow
WC7	Wongawilli	Water Quality, Observations, Photo, Water Level

Native Dog	Native Dog	Water Quality, Observations, Photo, Water Level, Flow
ND1	Native Dog	Water Quality, Observations, Photo, Water Level, Flow, Aquatic Ecology
ND1A	Native Dog	Water Observations, Water Level
ND1B	Native Dog	Water Observations, Water Level
ND1C	Native Dog	Water Observations, Water Level
ND2	Native Dog	Water Quality, Observations, Photo, Water Level
LA1	Lake Avon	Water Quality, Observations, Water Level, Photo
LA2	Lake Avon	Water Quality, Observations, Photo, Water Level, Flow
Area 3B Monitoring Sites		
Donalds Castle	Donalds Castle	Water Quality, Observations, Photo, Water Level, Flow, Aquatic Ecology
DC13	Donalds Castle	Water Quality, Observations, Photo, Water Level, Flow
WC21	Wongawilli	Water Quality, Observations, Photo, Water Level, Flow, Aquatic Ecology
WC18	Wongawilli	Water Quality, Observations, Photo, Water Level
WC16	Wongawilli	Water Quality, Observations, Photo, Water Level
WC9	Wongawilli	Water Quality, Observations, Photo, Water Level
WC8	Wongawilli	Water Quality, Observations, Photo, Water Level
WC6	Wongawilli	Water Quality, Observations, Photo, Water Level
LA3	Lake Avon	Water Quality, Observations, Photo, Water Level, Flow
LA4	Lake Avon	Water Quality, Observations, Photo, Water Level, Flow
LA5	Lake Avon	Water Quality, Observations, Photo, Water Level
LC5	Lake Cordeaux	Water Quality, Observations, Photo, Water Level, Flow

* Not located within 600 m boundary of the longwall.

3.3 Observational Monitoring

IMC has conducted ongoing monitoring of watercourses in the Dendrobium area since 2001 (**Figure 1-1**). This monitoring builds upon the understanding of processes within the watercourses, along with identifying and assessing any episodic or temporal changes.

This monitoring (along with other monitoring programs described in the WIMMCP) is consistent with (in part) *Condition 4 Schedule 3* "*include a general monitoring and reporting program addressing surface water levels, water flows, water quality, surface slope and gradient, erodibility, aquatic flora and fauna (including Macquarie Perch, any other threatened aquatic species and their habitats) and ecosystem function*".

The IMC Environmental Field Team is continuing to undertake structured monitoring assessments, including:

- Water: location, volume and flow characteristics;
- Significant features: rockbars, pools and flow channels;
- Vegetation: location, species and observed health; and
- Sediment: composition, depth and moisture.

Monitoring sites and frequencies are provided in **Table 1.1 (Appendix A)**. Additional monitoring within Dendrobium Area 3B will be installed ahead of longwall mining to achieve 2 years baseline data (subject to timing and approval timeframes of any request to install additional monitoring).

Observations of any surface water and vegetation appearance for prominent species are undertaken. Where surface water is present within a swamp or a watercourse the data collected includes water quality parameters (using a monitoring probe) and water levels from installed benchmarks established at the pool. Observations of any surface flow are also made during monitoring.

This data is used to compare differences in site conditions of swamps and watercourses before and after mining. Sites that will not be mined under are also monitored to provide a comparison of sites mined under and sites not mined under during different climatic conditions.

Schedule 4, Condition 12(b) of the Area 3B SMP Approval requires that potential baseflow losses along Wongawilli Creek be monitored and assessed. IMCEFT routinely make qualitative observations of flow conditions (e.g. “surface flow”/”subsurface flow”/”not flowing”) along watercourses in Area 3B. Observations are usually at pools, where the inflow to and outflow from pools are described. Of these, the outflow condition is considered more reliable. Details on the assessment process and triggers for potential baseflow reductions on Wongawilli Creek are detailed in Watershed Hydrogeo (2019) and **Appendix A**.

This monitoring provides key data to assess the Donalds Castle and Wongawilli Creek’s performance measure of minor impacts: such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality.

The following Area 3B sites along watercourses and swamps are included in the observational monitoring program:

- Features (**Figure 3-1 to Figure 3-10 and Figure 3-24 to Figure 3-32**) :
  - WC21, Native Dog Creek, ND1, LA1 Wongawilli and Donalds Castle Creeks (commenced 2001);
  - Swamps 5, 10, 11, 13, 14, 23, 35a, and 35b (commenced March 2005);
  - WC15 and LA4 (commenced 2006);
  - DC13 (commenced 2011);
  - Swamps 1a and 1b (commenced May 2012);
  - Swamp 8 (commenced February 2013);
  - LA4 and LA5 (commenced May 2013);
  - LA2 (commenced 2012);
  - Swamp 4 (commenced December 2013);
  - Swamp 3 (commenced January 2014);
  - WC16 and WC18 (commenced October 2015); and
  - WC6, WC7, WC8, WC9, WC12 (commenced May 2018).
- Reference sites (**Figure 3-11 to Figure 3-24, Figure 3-27, Figure 3-28** to **Figure 3-30, Figure 3-33 to Figure 3-35**):
  - Swamps 2, 7, 15a, 22 (tributary to Cordeaux River), 24, 25, 33, 84, 85, 86, 87 and 88.
  - Wongawilli Creek, Sandy Creek, LC5 (tributary to Lake Cordeaux), WC11 (Swamp 33), SC9A (Swamp 84), SC10A, NDC1, DC10 (Swamp 85), D10 and Gallahers Creek (Swamp 88).

The monitoring sites above include existing and proposed monitoring sites. Due to the steep terrain, dense vegetation and shallow sediment depth, proposed monitoring sites may be relocated to a more suitable site. Additionally, proposed monitoring site locations have not been assigned site identification numbers at this time, as they may be subject to change until site suitability is confirmed. Proposed pool water level and observation monitoring sites will be finalised to allow for two years of baseline monitoring.

3.4 Surface Water Flow and Pool Water Level

Pool water levels in swamps and streams are measured using installed benchmarks in impact sites (**Figure 3-24 to Figure 3-32**) and reference sites (**Figure 3-15, Figure 3-18, Figure 3-24, Figure 3-27, Figure 3-28** to **Figure 3-30, Figure 3-33 and Figure 3-34**).

Pool water level/flow gauges and data loggers are installed at stream flow monitoring sites (**Figure 3-35**). Data has been collected since 2003 and has been compiled within monitoring and field inspection reports (Illawarra Coal 2011), EoP Reports and regular impact update reports. Pool water level and flow monitoring sites have been established in Dendrobium Area 3B for monitoring before, during and after mining.

Pool water levels will be measured monthly before and after mining, on a weekly basis during active subsidence and in response to any identified impacts. Water level measurements will be undertaken relative to benchmarks installed on rocks or other stable features on the edge of the pools.

This data is used to compare differences in pool water levels within swamps and streams before and after mining. Sites that will not be mined under are also monitored to provide a comparison of mined and not mined under sites during different climatic conditions.

This monitoring provides key data to assess the Donalds Castle and Wongawilli Creeks Performance Measure of Minor impacts: such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality.

Performance against this measure will be based on comparing pool water levels before mining with after mining. Exceeding prediction is defined as fracturing resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period along Donalds Castle Creek or Wongawilli Creek. Pool water level data would also be used to determine the success of any pool/rockbar mitigation or rehabilitation.

Surface water flow data for the Dendrobium area is available from a series of flow gauges operated by IMC. These gauging stations provide estimates of stream flow via:

- A structure behind which water pools and flows over. The structures can be:
  - A natural, e.g. a rock bar, or
  - A man-made, e.g. a half-pipe flume.
- A sensor and logger that measure and record the water level ("stage") in the pool at 15-minute intervals.
- A "rating curve" which is a chart or graph of discharge (flow) versus stage for each gauging station. The rating curve is developed via periodic measurements of flow in the channel at a known water level.
- Estimates of mean daily flow are then provided.

An independent hydrologist are currently working to systematically identify and quantify the accuracy or error involved in each part of the process. The aim of the assessment is to document accuracy across the range of flows at a sample of representative sites.

The flow monitoring sites are installed downstream of the mining area to assess any changes in surface flow from a catchment resulting from the mining. Sites have previously been installed using natural flow control features such as rockbars. However, in line with the recommendations of the IEP (2019a) and approval from WaterNSW, the installation of low-flow weirs has commenced, in order to gain high quality low-flow data. Flow monitoring sites are not installed directly over the longwalls as mining induced surface fracture networks typically result in recession flows being significantly or entirely diverted below the surface. The downstream monitoring sites are installed to measure catchment flow and monitor for reductions downstream of the mining area.

Flow gauges have been installed on Sandy Creek (Area 3A); Wongawilli Creek (Area 3B and 3A) and its tributaries WC21, WC15 and WC12 (DA3B); Donalds Castle Creek and its tributary DC13 (DA3B) and Lake Avon tributaries LA2, LA3, LA4 and NDT1 (Area 3B). The historical flow record has been plotted alongside the record from a nearby 'control' gauge i.e. a gauge that was not mined under, either at all or not during the period of interest (**Figure 3-37**).

A review of the Trigger Action Response Plan (TARP) regarding surface water flows was undertaken in consultation with WaterNSW, DPIE and BCD between 2018 and 2020 (**Appendix A**). Key features of the updated TARPs are:

- Inclusion of a comparison of flows recorded at relevant sub-catchment monitoring sites around the Dendrobium mining area against reference sites, supplemented by rainfall-runoff modelling.
- Assessment of sub-catchment hydrology against indicators appropriate to identify and quantify potential effects on the broad hydrological behaviour within each sub-catchment; including effects on cease-to-flow conditions that may be significant to ecological values, and effects on median flow which is significant for the water resource potential.

A further assessment has been implemented to analyse the mining effects on low-flows that are known to occur along the "middle reach" of Wongawilli Creek, between Areas 3A and 3B.

This review determined that two key flow reference sites were suitable:

- Wongawilli Creek at WWU (300024). This station is operated by IMC. Monitoring commenced more than 2 years prior to mining in Area 3A, so has an appropriate pre-mining baseline record. This catchment is adjacent to Dendrobium Areas 3A and 3B and has the same geology and land use. The catchment size (3.2 sq.km) is slightly larger or similar in magnitude to many of the gauged sub-catchments to be assessed at Dendrobium. Despite proximity to Elouera Colliery, it is considered to be close to natural.
- O'Hares Creek at Wedderburn (#213200). This station has a long record, extending back to the late 1970s. The catchment is large (73 sq.km) compared to the area of mining, but is considered to be appropriate as a control site. This gauging station is approximately 28 km north of Area 3B.

Surface water flow sites in the mining area will be assessed against the key flow reference sites during assessments for the EoP Report. The assessment comprises three checks of pre- versus post-mining behaviour for each assessment site.

Trigger values are proposed for water flow parameters in the TARP (**Appendix A**). The TARPs are based on the following parameters and assessments:

A. Change in flow exceedance ("Q%ile") behaviour compared to key flow reference sites. In essence, this aims at quantifying an otherwise visual or qualitative assessment of flow behaviour (compared to normalised key flow reference site flow).

B. Relative change in the frequency of cease-to-flow days compared to key reference sites;

C. Relative change in Q50 (median flow) compared to key reference sites flows; and

D. Baseflow reduction along Wongawilli Creek, between Areas 3A and 3B.

A more detailed discussion of these assessments, developed and refined in consultation with agencies, is provided in Watershed HydroGeo (2019). If any of these indicate an impact is likely to have occurred, then the EoP Report will describe the impact as it relates to one or more of the broad hydrological behaviours, a reduction in the water resource Indicator, or Impact that could affect the ecological values of the stream. In the event that there is a reduction in Q50 median flow (Assessment C) or base flow reduction (Assessment D, and there is a Performance Measure related to that watercourse, then the reduction would be compared against the predicted losses (from contemporary Groundwater and Surface Water Assessments (e.g. those in **Section 5.2.5**) to assess whether effects that cannot be explained by natural variability "exceed prediction". The assessment will determine if the impact is 'within Prediction' or 'exceeding Prediction', with further actions triggered by that outcome.

IMC commissioned the development of a regional-scale numerical groundwater flow model in support of mining at Dendrobium Colliery (Coffey Geotechnics 2012). IMC commissioned HydroSimulations (2014) to review and enhance the Model and this model has been updated and revised at regular intervals since then.

3.5 Near-Surface Groundwater and Soil Moisture

The surface area above Dendrobium Area 3B is characterised by a series of drainage basins separated by steep ridges. The drainage basins drain to Wongawilli Creek, Donalds Castle Creek and directly into Lake Avon (Ecoengineers 2012).

Monitoring of shallow groundwater levels allows for the indirect measurement of water storage and transmission parameters within the saturated part of hill-slope/upland swamp complexes. Shallow groundwater piezometers have been installed within and around several swamps and associated watercourses in Area 3 (**Figure 3-1** to **Figure 3-23**), including the hill-slope aquifers on the eastern side of Sandy Creek; within Swamp 15b (SC10C) and Swamp 12 (WC17). Within Area 3B long-term piezometer records are available for Swamp 11 (LA4A1) as well as additional sites installed since 2011 (**Figure 3-1 to Figure 3-10**). Swamps 2 (Donalds Castle Creek), 7 (LC5 Lake Cordeaux tributary), 15a (SC10), 22, 24, 25, 33 (WC11), 84 (SC9A), 85 (DC10), 86, 87 and 88 (Gallahers Creek) have been selected as reference monitoring sites (**Figure 3-11 to Figure 3-23**). This data is used to compare differences in shallow groundwater levels within swamps, streams and hill-slope aquifers before and after mining. Sites that will not be mined under are also monitored to provide a comparison of sites mined under and not mined under during different climatic conditions.

The piezometric monitoring directed at shallow groundwater levels is supplemented with monitoring of soil moisture profiles up to a maximum 1.2 m (**Figure 3-4 to Figure 3-23**). Key monitoring sites have been installed with loggers to provide a continuous soil moisture record.

The shallow groundwater piezometers and soil moisture probe data is compared with the Cumulative Monthly Rainfall Residuals (a key parameter for interpreting temporal soil and shallow groundwater data). Comparisons of the Cumulative Monthly Rainfall Residuals against mean monthly water heads in shallow groundwater piezometers and soil moisture profiles will take into account the known distribution of rainfall isohyets (contours of equal annual precipitation) in the local region (these being denser and less smooth closer to the Illawarra Escarpment and much wider proceeding northwest).

Several climate stations are available for analysis and modelling in Dendrobium Area 3B with the most appropriate data taking into account proximity, length of record and data quality.

A comprehensive array of multi-level piezometers have been installed on the centreline of panels at Dendrobium Mine in order to monitor pore pressure changes associated with subsidence. These monitoring holes include at least five transducers per borehole with installation at least 2 years prior to undermining, in line with the recommendations of the IEP (2019a and b). Where these monitoring sites are damaged as a result of undermining they are reinstalled after subsidence movements cease. Daily monitoring of local rainfall and mine water ingress from overlying and surrounding strata, and separation of rainfall correlated inflows for base flow volumetric analyses is also undertaken (IEP 2019a).

3.6 Water Quality and Chemistry

Monitoring undertaken by IMC since 2003 (**Figure 3-35**) includes water quality monitoring of parameters such as pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Oxygen Reduction Potential (ORP) and temperature. Water chemistry sites are tested for analytes in a laboratory including DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si.

The key field parameters of DO, pH, EC and ORP for monitoring sites within Dendrobium Area 3B (**Figure 3-24 to Figure 3-32**) will be analysed to identify any changes in water quality resulting from the mining. Pools and streams away from mining (**Figure 3-24, Figure 3-27, Figure 3-28** to **Figure 3-30 and Figure 3-33 to Figure 3-35**) are monitored to allow for a comparison against sites not influenced by mining.

Over time some water quality-specific site names have changed. These changes have been implemented to align monitoring site's names with mapped stream features. These changes are shown in **Table 4** below.

Table 4 Changes to Water Quality site names

Previous Site Name	Current Site Name	Watercourse
SCL	SCk_Rockbar 5	Sandy Creek
WWL2	Wongawilli Ck (FR6)	Wongawilli Creek
WWM1	WC_Pool 46	Wongawilli Creek
WWM3	WC_Pool 43b	Wongawilli Creek
DC_S2	DC_Pool 22	Donalds Castle Creek
DCU3	Donalds Castle Ck (FR6)	Donalds Castle Creek
WC15_S1	WC15_Pool 9	WC15
WC21_S1	WC21_Pool 5	WC21
DC13_S1	DC13_Pool 2b	DC13

Trigger values for water quality parameters are in detailed in the TARP (**Appendix A**). The TARPs are based on the field parameters pH, EC and DO due to the ability of these parameters to indicate potential mining impacts on water quality, the rapid and in situ nature in which they are determined, and the quantity of baseline data available, which for Wongawilli and Donalds Castle Creeks is greater than 18 years (since August 2001).

A change of three standard deviations (enclosing approximately 99.7% of the baseline data assuming a normal distribution) from the respective parameter means resulting from mining, will be used for determining potential exceedances of water quality performance measures.

Statistical analysis of baseline and impact period data will be provided in EoP Reports, including clearly specifying the duration of the baseline monitoring period. Any historical mining outside the project area (e.g. Wongawilli Creek mined beneath by Elouera) will be acknowledged and if required reflected in the baseline monitoring assessment.

Exceedances of these levels have occurred occasionally in the baseline period. This is to be expected assuming a normal statistical distribution of the data, in addition to random natural environmental effects on water quality such as storms (effects of decomposition of detrital organic matter), wildfires (ash wash off and dissolution effects), prolonged dry weather and drought (evaporative concentration effects).

As such, exceedance of the water quality performance measures will be quantitatively defined by "mining resulting in exceedance of the ± 3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean, for a minimum of two consecutive monitoring events". The performance measure is applied at the FR6 monitoring sites on both Donalds Castle Creek and Wongawilli Creek. For Avon Reservoir, the performance measure is applicable to monitoring site LA4, see Appendix A for further detail.

The water chemistry, algae and level of water in Avon Reservoir will be monitored as a basis for comparison to the mine water. The locations of the samples and the testing procedure have been developed in consultation with the Dam Safety NSW and WaterNSW.

3.7 Slopes and Gradients

Slopes within Area 3B have been mapped according to their gradients and are identified on Drawing 8 in MSEC (2020). Monitoring of landscape features such as cliffs, slopes and rock outcrop is undertaken in Area 3B (**Figure 3-38**).

Monitoring of these sites allows for the measurement of any changes to the surface including soil cracking, erosion and/or sedimentation impacts resulting from subsidence.

The inspection and monitoring includes the following:

- Monitoring sites based on an assessment of risk of impact where pre-mining measurements have been undertaken and reported;
- Areas of steep slopes that are en route or near monitoring sites;
- Rock outcrops that are en route or near monitoring sites;
- Any other sites where impacts have been previously observed that warrant follow-up inspection (i.e. rockfalls and soil cracking); and
- The general areas above the current mining location at the time of inspection.

The monitoring sites include comprehensive investigation as described below, and the wider area around the monitoring site is subject to inspection during monitoring events.

Observations on landform and land surface at the monitoring sites are recorded to account for the Australian Soil and Land Survey, Field Handbook, 2nd Edition (McDonald, Isbell, Speight, Walker and Hopkins 1990) as modified for subsidence monitoring.

Observations have been made of the landform elements in accordance with the Landform section of the Field Handbook. The landform element has generally been described in terms of the following attributes:

- Slope;
- Morphological type;
- Dimensions;
- Mode of geomorphological activity; and
- Geomorphological agent.

In addition, observation has been made of the land surface in accordance with the Land Surface section of the Field Handbook. The land surface has generally been described in terms of the following attributes:

- Aspect, elevation and drainage height;
- Disturbance at the site, including erosion and aggradations;
- Micro relief;
- Inundation;
- Coarse fragments and rock outcrop;

- Depth to free water; and
- Runoff.

A watercourse reach of between ten and twenty times the channel width is monitored to cover local geomorphological units (e.g. pool/riffle).

For each watercourse monitoring site, a range of measurements and observations of the watercourse characteristics are recorded along with established photo points. Measurements and observations incorporate the relevant parts of the Field Handbook, and relevant parts of the Riparian-Channel-Environmental Assessment (RCE) methodology (Petersen 1992).

While in most cases, impacts on steep slopes are likely to be restricted to surface cracks, there remains a low probability of large scale downslope movements. Steep slopes are therefore monitored throughout the mining period and until any necessary rehabilitation is complete. Slopes and gradients are monitored prior to mining as well as monthly during active subsidence during mining. The monitoring is undertaken at six monthly intervals for two years following completion of mining.

3.8 Erodibility

Most of the surface of Area 3B has been identified as highly weathered Hawkesbury Sandstone outcrops and Sandstone derived-soils. This soil landscape has been identified to have high to extreme erosion susceptibilities to concentrated flows. This results in potential flow on effects to slope stability and erosion from any cracking resulting from subsidence (Ecoengineers 2012). Landscape monitoring of slopes is undertaken in Area 3B to identify any erosion of the surface (**Figure 3-38**).

An extensive survey network has been implemented with some emphasis given to swamps and Wongawilli and Donalds Castle Creeks. Swamps 1a, 1b, 4, 5, 10, 11, 13 and 23 are monitored for relative and absolute horizontal and vertical movements. Additional swamps will be incorporated into the monitoring program prior to subsidence movements impacting the sites.

Due to terrain, vegetation and access restrictions, the primary method of identifying any erosion over Area 3B will be Airborne Laser Scanning (ALS). This technique has proven to be successful in generating topographic models of subsidence over entire longwalls and mining domains and will also provide identification of any erosion. The maximum areas, length and depth of erosion will be measured by standard survey methods.

Base surveys over Area 3B using ALS were completed in December 2005, with a verification base survey performed in 2013, immediately prior to the commencement of Longwall 9 extraction. Subsidence landscape models using the same methodology after the completion of subsidence at each longwall will provide a new (subsided) baseline surface dataset. For a period of up to ten years after mining repeat ALS datasets and surface modelling will be completed to identify new or increases in existing erosion. Erosion will be quantified by comparison of the immediate post subsidence landscape model with the long-term monitoring model. Targeted ALS scans will be completed where erosion is observed via the observational and landscape monitoring programs or after significant events such as bushfire and flooding.

The pre-mining landscape model from the ALS scan of Swamp 1A is provided as **Figure 3-39**. This landscape model identifies active pre-mining erosion of 179 m in DC13, adjacent to Swamp 1A, and 8 m within the swamp. The erosion is not visible in orthophotos (**Figure 3-40**) prior to the area being burnt in 2001-2002. The erosion was identified in 2003 (**Figure 3-41**) and has persisted during and following extraction of Longwall 9 in 2013 (**Figure 3-42**).

The nominal accuracy of ALS derived subsidence contours are in the order of +/- 0.10 m and effective algorithms have been developed to allow the use of ground strike data only within the assessment. This effectively allows the analysis to see through vegetation to the ground surface.

General observational inspections of the mining area will be undertaken at regular intervals, during active subsidence. In addition to erosion, these observations aim to identify any surface cracking, surface water loss, soil moisture changes, vegetation condition changes, and slope and gradient changes.

The observational monitoring program incorporates both impact (**Figure 3-1 to Figure 3-10 and Figure 3-24 to Figure 3-32**) and reference (**Figure 3-11 to Figure 3-23 and Figure 3-33 to Figure 3-35**) sites.

3.9 Flora, Fauna and Ecosystem Function

Terrestrial flora and vegetation communities in the Study Area are described in the SMP Terrestrial Ecology Assessment (Niche 2020). Aquatic flora and fauna in the Study Area are described in the Aquatic Ecology Assessment (Cardno 2020).

A monitoring program designed to detect potential impacts to ecology and ecosystem function from subsidence has been implemented for Area 3B. As recommended by the IEP (2019a), the monitoring program is based on a BACI design with sampling undertaken at impact and control locations prior to the commencement of extraction, during extraction and after extraction.

Over two years of baseline data is available for Area 3B and this data indicates that the habitat in this area is relatively undisturbed. There is sufficient baseline data to enable the detection of changes to ecology associated with mining related impacts.

The study focuses on flora, fauna and ecosystem function of swamps and watercourses and is measured via the following attributes:

- The size of the swamps and the groundwater dependent communities contributing to the swamps;
- The composition and distribution of species within the swamps;
- RCE including a photographic record of each stream assessment site;
- Water quality, including pH, DO, ORP, temperature, turbidity and EC;
- Aquatic macrophytes, including presence, species composition and total area of coverage;
- Aquatic macroinvertebrates using the Australian River Assessment System (AUSRIVAS) sampling protocol and artificial aquatic macroinvertebrate collectors;
- Fish presence and numbers using backpack electro fisher and/or baited traps; and
- Presence of threatened species (including Macquarie perch, Littlejohn's tree frog, Giant burrowing frog, Adams emerald dragonfly, Giant dragonfly and Sydney hawk dragonfly).

Standardised transects in potential breeding habitat for the threatened frog species Littlejohn's tree frog and Giant burrowing frog have been established in Dendrobium Area 3B. These repeatable surveys enable direct comparison of the numbers of individuals recorded at each site from one year to the next.

The following frog monitoring is undertaken in Area 3B streams:

- DC13 commenced 2007 (**Figure 3-43**);
- DC(1) commenced 2012 (**Figure 3-44**);
- WC21 commenced 2012 (**Figure 3-45**);
- LA4A commenced 2007 (**Figure 3-46**);
- ND1 commenced 2011 (**Figure 3-47**); and
- WC15 commenced 2011 (**Figure 3-48**)

Additional monitoring will commence in other streams two years prior to mining. Monitoring is also undertaken away from mining to act as control sites for the mining versus non-mining comparative assessment (**Figure 3-49 to Figure 3-57**). Although there has been mining upstream of Sites SC6, SC8 and NDC, data to date indicates there are strong numbers of frogs in these areas for monitoring purposes.

Along each transect the monitoring includes: counts of frogs, an assessment of pools being used for breeding as well as counts of tadpoles and egg masses. This will enable a quantitative as well as qualitative assessment of breeding habitat for these species prior to, during and after mining.

Observations of the sites, photo points and pool water level data will also be collected as part of the frog and observational monitoring programs (**Figure 3-43 to Figure 3-48**). Locations where significant changes have been observed (e.g. drainage of pools) will be mapped, documented and reported.

Aquatic ecology monitoring includes direct measures of aquatic flora and fauna as well as biophysical measures. Aquatic ecology monitoring sites for Area 3B are shown in (**Figure 3-58**). These sites are located in watercourses that contain “significant” or “moderate” aquatic habitat and are suitable for AUSRIVAS assessment (i.e. are at least 100m long).

During the baseline study the condition of the aquatic habitat at each site was assessed using a modified version of RCE (Chessman *et al.* 1997).

At each site where instream aquatic macrophytes are present, their species composition and total area of coverage is recorded. Features such as the presence of algae or flocculent on the surface of macrophytes would also be noted.

Two methods are used to sample aquatic macroinvertebrates: the AUSRIVAS protocol for NSW streams (Turak *et al.* 2004) and artificial aquatic macroinvertebrate collectors, a quantitative method developed by CEL for freshwater environmental impact assessment.

In consideration of the possible presence of threatened macroinvertebrate species within the SMP Area, all dragonfly larvae collected in invertebrate sampling will be identified to the taxonomic level of family. Any individuals of the genus Petalura, Austrocorduliidae and Gomphomacromiidae will be further identified to species level if possible, and if there is any confusion, specimens will be referred to a specialist taxonomist. The confirmed presence of a threatened species will trigger further investigation into the species and its habitats in relation to potential subsidence impacts.

Fish are sampled using a back-pack electrofisher (model LR-24 Smith-Root) and baited traps. At each site, eight baited traps are deployed in a variety of habitats such as amongst aquatic plants and snags, in deep holes and over bare substratum. The back-pack electrofisher is operated around the edge of pools and in riffles. At each site, four, two-minute shots are performed. Fish stunned by the current are collected in a scoop net, identified and measured. Native species are released unharmed while exotics are not returned to the water.

Ongoing monitoring uses the BACI design with two types of monitoring sites included in the program:

- Potential impact sites - these may be subject to mine subsidence impacts during and after longwall extraction; and
- Control sites - these will provide a measure of background environmental variability within the catchments as distinct from any mine subsidence impacts.

The “potential impact” sites are as follows:

- Wongawilli Creek - Sites 1, 2, 3 and 4 situated adjacent to the eastern ends of Longwalls 15, 13, 11 and 9, respectively and Sites X4, X5 and X6, distributed adjacent to the eastern ends of Longwalls 17 and 18;
- Donalds Castle Creek – Site X1 situated adjacent to Longwall 9 (where the creek emerges from an upland swamp); and
- WC21 - Sites X2 and X3 which are located above Longwalls 9 and 11 where there is suitable aquatic habitat.

Sites 2, 3 and 4 are also “potential” impact sites for Dendrobium Area 3A. The control sites for Area 3B are the same as those for Area 3A and are as follows:

- Wongawilli Creek – Site 5 downstream of the potential impact zone;
- Donalds Castle Creek - Site 14;
- WC21 - Site 6 situated near the confluence of WC21 and Wongawilli Creek;
- Sandy Creek - Site 7 situated well upstream of the potential impact zone for Dendrobium Area 3A; and
- Kentish Creek - Sites 15 and 16.

Observation data will also be collected as part of the monitoring program. Locations where significant changes have been observed (e.g. drainage of pools) will be mapped, documented and reported.

3.10 Pools and Controlling Rockbars

Dendrobium Mine lies in the southern part of the Permo-Triassic Sydney Basin. The geology mainly comprises sedimentary sandstones, shales and claystones, which have been intruded by igneous sills.

The sandstone units vary in thickness from a few metres to as much as 120 m. The major sandstone units are interbedded with other rocks and, though shales and claystones are quite extensive in places, the sandstone predominates.

The major sedimentary units at Dendrobium are, from the top down:

- The Hawkesbury Sandstone.
- The Narrabeen Group (including the Bulgo Sandstone).
- The Eckersley Formation.

Extensive geomorphological mapping has been completed for Dendrobium Area 3, including the location of pools and rockbars (**Figure 3-59**).

The eastern area is broadly sited on a plateau dissected by a number of relatively shallow sub-catchments draining either into Cordeaux River via Wongawilli Creek or Donalds Castle Creek or five un-named 1st and 2nd order streams draining directly to the southern end of Lake Avon.

The largest watercourse within Area 3B is Wongawilli Creek (**Figure 3-24**) which is located between Areas 3A and 3B. The headwaters of Wongawilli Creek are located along a drainage divide separating surface runoff and shallow groundwater outflow runoff from Native Dog Creek and Lake Avon to the west.

Donalds Castle Creek and its tributaries (**Figure 3-27**, **Figure 3-28** and **Figure 3-29**) also drain the north-western part of Area 3B through a weakly incised plateau. Donalds Castle Creek catchment on this plateau is characterised by low topography, upland swamps and numerous unconfined shallow hillslope aquifers. Much of the soil is derived from weathering of shale-rich Mittagong Formation and is more clayey and of lower permeability than residual soils developed purely on Hawkesbury Sandstone outcrop.

The south western area drains directly to Lake Avon via five 1st and 2nd order streams designated as Native Dog Creek tributary No. 1 (**Figure 3-30**) and LA2, LA3, LA4 and LA5 (**Figure 3-31** and **Figure 3-32**).

The geomorphology of tributary sub-catchments in Area 3B is typically characterised by upland plateau and a series of ‘benches’ comprised of catenary hill-slopes and swamps enclosed in roughly crescent-shaped cliff lines.

The upstream southern end of the catchment consists of a ridge containing a thin sandy soil profile accumulated on a generally dome shaped outcrop. This outcrop exhibits pronounced removal of the sandstone's kaolinite clay cement and is typically white and friable (Hazelton and Tille 1990).

Drainage is to the north east and south west down slopes, with little evidence of surface drainage channels. This is consistent with headwater hill-slope aquifer zones and overland sheet flow during extreme rainfall events.

Wongawilli, Sandy and Donalds Castle Creeks are perennial flowing streams with small base flows and increased flows for short periods of time after each significant rain event.

Beds of the creeks are typically formed within Bulgo Sandstone, which overlies the Stanwell Park Claystone; however, there are sections of the headwaters of these creeks which are formed within the Hawkesbury Sandstone.

Three distinct channel types may be recognised in the main channel uplands, and in the tributaries of Wongawilli and Donalds Castle Creeks:

- Narrow indistinct channels associated with low sedge/heath type vegetation cover and a relatively thick sandy riparian soil profile. The streambed consists of weathered bedrock and/or sandy materials. This is the situation in which valley infill swamps may be found.
- Rock platforms of variable width which are usually smooth except for minor depressions on joint planes and occasional potholes. These platforms normally grade to a thinly vegetated sandy soil on both sides and usually exhibit the effects of chemical deposition of hydrated iron oxides. This deposition ranges from a slight colouration of the surface strata to intense replacement of the rock fabric.
- Channels that are erosive into cross-bedded sandstone and exhibit a rough riffle like surface usually with accumulations of boulders and other sediments. These channels are usually bounded by solid rock outcrop.

A number of semi-permanent pools may be found within the channels of these drainage lines and creeks. The mechanisms of pool stability are variable and uniquely depend on local stratigraphy, structure and gradient. Pools range from:

- Water accumulations in depression of an impermeable bedrock shelf (analogous to a bathtub) that is fed by direct precipitation, seepage or flood events; to
- Pools within eroded sections of sandy sediment and a free water surface that is dependent on surface flows and the local groundwater regime for stability.

A number of distinct pool types can be recognised:

- Shallow, usually linear, small pools located in depressions formed by joint systems or cross-bedding and sometimes associated with potholes. Accumulated water is usually less saline than surrounding pools and has little interaction with the local groundwater system.
- Linear pools associated with narrow erosion channels in sandy soil profiles. The soil profile is usually vegetated with heath/sedge like species. The downstream end is usually associated with a low rockbar or outcrop.
- Larger pools constrained by a rockbar on the downstream end. These rockbars are usually undercut by erosion and exhibit signs of chemical weathering.
- Larger pools constrained mainly by sediments on the downstream end. The sediments may extend for a considerable distance downstream and are associated with valley infill channels described above.

Pools within unconsolidated (sandy) sediments are in a state of equilibrium between water in (from a higher part of the phreatic groundwater surface either upstream or laterally) and water out (flowing down the phreatic surface).

Most bedrock pools and riffle complexes rely on equilibrium between excess water in compared to water out. If the water inflow is less than the outflow then the pool level declines. The nature of this equilibrium is ultimately dependent on the position of the pool on the overall stream gradient. Many pools in the streams naturally develop at rockbars and at sediment and debris accumulations.

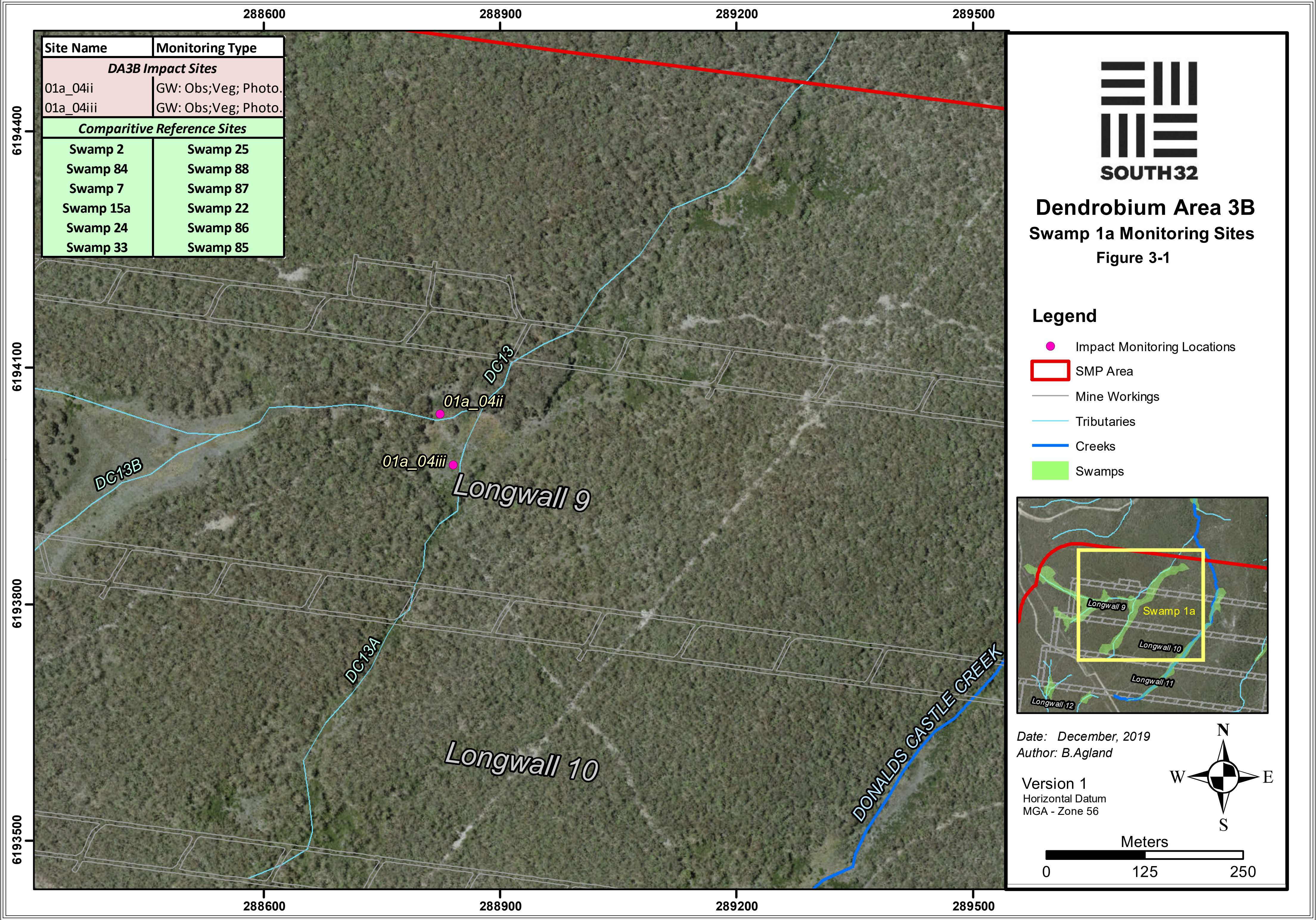
Rockbars and pools in Donalds Castle and Wongawilli Creeks (**Figure 3-59**) have been mapped. Donalds Castle Creek Pool 33 (**Figure 3-60**) is a significant permanent pool within Area 3B. All mapped rockbar controlled pools in Wongawilli Creek are significant permanent pools.

3.11 Reporting

EoP Reports are prepared in accordance with Condition 9 Schedule 3 of the Dendrobium Development Consent. Results from the monitoring program are included in the EoP Report and in the AEMR. These reports detail the outcomes of monitoring undertaken; provide results of visual inspections, and determine whether performance indicators have been exceeded.

Monitoring results will be reviewed monthly by the IMC Subsidence Management Committee. However, if the findings of monitoring are deemed to warrant an immediate response, the Principal Approvals will initiate the requirements of the TARPs (**Appendix A**).

Monitoring results are included in the Annual Reporting requirement under Condition 5, Schedule 8 in accordance with the Dendrobium Development Consent and are made publicly available in accordance with Condition 11, Schedule 8.



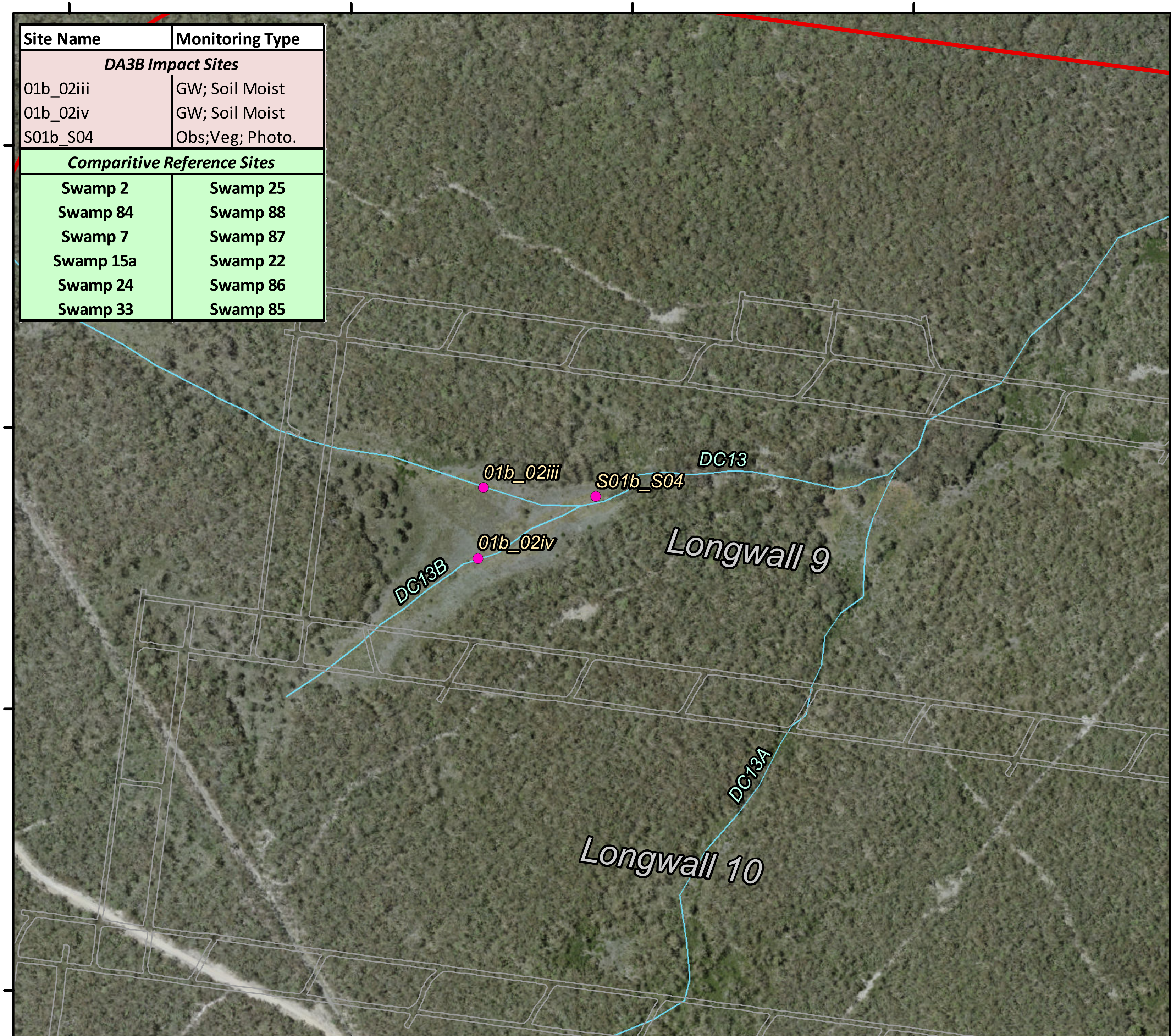
Site Name	Monitoring Type
DA3B Impact Sites	
01a_04ii	GW: Obs;Veg; Photo.
01a_04iii	GW: Obs;Veg; Photo.
Comparitive Reference Sites	
Swamp 2	Swamp 25
Swamp 84	Swamp 88
Swamp 7	Swamp 87
Swamp 15a	Swamp 22
Swamp 24	Swamp 86
Swamp 33	Swamp 85

Dendrobium Area 3B

Swamp 1b Monitoring Sites

Figure 3-2

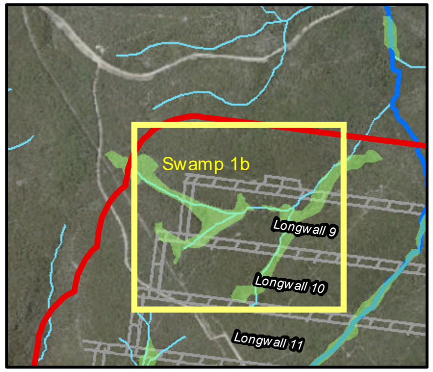
Site Name	Monitoring Type
DA3B Impact Sites	
01b_02iii	GW; Soil Moist
01b_02iv	GW; Soil Moist
S01b_S04	Obs;Veg; Photo.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**



SOUTH32

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Tributaries
- Creeks
- Swamps



Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
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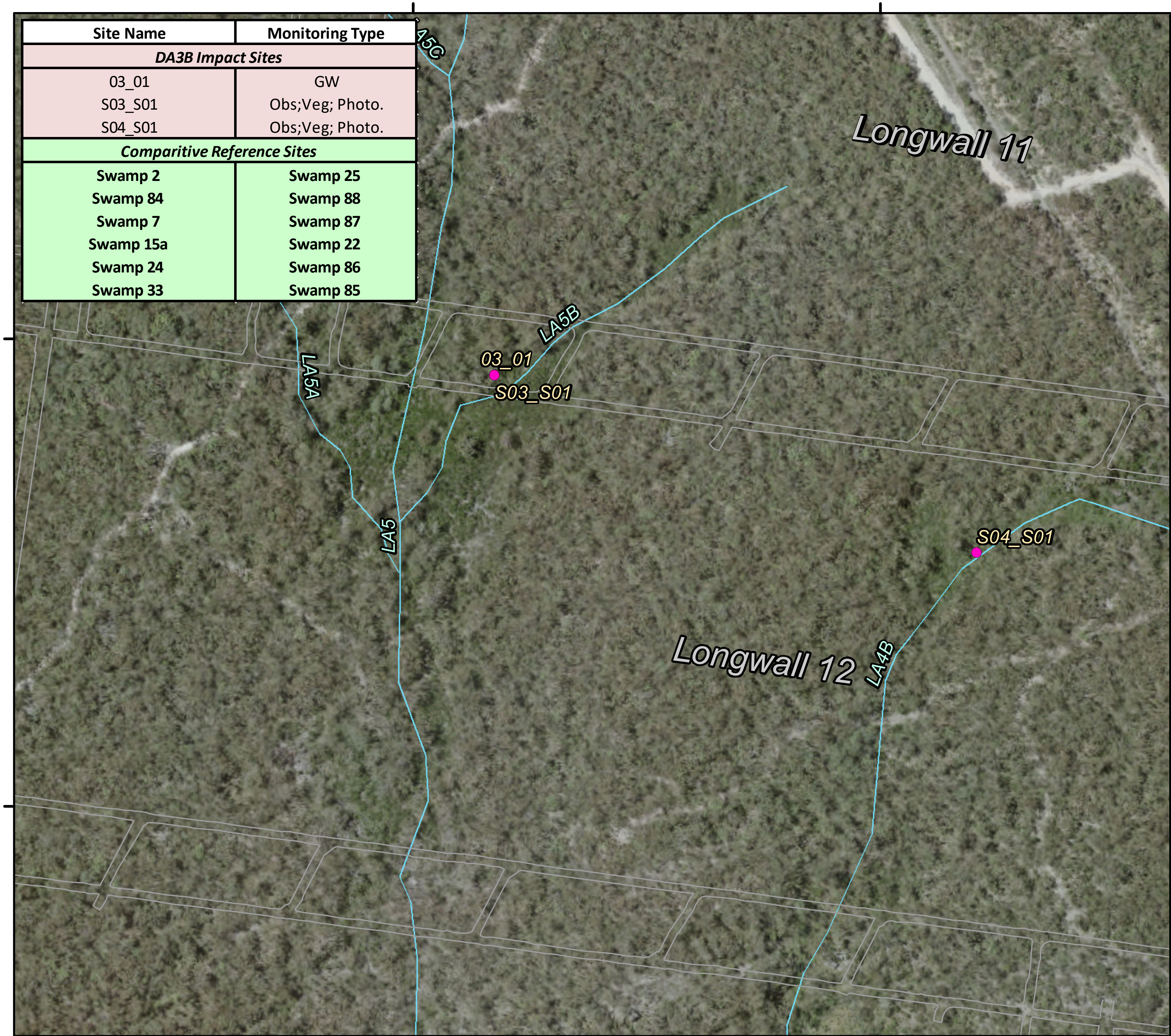
Meters
0 125 250

Site Name	Monitoring Type
DA3B Impact Sites	
03_01	GW
S03_S01	Obs;Veg; Photo.
S04_S01	Obs;Veg; Photo.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**



SOUTH32

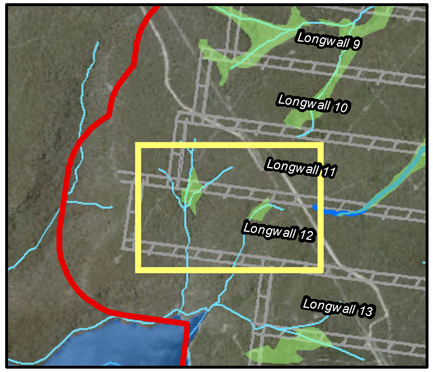
Dendrobium Area 3B

Swamp 3 & 4 Monitoring Sites

Figure 3-3

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Tributaries
- Swamps



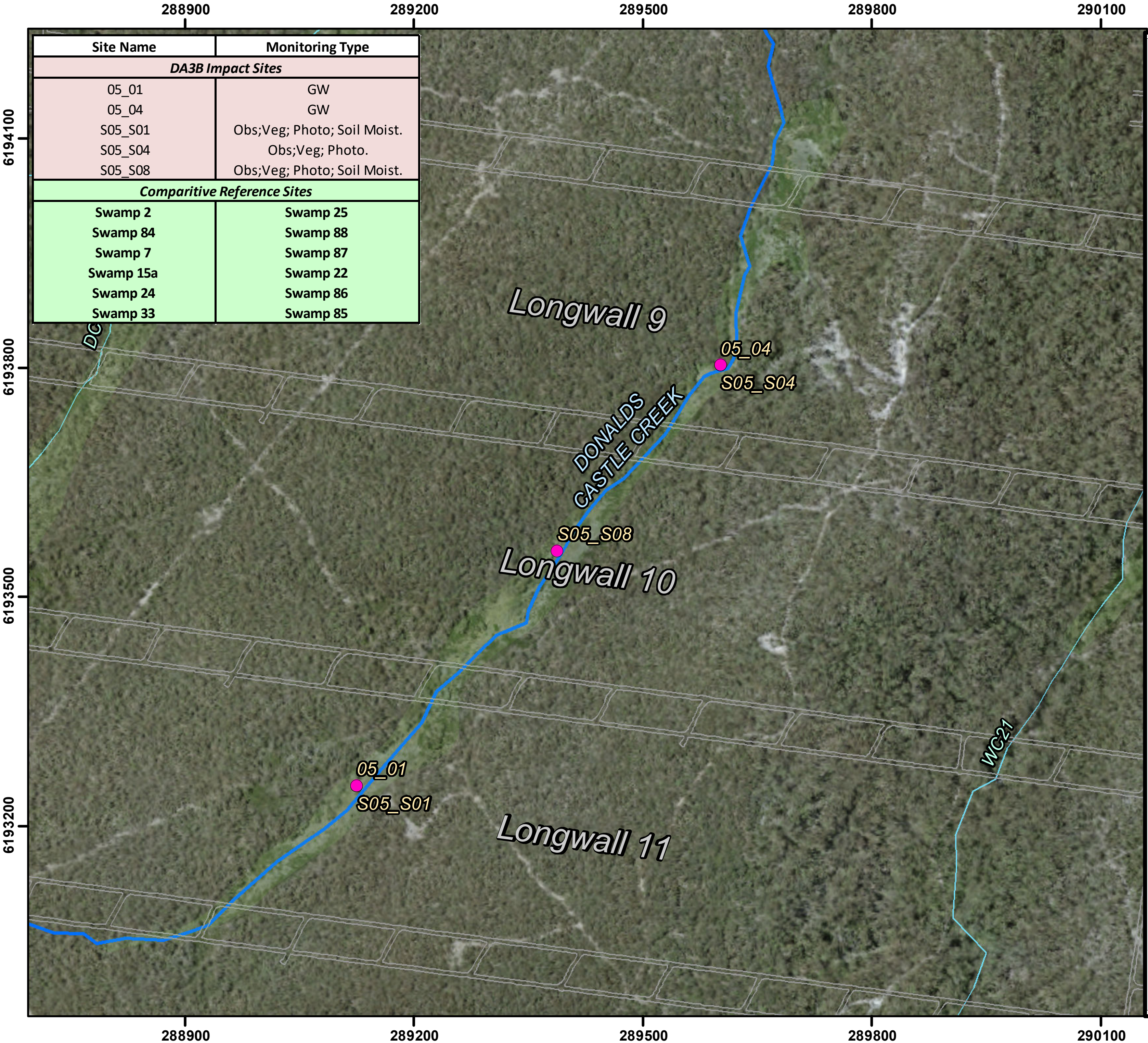
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 50 100

Site Name	Monitoring Type
DA3B Impact Sites	
05_01	GW
05_04	GW
S05_S01	Obs;Veg; Photo; Soil Moist.
S05_S04	Obs;Veg; Photo.
S05_S08	Obs;Veg; Photo; Soil Moist.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**



SOUTH32

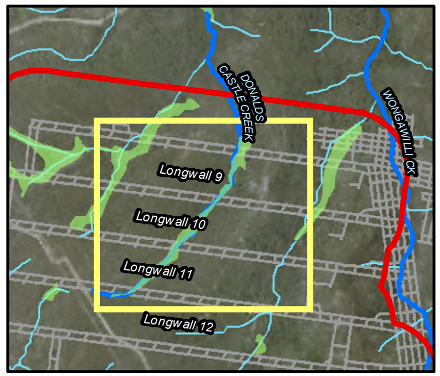
Dendrobium Area 3B

Swamp 5 Monitoring Sites

Figure 3-4

Legend

- Impact Monitoring Locations
- Swamps
- SMP Area
- Mine Workings
- Tributaries
- Creeks

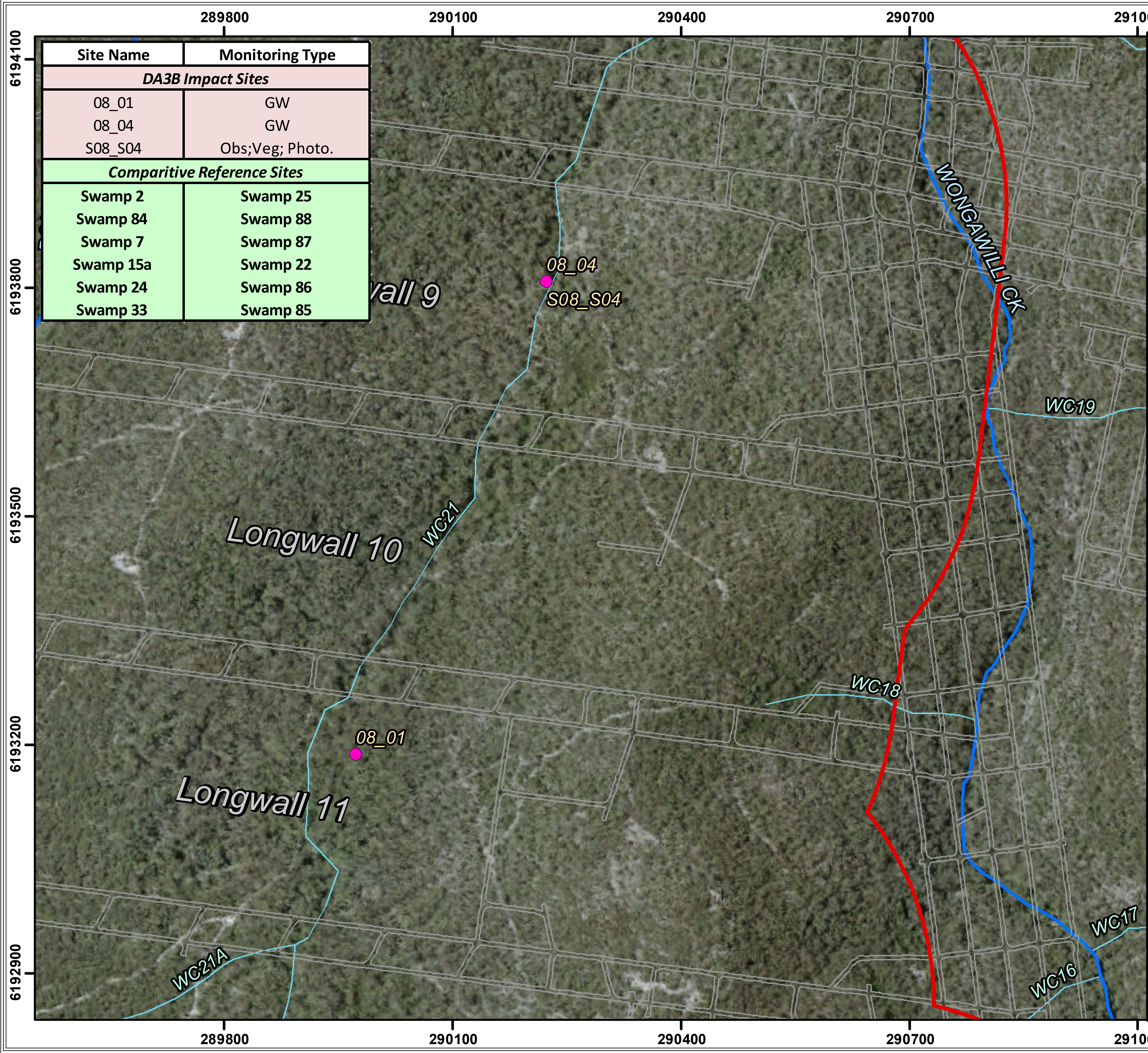


Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W
E
S

Meters
0 125 250



Site Name	Monitoring Type
DA3B Impact Sites	
08_01	GW
08_04	GW
S08_S04	Obs;Veg; Photo.
Comparitive Reference Sites	
Swamp 2	Swamp 25
Swamp 84	Swamp 88
Swamp 7	Swamp 87
Swamp 15a	Swamp 22
Swamp 24	Swamp 86
Swamp 33	Swamp 85

SOUTH32

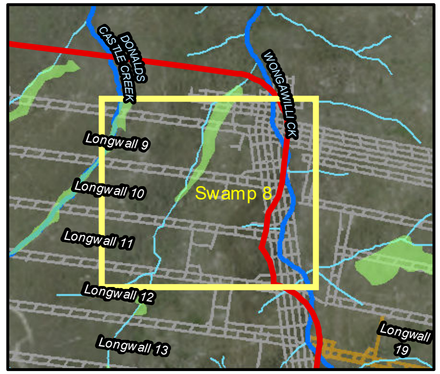
Dendrobium Area 3B

Swamp 8 Monitoring Sites

Figure 3-5

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries
- Creeks

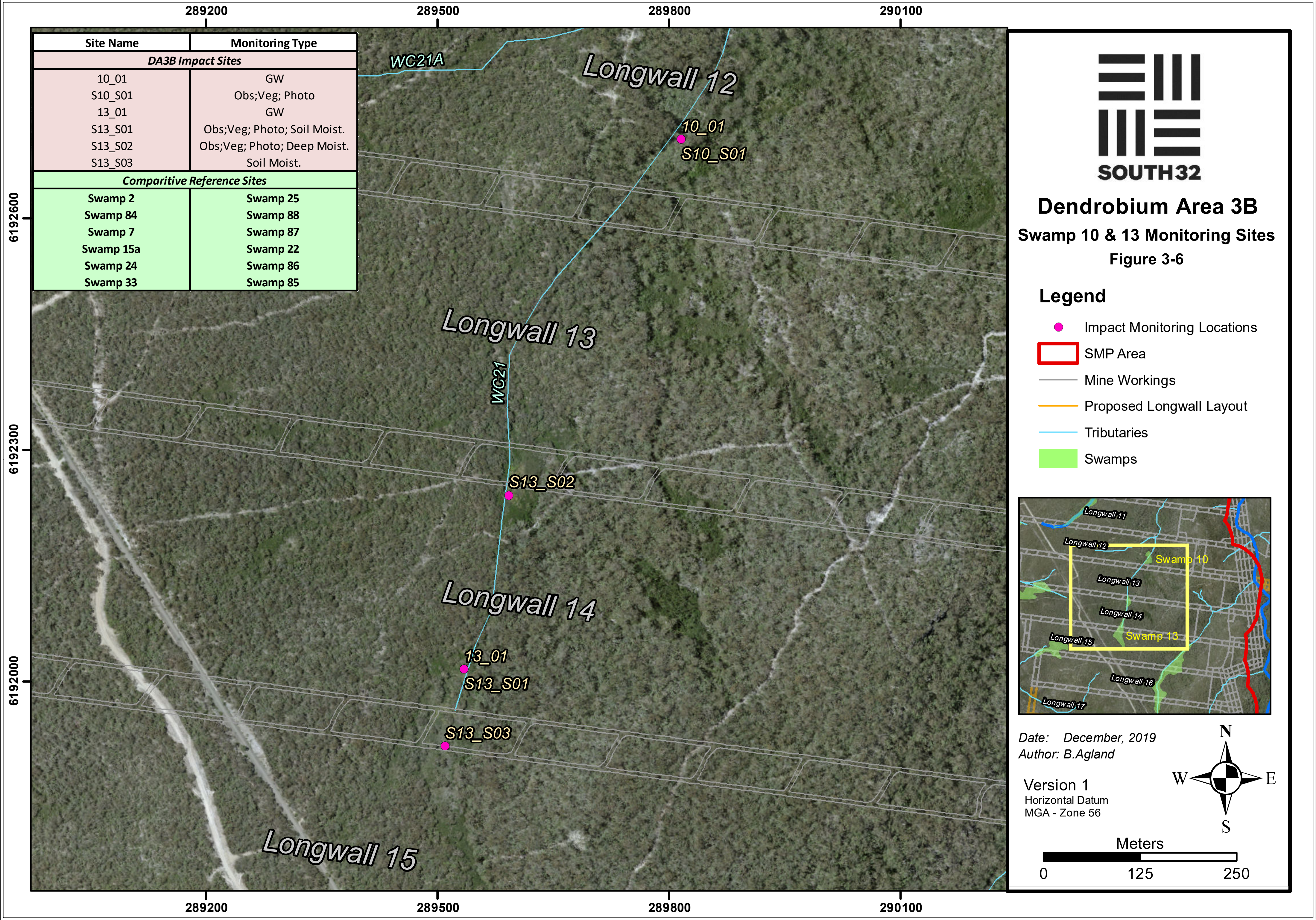


Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

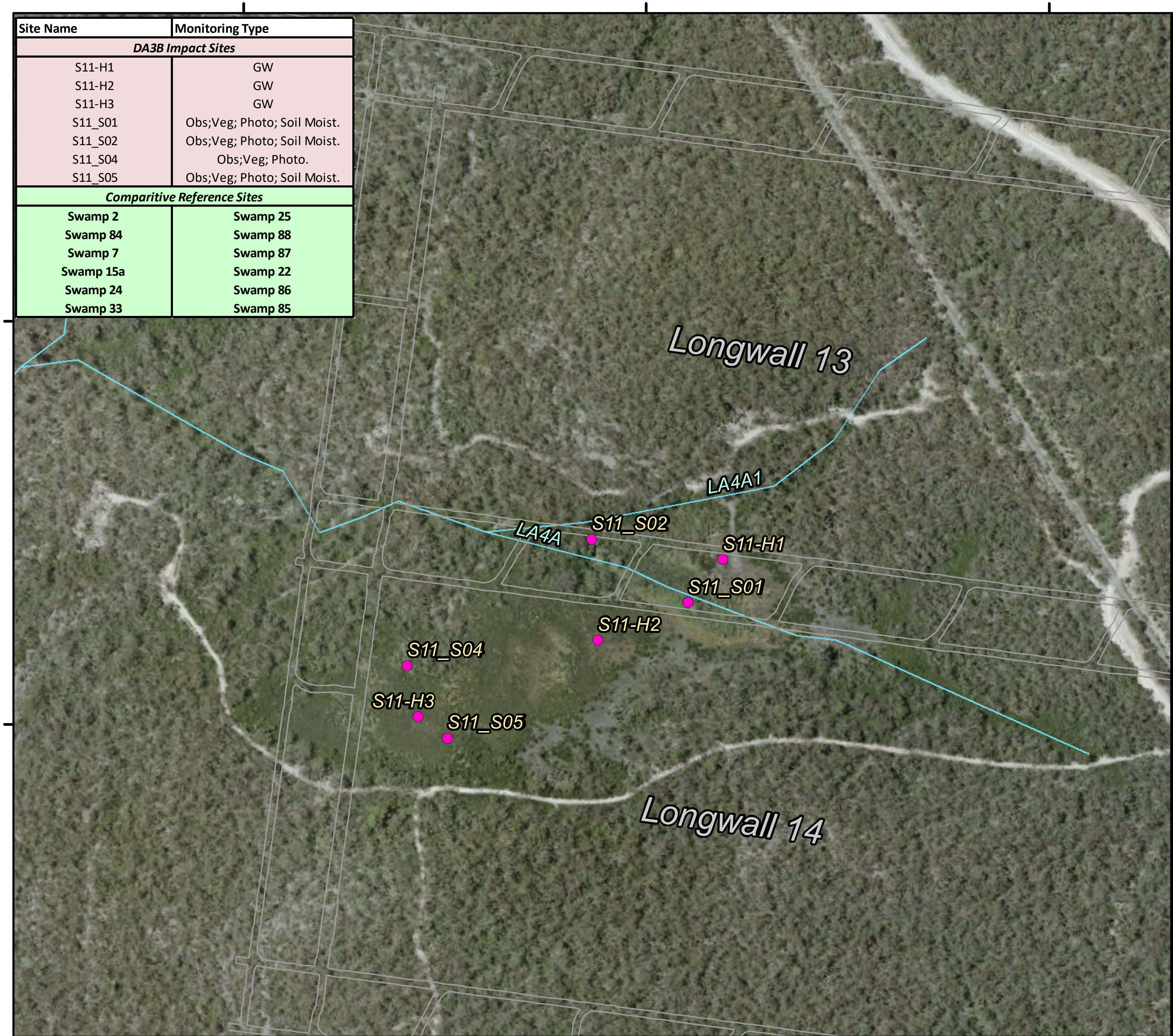
N W E S

Meters
0 125 250



Site Name	Monitoring Type
DA3B Impact Sites	
10_01	GW
S10_S01	Obs;Veg; Photo
13_01	GW
S13_S01	Obs;Veg; Photo; Soil Moist.
S13_S02	Obs;Veg; Photo; Deep Moist.
S13_S03	Soil Moist.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**

Site Name	Monitoring Type
DA3B Impact Sites	
S11-H1	GW
S11-H2	GW
S11-H3	GW
S11_S01	Obs;Veg; Photo; Soil Moist.
S11_S02	Obs;Veg; Photo; Soil Moist.
S11_S04	Obs;Veg; Photo.
S11_S05	Obs;Veg; Photo; Soil Moist.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**



SOUTH32

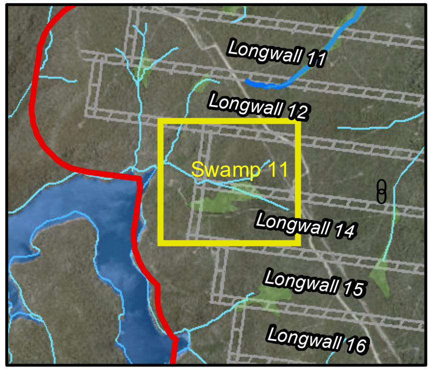
Dendrobium Area 3b

Swamp 11 Monitoring Sites

Figure 3-7

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries

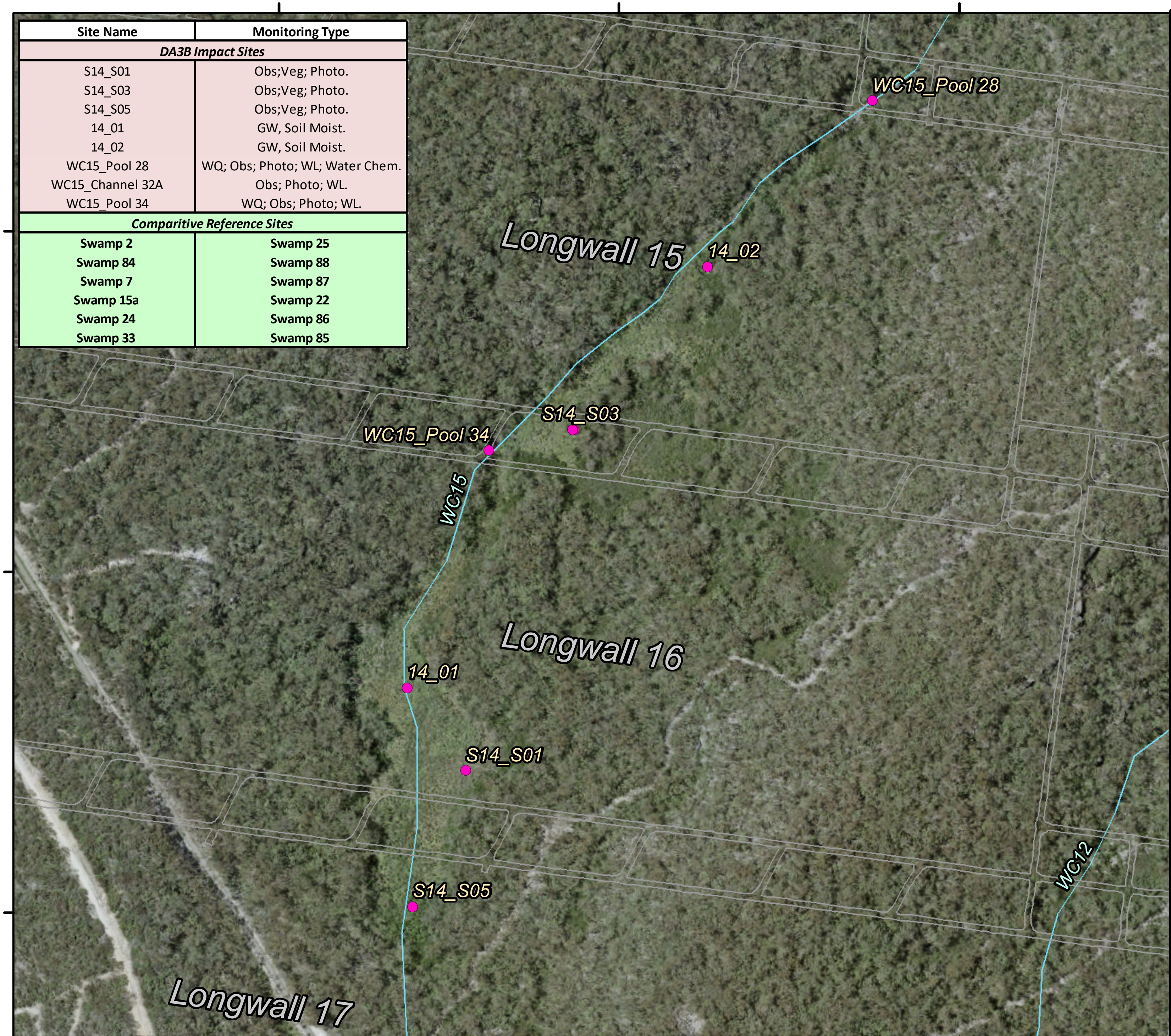


Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 100 200



Site Name	Monitoring Type
DA3B Impact Sites	
S14_S01	Obs;Veg; Photo.
S14_S03	Obs;Veg; Photo.
S14_S05	Obs;Veg; Photo.
14_01	GW, Soil Moist.
14_02	GW, Soil Moist.
WC15_Pool 28	WQ; Obs; Photo; WL; Water Chem.
WC15_Channel 32A	Obs; Photo; WL.
WC15_Pool 34	WQ; Obs; Photo; WL.
Comparitive Reference Sites	
Swamp 2	Swamp 25
Swamp 84	Swamp 88
Swamp 7	Swamp 87
Swamp 15a	Swamp 22
Swamp 24	Swamp 86
Swamp 33	Swamp 85

SOUTH32

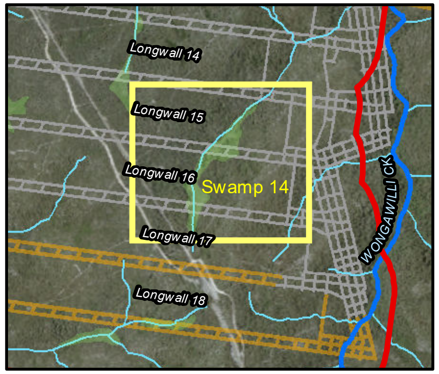
Dendrobium Area 3B

Swamp 14 Monitoring Sites

Figure 3-8

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries
- Creeks



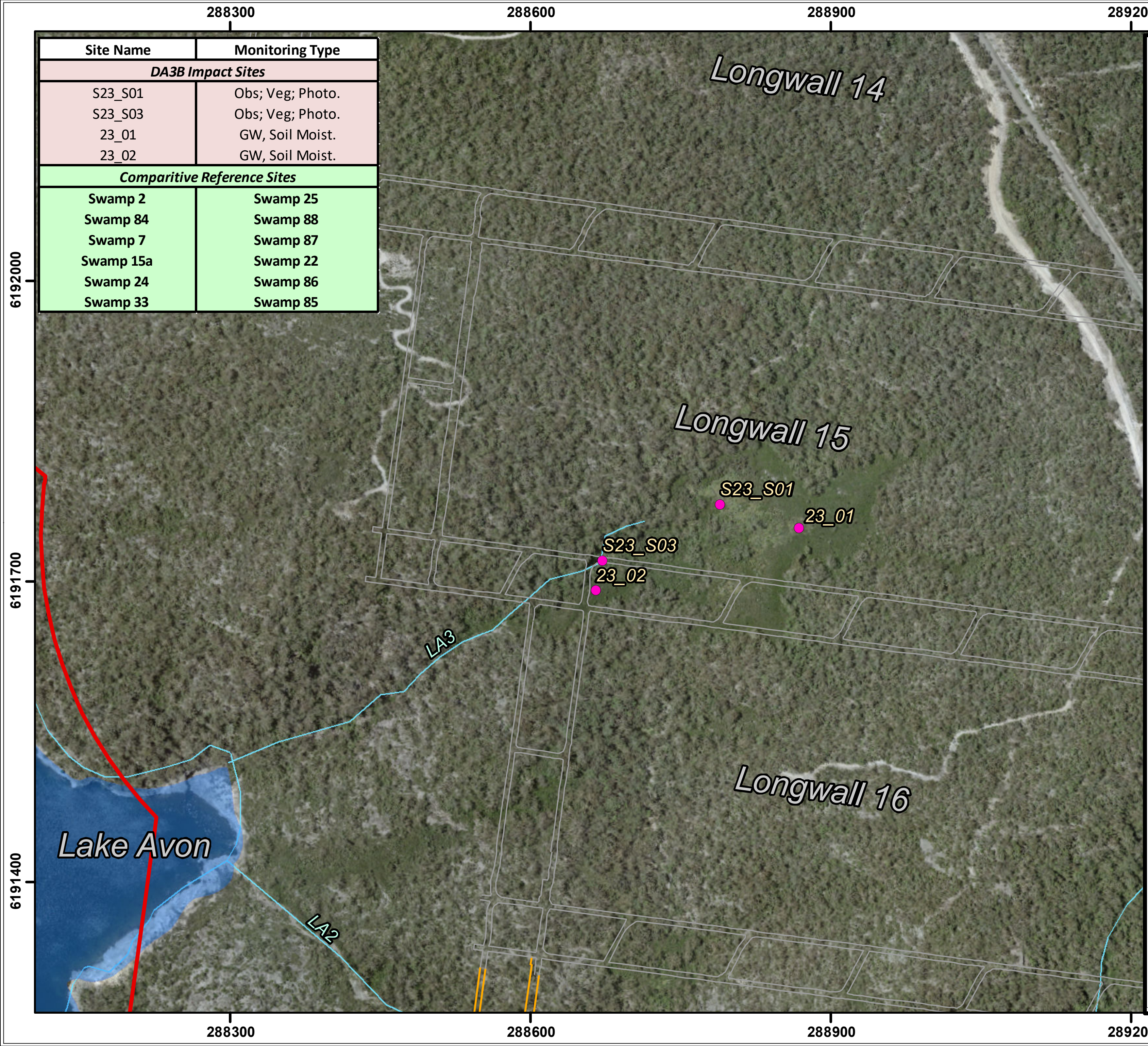
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N S W E

Meters
0 100 200

Site Name	Monitoring Type
DA3B Impact Sites	
S23_S01	Obs; Veg; Photo.
S23_S03	Obs; Veg; Photo.
23_01	GW, Soil Moist.
23_02	GW, Soil Moist.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**



SOUTH32

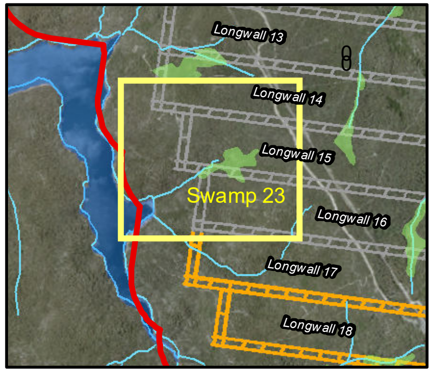
Dendrobium Area 3B

Swamp 23 Monitoring Sites

Figure 3-9

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries
- Swamps

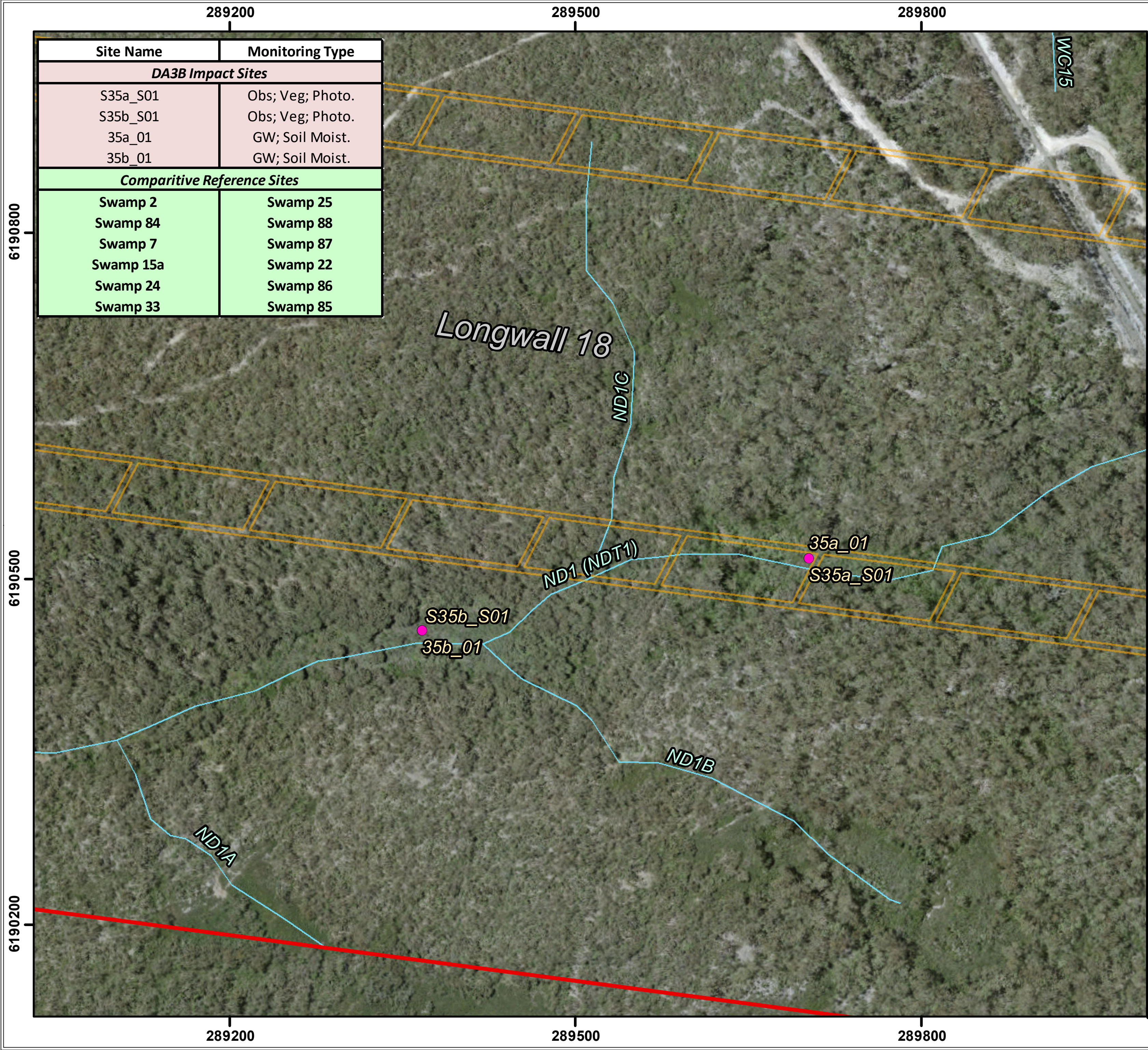


Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W E
S

Meters
0 125 250



Site Name	Monitoring Type
DA3B Impact Sites	
S35a_S01	Obs; Veg; Photo.
S35b_S01	Obs; Veg; Photo.
35a_01	GW; Soil Moist.
35b_01	GW; Soil Moist.
Comparitive Reference Sites	
Swamp 2	**Swamp 25**
Swamp 84	**Swamp 88**
Swamp 7	**Swamp 87**
Swamp 15a	**Swamp 22**
Swamp 24	**Swamp 86**
Swamp 33	**Swamp 85**

SOUTH32

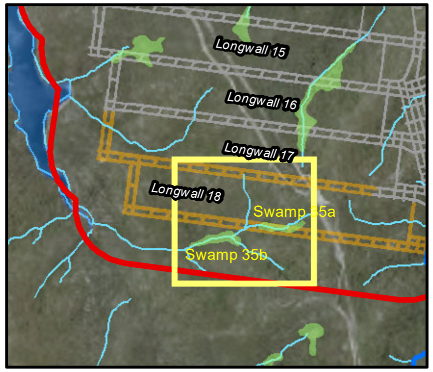
Dendrobium Area 3B

Swamp 35a & 35b Monitoring Sites

Figure 3-10

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries
- Swamps

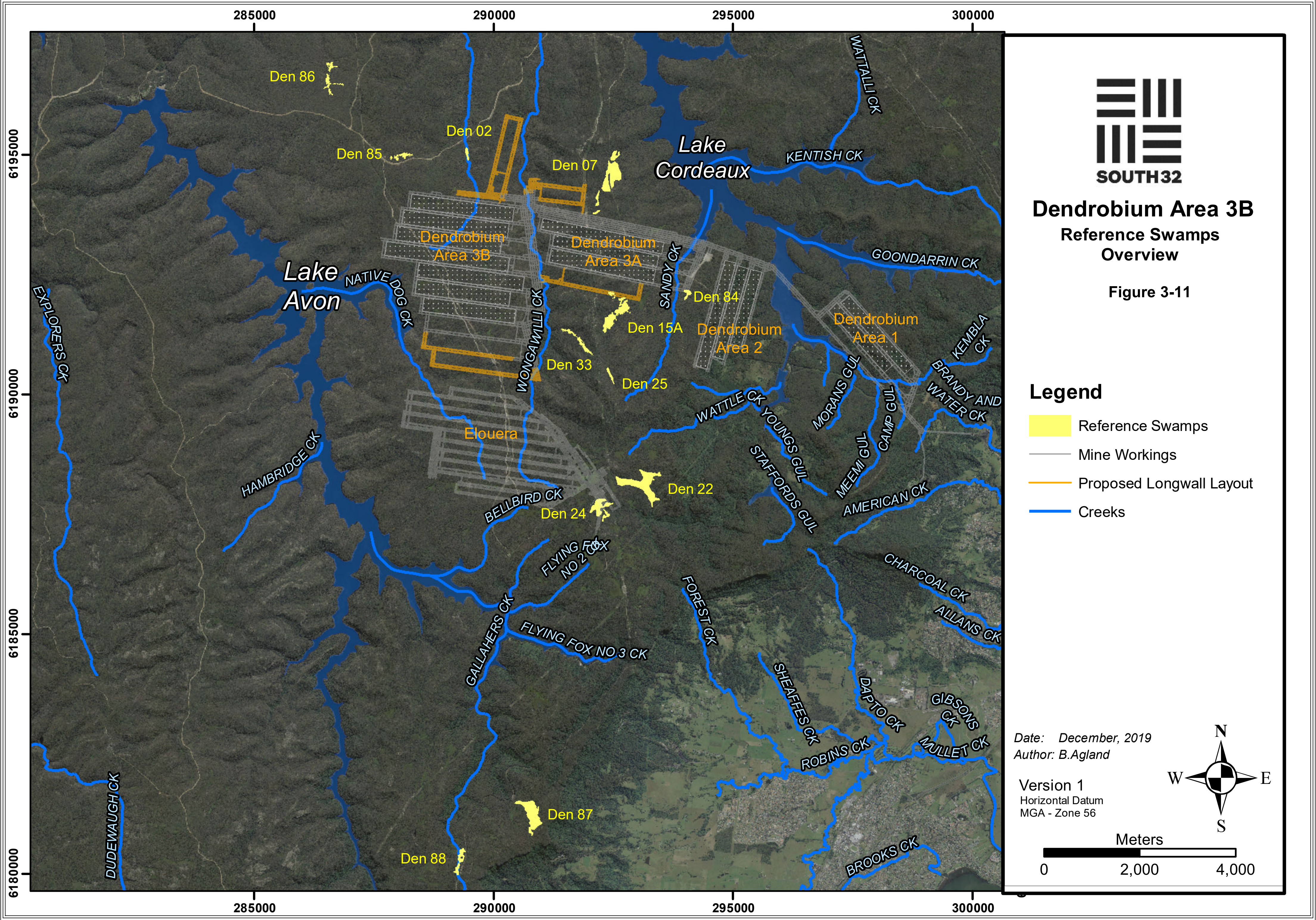


Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

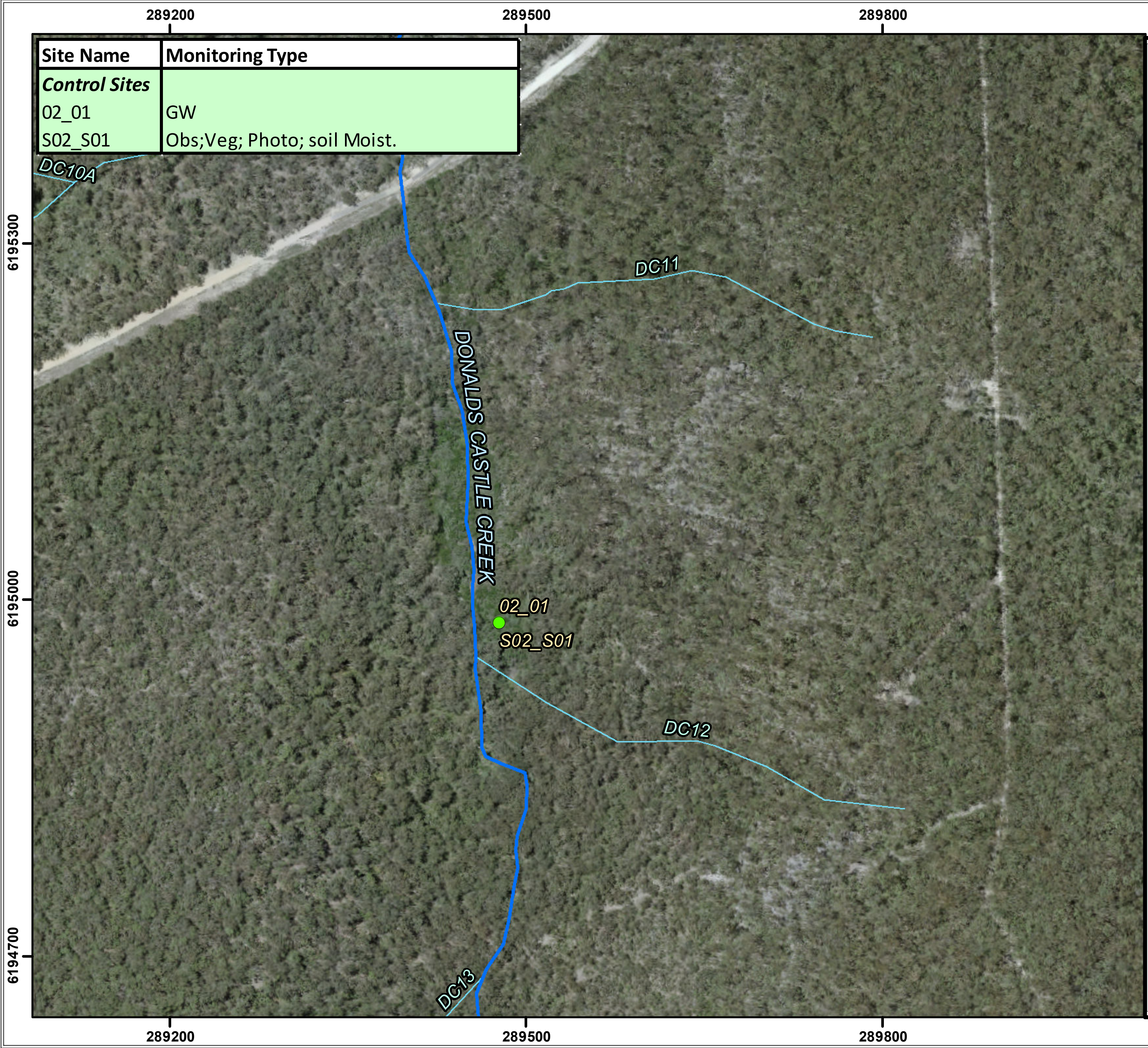
N W E S

Meters
0 100 200



Dendrobium Area 3B
Reference Swamps Overview
Figure 3-11
SOUTH32
Legend
Reference Swamps
Mine Workings
Proposed Longwall Layout
Creeks
Date: December, 2019
Author: B.Agland
Version 1
Horizontal Datum
MGA - Zone 56
Meters
0
2,000
4,000
N
S
E
W
285000
290000
295000
300000
6195000
6190000
6185000
6180000
Lake Cordeaux
Lake Avon
Dendrobium Area 3B
Dendrobium Area 3A
Dendrobium Area 2
Dendrobium Area 1
Elouera
Den 86
Den 02
Den 85
Den 07
Den 84
Den 15A
Den 33
Den 25
Den 22
Den 24
Den 87
Den 88
WATTALLI CK
KENTISH CK
GOONDARRIN CK
SANDY CK
NATIVE DOG CK
WONGAWILLI CK
EXPLORERS CK
KEMBLA CK
BRANDY AND WATER CK
MORANS GUL
CAMP GUL
MEEMI GUL
WATTLE CK
YOUNGS GUL
STAFFORDS GUL
AMERICAN CK
HAMBRIDGE CK
BELLBIRD CK
FLYING FOX NO 2 CK
CHARCOAL CK
ALLANS CK
FOREST CK
GALLAHERS CK
FLYING FOX NO 3 CK
SHEAFFES CK
DAPTO CK
GIBSONS CK
MULLET CK
ROBINS CK
BROOKS CK
DUDEWAUGH CK

Site Name	Monitoring Type
Control Sites	
02_01	GW
S02_S01	Obs;Veg; Photo; soil Moist.



SOUTH32

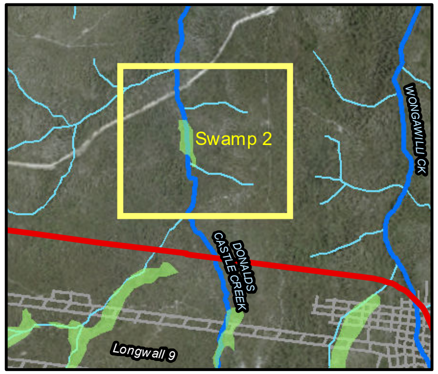
Dendrobium Area 3B

Swamp 2 Monitoring Sites

Figure 3-12

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Creeks
- Tributaries
- Swamps



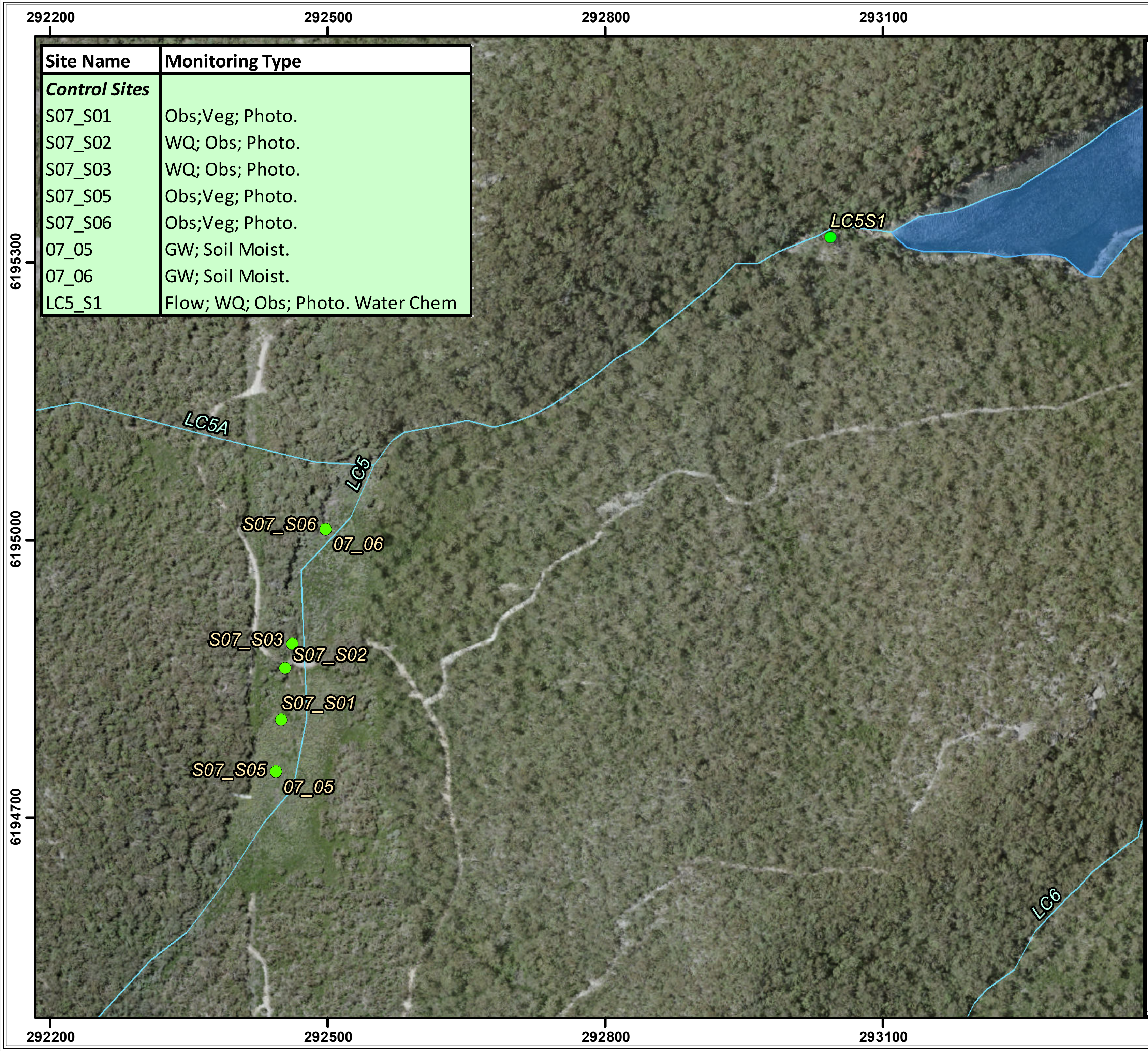
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W E
S

Meters
0 100 200

Site Name	Monitoring Type
Control Sites	
S07_S01	Obs;Veg; Photo.
S07_S02	WQ; Obs; Photo.
S07_S03	WQ; Obs; Photo.
S07_S05	Obs;Veg; Photo.
S07_S06	Obs;Veg; Photo.
07_05	GW; Soil Moist.
07_06	GW; Soil Moist.
LC5_S1	Flow; WQ; Obs; Photo. Water Chem

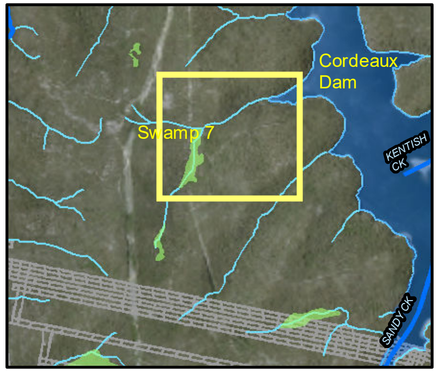


SOUTH32

Dendrobium Area 3B

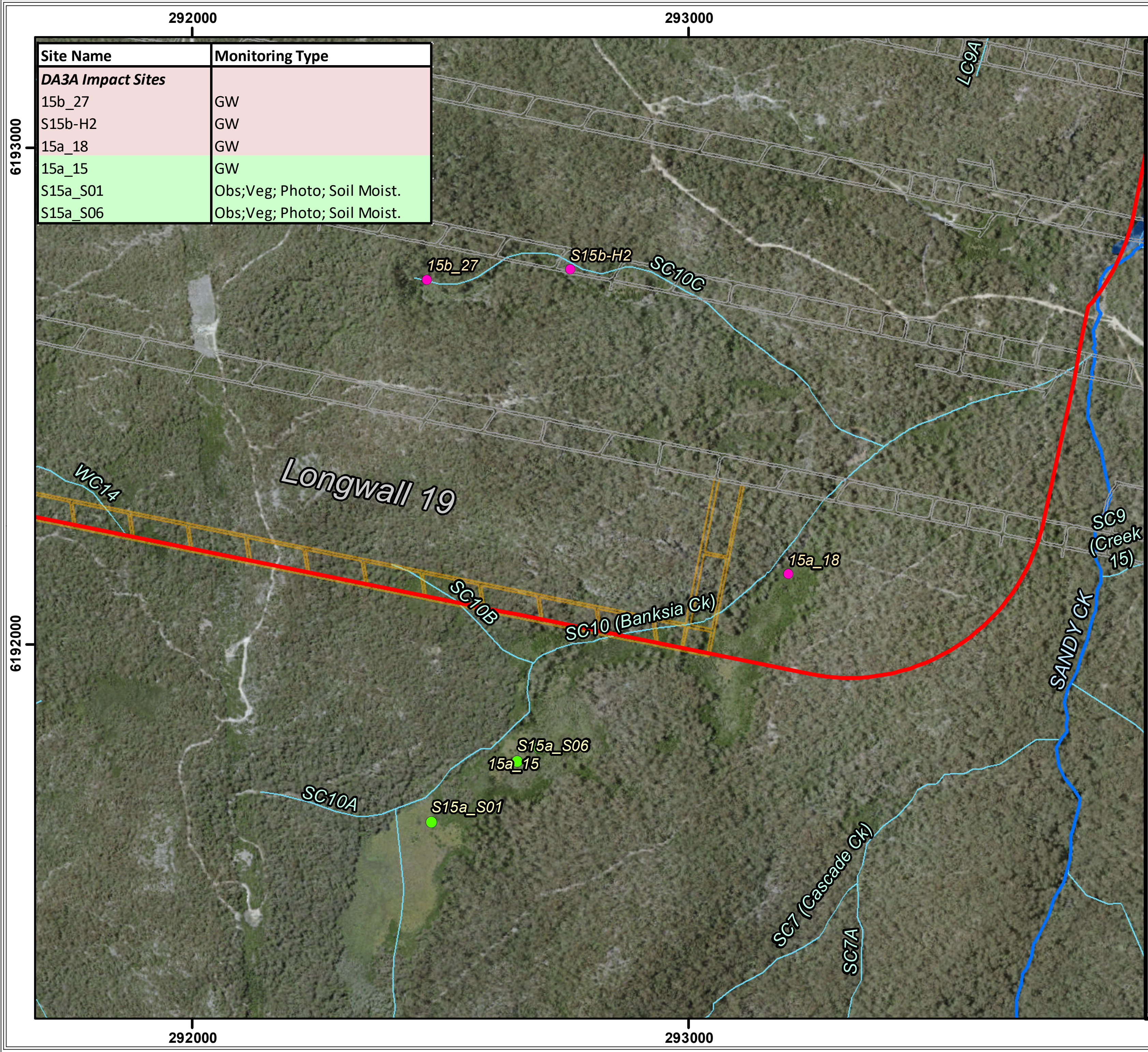
Swamp 7 Monitoring Sites

Figure 3-13



Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56



Site Name	Monitoring Type
DA3A Impact Sites	
15b_27	GW
S15b-H2	GW
15a_18	GW
15a_15	GW
S15a_S01	Obs;Veg; Photo; Soil Moist.
S15a_S06	Obs;Veg; Photo; Soil Moist.

SOUTH32

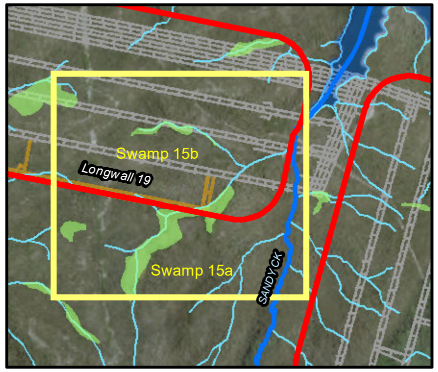
Dendrobium Area 3A

Swamp 15a &15b Monitoring Sites

Figure 3-14

Legend

- Reference Monitoring Sites
- Impact Monitoring Locations
- 400m Zone of Influence
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries
- Swamps

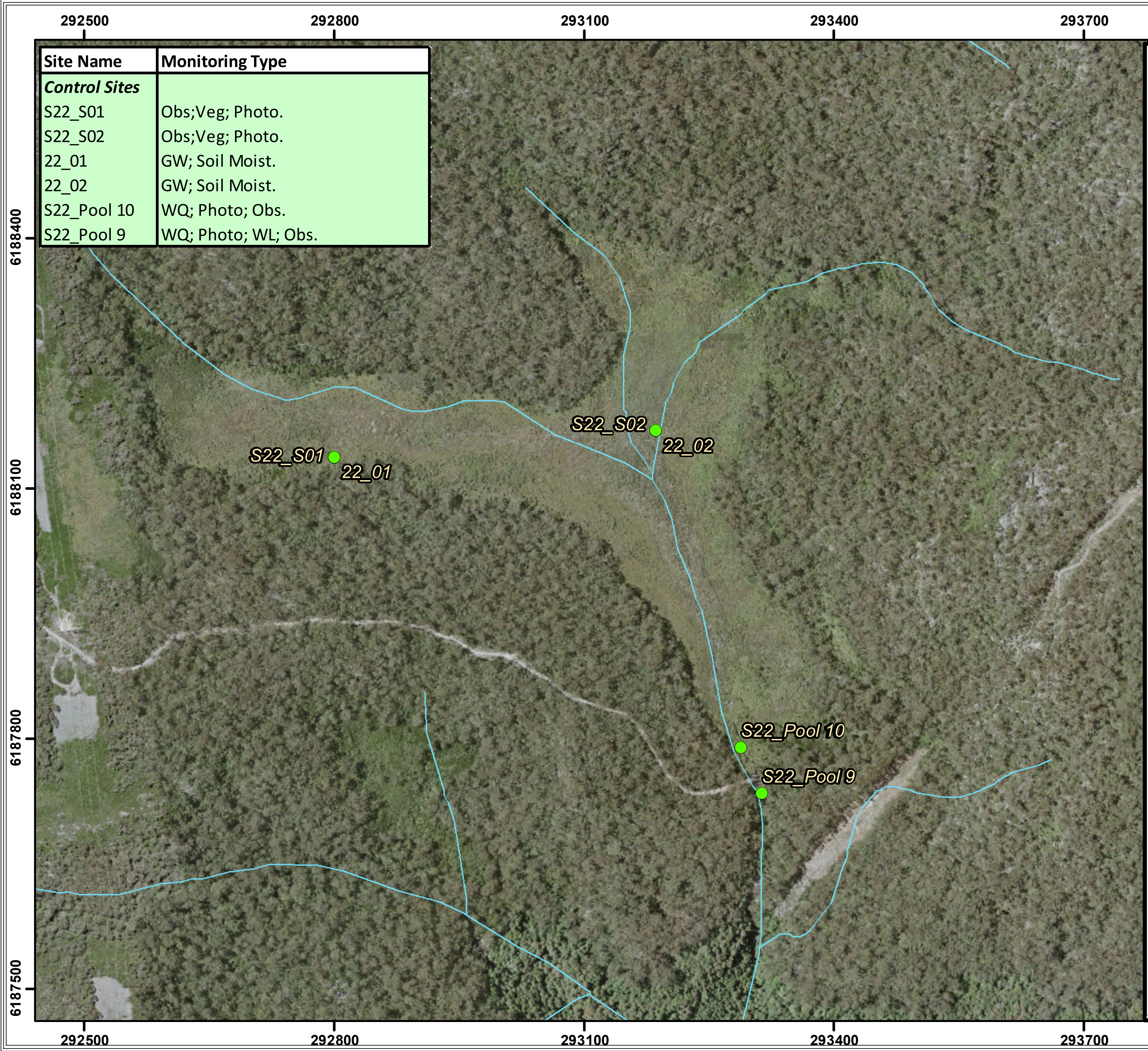


Date: January, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W E
S

Meters
0 250 500



Site Name	Monitoring Type
Control Sites	
S22_S01	Obs;Veg; Photo.
S22_S02	Obs;Veg; Photo.
22_01	GW; Soil Moist.
22_02	GW; Soil Moist.
S22_Pool 10	WQ; Photo; Obs.
S22_Pool 9	WQ; Photo; WL; Obs.

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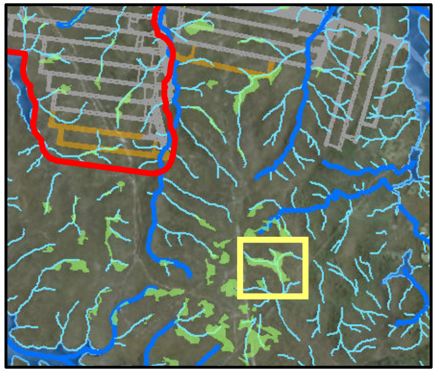
Dendrobium Area 3B

Swamp 22 Monitoring Sites

Figure 3-15

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries
- Swamps



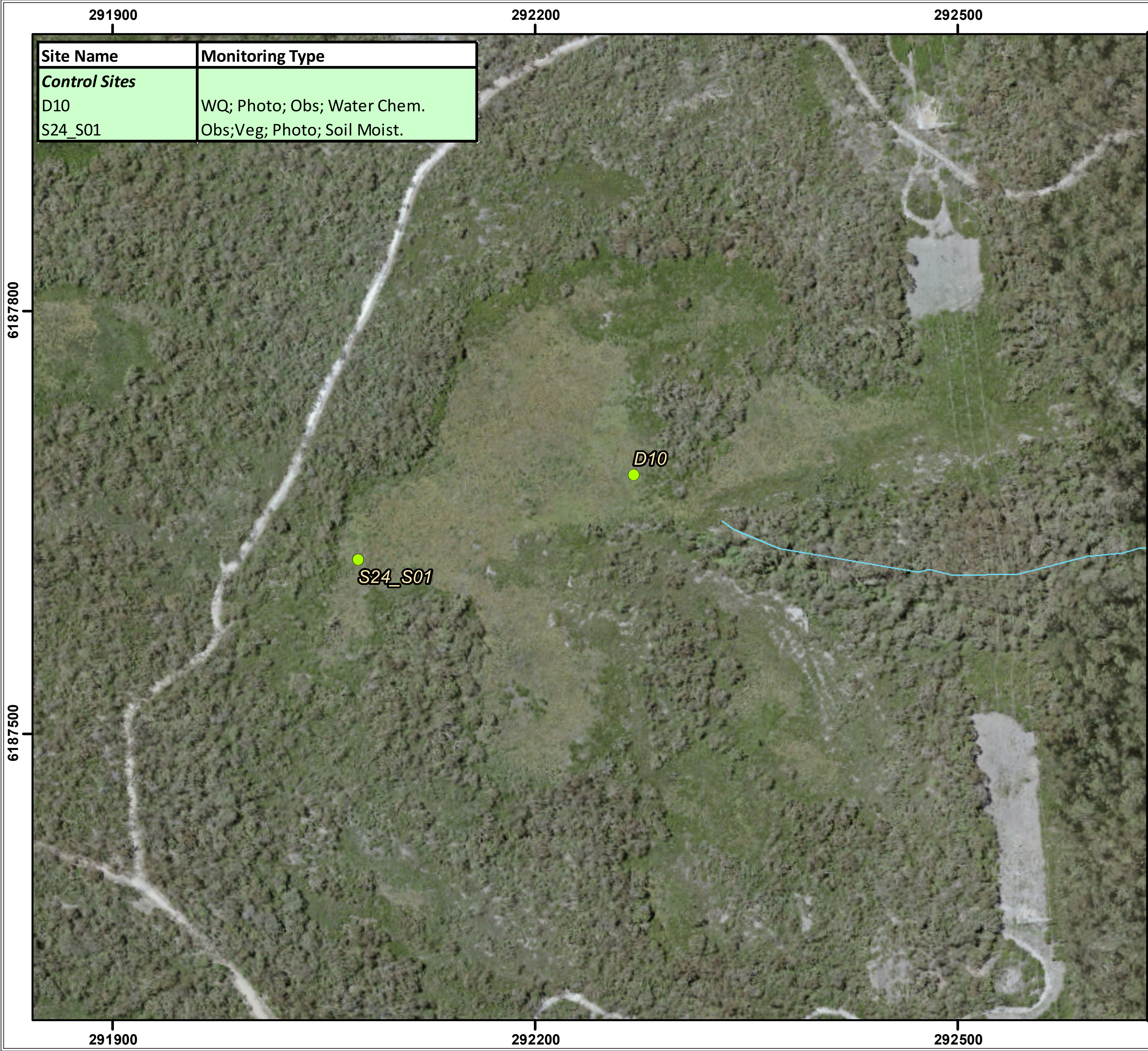
Date: February, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 125 250

Site Name	Monitoring Type
Control Sites	
D10	WQ; Photo; Obs; Water Chem.
S24_S01	Obs;Veg; Photo; Soil Moist.



SOUTH32

Dendrobium Area 3B

Swamp 24 Monitoring Sites

Figure 3-16

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries
- Swamps

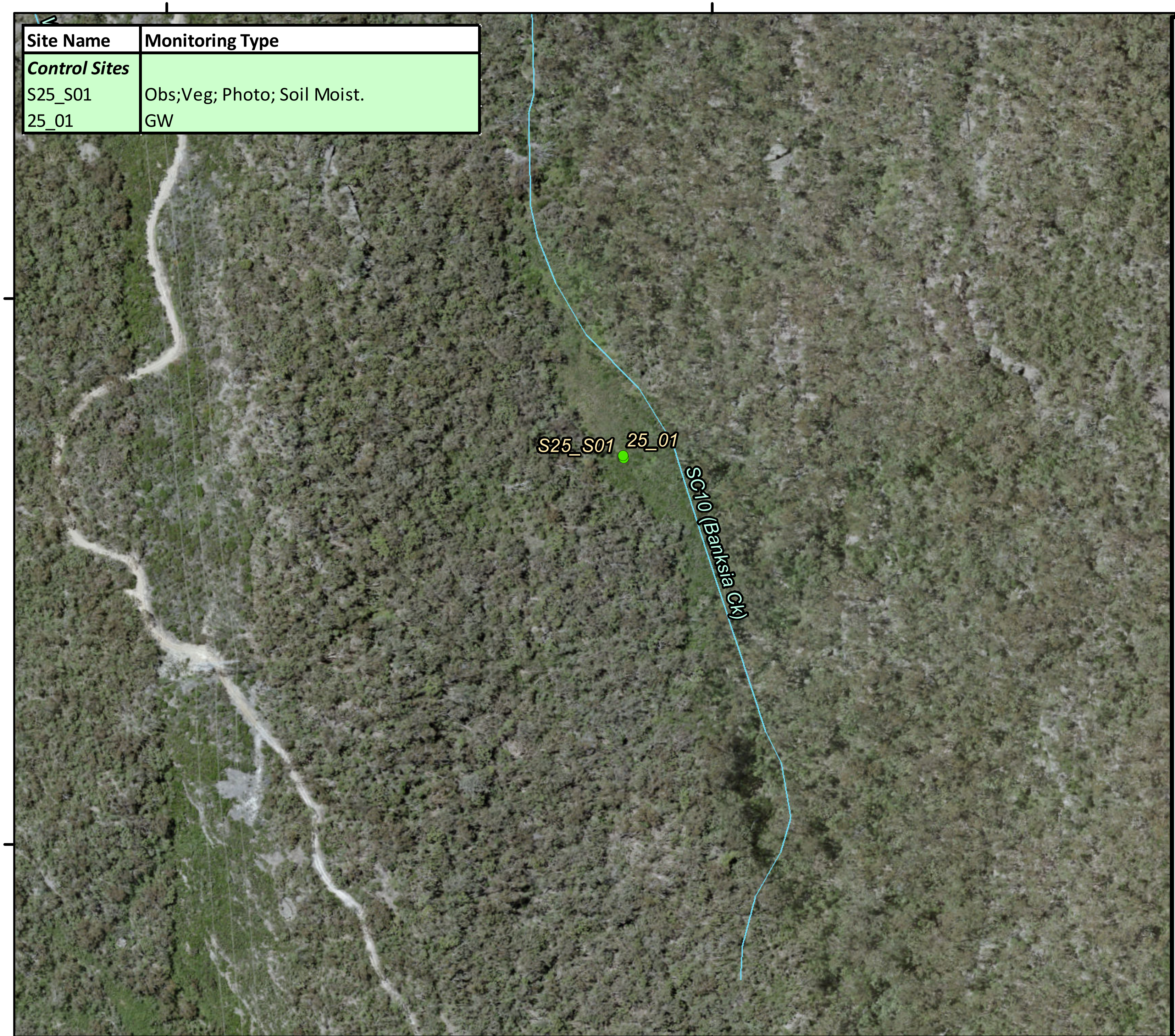
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W E
S

Meters
0 75 150

Site Name	Monitoring Type
Control Sites	
S25_S01	Obs;Veg; Photo; Soil Moist.
25_01	GW



SOUTH32

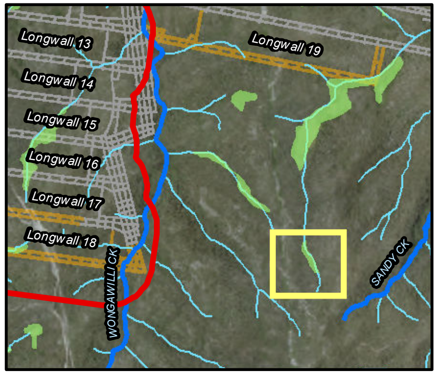
Dendrobium Area 3B

Swamp 25 Monitoring Sites

Figure 3-17

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries
- Creeks
- Swamps



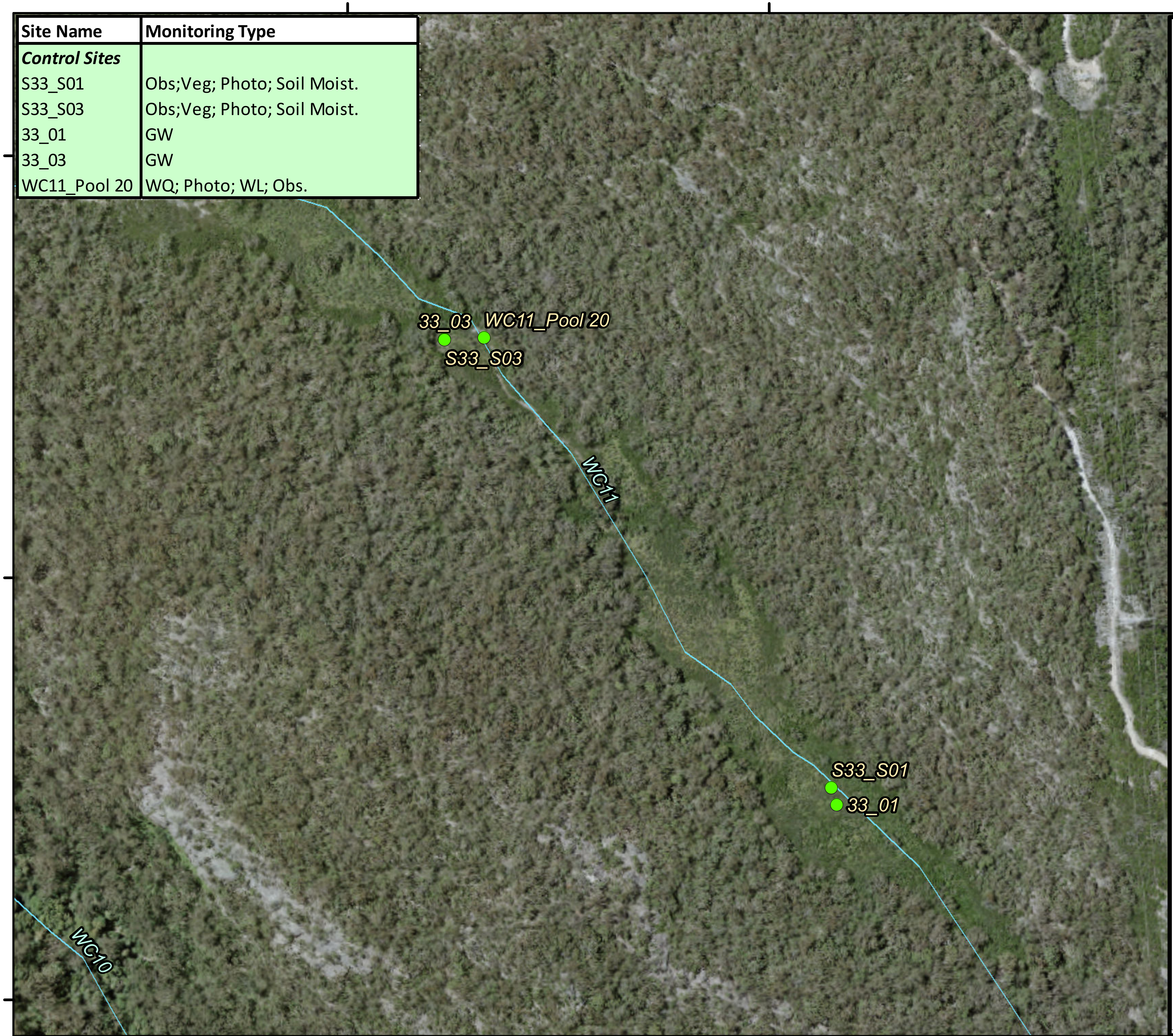
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W E
S

Meters
0 75 150

Site Name	Monitoring Type
Control Sites	
S33_S01	Obs;Veg; Photo; Soil Moist.
S33_S03	Obs;Veg; Photo; Soil Moist.
33_01	GW
33_03	GW
WC11_Pool 20	WQ; Photo; WL; Obs.



SOUTH32

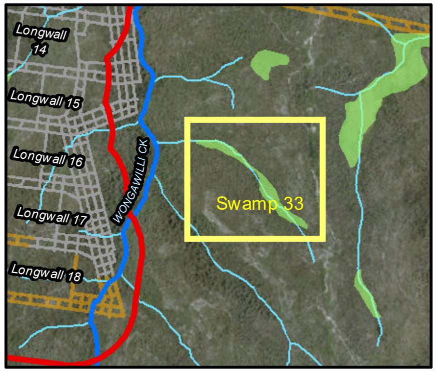
Dendrobium Area 3B

Swamp 33 Monitoring Sites

Figure 3-18

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries
- Swamps



Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

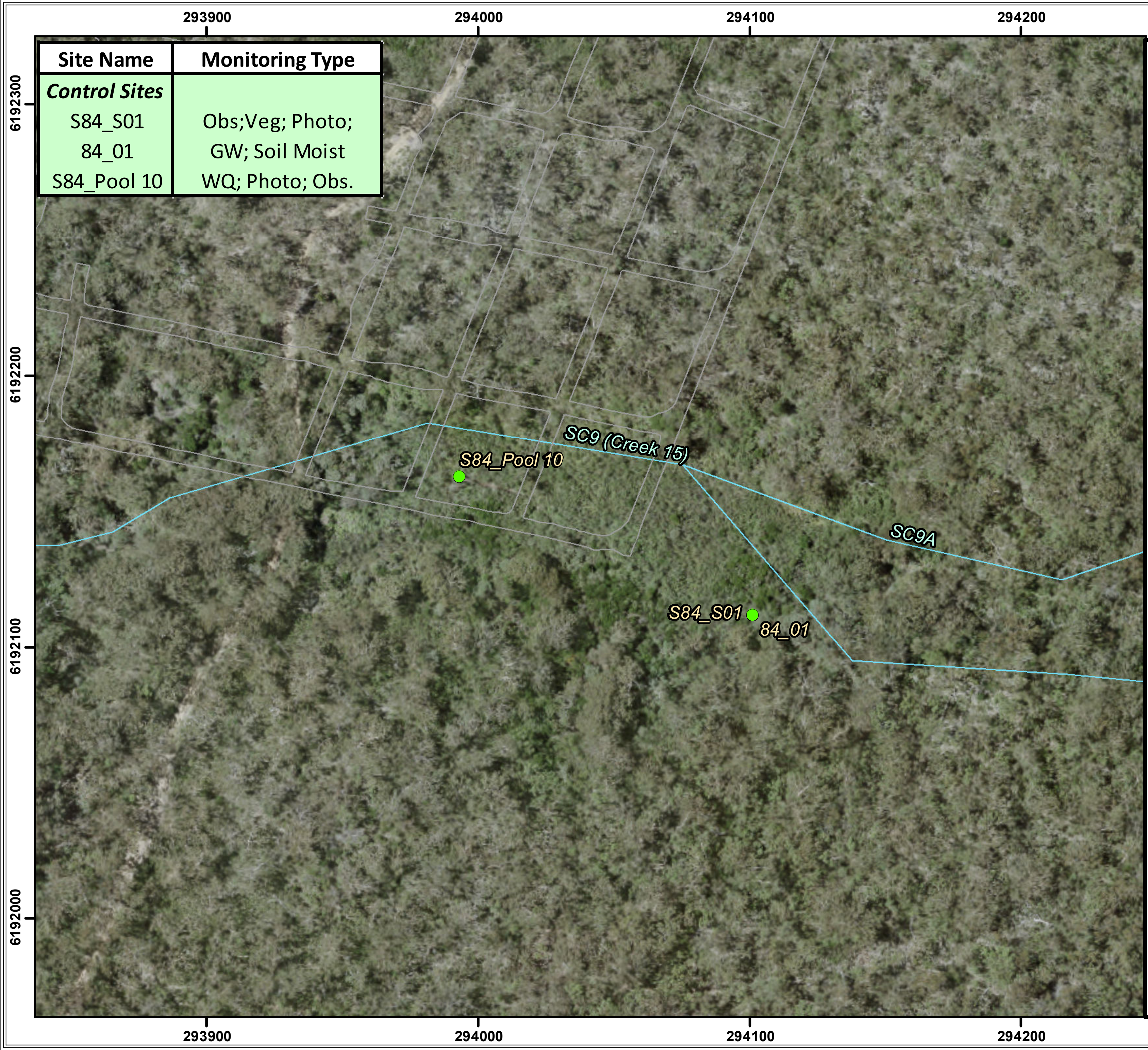
Meters
0 75 150

Dendrobium Area 3B

Swamp 84 Monitoring Sites

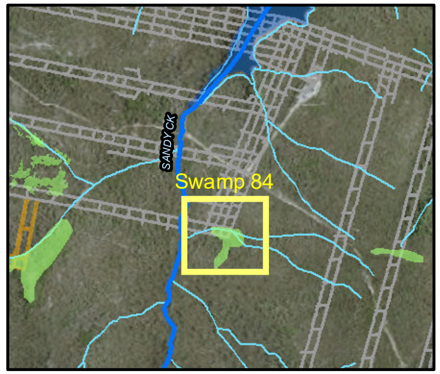
Figure 3-19

Site Name	Monitoring Type
Control Sites	
S84_S01	Obs;Veg; Photo;
84_01	GW; Soil Moist
S84_Pool 10	WQ; Photo; Obs.



Legend

- Reference Monitoring Locations
- Mine Workings
- Tributaries
- Swamps



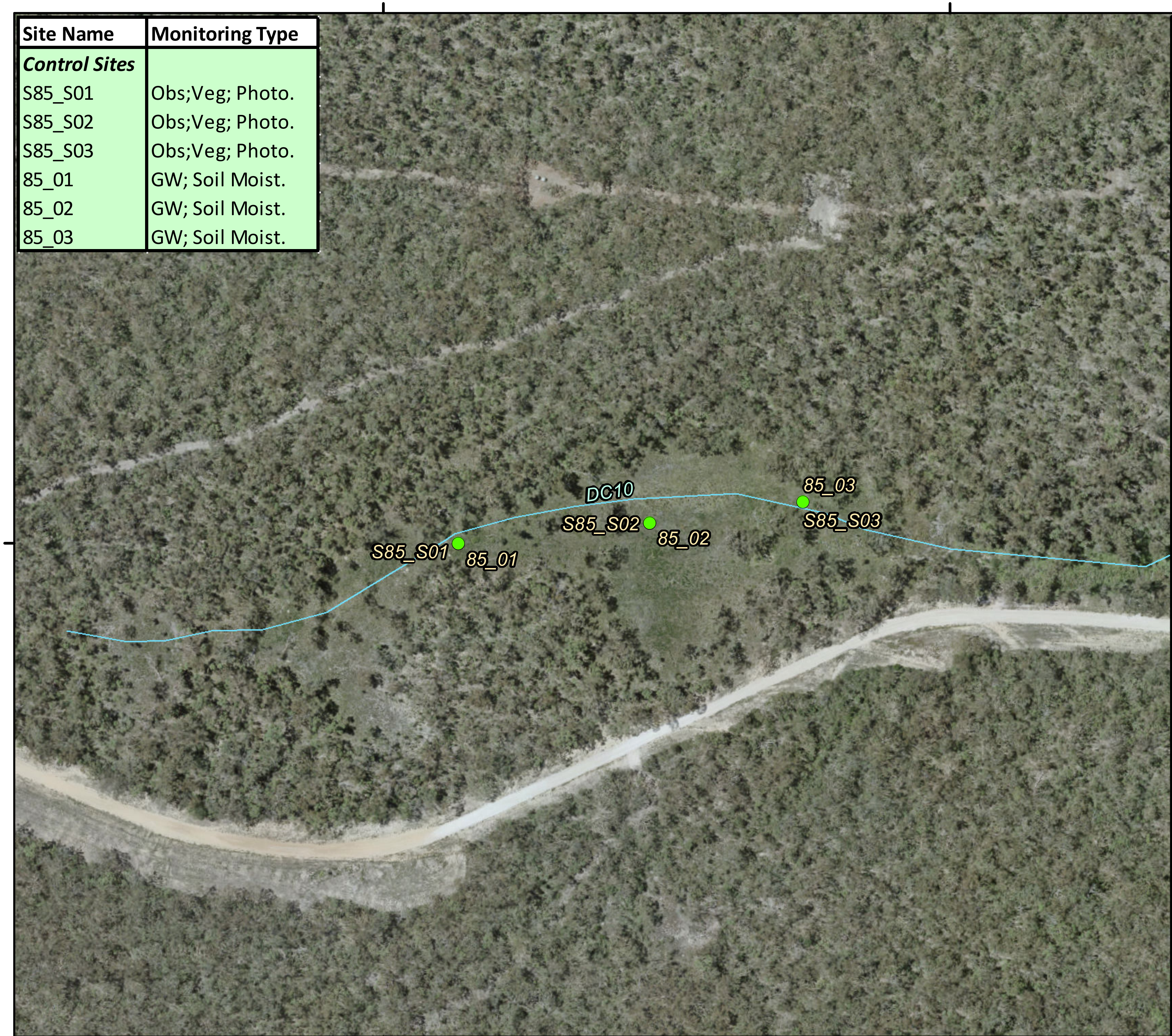
Date: Februray, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W E
S

Meters
0 50 100

Site Name	Monitoring Type
Control Sites	
S85_S01	Obs;Veg; Photo.
S85_S02	Obs;Veg; Photo.
S85_S03	Obs;Veg; Photo.
85_01	GW; Soil Moist.
85_02	GW; Soil Moist.
85_03	GW; Soil Moist.



SOUTH32

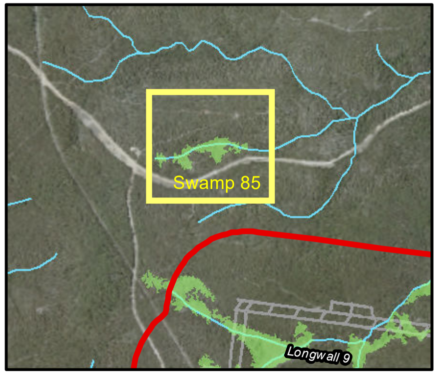
Dendrobium Area 3B

Swamp 85 Monitoring Sites

Figure 3-20

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Tributaries
- Swamps



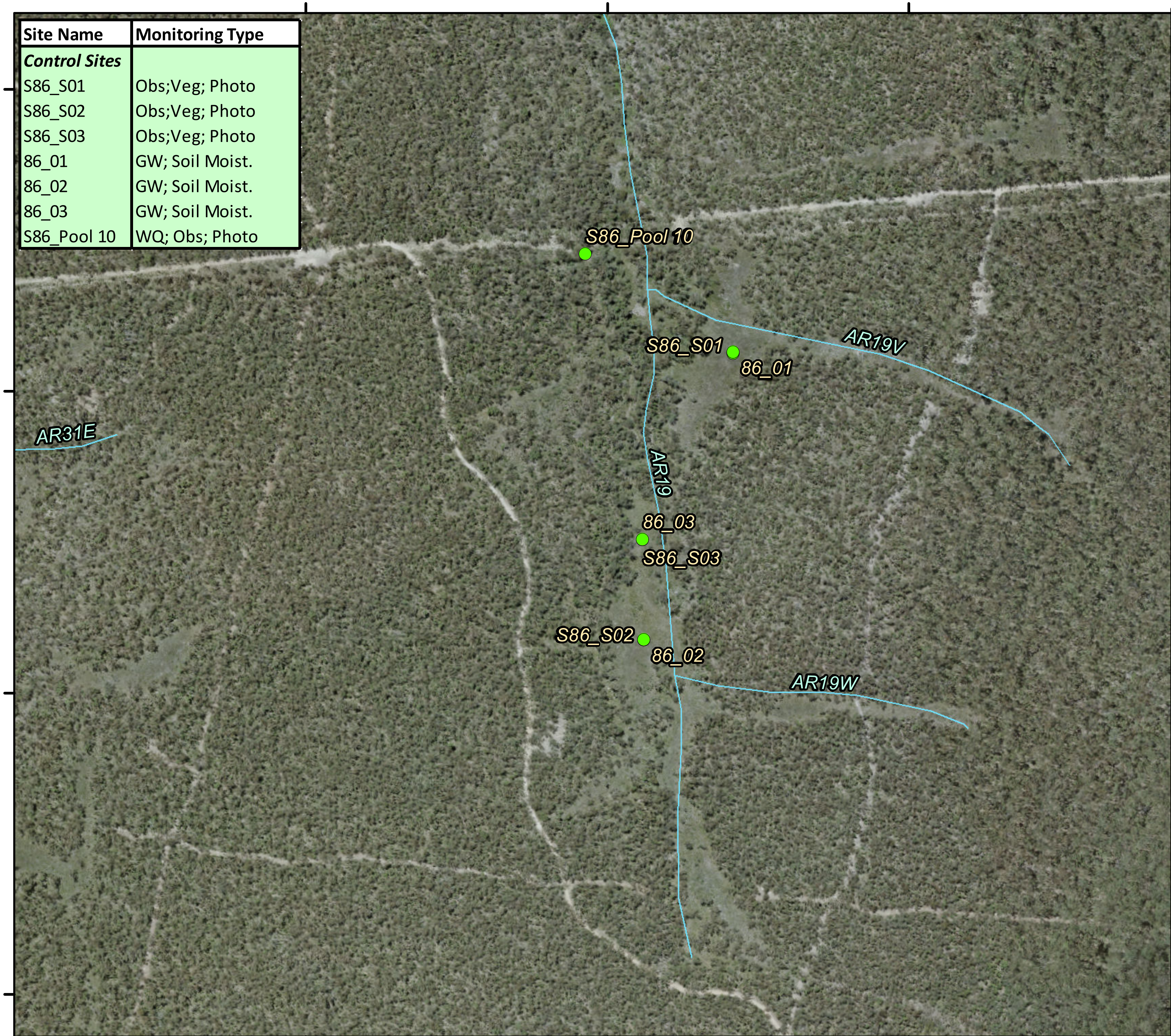
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 50 100

Site Name	Monitoring Type
Control Sites	
S86_S01	Obs;Veg; Photo
S86_S02	Obs;Veg; Photo
S86_S03	Obs;Veg; Photo
86_01	GW; Soil Moist.
86_02	GW; Soil Moist.
86_03	GW; Soil Moist.
S86_Pool 10	WQ; Obs; Photo



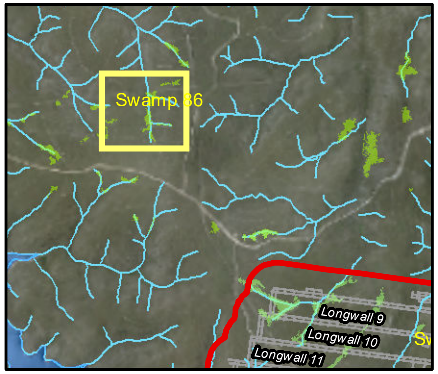
Dendrobium Area 3B

Swamp 86 Monitoring Sites

Figure 3-21

Legend

- Reference Monitoring Locations
- SMP Area
- Mine Workings
- Tributaries
- Creeks
- Swamps



Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N
W
E
S

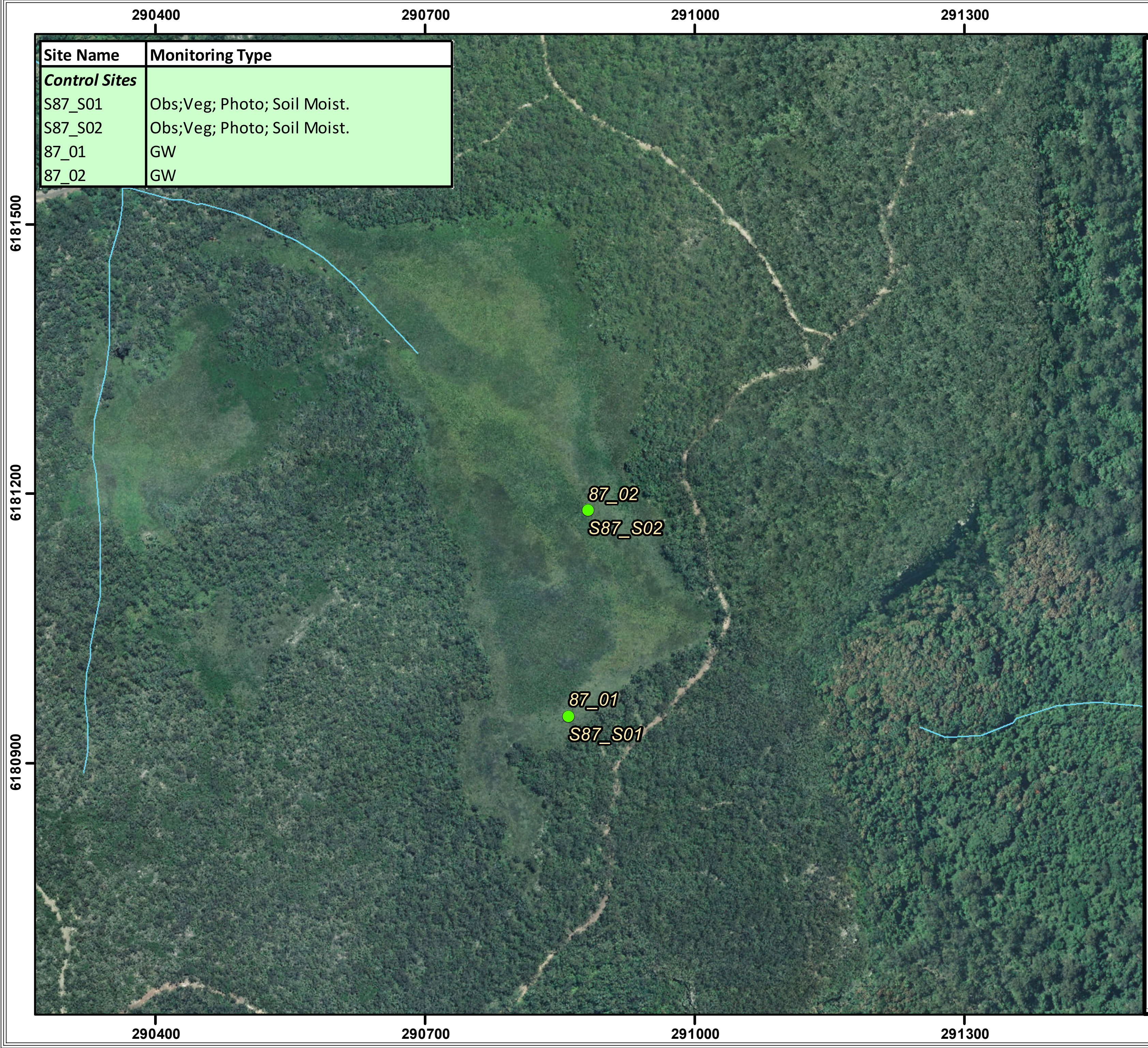
Meters
0 125 250

Dendrobium Area 3B

Swamp 87 Monitoring Sites

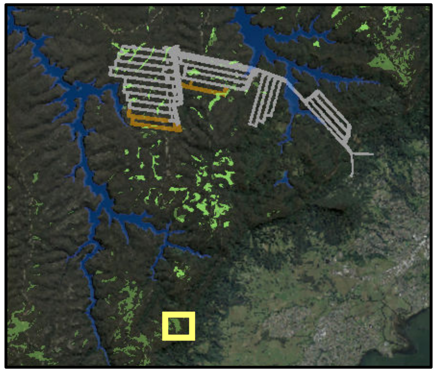
Figure 3-22

Site Name	Monitoring Type
Control Sites	
S87_S01	Obs;Veg; Photo; Soil Moist.
S87_S02	Obs;Veg; Photo; Soil Moist.
87_01	GW
87_02	GW



Legend

- Reference Monitoring Locations
- Tributaries
- Swamps



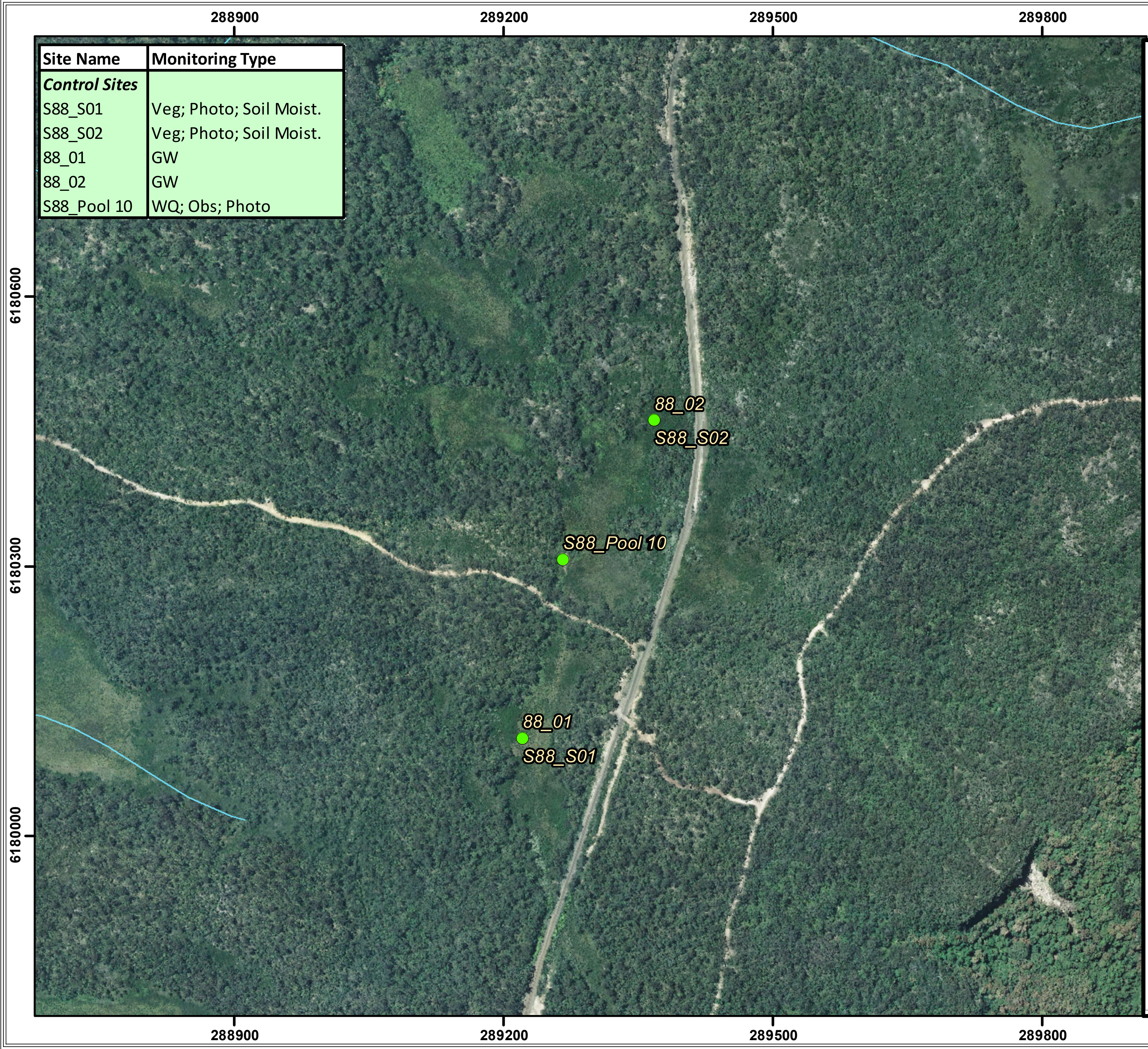
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 125 250

Site Name	Monitoring Type
Control Sites	
S88_S01	Veg; Photo; Soil Moist.
S88_S02	Veg; Photo; Soil Moist.
88_01	GW
88_02	GW
S88_Pool 10	WQ; Obs; Photo



SOUTH32

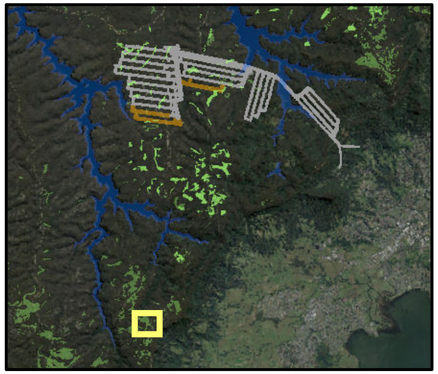
Dendrobium Area 3B

Swamp 88 Monitoring Sites

Figure 3-23

Legend

- Reference Monitoring Locations
- Tributaries
- Swamps



Date: December, 2018
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

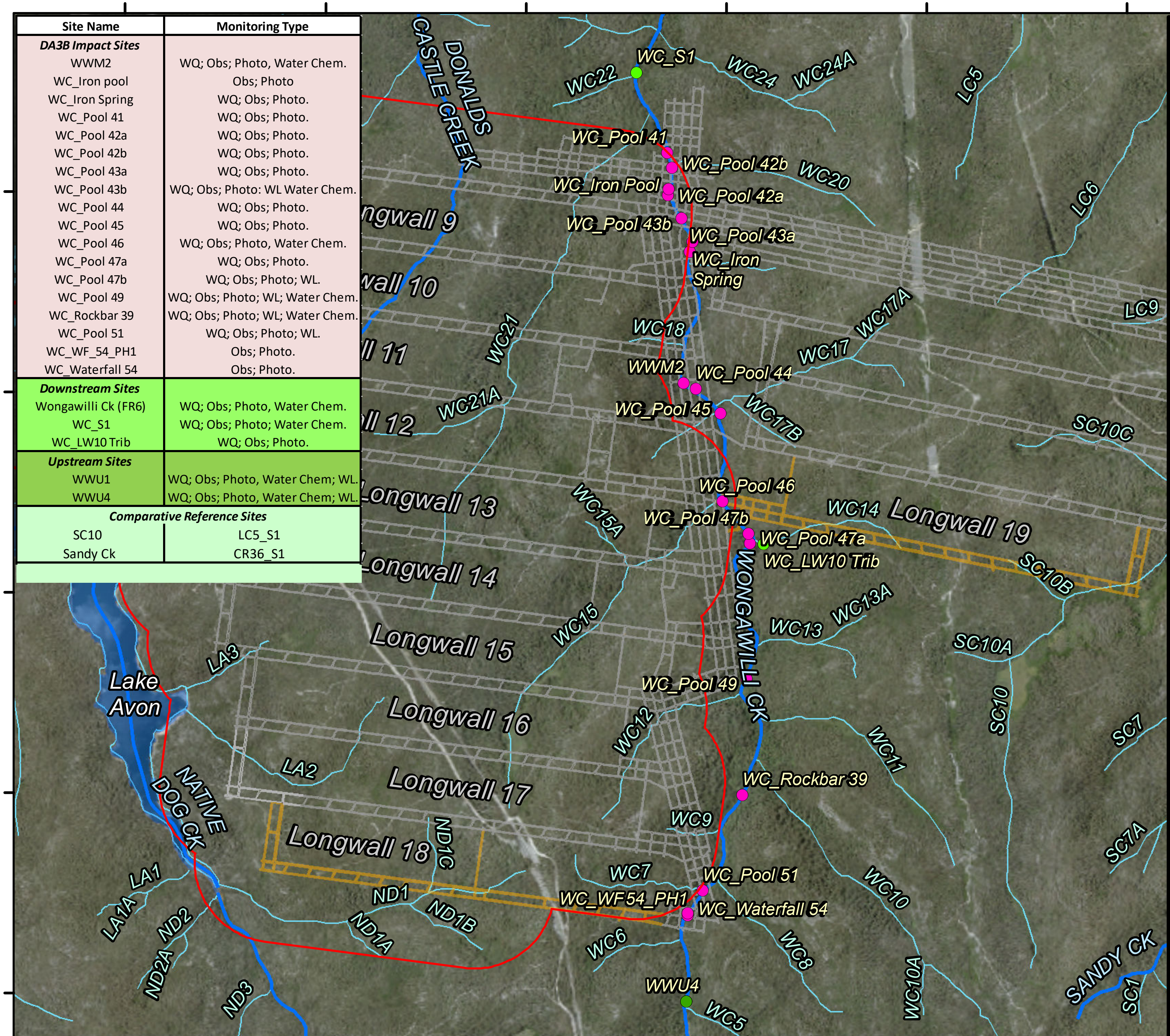
Meters
0 125 250

Dendrobium Area 3B

Watercourse Monitoring Sites

Wongawilli Creek

Figure 3-24



Site Name	Monitoring Type
DA3B Impact Sites	
WWM2	WQ; Obs; Photo, Water Chem.
WC_Iron pool	Obs; Photo
WC_Iron Spring	WQ; Obs; Photo.
WC_Pool 41	WQ; Obs; Photo.
WC_Pool 42a	WQ; Obs; Photo.
WC_Pool 42b	WQ; Obs; Photo.
WC_Pool 43a	WQ; Obs; Photo.
WC_Pool 43b	WQ; Obs; Photo: WL Water Chem.
WC_Pool 44	WQ; Obs; Photo.
WC_Pool 45	WQ; Obs; Photo.
WC_Pool 46	WQ; Obs; Photo, Water Chem.
WC_Pool 47a	WQ; Obs; Photo.
WC_Pool 47b	WQ; Obs; Photo; WL.
WC_Pool 49	WQ; Obs; Photo; WL; Water Chem.
WC_Rockbar 39	WQ; Obs; Photo; WL; Water Chem.
WC_Pool 51	WQ; Obs; Photo; WL.
WC_WF_54_PH1	Obs; Photo.
WC_Waterfall 54	Obs; Photo.
Downstream Sites	
Wongawilli Ck (FR6)	WQ; Obs; Photo, Water Chem.
WC_S1	WQ; Obs; Photo; Water Chem.
WC_LW10 Trib	WQ; Obs; Photo.
Upstream Sites	
WWU1	WQ; Obs; Photo, Water Chem; WL.
WWU4	WQ; Obs; Photo, Water Chem; WL.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1

- SMP Area
- Upstream Monitoring Locations
- Impact Monitoring Locations
- Downstream Monitoring Locations
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries

Date: August, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N S W E

Meters
0 500 1,000

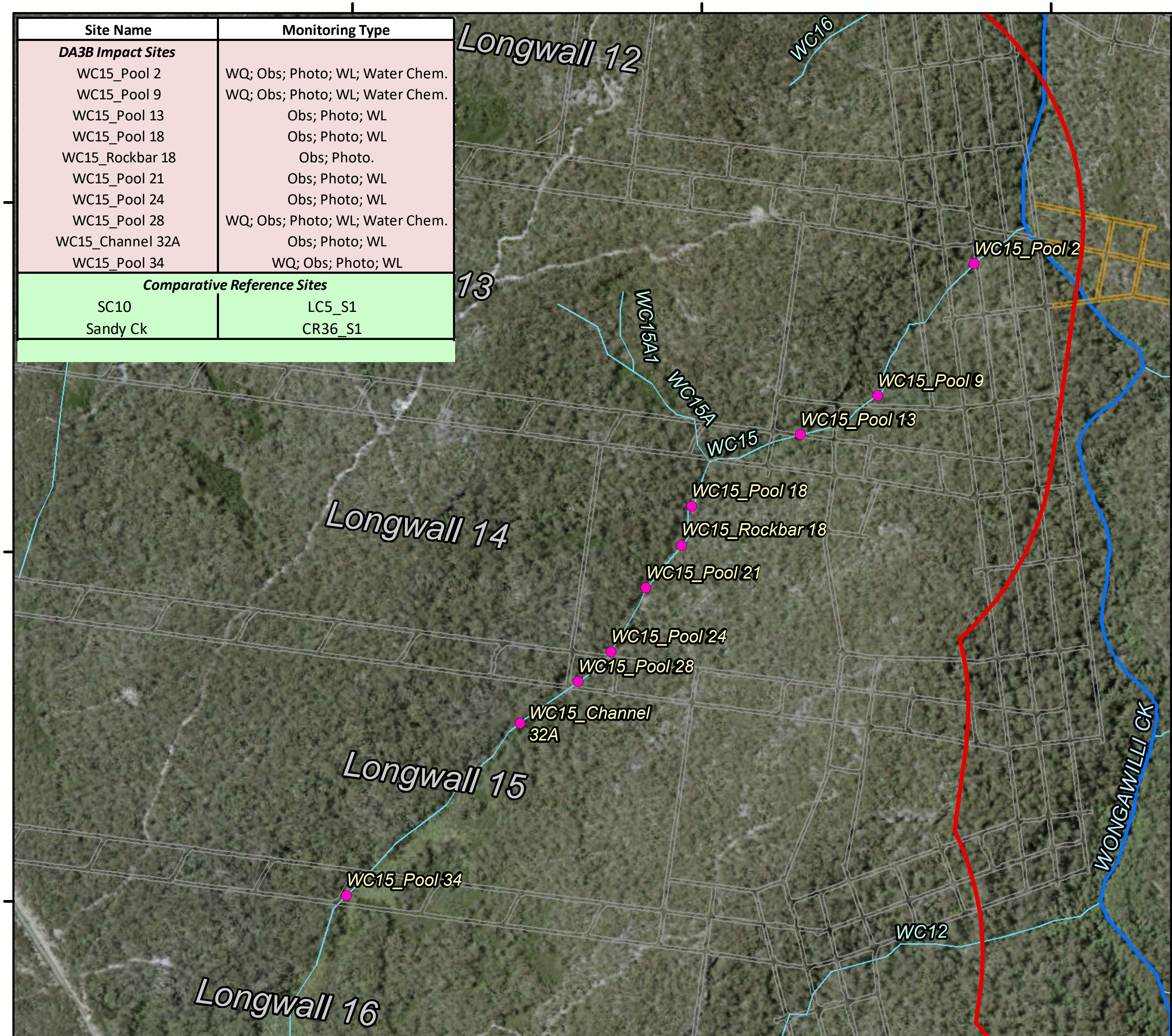
Dendrobium Area 3B

Watercourse Monitoring Sites

WC15

Figure 3-25

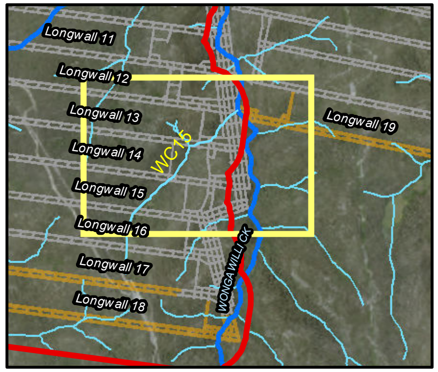
Site Name	Monitoring Type
DA3B Impact Sites	
WC15_Pool 2	WQ; Obs; Photo; WL; Water Chem.
WC15_Pool 9	WQ; Obs; Photo; WL; Water Chem.
WC15_Pool 13	Obs; Photo; WL
WC15_Pool 18	Obs; Photo; WL
WC15_Rockbar 18	Obs; Photo.
WC15_Pool 21	Obs; Photo; WL
WC15_Pool 24	Obs; Photo; WL
WC15_Pool 28	WQ; Obs; Photo; WL; Water Chem.
WC15_Channel 32A	Obs; Photo; WL
WC15_Pool 34	WQ; Obs; Photo; WL
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1



SOUTH32

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries



Date: February, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 175 350

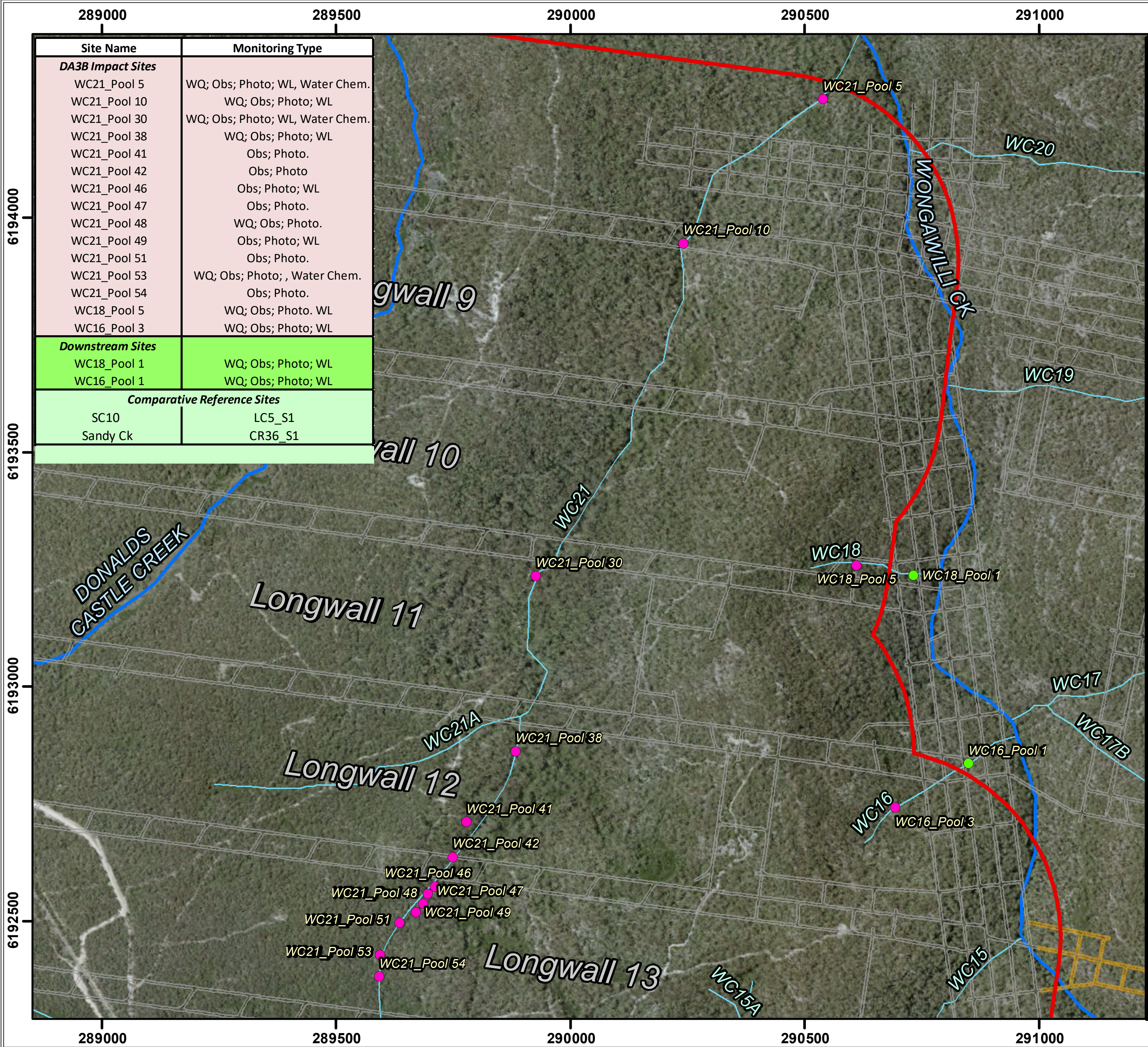
Dendrobium Area 3B

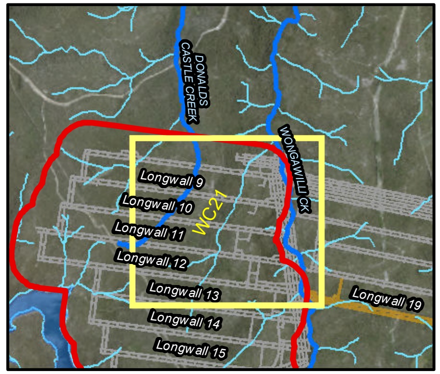
Watercourse Monitoring Sites

WC21, WC18 and WC16

Figure 3-26

Site Name	Monitoring Type
DA3B Impact Sites	
WC21_Pool 5	WQ; Obs; Photo; WL, Water Chem.
WC21_Pool 10	WQ; Obs; Photo; WL
WC21_Pool 30	WQ; Obs; Photo; WL, Water Chem.
WC21_Pool 38	WQ; Obs; Photo; WL
WC21_Pool 41	Obs; Photo.
WC21_Pool 42	Obs; Photo
WC21_Pool 46	Obs; Photo; WL
WC21_Pool 47	Obs; Photo.
WC21_Pool 48	WQ; Obs; Photo.
WC21_Pool 49	Obs; Photo; WL
WC21_Pool 51	Obs; Photo.
WC21_Pool 53	WQ; Obs; Photo; , Water Chem.
WC21_Pool 54	Obs; Photo.
WC18_Pool 5	WQ; Obs; Photo. WL
WC16_Pool 3	WQ; Obs; Photo; WL
Downstream Sites	
WC18_Pool 1	WQ; Obs; Photo; WL
WC16_Pool 1	WQ; Obs; Photo; WL
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1





SOUTH32

Legend

- Downstream Monitoring Locations
- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Creeks
- Tributaries

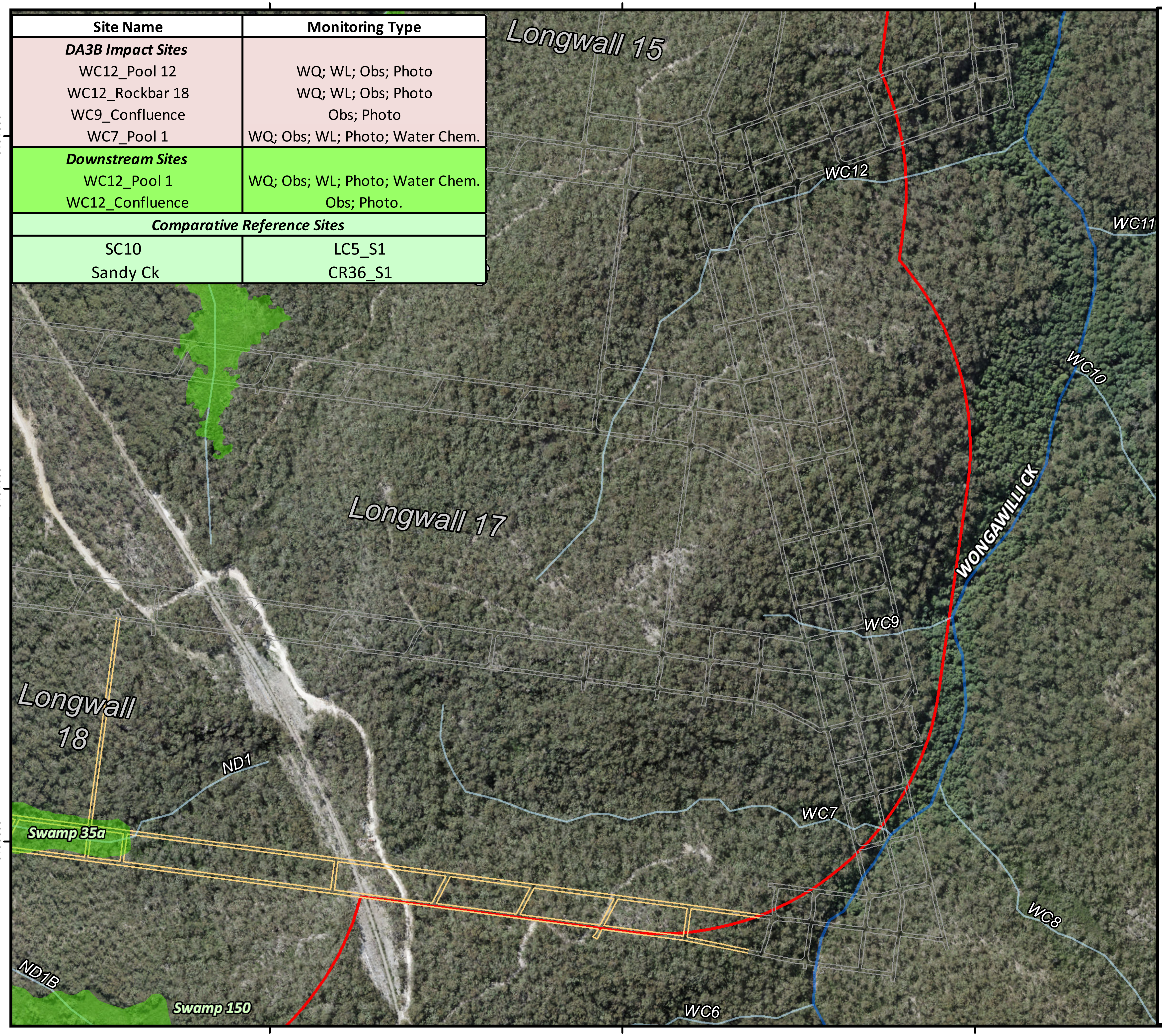
Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N S W E

Meters
0 250 500

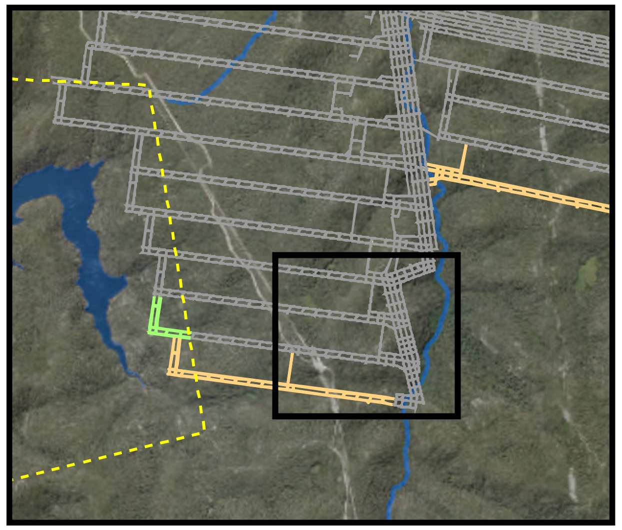
Site Name	Monitoring Type
DA3B Impact Sites	
WC12_Pool 12	WQ; WL; Obs; Photo
WC12_Rockbar 18	WQ; WL; Obs; Photo
WC9_Confluence	Obs; Photo
WC7_Pool 1	WQ; Obs; WL; Photo; Water Chem.
Downstream Sites	
WC12_Pool 1	WQ; Obs; WL; Photo; Water Chem.
WC12_Confluence	Obs; Photo.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1



SOUTH32

Dendrobium Area 3B Water Monitoring Sites and Observation Monitoring Sites WC7, WC9, WC12 Figure 3-27

- Downstream Monitoring Site
- Impact Monitoring Site
- Swamps
- Creeks
- Tributaries
- Existing Mine Workings
- Proposed Longwall Layout
- SMP Area
- DSC Notification Areas



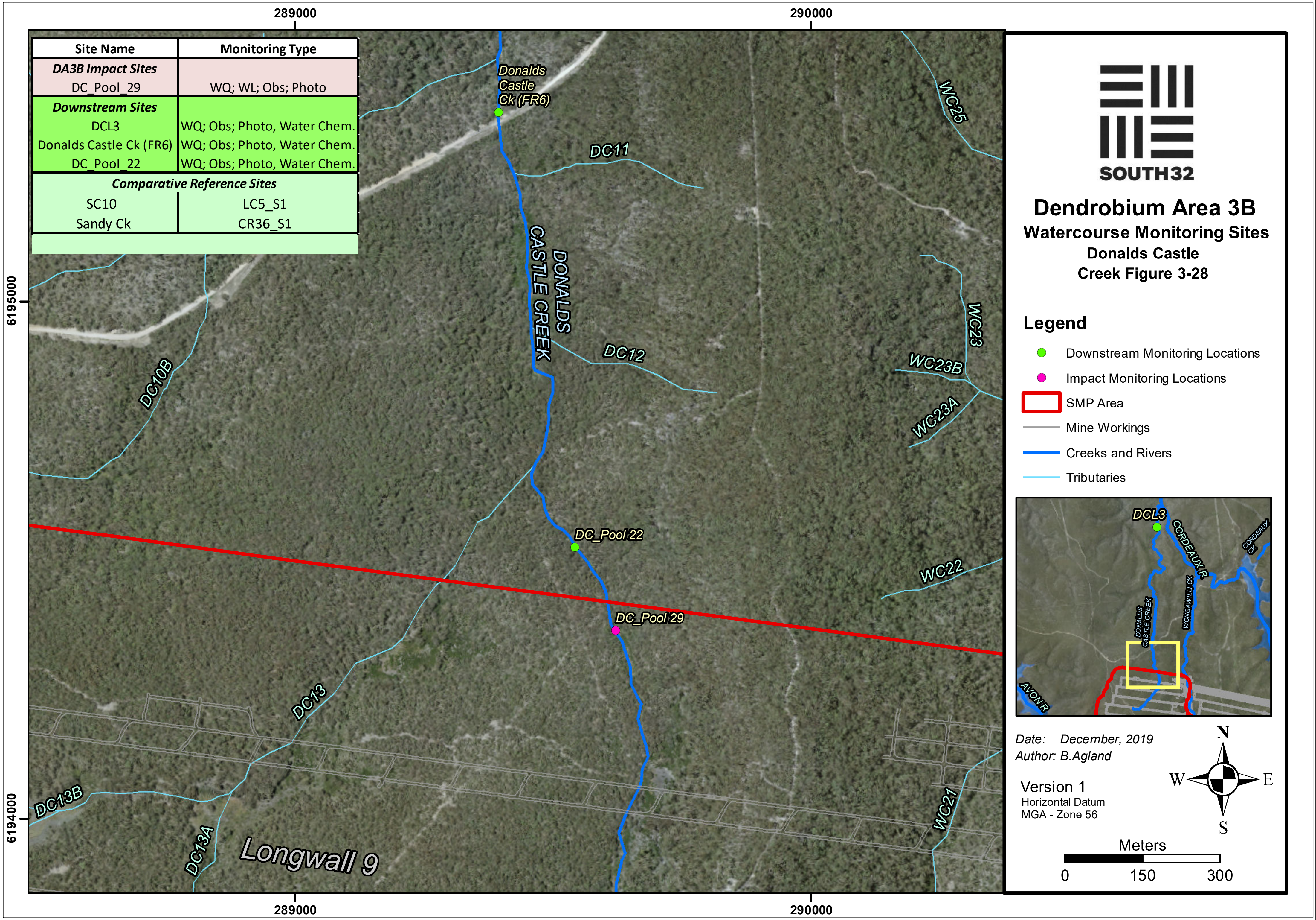
Date: August, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N E S W

Meters
0 150 300

Dendrobium Area 3B
Watercourse Monitoring Sites Donalds Castle Creek Figure 3-28



Site Name	Monitoring Type
DA3B Impact Sites	
DC_Pool_29	WQ; WL; Obs; Photo
Downstream Sites	
DCL3	WQ; Obs; Photo, Water Chem.
Donalds Castle Ck (FR6)	WQ; Obs; Photo, Water Chem.
DC_Pool_22	WQ; Obs; Photo, Water Chem.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1

Date: *December, 2019*
Author: B.Agland

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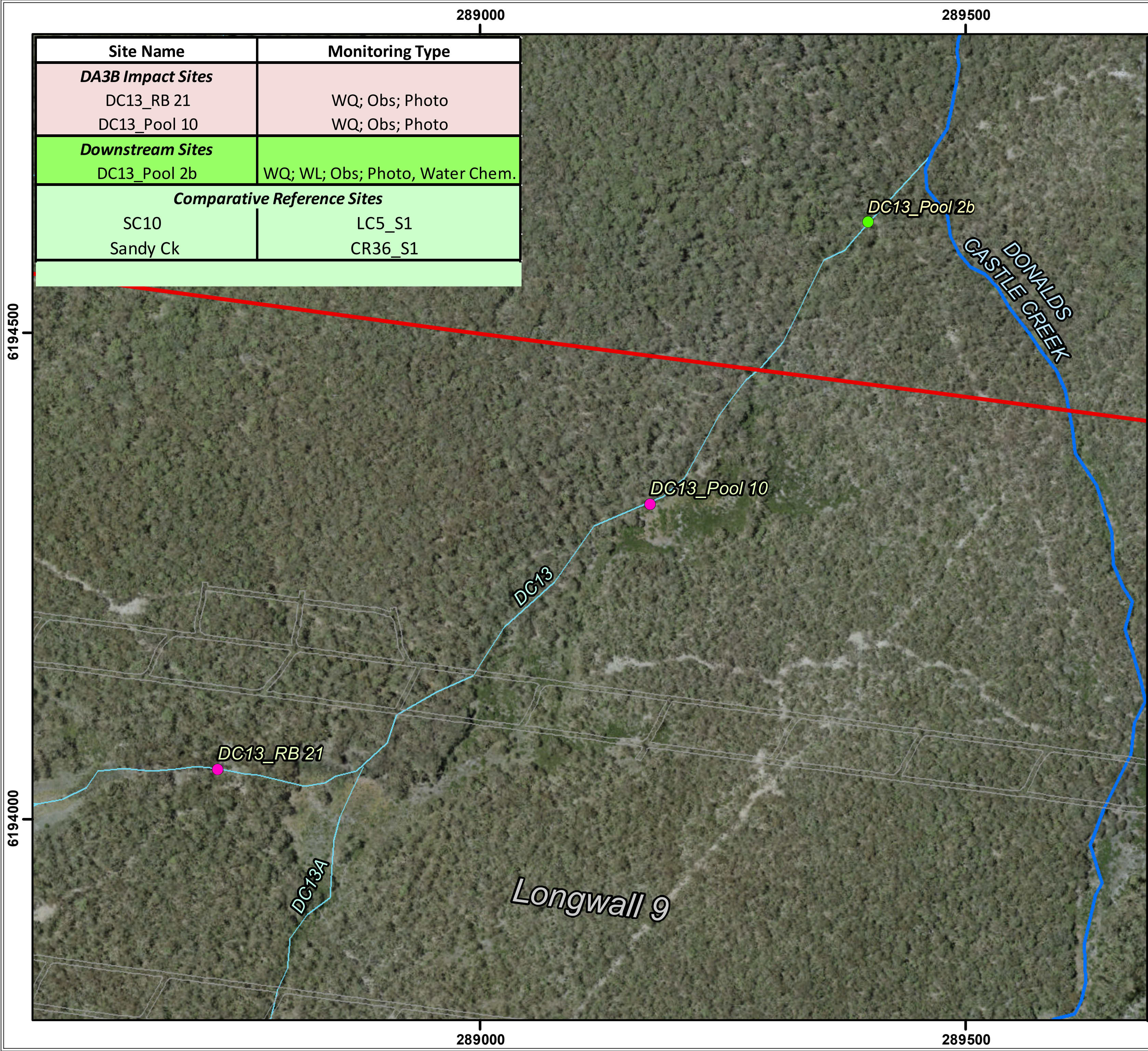
Horizontal Datum
MGA - Zone 56

Site Name	Monitoring Type
DA3B Impact Sites	
DC13_RB 21	WQ; Obs; Photo
DC13_Pool 10	WQ; Obs; Photo
Downstream Sites	
DC13_Pool 2b	WQ; WL; Obs; Photo, Water Chem.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1



SOUTH32

Dendrobium Area 3B

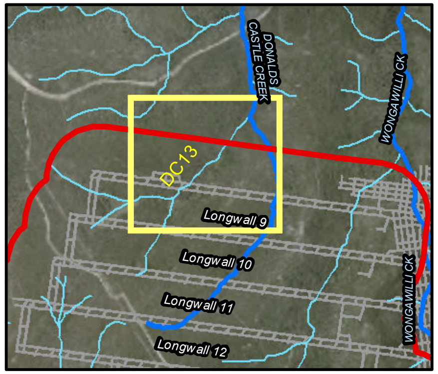
Watercourse Monitoring Sites

DC13

Figure 3-29

Legend

- Downstream Monitoring Site
- Impact Monitoring Site
- SMP Area
- Mine Workings
- Creeks
- Tributaries



Date: December, 2019

Author: B.Agland

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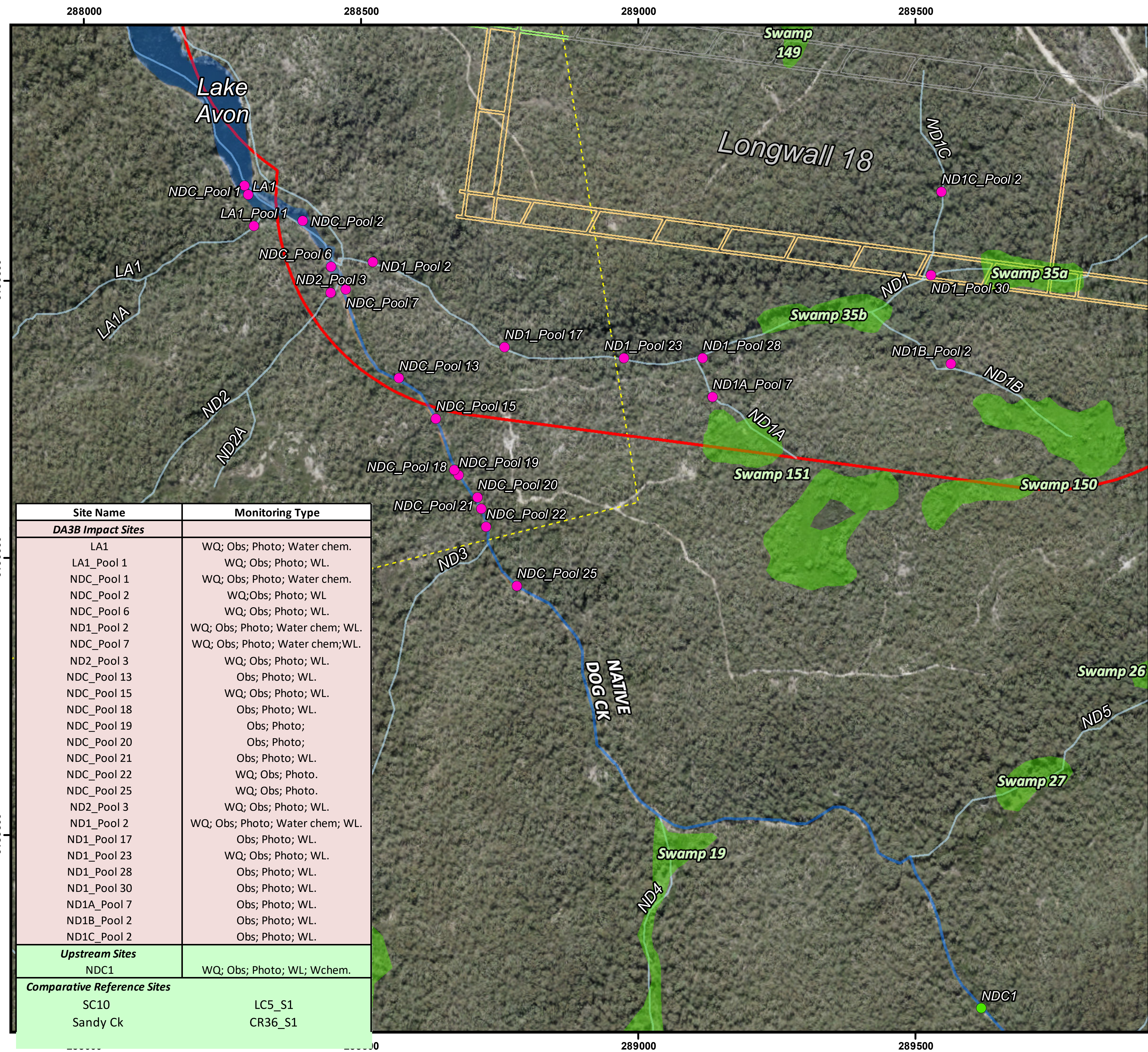
Horizontal Datum
MGA - Zone 56

Meters
0 125 250



Site Name	Monitoring Type
DA3B Impact Sites	
LA1	WQ; Obs; Photo; Water chem.
LA1_Pool 1	WQ; Obs; Photo; WL.
NDC_Pool 1	WQ; Obs; Photo; Water chem.
NDC_Pool 2	WQ;Obs; Photo; WL
NDC_Pool 6	WQ; Obs; Photo; WL.
ND1_Pool 2	WQ; Obs; Photo; Water chem; WL.
NDC_Pool 7	WQ; Obs; Photo; Water chem;WL.
ND2_Pool 3	WQ; Obs; Photo; WL.
NDC_Pool 13	Obs; Photo; WL.
NDC_Pool 15	WQ; Obs; Photo; WL.
NDC_Pool 18	Obs; Photo; WL.
NDC_Pool 19	Obs; Photo;
NDC_Pool 20	Obs; Photo;
NDC_Pool 21	Obs; Photo; WL.
NDC_Pool 22	WQ; Obs; Photo.
NDC_Pool 25	WQ; Obs; Photo.
ND2_Pool 3	WQ; Obs; Photo; WL.
ND1_Pool 2	WQ; Obs; Photo; Water chem; WL.
ND1_Pool 17	Obs; Photo; WL.
ND1_Pool 23	WQ; Obs; Photo; WL.
ND1_Pool 28	Obs; Photo; WL.
ND1_Pool 30	Obs; Photo; WL.
ND1A_Pool 7	Obs; Photo; WL.
ND1B_Pool 2	Obs; Photo; WL.
ND1C_Pool 2	Obs; Photo; WL.
Upstream Sites	
NDC1	WQ; Obs; Photo; WL; Wchem.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1

SOUTH32

Dendrobium Area 3B Water Monitoring Sites and Observation Monitoring Sites Native Dog Creek LA1, ND1, ND2 Figure 3-30

- Upstream Monitoring Site
- Impact Monitoring Site
- Swamps
- Creeks
- Tributaries
- Existing Mine Workings
- Proposed Longwall Layout
- SMP Area
- DSC Notification Areas

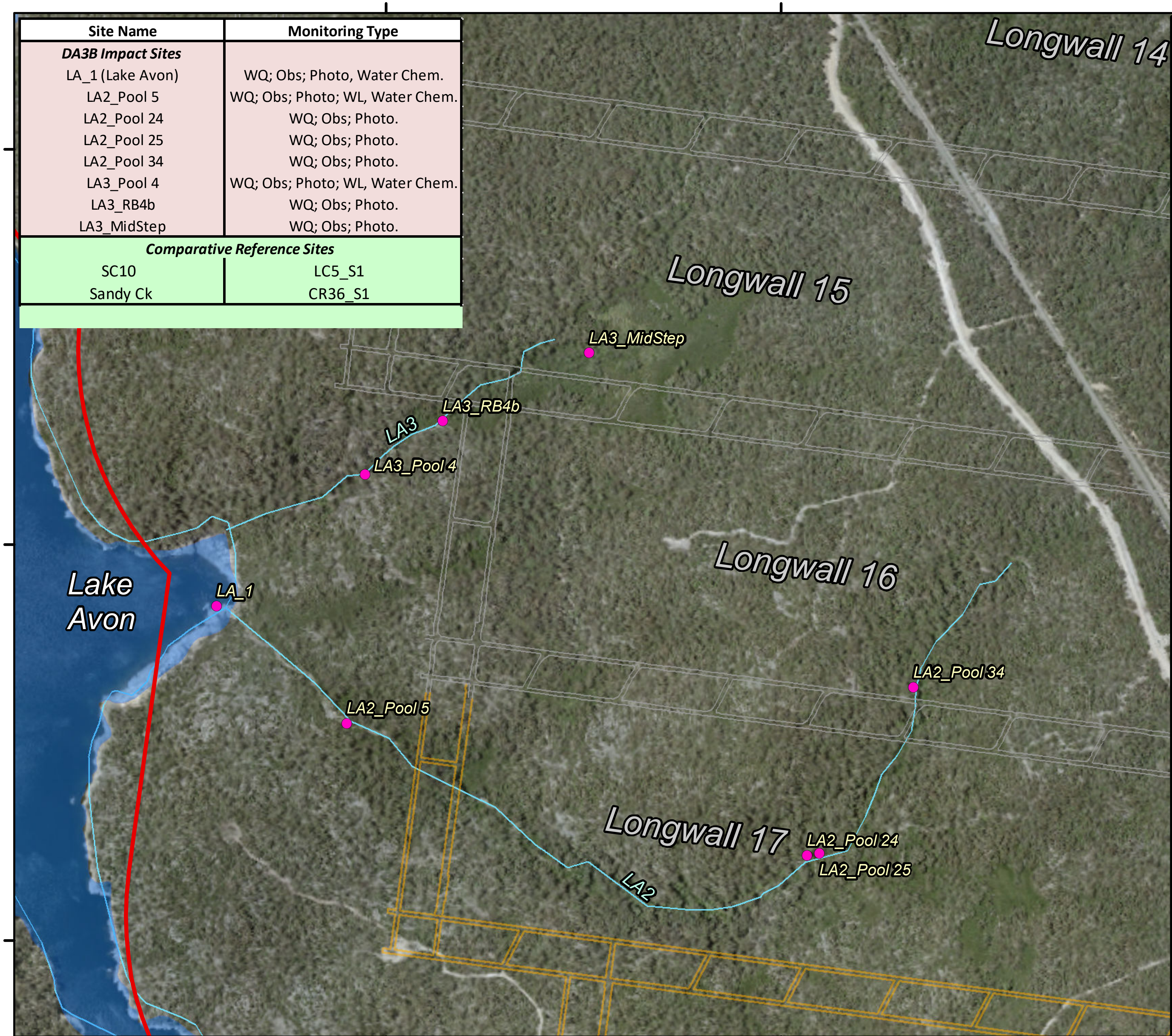
Date: August, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N S W E

Meters
0 250 500

Site Name	Monitoring Type
DA3B Impact Sites	
LA_1 (Lake Avon)	WQ; Obs; Photo, Water Chem.
LA2_Pool 5	WQ; Obs; Photo; WL, Water Chem.
LA2_Pool 24	WQ; Obs; Photo.
LA2_Pool 25	WQ; Obs; Photo.
LA2_Pool 34	WQ; Obs; Photo.
LA3_Pool 4	WQ; Obs; Photo; WL, Water Chem.
LA3_RB4b	WQ; Obs; Photo.
LA3_MidStep	WQ; Obs; Photo.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1



SOUTH32

Dendrobium Area 3B

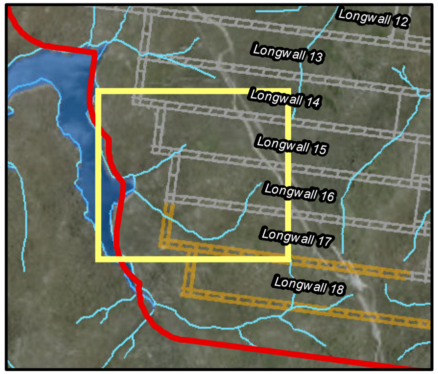
Watercourse Monitoring Sites

Lake Avon, LA2 and LA3

Figure 3-31

Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Proposed Longwall Layout
- Tributaries



Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

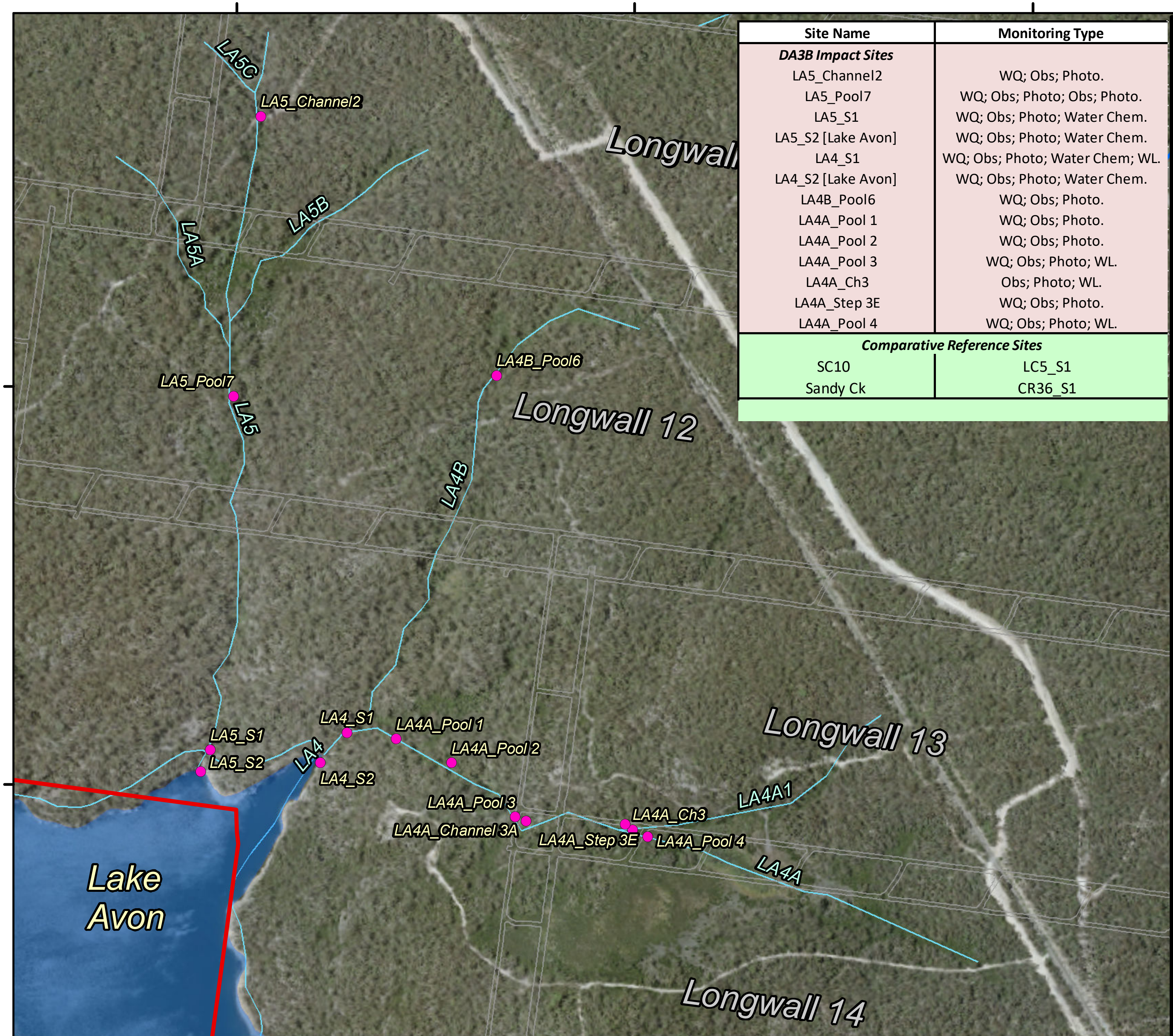
Meters
0 150 300

Dendrobium Area 3B

Watercourse Monitoring Sites
Lake Avon, LA4 and LA5
Figure 3-32

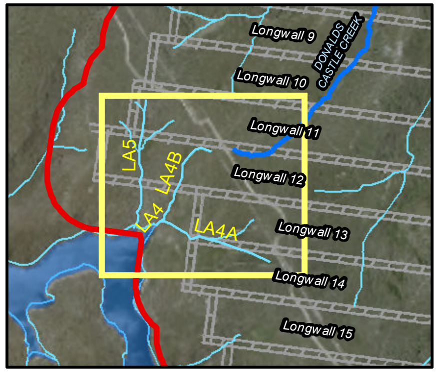
SOUTH32

Site Name	Monitoring Type
DA3B Impact Sites	
LA5_Channel2	WQ; Obs; Photo.
LA5_Pool7	WQ; Obs; Photo; Obs; Photo.
LA5_S1	WQ; Obs; Photo; Water Chem.
LA5_S2 [Lake Avon]	WQ; Obs; Photo; Water Chem.
LA4_S1	WQ; Obs; Photo; Water Chem; WL.
LA4_S2 [Lake Avon]	WQ; Obs; Photo; Water Chem.
LA4B_Pool6	WQ; Obs; Photo.
LA4A_Pool 1	WQ; Obs; Photo.
LA4A_Pool 2	WQ; Obs; Photo.
LA4A_Pool 3	WQ; Obs; Photo; WL.
LA4A_Ch3	Obs; Photo; WL.
LA4A_Step 3E	WQ; Obs; Photo.
LA4A_Pool 4	WQ; Obs; Photo; WL.
Comparative Reference Sites	
SC10	LC5_S1
Sandy Ck	CR36_S1



Legend

- Impact Monitoring Locations
- SMP Area
- Mine Workings
- Creeks
- Tributaries



Date: December, 2019
Author: B.Agland

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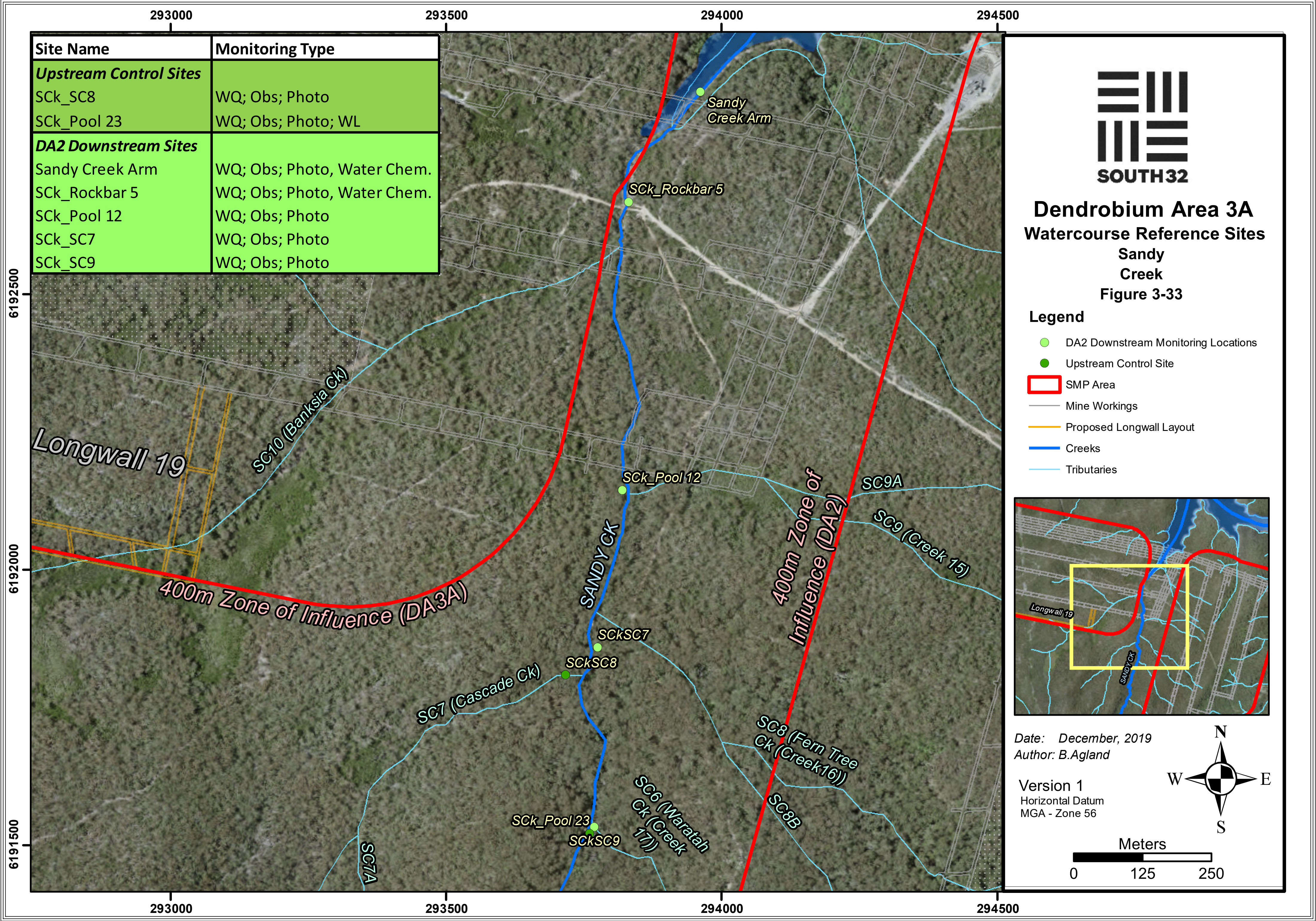
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 150 300



Site Name	Monitoring Type
Upstream Control Sites	
SCk_SC8	WQ; Obs; Photo
SCk_Pool 23	WQ; Obs; Photo; WL
DA2 Downstream Sites	
Sandy Creek Arm	WQ; Obs; Photo, Water Chem.
SCk_Rockbar 5	WQ; Obs; Photo, Water Chem.
SCk_Pool 12	WQ; Obs; Photo
SCk_SC7	WQ; Obs; Photo
SCk_SC9	WQ; Obs; Photo

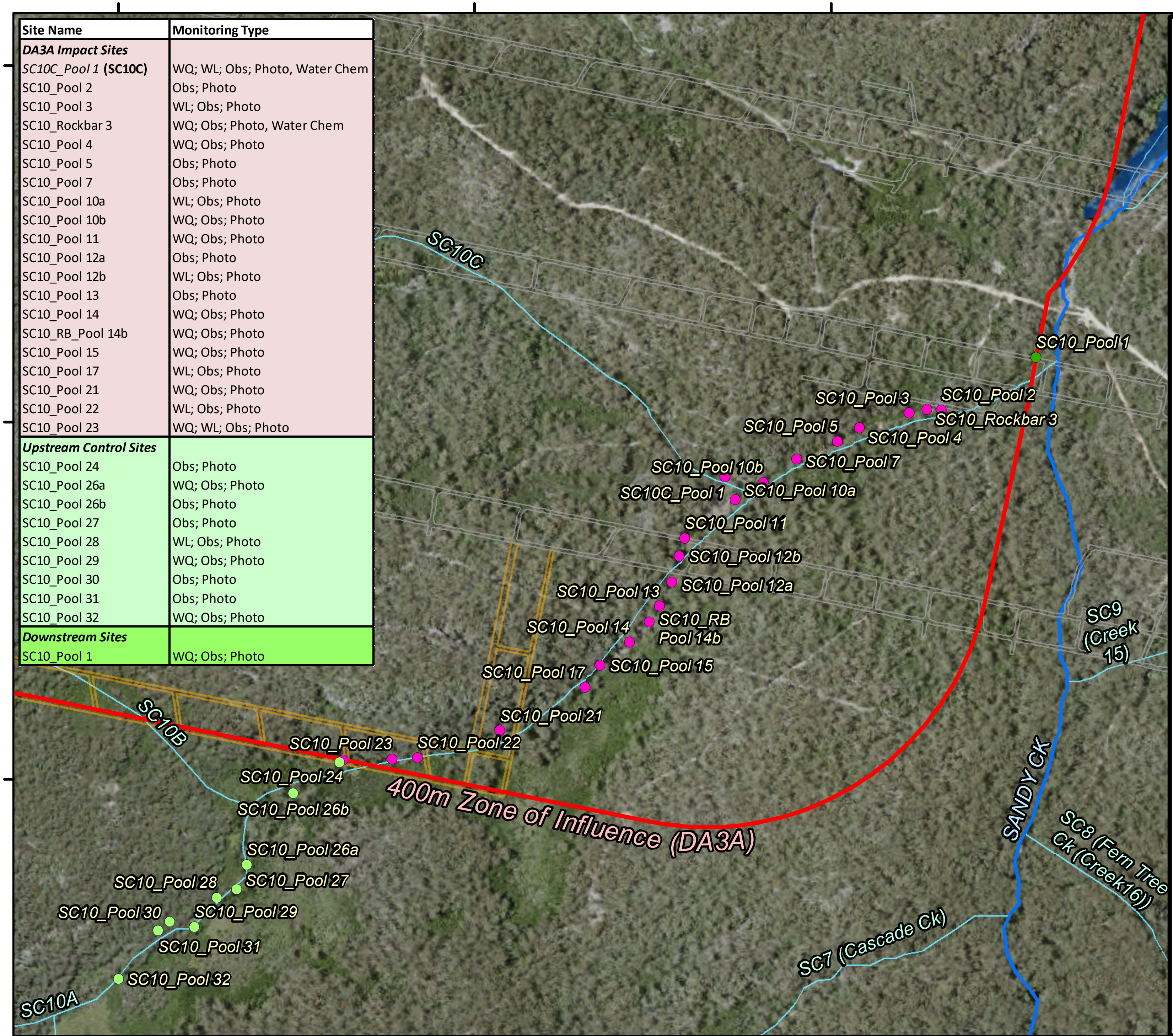
Dendrobium Area 3A

Watercourse Monitoring Sites

SC10

Figure 3-34

Site Name	Monitoring Type
DA3A Impact Sites	
SC10C_Pool 1 **(SC10C)**	WQ; WL; Obs; Photo, Water Chem
SC10_Pool 2	Obs; Photo
SC10_Pool 3	WL; Obs; Photo
SC10_Rockbar 3	WQ; Obs; Photo, Water Chem
SC10_Pool 4	WQ; Obs; Photo
SC10_Pool 5	Obs; Photo
SC10_Pool 7	Obs; Photo
SC10_Pool 10a	WL; Obs; Photo
SC10_Pool 10b	WQ; Obs; Photo
SC10_Pool 11	WQ; Obs; Photo
SC10_Pool 12a	Obs; Photo
SC10_Pool 12b	WL; Obs; Photo
SC10_Pool 13	Obs; Photo
SC10_Pool 14	WQ; Obs; Photo
SC10_RB_Pool 14b	WQ; Obs; Photo
SC10_Pool 15	WQ; Obs; Photo
SC10_Pool 17	WL; Obs; Photo
SC10_Pool 21	WQ; Obs; Photo
SC10_Pool 22	WL; Obs; Photo
SC10_Pool 23	WQ; WL; Obs; Photo
Upstream Control Sites	
SC10_Pool 24	Obs; Photo
SC10_Pool 26a	WQ; Obs; Photo
SC10_Pool 26b	Obs; Photo
SC10_Pool 27	Obs; Photo
SC10_Pool 28	WL; Obs; Photo
SC10_Pool 29	WQ; Obs; Photo
SC10_Pool 30	Obs; Photo
SC10_Pool 31	Obs; Photo
SC10_Pool 32	WQ; Obs; Photo
Downstream Sites	
SC10_Pool 1	WQ; Obs; Photo



SOUTH32

Legend

- Upstream Control Sites
- DA3A Impact Monitoring Sites
- Downstream Control Site
- 400m Zone of Influence
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries

Date: December, 2019
Author: B.Agland

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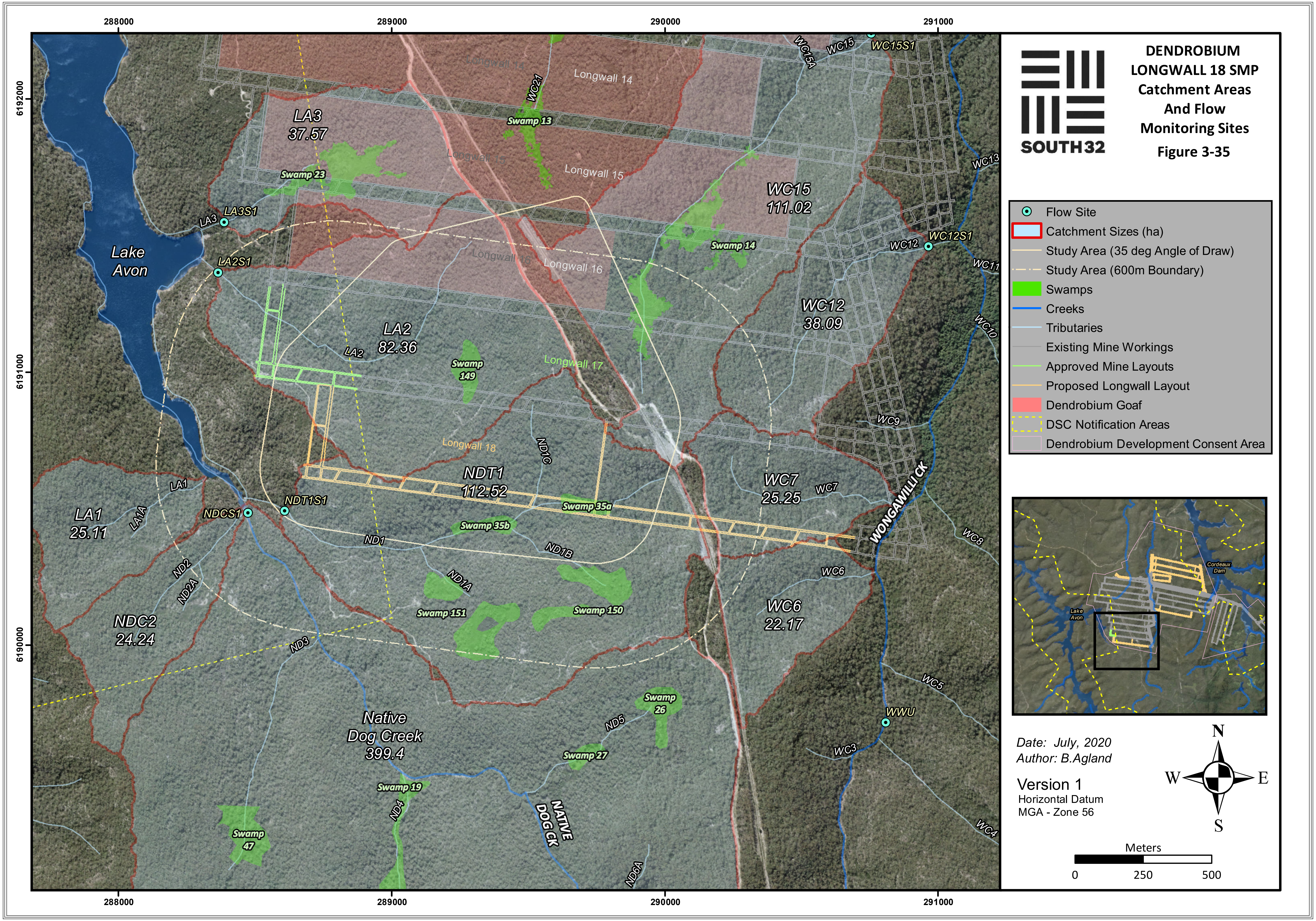
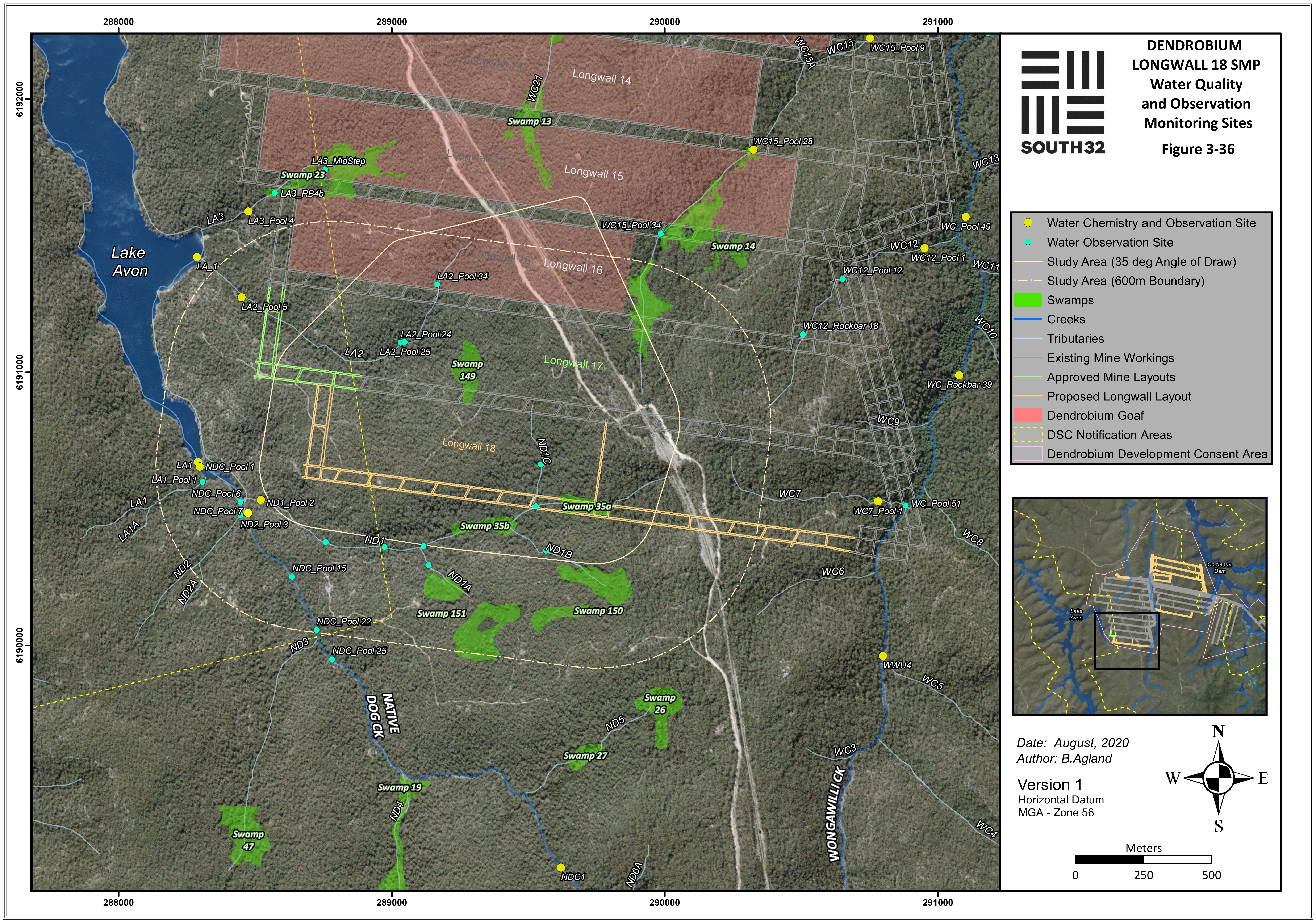
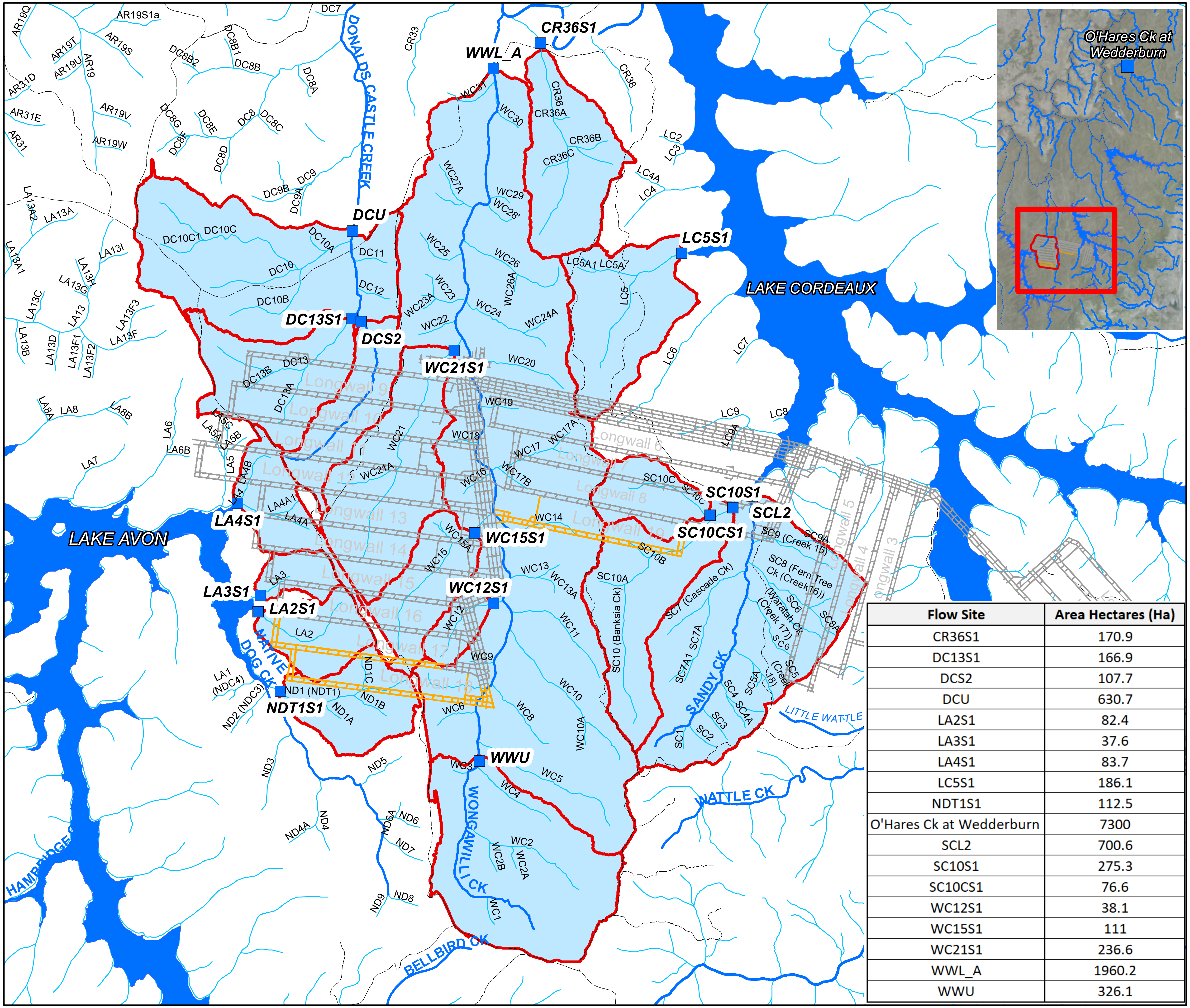
Horizontal Datum
MGA - Zone 56


DENDROBIUM
LONGWALL 18 SMP
Catchment Areas
And Flow
Monitoring Sites
Figure 3-35
SOUTH32
Flow Site
Catchment Sizes (ha)
Study Area (35 deg Angle of Draw)
Study Area (600m Boundary)
Swamps
Creeks
Tributaries
Existing Mine Workings
Approved Mine Layouts
Proposed Longwall Layout
Dendrobium Goaf
DSC Notification Areas
Dendrobium Development Consent Area
Date: July, 2020
Author: B.Agland
Version 1
Horizontal Datum
MGA - Zone 56
Meters
0
250
500
N
S
E
W
288000
289000
290000
291000
6192000
6191000
6190000
Lake Avon
LA3 37.57
LA2 82.36
LA1 25.11
NDC2 24.24
NDT1 112.52
WC15 111.02
WC12 38.09
WC7 25.25
WC6 22.17
Native Dog Creek 399.4
Longwall 14
Longwall 15
Longwall 16
Longwall 17
Longwall 18
Swamp 13
Swamp 23
Swamp 14
Swamp 149
Swamp 35a
Swamp 35b
Swamp 151
Swamp 150
Swamp 26
Swamp 27
Swamp 19
Swamp 47
LA3S1
LA2S1
NDCS1
NDT1S1
WC15S1
WC12S1
WWU
WONGAWILLI CK
NATIVE DOG CK
Cordeaux Dam
Lake Avon



DENDROBIUM LONGWALL 18 SMP Water Quality and Observation Monitoring Sites
Figure 3-36
SOUTH32
Water Chemistry and Observation Site
Water Observation Site
Study Area (35 deg Angle of Draw)
Study Area (600m Boundary)
Swamps
Creeks
Tributaries
Existing Mine Workings
Approved Mine Layouts
Proposed Longwall Layout
Dendrobium Goaf
DSC Notification Areas
Dendrobium Development Consent Area
Date: August, 2020
Author: B.Agland
Version 1
Horizontal Datum
MGA - Zone 56
Meters
0
250
500
N
S
W
E
Lake Avon
Cordeaux Dam
288000
289000
290000
291000
6192000
6191000
6190000
Lake Avon
Longwall 14
Longwall 15
Longwall 16
Longwall 17
Longwall 18
Swamp 13
Swamp 14
Swamp 23
Swamp 149
Swamp 35a
Swamp 35b
Swamp 151
Swamp 150
Swamp 26
Swamp 27
Swamp 19
Swamp 47
LA3_MidStep
LA3_RB4b
LA3_Pool 4
LA3
LA_1
LA2_Pool 5
LA2_Pool 34
LA2_Pool 24
LA2_Pool 25
LA2
LA1
NDC_Pool 1
LA1_Pool 1
NDC_Pool 6
NDC_Pool 7
ND1_Pool 2
ND2_Pool 3
LA1A
ND2
ND2A
ND1
ND1A
ND1B
ND1C
NDC_Pool 15
NDC_Pool 22
NDC_Pool 25
ND3
NATIVE DOG CK
ND4
ND5
ND6A
NDC1
WC21
WC15
WC15A
WC15_Pool 9
WC15_Pool 28
WC15_Pool 34
WC13
WC_Pool 49
WC12
WC12_Pool 1
WC11
WC12_Pool 12
WC12_Rockbar 18
WC10
WC_Rockbar 39
WC9
WC7
WC7_Pool 1
WC_Pool 51
WC8
WC6
WWU4
WC5
WC3
WONGAWILLI CK
WC4



Flow Site	Area Hectares (Ha)
CR36S1	170.9
DC13S1	166.9
DCS2	107.7
DCU	630.7
LA2S1	82.4
LA3S1	37.6
LA4S1	83.7
LC5S1	186.1
NDT1S1	112.5
O'Hares Ck at Wedderburn	7300
SCL2	700.6
SC10S1	275.3
SC10CS1	76.6
WC12S1	38.1
WC15S1	111
WC21S1	236.6
WWL_A	1960.2
WWU	326.1

SOUTH32

Dendrobium Flow Monitoring Catchments and Sites

Figure 3-37

Legend

- Flow Monitoring Sites
- Flow Monitoring Catchments
- Mine Workings
- Proposed Longwall Layout
- Creeks
- Tributaries
- Fire Roads

Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

0 0.5 1 2 Kms

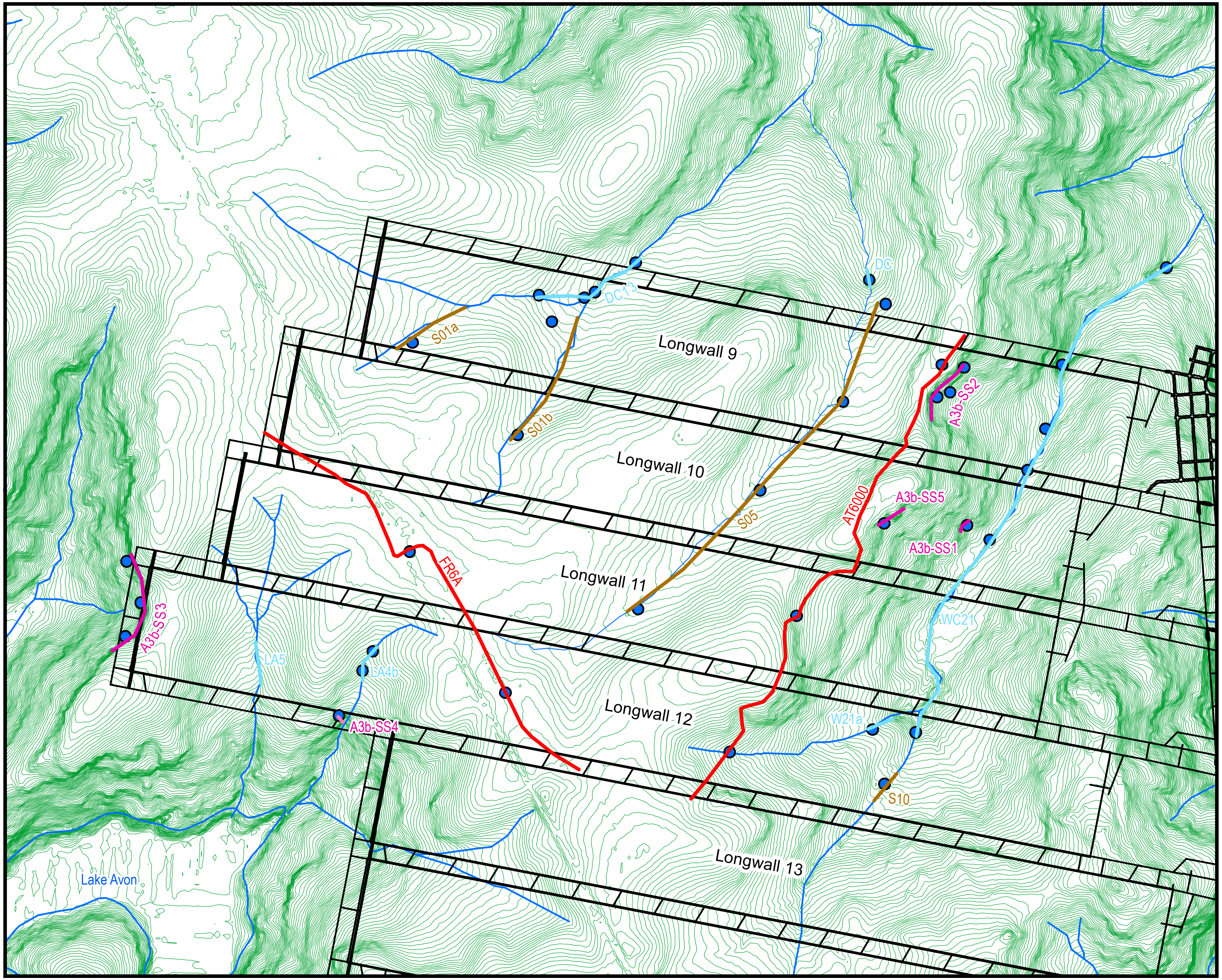


Figure 3-38

Title: SMP Landscape Monitoring Sites Area 3B (Longwall 9 to 12) Baseline Survey

Project: Dendrobium Mine Area 3B

Client: South 32 Illawarra Coal

Legend:

- Access Track/Fire Road
- Steep Slope
- Steep Slope (Rock Ledge Only)
- Swamp
- Watercourse
- Official Photo Site
- Creeklines
- Longwall Plan
- Contours (1metre)

Drawing No: BIC01-007_Figure_1

Date: 19/02/2013 **Drawing size:** A4

Drawn by: NT **Reviewed by:** DJ

Scale: 1:15,000

0 0.125 0.25 0.5 Kilometers

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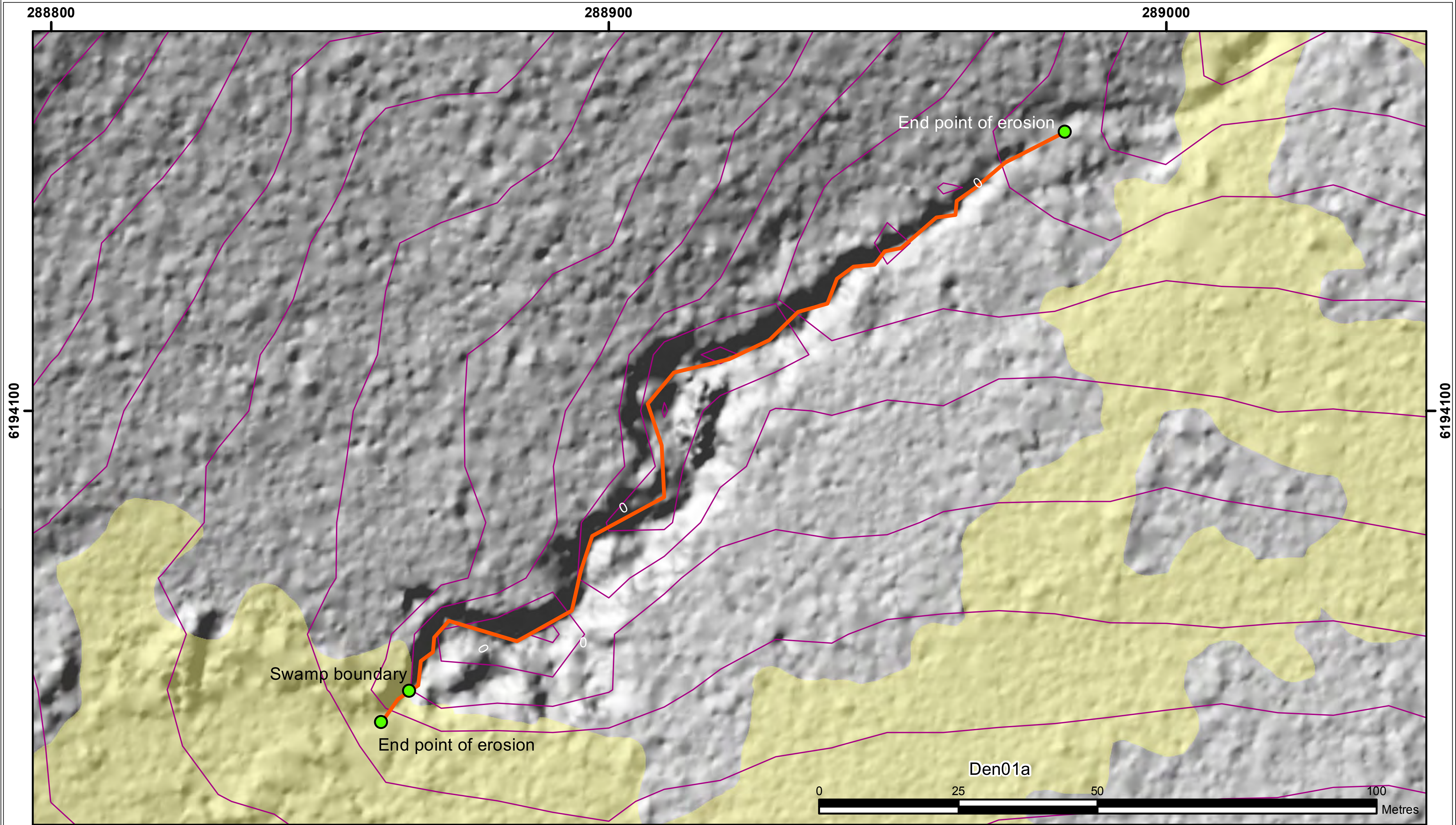
Document Path: V:\BIC01-007\Figures\ArcGIS\Map Documents\BIC01-007_Figure_1.mxd



SOUTH32

Illawarra Coal

Legend

- Total Active Erosion
- 1m contours
- Swamp Subcommunity Mapping

Shaded Relief (derived from ALS imagery)

Dendrobium Area 3B

Mapped Erosion- Swamp 01a

Figure 3.39

Date: 20 May, 2014
Author: T. McMahon
Authoriser: G. Brassington

Version 1

Horizontal Datum
MGA - Zone 56

N S W E

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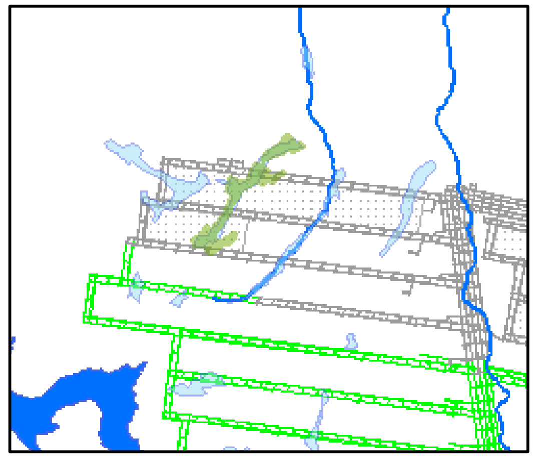
Illawarra Coal

Dendrobium Area 3B
Swamp 1A

Figure 3.40
Orthophoto Pre-fire

Swamp 1A in
Regional Context



Date: 10 April, 2014
Author: P.Crowe
Signed Off: G.Brassington

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Horizontal Datum
MGA - Zone 56

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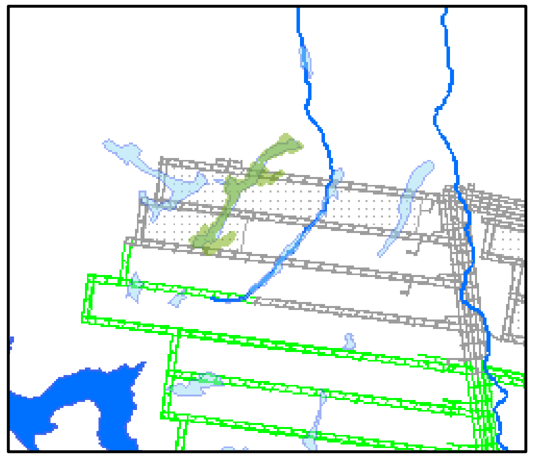
Illawarra Coal

Dendrobium Area 3B
Swamp 1A

Figure 3.41
Orthophoto Post-fire

Swamp 1A in
Regional Context



Date: 10 April, 2014
Author: P.Crowe
Signed Off: G.Brassington

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Horizontal Datum
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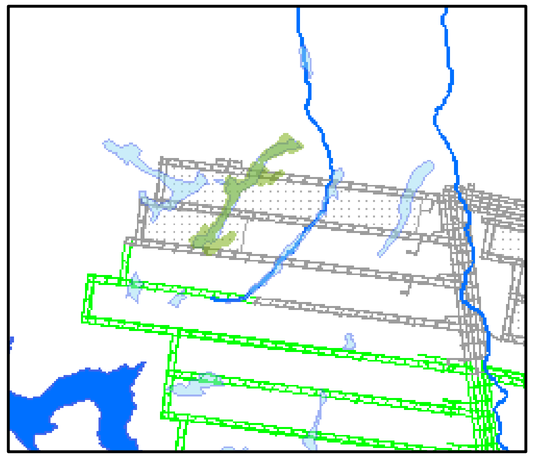
Illawarra Coal

Dendrobium Area 3B
Swamp 1A

Figure 3.42
Orthophoto May 2013

Swamp 1A in
Regional Context



Date: 10 April, 2014
Author: P.Crowe
Signed Off: G.Brassington

Version 1
Horizontal Datum
MGA - Zone 56

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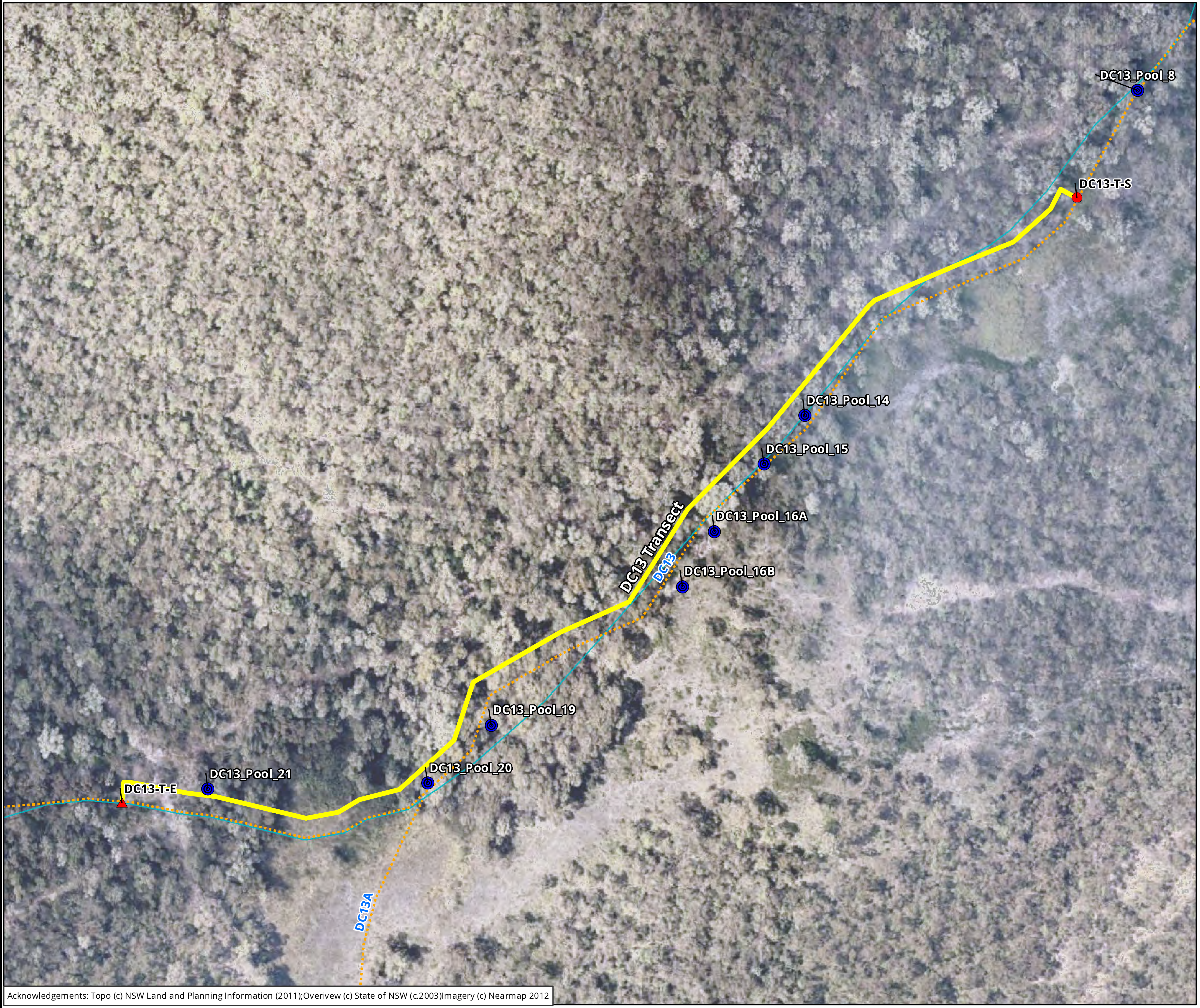

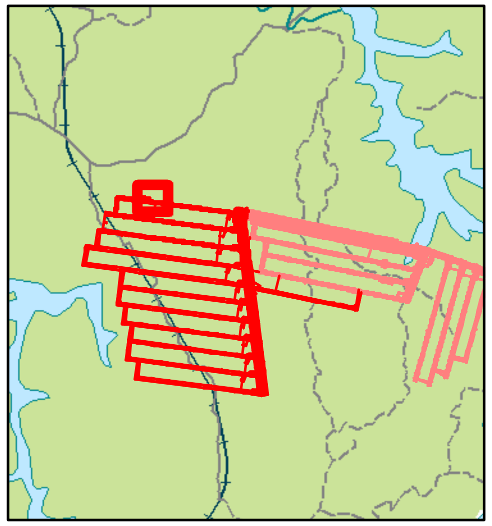

Legend

Pool Level Monitoring Sites

Threatened Frog Monitoring

Impact - Transect Start

Impact - Transect End

Threatened Frog Transect

BHP Creek and Swamp Naming

BHP Creekline

Figure 3.43: DC13 Transect

0 10 20 30 40 50

Metres

Scale: 1:1,820 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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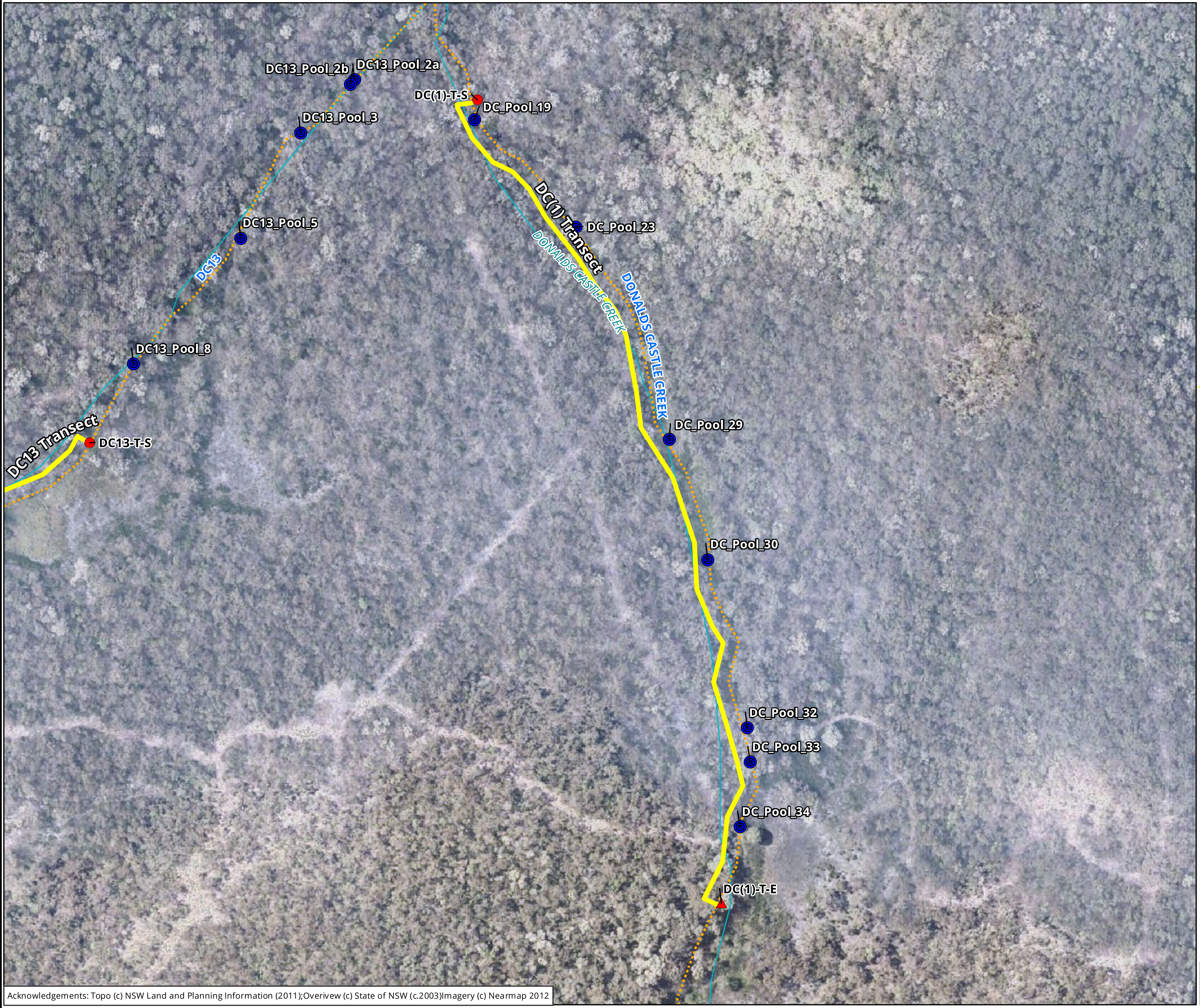
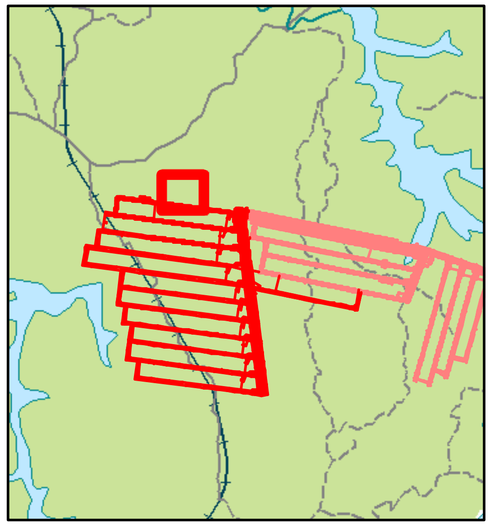
Location:P:\17900s\17994\Mapping
17994 Dend 3B TF Transects





Legend

Pool Level Monitoring Sites

Threatened Frog Monitoring

Impact - Transect Start

Impact - Transect End

Threatened Frog Transect

BHP Creek and Swamp Naming

BHP Creekline

Figure 3.44: DC(1) Transect

0 25 50 75 100 125

Metres

Scale: 1:2,480 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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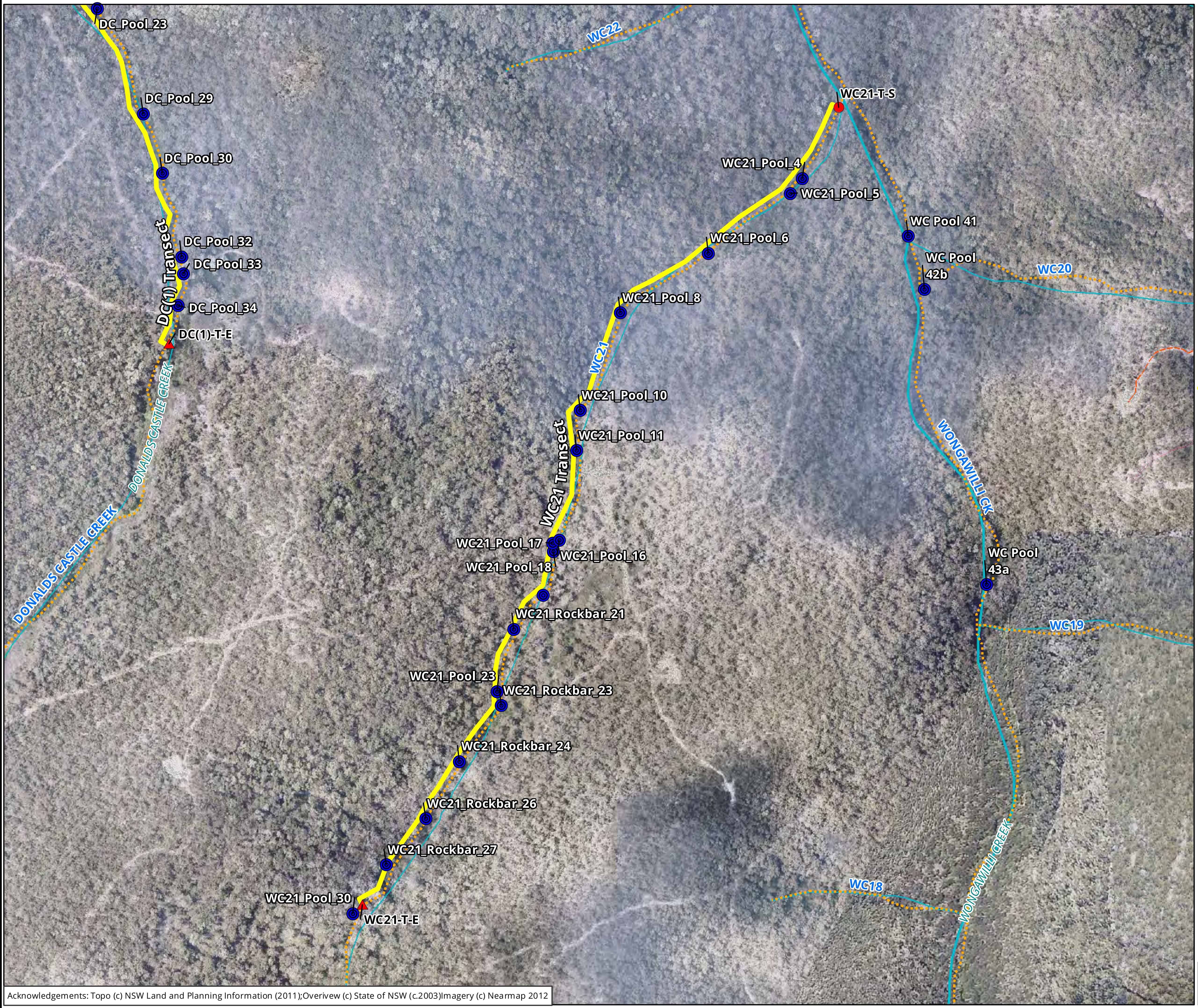

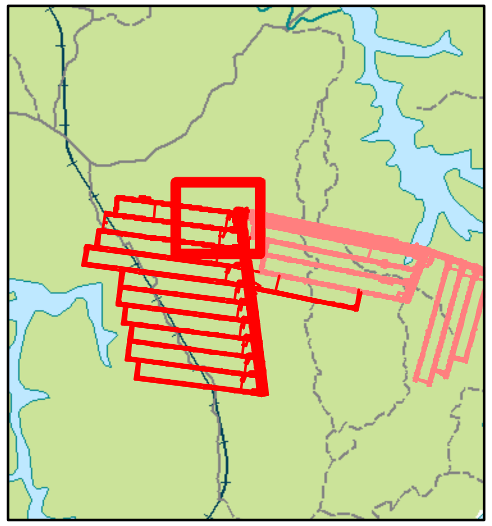

Legend

- Pool Level Monitoring Sites

Threatened Frog Monitoring

- Impact - Transect Start
- Impact - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.45: WC21 Transect

0 50 100 150 200 250
Metres
Scale: 1:5,000 @ A3
Coordinate System: GDA 1994 MGA Zone 56

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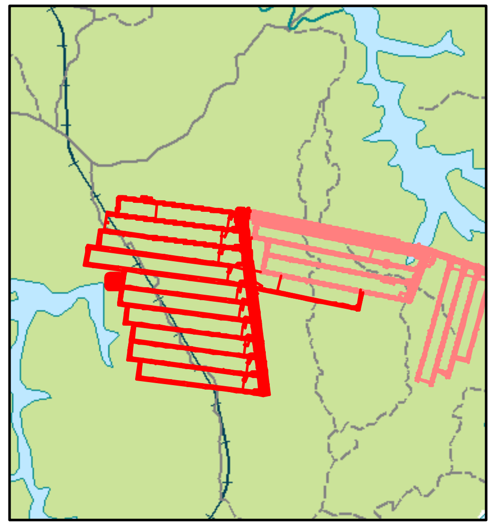
Acknowledgements: Topo (c) NSW Land and Planning Information (2011);Overivew (c) State of NSW (c.2003)Imagery (c) Nearmap 2012



Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.46: LA4A Transect

0 6 12 18 24 30

Metres

Scale: 1:610 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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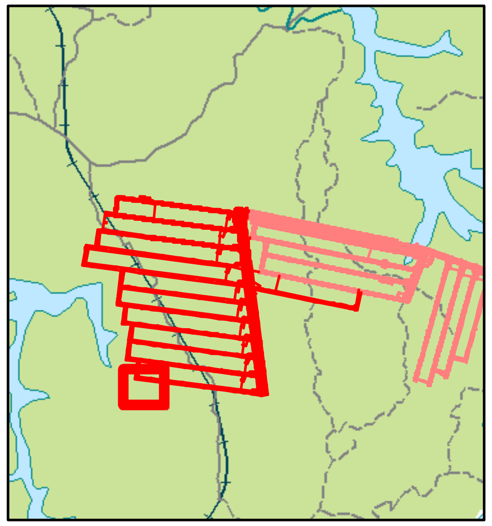

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.47: ND1 Transect

0 25 50 75 100 125

Metres

Scale: 1:2,470 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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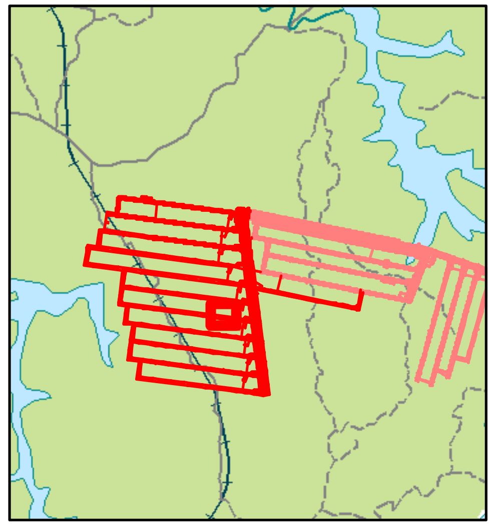

Legend

Pool Level Monitoring Sites

Threatened Frog Monitoring

Control - Transect Start

Control - Transect End

Threatened Frog Transect

BHP Creek and Swamp Naming

BHP Creekline

Figure 3.48 WC15 Transect

0 10 20 30 40 50

Metres

Scale: 1:1,550 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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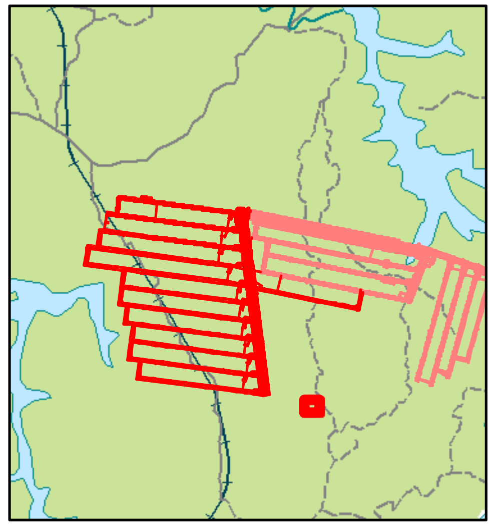

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.49: WC10 Transect

0 9.5 19 28.5 38 47.5

Metres

Scale: 1:940 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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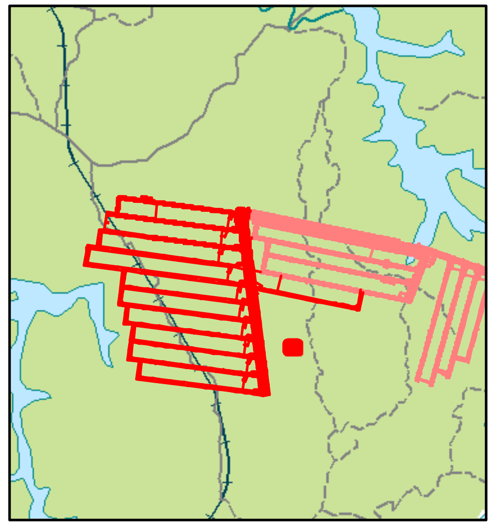

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.50: WC11 Transect

0 5.5 11 16.5 22 27.5

Metres

Scale: 1:550 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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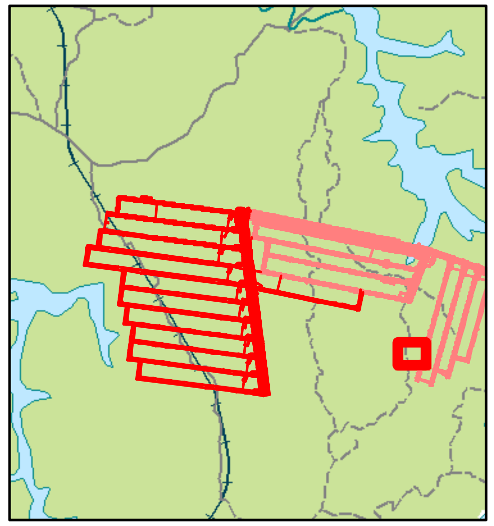

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.51: SC6 Transect

0 10 20 30 40 50

Metres

Scale: 1:1,620 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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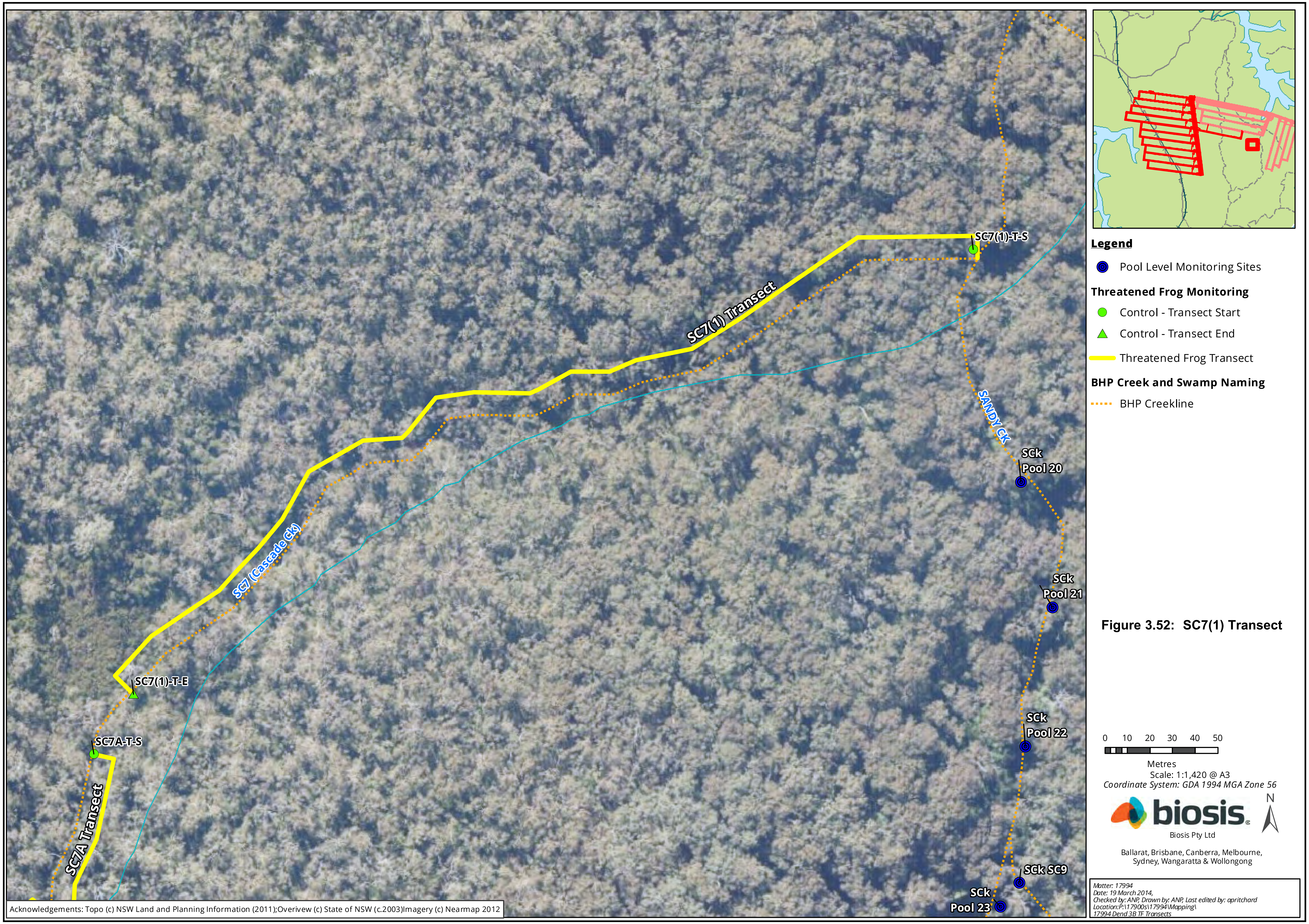
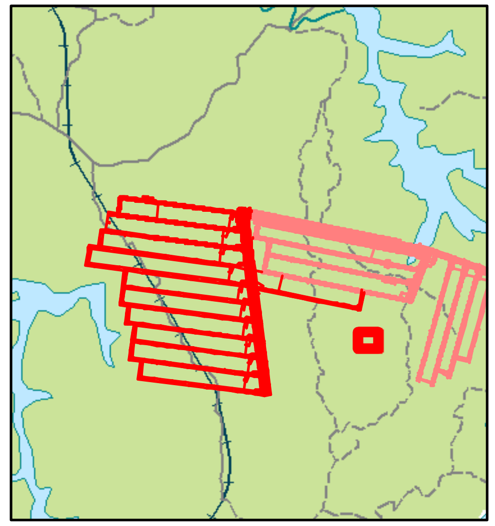


Figure 3.52: SC7(1) Transect

Acknowledgements: Topo (c) NSW Land and Planning Information (2011);Overivew (c) State of NSW (c.2003)Imagery (c) Nearmap 2012



Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.53: SC7(2) Transect

0 10 20 30 40 50

Metres

Scale: 1:1,210 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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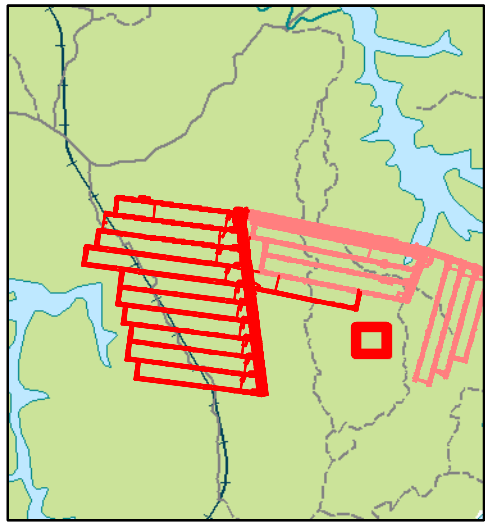

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.54: SC7A Transect

0 10 20 30 40 50

Metres

Scale: 1:1,830 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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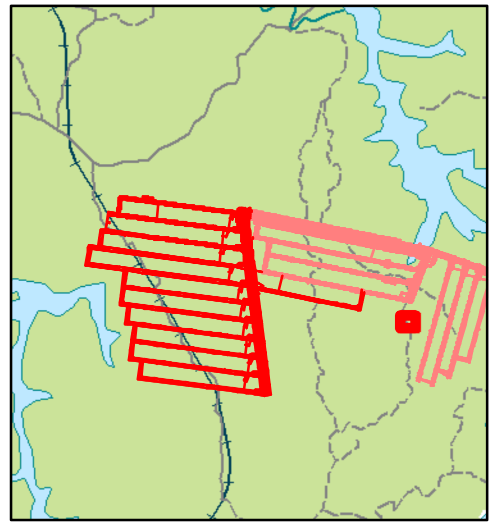

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.55: SC8 Transect

0 9 18 27 36 45

Metres

Scale: 1:890 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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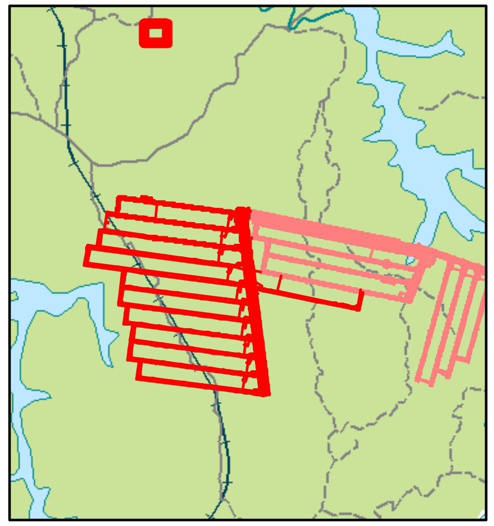

Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.56: DC8 Transect

0 10 20 30 40 50

Metres

Scale: 1:1,370 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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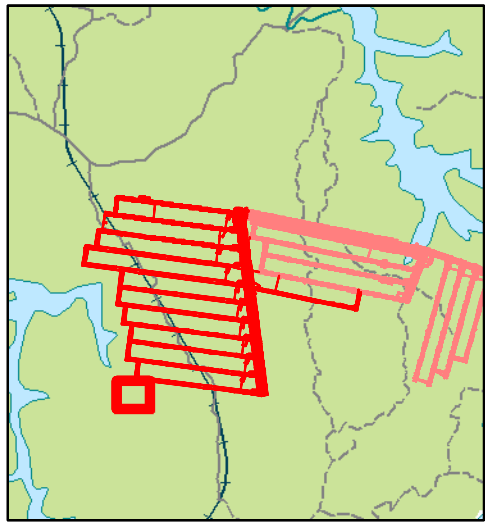
Acknowledgements: Topo (c) NSW Land and Planning Information (2011);Overivew (c) State of NSW (c.2003)Imagery (c) Nearmap 2012



Legend

Threatened Frog Monitoring

- Control - Transect Start
- Control - Transect End
- Threatened Frog Transect

BHP Creek and Swamp Naming

- BHP Creekline

Figure 3.57: NDC Transect

0 20 40 60 80 100

Metres

Scale: 1:1,970 @ A3

Coordinate System: GDA 1994 MGA Zone 56

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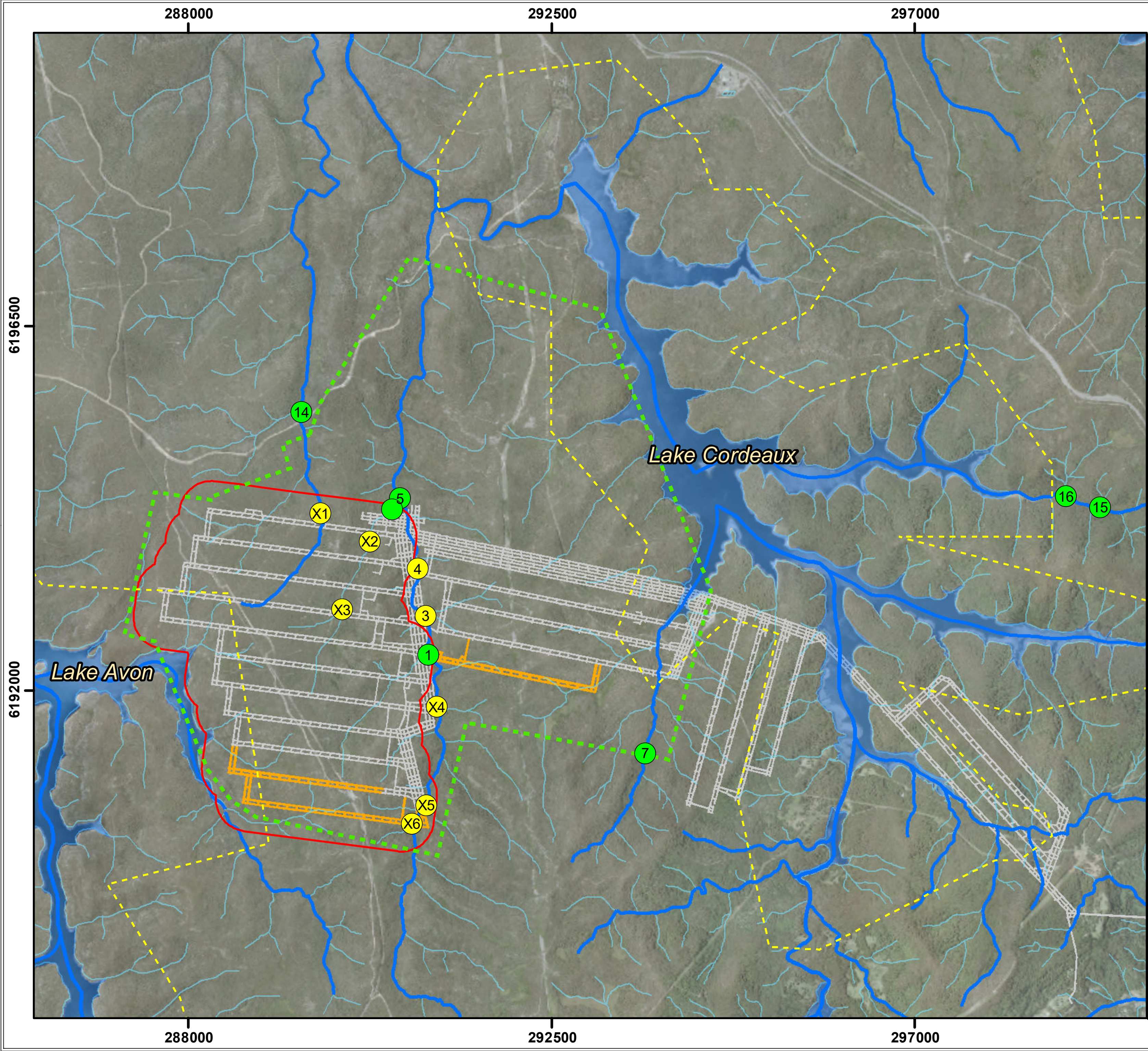

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Aquatic Ecology Monitoring Locations

DENDROBIUM AREA 3B SMP

Figure 3-58

Legend

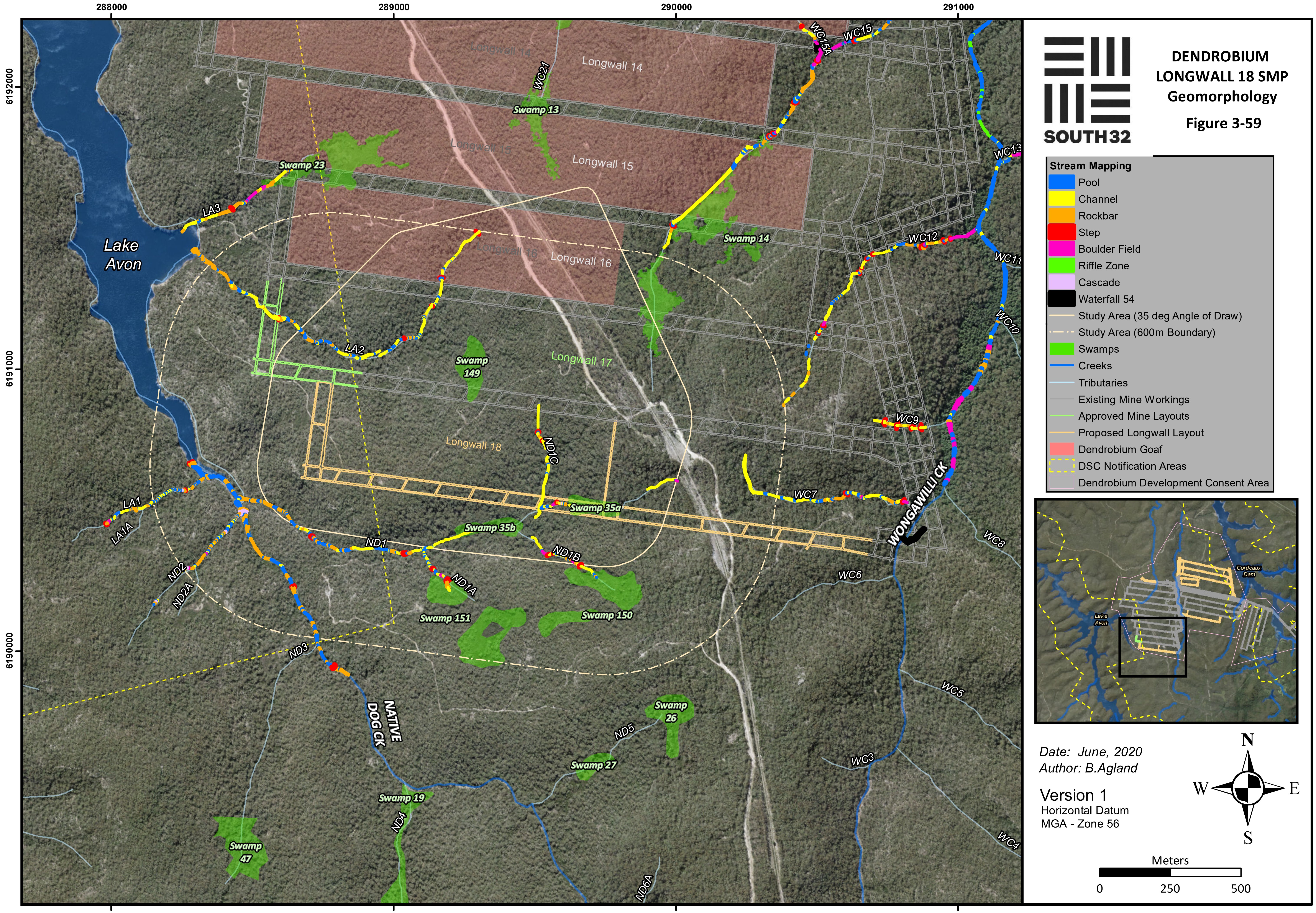
- Control Sites
- Potential Impact Sites
- SMP Area
- Dendrobium Area 3
- DSC Notification Areas
- Mine Workings
- Proposed Longwall Layout
- Tributaries
- Rivers and Creeks

Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

N W E S

Meters
0 1,250 2,500



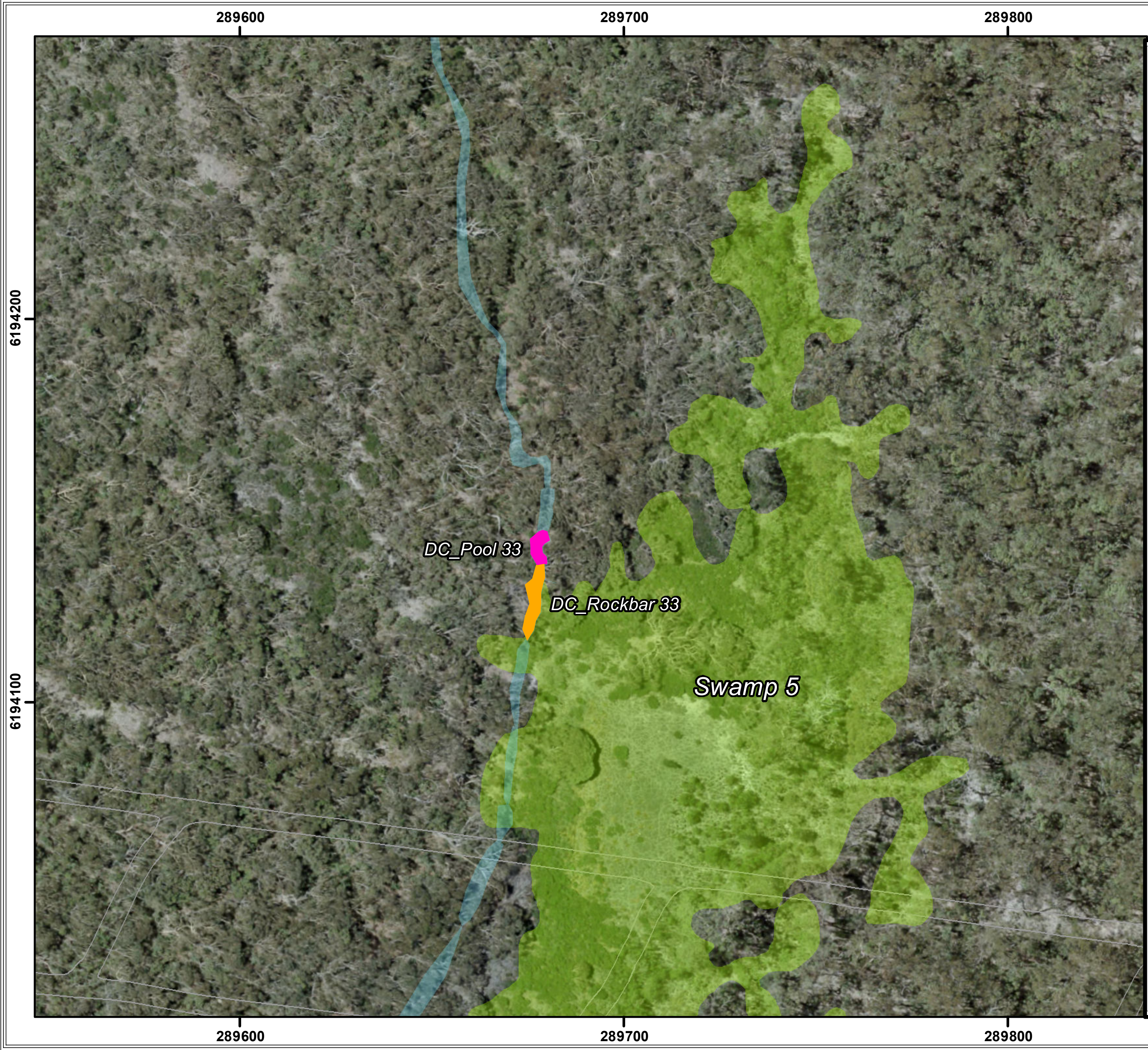
DENDROBIUM LONGWALL 18 SMP Geomorphology

Figure 3-59

SOUTH32

Date: June, 2020
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56



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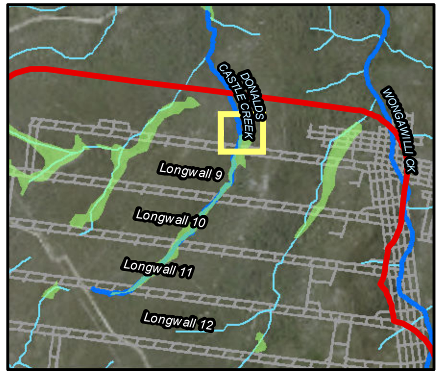
Dendrobium Area 3B

Donalds Castle Creek Significant Permanent Pools

Figure 3-60

Legend

- Significant Pool
- Basal Rockbar
- Donalds Castle Creek
- Swamps
- SMP Area
- Mine Workings



Date: December, 2019
Author: B.Agland

Version 1
Horizontal Datum
MGA - Zone 56

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Meters
0 25 50

4 PERFORMANCE MEASURES AND INDICATORS

Performance measures and indicators have been derived from the Dendrobium Development Consent and the Area 3B SMP Approval (2019). These performance measures are presented in **Table 5** and will be applied to the Dendrobium Area 3B mining area.

Table 5 Subsidence Impact Performance Measures

Dendrobium Development Consent
• Operations shall not cause subsidence impacts at Wongawilli Creek other than "minor impacts" (such as minor fracturing, gas release, iron staining and minor impacts on water flows, water levels and water quality); • Operations will not result in reduction (other than negligible reduction) in the quality or quantity of surface water or groundwater inflows to Lake Cordeaux or Lake Avon or surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek.
Area 3B SMP Approval

Waterfall WC-WF54
• Negligible environmental consequences including:
  o no rock fall occurs at the waterfall or from its overhang;
  o no impacts on the structural integrity of the waterfall, its overhang and its pool;
  o negligible cracking in Wongawilli Creek within 30 m of the waterfall; and
  o negligible diversion of water from the lip of the waterfall.
Wongawilli Creek and Donalds Castle Creek
• Minor environmental consequences including:
  o minor fracturing, gas release and iron staining; and
  o minor impacts on water flows, water levels and water quality.
Water Storages
• Negligible environmental consequences including:
  o negligible reduction in the quality or quantity of surface water inflows to the reservoir;
  o negligible reduction in the quality or quantity of groundwater inflows to the reservoir; and
• negligible leakage from the reservoir to underground mine workings.

A detailed list of performance measures and triggers is included in the TARPs in **Appendix A**.

4.1 Impact Mechanisms

Subsidence is an unavoidable consequence of longwall mining and includes vertical and horizontal movement of the land surface. Subsidence effects include surface and sub-surface cracking, buckling, dilation and tilting. These effects can result in changes to the hydrology of watercourses.

Changes to watercourse hydrology and water quality can result in environmental consequences. The likelihood and timing of these consequences relate to the size and duration of the effect. The potential consequences of mining on groundwater and surface water in the Special Areas are (IEP 2019a and b):

- Groundwater depressurisation
  - The creation of an excavation below the water table can affect groundwater in a number of basic ways. In all cases, because the fluid pressure in an excavation is much lower than that of the fluid that originally occupied the space, a flow system is established with the excavation acting as a sink into which surrounding groundwater flows. The rate of flow and observed extent of depressurisation depend on the hydrogeological properties of the rock mass. If the excavated area is sufficiently large, the spatial extent and rate of flow into the sink can be enhanced by the formation of fractures.

- Surface water diversions
  - Diversions into a shallow, localised fracture network, where loss of flow from a surface water is likely to return to the system at some point downstream, which based on observations of the SCI (2008) may vary from 20 m for specific rockbars to more than 200 m.
- Surface water permanent losses
  - Diversions into deeper, dilated shear surfaces on bedding planes, where these form a conduit for lateral water flow, which may or may not report to the same catchment (i.e. it may become a permanent loss).
- Groundwater depressurisation
  - Groundwater within the Hawkesbury Sandstone and Narrabeen Group as well as the Permian coal measures is recharged from rainfall and water bodies where the lithologies occur at outcrop, as well as potential downward leakage from overlying strata (Hydrosimulations 2018).
- Water quality
  - Water quality within watercourses is affected by numerous factors including runoff from swamps and interactions between bedrock and water, with fracturing of bedrock due to mining causing local water quality impacts.

The environmental consequences which could relate to changes in hydrology and water quality include:

- Species composition change and/or changes in vegetation communities.
- Loss of aquatic ecology and/or changes in aquatic habitat resulting from a reduction of surface water quality and/or flows and standing pools.
- Water-borne inputs to Lake Avon and Cordeaux River such as erosive export of fine sands and clays and/or ferruginous precipitates.
- Reduced inflows into Lake Avon and Cordeaux River.

4.2 Potential for Connectivity to the Mine Workings

The fracture zone comprises in-situ material lying immediately above the caved zone which have sagged downwards and consequently suffered significant bending, fracturing, joint opening and bed separation (Singh and Kendorski, 1981; Forster, 1995). Where the panel width-to-depth ratio is high and the depth of cover is shallow, the fracture zone would extend from the seam to the surface. Where the panel width-to-depth ratio is low, and where the depth of cover is high, the fracture zone would not extend from the seam to the surface.

The possible height of the fracture zone is dependent upon the angle of break, the width of the panel, the thickness of seam extracted and the spanning capacity of a competent stratum at the top of the fracture zone (MSEC 2012). Based on mining geometry, the height of the fracture zone equals the panel width, minus the span, divided by twice the tangent of the angle of break.

It should be noted that the height of the fracture zone should be viewed in the context of fracturing only and should not necessarily be directly associated with an increase in vertical permeability. There are numerous models for the height of fracturing and height of desaturation. A review of these matters was conducted for the Bulli Seam Operations Project Response to PAC deliberations (Hebblewhite 2010).

The Regional Groundwater Models at Dendrobium uses site specific data to determine the height of desaturation. Dendrobium monitors in excess of 1,000 piezometers in ~100 boreholes (including a comprehensive array of piezometers above the centreline of longwall goafs) and has analysed many thousands of samples for field parameters, laboratory analysis, algae and isotopes.

The results of water analysis and the interpretation of the height of connective fracturing was peer reviewed by Parson Brinckerhoff (2012). The peer review states that "the use of standard hydrogeochemical tools clearly demonstrated the geochemical difference between water from the Wongawilli Coal Seam and goaf, and the overlying sandstone formations and surface water from Lake Cordeaux". Although the report acknowledged limitations of the available data, this review is based on one of the most comprehensive datasets available in the Southern Coalfield.

In January 2015 SRK Consulting conducted a detailed independent review of the Dendrobium water chemistry data to:

- Assess the level of detail, quality of science, depth and technical appropriateness of the water chemistry data.
- Evaluate associated interpretations in relation to underground operations of Dendrobium Mine, with specific focus on how these address the question of hydraulic connectivity between the mined areas and the reservoirs.

Based on the review SRK concluded that the observed geochemical trends are not consistent with a high degree of hydraulic connectivity between the underground workings and the surface water bodies.

As reported in Coffey (2012) most of the change in aquifer properties occurs within the collapsed zone. Changes in aquifer properties above the collapsed zone are less severe and largely restricted to increases in storativity. Groundwater drawdown due to sudden storativity increases will ultimately impact the surface, either directly (as seepage from watercourses or lakes to satisfy the drawdown), or by intercepting baseflow.

Predictions of fracture zone dimensions for Dendrobium (MSEC 2012 and Coffey 2012) refer to geotechnical fracturing behaviour, and are not necessarily directly related to groundwater responses resulting from increased vertical permeability.

Parson Brinckerhoff and IMC have completed testing to characterise the pre- and post-mining permeability above Longwall 9, the first longwall in a new domain, not affected by previous mining. After Longwall 9 mined under the site it was tested to quantify the change to vertical and horizontal permeability of the strata, including the Bulgo and Hawkesbury Sandstones and the Bald Hill Claystone. The testing involved core, packer and borehole interference testing, groundwater flow and tracer testing.

Mining of Longwall 9 resulted in a significant increase in subsurface fracturing compared with pre-mining. Down-hole camera surveys identified a number of open horizontal and inclined fractures with apertures of several centimetres. Groundwater ingress was noted at several open fractures.

Most post-mining test bores showed decreases in groundwater level and strong downward hydraulic gradients, particularly in the lower Bulgo Sandstone. Significantly however, groundwater levels in the shallow Hawkesbury Sandstone remained perched at the study site.

Horizontal hydraulic conductivity increased between one to three orders of magnitude due to mine subsidence and strata fracturing. Increases in hydraulic conductivity are observed in every geological unit, but are greatest below the base of the Hawkesbury Sandstone.

In contrast to pre-mining testing in which no breakthrough was observed, horizontal tracer testing after the passage of Longwall 9 resulted in breakthrough in about 40 minutes. This indicates a bulk hydraulic conductivity in the order of 10 m/day; at least two orders of magnitude higher than pre-mining conditions.

No breakthrough in tracer was observed in either the pre-mining or the post-mining tests of the Bald Hill Claystone and this indicates that the vertical conductance at the research site was below the detection limit of the test, estimated to be approximately 0.7 m/day.

Activated carbon samplers deployed in streams adjacent to the research site detected no breakthrough of tracer and therefore there is no evidence of preferential flow paths either existing or induced between the research site and adjacent streams.

Sampling of water from the underground mine detected no breakthrough of tracer and therefore there is no evidence of preferential flow paths induced between the research site and the workings.

Although current observations do not allow a precise definition of the height of intense fracturing using any criteria (and the boundaries are gradational in any case), most evidence suggests that the zone of most intense and vertically connected fracturing in Area 3B extends into the Bulgo Sandstone.

Estimates for the height of fracturing at Dendrobium based on published methods range from 122 m to 357 m. This range in estimates is large and presents a challenge to those wishing to model hydrogeological impacts of mining on a regional scale based on mine site data.

The pre- and post-mining investigations carried out in this research study provide important constraints on the extent of mining related disturbance and its effect on groundwater systems.

A review of methods for estimating the height of fracturing above longwall panels at Dendrobium Mine was commissioned by DPE, and carried out by geotechnical consultants Pells Sullivan Meynink (PSM). The PSM report was finalised in June 2017 and made available to South32 on 7 September 2017.

Recommendations by PSM regarding additional monitoring and research to add to our understanding of the catchment are generally sensible and many of these have been acted on.

HysroSimulations believe there is a flaw in PSM's hydrogeological conceptual model, which leads to some errors in their conclusions about the extent of connective fracturing. PSM seems to have assumed vertical connected fracturing on the strength of pressure reductions at piezometers, when pressure reductions could occur due to several factors, including increased horizontal permeability, increased porosity or increasing downward hydraulic gradient due to depressurisation in the goaf.

The IEP (2019b) Part 2 Report further considered mining operations within the special areas and reiterated its earlier position stated in IEP (2019a*):*

The Panel has given detailed consideration to the equations in the Part 1 Report and concluded that it cannot endorse either at this point in time. For a range of reasons, neither or either may ultimately prove to be sufficiently reliable. It recommended erring on the side of caution and deferring to the Tammetta equation until:

i. field investigations quantify the height of complete drainage at Metropolitan and Dendrobium mines; and/or

ii. geomechanical modelling of rock fracturing and fluid flow are shown to be sufficiently reliable for informing the calibration of groundwater models at mine sites in the catchment.

The Regional Groundwater Model for Dendrobium Mine has been revised to consider the findings of the PSM report and IEP Reports (2019a), including the use of the Tammetta model and modelling connectivity to the surface. HydroSimulations state that regardless of the method used to assess fracturing, they believe the current groundwater modelling approach is sound.

IMC have installed a series of investigation boreholes and piezometers within the "barrier pillar" between the Avon Reservoir and the longwalls at Dendrobium Mine Area 3B. The investigation was designed to assess geological strata (fracturing and permeability) and groundwater conditions both before and after longwall mining adjacent to Lake Avon. As of late 2019, investigation holes have been drilled and piezometers installed at eight sites. Monitoring of groundwater pressures and standing water levels are periodically assessed and modelled to determine the seepage rate from Avon Reservoir into Dendrobium Mine. The current model estimates the seepage rate from Avon Reservoir along 1.93 km of shoreline adjacent to Longwalls 12 to 17at a total flux of 0.71 ML/day HGEO 2019.

In accordance with Schedule 3, Condition 19(c) of the Area 3B SMP Approval, height of connective fracturing investigations across longwalls in Area 3B are undertaken and reported to the Department prior to each longwall extraction. The most recent report, Hebblewhite (2019) states:

.. further data and analysis is still pending from many of the monitoring sites. From the sites that have been reported, the observations made during the intensive monitoring campaign over Longwall 9 have been reinforced as being reasonably typical for Area 3B, to date. These can be summarised as follows:

- *Strong drawdown of groundwater from the Wongawilli Seam upwards through the overburden, from the time of mining (including early drawdown effects prior to direct undermining, as a result of adjacent mining).*
- *Regional drawdown in the Wongawilli Seam is evident and may also be related to the presence of previous mining to the south of the lease by Elouera Mine.*
- *Repeated evidence of depressurisation extending to the base of the Hawkesbury Sandstone, and extending upwards within it in some, but not all locations – indicating a lack of any evidence of a constrained zone.*
- *Multiple examples of perched aquifers within the Hawkesbury Sandstone, especially outside the immediate mining footprint, but in some cases also directly above mining.*

It is expected that further insights into the role of mining on fracture and deformation of overburden leading to depressurisation will be obtained once the planned investigation program is implemented, fully analysed and reported in the coming months.

4.3 Potential for Fracturing Beneath the Watercourses

Based on the predicted systematic and non-systematic subsidence movements (MSEC 2020) the bedrock below the watercourses are likely to fracture as a consequence of subsidence induced strains.

Surface flows captured by the surface subsidence fracture network resulting from valley related movements which do not connect to a deeper storage, aquifer or the mine workings will re-emerge further downstream (see **Section 4.2**). This prediction is based on an assessment of the depth of valley closure induced vertical fracturing from the surface and measurements of water balance downstream of mining areas.

The depth of fracturing in the “surface zone” is addressed in the Bulli Seam Operations Environmental Assessment: Section 5.2.1, Appendix A, Appendix B and Appendix C as well as in the Response to Submissions and Response to the NSW Planning Assessment Commission. The BSO Independent Peer Review of strata deformation provided by Professor Bruce Hebblewhite concurs with the concept of the “surface zone” fracture network related to down-slope or valley movements. Several studies have determined the depth of these vertical fracture networks are restricted to approximately 15 to 20 m below the surface.

The depth and other attributes of the surface fracture zone have been comprehensively determined using the following instruments and techniques:

- Calliper logging;
- Straddle packer permeability testing;
- Overcore stress measurements;
- Core logging and geotechnical testing;
- Geophysical testing;
- Water level monitoring;
- Borehole cameras;
- Subsidence, extensometer monitoring and shear deformation monitoring;
- Stress change and fracture logging;
- Permeability testing and falling head tests; and
- Mapping of pressured air drilling fines.

The following sites have been comprehensively investigated to demonstrate the dimensions of the “surface fracture zone”:

- Two rockbars on the Waratah Rivulet; and
- Four rockbars on Georges River.

Monitoring from Dendrobium Mine indicates the surface fracture network over the goaf connects to or is concurrent with the fracture network which propagates from the seam to the surface (IEP 2018). In this instance the diversion of surface flow to deep strata storage or the mine relates to vertical permeability increases associated with this fracturing.

Prior to any remediation works within Area 3B that target surface/shallow fracture networks, the depth of the fracturing will be characterised by standard techniques such as drilling, down hole cameras and calliper measurements. The hydraulic conductance of these fracture networks will also be determined prior to implementing any rehabilitation.

The effects of mining on surface water flow following the completion of Longwall 15 was measured and assessed in the Longwall 15 EoP Report using the revised surface flow TARPs. The assessments indicate that sub-catchments in the upper part of the Donalds Castle Creek catchment (i.e. DC13S1 and DCS2) have been and continue to be affected by mining, as is the tributary LA4 of Lake Avon (at LA4S1) and probably in the neighbouring tributary LA3 (although analysis is hampered by a short baseline flow record) (HGEO 2020). The findings for DC13, DCS2 (both at Level 3 for all three flow assessments), and LA4 (effects identified by all three assessments) are similar to those for the EoP report for Longwall 14, as presented in Watershed HydroGeo (2019). LA3 has been affected by mining for the first time by Longwall 15.

Similarly, the flow characteristics at WC21S1 and WC15S1 within the Wongawilli Creek catchment have altered as a result of mining, with these sites triggering Levels 2 and 3 for the three assessments. As with the sub-catchments above, the effects at WC21 and WC15 are similar to those for the previous longwall. WC12 is as yet unaffected by mining (HGEO 2020).

Changes to stream flow characteristics are not evident at the downstream gauge on Wongawilli Creek Lower (WWL), despite mining-related effects being clear and significant at upstream tributaries (e.g. WC21, WC15).

This suggests that some or all flow lost in headwater catchments is returned downgradient, and/or that upstream diversions or losses are not significant in relation to the larger catchment water balance given the natural variability and the accuracy of flow measurements. Analysis of available surface water flow observation records for Wongawilli Creek triggered a Level 2 TARP in February 2020. TARP Assessment D was carried out, and indicated that flow reductions due to mining were in the order of 0.008 to 0.015 ML/d.

The assessment for Donalds Castle Creek, Wongawilli Creek, Lake Avon and Cordeaux River concluded that the performance measures for these streams had been met (HGEO 2020).

4.4 Potential for Erosion Within the Watercourses

Tilting, cracking, desiccation and/or changes in vegetation health could result in erosion within the watercourses. The likelihood and timing of these consequences relate to the size and duration of the effect.

Subsidence predictions were carried out to assess the potential impacts of longwall mining in Area 3B. The assessment indicated that the levels of impact on the natural features were likely to be similar to the impacts observed within Area 3A and Area 3B to date. A summary of the maximum predicted values of subsidence, tilt and strain at the watercourses is provided in **Section 5**.

Tilting of sufficient magnitude could change the catchment area of a watercourse or re-concentrate runoff leading to scour and erosion.

Changes in gradients predicted to occur following mining are shown in **Section 5**. These changes have been considered in relation to the likelihood of change in drainage line alignment by MSEC (2020). The assessment takes into account the nature of the drainage channel and whether the predicted tilt is significant when compared to the existing slopes.

Landscape monitoring commenced in 2004 for Dendrobium Area 1. This monitoring program has been continued and updated throughout the mining period for Areas 2, 3A and 3B. The monitoring includes inspections of watercourses at regular intervals prior to mining, during active subsidence and following the completion of subsidence movements. In addition to erosion (increased incision and/or widening), these observations target any surface cracking, surface water loss, soil moisture changes, vegetation condition changes, slope and gradient changes and the condition of rockbars.

The observed impacts on natural features above Area 3B to date are generally consistent with those predicted in the assessments undertaken prior to mining.

4.5 Potential for Aquatic Ecology Changes Within the Watercourses

Where there are changes to watercourse hydrology that are large and persistent there is likely to be an aquatic ecology response. Aquatic species which do not have life-cycles adapted to temporary loss of aquatic habitat are likely to be relatively susceptible to changes in pool water level. In comparison, riparian vegetation is likely to be relatively resilient to short term changes in groundwater level and soil moisture, demonstrated by the persistence of these vegetation communities during extended periods of drought.

Cardno undertakes a monitoring program designed to detect mining-related subsidence impacts to indicate the condition of aquatic ecology.

The monitoring program is based on a Before, After, Control, Impact (BACI) design that provides a measure of natural spatial and temporal variability in key aquatic ecology indicators at potential impact and control sites before, during and after mining. This enables changes in the mining area to be distinguished from changes due to natural variability.

The monitoring program focuses on the following key indicators:

- Habitat condition assessed using the RCE Inventory method and by establishing a photographic record through time;
- Aquatic macroinvertebrates sampled in accordance with AUSRIVAS;
- Aquatic macroinvertebrates sampled quantitatively using artificial collectors;
- Sampling of fish using bait traps and backpack electrofishing; and

- Limited in situ water quality sampling is undertaken to assist with interpretation of trends in the above indicators.

Monitoring is undertaken within Wongawilli Creek, WC21 (a tributary of Wongawilli Creek) and Donalds Castle Creek, and at comparable Control sites established on Wongawilli, Sandy, Donalds Castle and Kentish creeks. Univariate and multivariate statistical analyses have been conducted on the AUSRIVAS sampling and artificial collectors. Surveys and reporting have been completed in 2010, 2011, 2013, 2014, 2015, 2017 and 2019. Monitoring was undertaken by Cardno (2020b) in 2019 and is summarised below.

There were changes in water quality in Wongawilli Creek and Donalds Castle Creek downstream of DA3B, though these were short-term, generally minor and occurred some distance downstream of the mine area. In 2018, prior to the current survey, a reduction in water levels and flow in Wongawilli Creek resulted in a direct loss / partial loss of aquatic habitat along approximately 1.4 kilometres (km), representing about 10% of its 12 km total length. This was associated with mining induced groundwater depressurisation at a time of low rainfall and surface run-off. By October 2018, water levels and flow in Wongawilli Creek had returned to normal. Similar impacts in other smaller watercourses persisted throughout 2019. This included the reductions in water levels in approximately 1.4 km of Donalds Castle Creek and represent about 15% of its 9 km total length. Reductions in WC21 represent a greater proportion of the total length, around 50%. A reduction in the amount of ephemeral aquatic habitat has also occurred in WC15 and LA4.

The loss of this habitat is expected to have resulted in a loss of associated biota and a reduction in longitudinal connectivity of remaining aquatic habitat. The reductions in pool water levels and flow in Wongawilli Creek in 2018 likely represented the highest level of impact to aquatic habitat and biota that has occurred due to mining in the Dendrobium Mine. Wongawilli Creek provides relatively substantial and permanent watercourse habitat in the Metropolitan Special Area, second only to that provided by Avon and Cordeaux Rivers (located outside the DA3B mine area). In isolation, the observed impacts to aquatic habitat in Donalds Castle Creek, WC21, WC15 and LA4 are relatively minor in the context of the upper Avon and Cordeaux River catchments and Metropolitan Special Area.

While some biota would have been lost from Wongawilli Creek in 2018, there was no evidence of impacts to aquatic macroinvertebrates on Wongawilli Creek in data collected in 2019. This suggests that impacts to aquatic biota were temporary and restricted to the period of low pool water levels and flow during 2018 and potentially up to approximately 6 months afterwards (when monitoring re-commenced in the first half of 2019).

Physical impacts in Lake Avon tributary LA4B, including fracturing and flow diversion has resulted in a reduction in aquatic habitat. Fracturing of bedrock and diversion of flows in Lake Avon tributaries is likely to have resulted in some minor reduction in quantity and connectivity of aquatic habitat.

WC21 has been mined beneath by Longwalls 9 to 14 with fracturing of bedrock, flow diversions and associated reductions in pool water levels and flow. Following the extraction of Longwall 14, these impacts have been observed in 1.7 km (over 50 %) of the total length of the watercourse.

In the Southern Coalfield, impacts to riparian vegetation as a result of subsidence are minor in occurrence. Furthermore, no impacts to riparian vegetation have been observed in Dendrobium Mine to date (Niche 2012). Previous examples of impacts include: dieback of riparian vegetation as a result of subsidence of the Cataract River during the 1990s (Eco Logical Australia, 2004 in TEC 2997), and small localised changes to riparian vegetation along a section of the Waratah Rivulet (Helensburgh Coal 2007).

4.6 Potential for Raw Water Quality Changes

From several years of monitoring there has been no evidence of short or long-term impacts to water quality or drinking water quality in Lake Avon, despite tributaries of the lake being directly undermined by Elouera Colliery and Dendrobium Mine longwalls, causing bedrock fracturing.

Due to the standoffs from Wongawilli Creek of the Area 3B longwalls, it is not expected any significant fracturing and sub-bed flow diversions in Wongawilli Creek would alter flows or water quality other than minor impacts. Due to the substantial distance downstream, it is predicted there will be no reduction (other than negligible reduction) in the quality or quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek.

Based on past experience from Wongawilli and Native Dog Creeks which were directly mined under by Elouera Colliery longwalls, it is also considered highly unlikely that there would be any adverse effect on bulk drinking water supply quality in the Lake Avon or Cordeaux River (into which Donalds Castle and Wongawilli Creeks discharge) systems.

Any water-borne inputs to Lake Avon and Cordeaux River would likely be restricted to a possible erosive export of fine sands and clays and/or ferruginous precipitates near the mouths of minor creeks designated Native Dog Creek, ND1, ND2, LA1,LA2, LA3, LA4 and LA5 (Lake Avon) during mining of Area 3B. It is predicted that these water-borne inputs will result in negligible environmental consequences.

These creeks are all remote from their respective dam off-takes and outflows. Such zones would be localised around the point of input to the Lake and would be unlikely to have any detrimental effect on local freshwater ecology and unable to affect bulk water supply quality.

4.7 Achievement of Performance Measures

Longwall mining can result in surface cracking, heaving, buckling and stepping at the surface. Surface deformations can also develop as the result of downslope movements where longwalls are extracted beneath steep slopes.

In these cases, the downslope movements can result in the development of tension cracks at the tops of the steep slopes and compression ridges at the bottoms of the steep slopes. Fracturing of bedrock can also occur in the bases of stream valleys due to the compressive strains associated with valley closure movements. The extent and severity of these mining induced ground deformations are dependent on a number of factors, including the mine geometry, depth of cover, overburden geology, geomorphology, locations of natural jointing in the bedrock and the presence of near surface geological structures.

A number of large surface cracks were observed at the commencing end of Longwall 3 in Area 2 at Dendrobium Mine. The depth of cover at the commencing end of Longwall 3 was as shallow as 145 m, which is less than that above Longwalls 9 to 18 in Area 3B, which varies between 310 m and 450 m. It is expected, therefore, that the widths of surface cracking resulting from the extraction in Area 3B would be generally less than that observed above the commencing end of Longwall 3.

The experience gained from mining in Dendrobium Areas 1, 2 and 3A indicate that mining-induced fracturing in bedrock and rockbars are commonly found in sections of streams that are located directly above extracted longwalls. However, minor fracturing has also been observed in some locations beyond extracted longwall goaf edges, the majority of which have been within the limit of conventional subsidence or associated with valley closure or bedding plane shear.

4.7.1 Wongawilli Creek

The maximum predicted total conventional tensile and compressive strains for Wongawilli Creek, based on applying a factor of 15 to the maximum predicted conventional curvatures, are in the order of survey tolerance (i.e. less than 0.3 mm/m). The creek is likely to also experience elevated compressive strains, resulting from the valley related movements, which could be in the order of 5 mm/m based on observations at valleys with similar heights at similar distances from extracted longwalls.

An empirical database has been developed of pool and rockbar sites in the Southern Coalfield that have experienced mining induced valley related movements. The upsidence and closure movements at these sites have been predicted, using the ACARP Method of predicting valley closure, at the time when the first pool impact occurred, or after this time, when pool water loss was first recorded.

An analysis of impact rates has been undertaken using the currently available database of pools and rockbar case studies. This database is being continually developed and, to date, research has mainly concentrated on collating knowledge on the known pool and rockbar impact sites, whilst less data has been included for sites that had no impacts as a result of mining. The current reference to the 200 mm predicted total closure value should therefore be viewed as an indication of low probability of impact (i.e. around 10 %).

It has been assessed, therefore, that it is unlikely that significant fracturing or surface water flow diversions would occur along Wongawilli Creek as a result of the extraction. This assessment has been based on limiting the predicted closure at the mapped rockbars and riffles to 200 mm and, as a result, the longwalls have been setback more than 150 m from the majority of the mapped rockbars and more than 150 m from all of the mapped riffles.

It should be noted, however, that minor fracturing has occurred and is expected in the bed of Wongawilli Creek as a result of the extraction of the proposed longwalls. Fracturing that does occur in the bed of the creek would be isolated and of a minor nature and not result in any significant surface water flow diversions.

After the extraction of Longwalls 6 to 8 in Area 3A to the east of Wongawilli Creek and the extraction of Longwall 9 in Area 3B to the west of Wongawilli Creek a fracture was identified in Wongawilli Creek. The rock fracture is in the base of WC_Pool 43a and has a length of approximately 2 m and a width of up to 0.02 m. This fracturing is consistent with the impact model described above.

During the Longwall 13 extraction period, low water levels in Pool 43a were observed. Additionally, approximately 1.5 km reach of Wongawilli Creek, extending from Pool 43a, was observed to be dry (Longwall 13 EoP Report). Although the fracture in the base of Pool 43a was caused by mine subsidence, water levels in the pool were declining prior to the fracture occurring, with no significant changes in pool water-level recession (Watershed HydroGeo 2018). Investigation and analyses showed that reductions in baseflow to Wongawilli Creek, in-line with predictions, had occurred due to mining in Areas 3A and 3B and subsequent reductions in groundwater levels in the Upper Bulgo Sandstone and Lower Hawkesbury Sandstone (Watershed HydroGeo 2018). However, the dominant process contributing to the low pool water-levels was the severe rainfall deficit and depressed groundwater levels (Watershed HydroGeo 2018).

The EoP Report for Longwall 15, submitted to the Department in May 2020, found that the Performance Measures for Donalds Castle Creek, Wongawilli Creek, Lake Avon and Cordeaux River were all met (HGEO 2020).

IEP (2019a) reviewed the valley closure impact model and made the following recommendation: *the concept of restricting predicted valley closure to a maximum of 200 mm to avoid significant environmental consequences should be revised for watercourses*.

As described above, the closure impact model has been successfully used at Dendrobium Mine to date, with the target value of 200 mm predicted closure resulting in a low-likelihood of impact (consistent with the model predictions). The valley closure impact model undergoes continuous review as part of the EoP Reporting process to determine the applicability of the predicted valley closure target for each stream.

IMC has adopted a 200 mm predicted closure as a key design constraint for the setback of longwall panels from named watercourses at Dendrobium Mine, where a setback is provided to reduce impacts to that stream. The empirical data used to develop the 200 mm closure target includes only streams with a setback from mining. An alternative target would need to be developed for streams directly mined under.

When applied on a case-by-case basis, the closure impact model can be refined and continue to be used to achieve a specified level of impact likelihood. While ongoing review of data to refine the closure impact model and closure target is supported, monitoring data to date does not indicate that the target of 200 mm predicted closure for named streams at Dendrobium Mine requires significant change at this time.

4.7.2 Waterfall WC-WF54

The Waterfall WC-WF54 is located 440 m south-east of Longwall 17 and over 1 km east of the Longwall 18 finishing end. The waterfall is predicted to experience less than 20 mm vertical subsidence due to the extraction of Longwall 17. While it is possible that the waterfall could experience low levels of vertical subsidence, it is not expected to experience measurable tilts, curvatures or conventional strains.

The maximum predicted valley related movements at the waterfall are less than 20 mm upsidence and 25 mm closure due to the extraction of Longwall 17. As described in the previous section, minor fracturing has occurred in the bed of Wongawilli Creek. Fracturing resulting in surface water flow diversions has not occurred and the likelihood of this occurring is considered low. The method of assessment for surface water flow diversions has been predominately based on the previous experience of mining near to and beneath relatively flat streams in the Southern Coalfield. The impact assessments for the pools immediately upstream of the waterfall, therefore, need to take into account the steep gradient (i.e. the waterfall) immediately downstream.

The waterfall has adjacent “horse-shoe” shaped cliffs which wrap around both sides of the valley of Wongawilli Creek. A similar shaped cliff is located at Elouera Colliery, on a tributary to Wongawilli Creek, where mining has occurred on both sides of this cliff. The Elouera longwalls were extracted on the western side of the cliff, with Longwall 2 located at a distance of 160 m from the cliff, at the closest point. Delta Longwall 17 was extracted on the eastern side of the cliff, which was located at a distance of 120 m from the cliff, at its closest point. The predicted valley related movements for the cliff at Elouera Colliery, resulting from the existing mining, are 60 mm upsidence and 80 mm closure. There have been no observed impacts on the cliff at Elouera Colliery after the completion of the Elouera longwalls and Delta Longwall 17.

Another “horse-shoe” shaped cliff is the waterfall on Sandy Creek in Dendrobium Area 3A, which has a length around 75 m long and an overall height of around 17 m. The waterfall has an overhang of up to 20 m, which varies in thickness from a maximum around 6 m to less than 1 m at the edge. Dendrobium Longwalls 6 and 7 have been mined to within 350 m and 400 m, respectively, of the waterfall with no adverse impacts observed.

There is also other extensive experience of mining in the vicinity of cliffs in the Southern Coalfield, including Appin Longwalls 301 and 302, which mined to within 50 m of the cliffs along the Cataract River, and Tower Longwalls 18 to 20 and Appin Longwalls 701 and 702, which mined to within 50 m of cliffs along the Nepean River.

In these cases, there were no large cliff instabilities where the longwalls at Appin and Tower Collieries mined to within 50 m of the cliffs (i.e. not directly mined beneath). There were, however, some minor rock falls or disturbances which occurred during mining, of which, some were considered likely to have occurred due to a significant rainfall event and natural instability of the cliff.

A comprehensive monitoring and management plan has been developed for WC-WF54, which includes the implementation of management strategies similar to that which was implemented for Sandy Creek Waterfall. The WC-WF54 Management Plan is included with the Longwall 18 SMP submission.

4.7.3 Water Storages

The western ends of Longwalls 11 to 18 lie within the Avon Notification Area. As was the case for Areas 1, 2 and 3A, none of the proposed Area 3B longwall extraction is undertaken below stored waters. Longwalls 9 and 10 are outside the Avon Dam Safety NSW Notification Area and Longwall 11 is just inside the Area. Longwalls 12 to 18 are set back from the Avon Reservoir Full Storage Level (FSL) a minimum of 300 m.

The depth of cover to the Wongawilli Seam directly above the longwalls varies between a minimum of 310 m, above the eastern end of Longwall 9, and a maximum of 450 m, above the eastern end of Longwalls 17.

The potential for loss of stored water from Avon Reservoir whilst mining Area 3B was considered in a risk assessment conducted by AXYS Consulting in February 2014, September 2016, March 2019 and July 2020. The objective of the assessments was to assist IMC control identified risks associated with the mining of Area 3B longwalls, which may cause loss of stored water.

Dendrobium Mine has Dam Safety NSW endorsement for development workings and extraction for Longwalls 11 to 16 and development workings for Longwall 17. An application for the extraction of Longwall 17 within the Dam Safety NSW Avon Notification Area is to be submitted to the Dam Safety NSW. The Dam Safety NSW approvals are supported by the following documents and data:

- Avon and Cordeaux Reservoirs Dam Safety NSW Notification Area Management Plan;
- Geology report for Area 3B;
- Geochemical review of connectivity between Lake Cordeaux and Dendrobium Area 2 and 3A and implications for monitoring Lake Avon and Area 3B;
- Dendrobium Area 3B Regional Groundwater Model;
- Hydrogeoleogical analysis regarding Dam Safety NSW's requirements for mining within the Avon Notification Area;
- Qualitative risk assessment for loss of stored water from Avon Reservoir from the mining of Longwalls 12-18; and
- Plans.

The successful mining at Dendrobium since 2005 with no significant inflow of water from the Cordeaux Reservoir or Avon Reservoir demonstrates that the proposed mining represents an acceptable risk. The systems and management plans that manage the risk to stored waters has been developed in consultation with the Dam Safety NSW.

Area 3B is a relatively simple sequence of sedimentary stratigraphy and there are no complications associated with overlying workings. The longwall domain is between geological features that have negligible risk of providing a conduit from the reservoir to the workings.

Dendrobium has installed and is currently monitoring an extensive array of piezometers in the area. In addition, the underground water balance and chemistry sampling provides data that can be used to trigger actions within the Avon and Cordeaux Reservoir Notification Area Contingency Plan. The Avon and Cordeaux Reservoir Notification Area Monitoring, Contingency and Closure Plans provide excellent tools for minimising the risk to the reservoir.

The proposed mining in Area 3B presents a tolerable risk to Avon Reservoir and the Area 3B SMP performance measures for Lake Avon will be met.

The IEP (2019b) summarised the current state of knowledge concerning reservoir leakage rates as follows:

> *There is no measured evidence of significant long-term leakage from reservoirs due to mining in the Special Areas. Due to concerns about future potential leakage, investigations have been and continue to be undertaken into potential leakage through faults and basal shears. Measured pressure gradients between the reservoirs and the mined coal seams are also used to estimate potential leakage rates. Reservoir water balance models have been used to conclude that expected rates of leakage due to the mines are not significant relative to other water balance components.*

The IEP (2019a) recommends:

> *Subsidence Management Plans for future longwall panels in Area 3B at Dendrobium Mine must:*
>
> *i. give very careful consideration to the risk to water quantity in the catchment presented by basal shear planes, lineaments, faults and mining-induced changes in permeability around the flanks of Avon Reservoir*
>
> *ii. give very careful consideration to the potential for further mining in the southern end of Area 3B to reduce confinement of fault planes and the implication of this for enhanced conductivity between Lake Avon and both the Elouera and Dendrobium mine workings*
>
> *iii. be supported by robust independent peer review, risk assessment and risk mitigation controls.*

McCallum *et al.* (2018) and Tonkin and Timms (2015) have been reviewed with particular focus on the conceptual models of how fault zones affect groundwater flow. The conceptual models described consider the cases of flow across a fault and where flow is along (parallel to) the fault or vertically along the fault.

Given the orientation of the Elouera Fault running between Dendrobium and the historical workings at Elouera, flow across or orthogonal to the fault is not the primary concern here.

The conceptual models that are a concern with respect to Area 3B longwalls are:

- Whether the fault and surround disturbed zone act as a more permeable conduit to flow along or parallel to the fault, potentially linking the workings to Lake Avon;
- Whether ground movement as a result of extraction of the later panels in Area 3B might result in the creation of such a high permeability zone or pathway. This would be the process of ‘unclamping’ described in IEPMC (2018),

IMC works closely with the Dam Safety NSW regarding potential seepage from the Avon Reservoir to Dendrobium Mine, both directly via fractures or shear planes in the barrier zone and via transmissive faults.

4.7.4 The Elouera Fault

In 2018 IMC commenced investigations to assess the structural and hydrogeological characteristics of the Elouera Fault in the vicinity of proposed mine workings at Area 3B. The Elouera Fault lies between Dendrobium Area 3B (proposed Longwall 18) and the Elouera Mine workings adjacent to Lake Avon. The investigation comprised drilling eleven vertical and inclined holes at three sites to intersect the fault zone at various stratigraphic depths. The main outcomes of the study are presented in HGEO (2020a) and summarised below:

- The Elouera Fault zone dips to the south at approximately 60° from horizontal with an average vertical displacement within the Colo Vale Sandstone (CVSS) of 39 m (the southern Elouera block downthrown relatively to the northern block). Displacement decreases up through the stratigraphy and is approximately 13 m at the Bald Hill Claystone (BACS) at drill Site 3. The fault zone likely extends to the surface. The projected fault trace appears to correspond to a prominent break in slope and several topographic lineaments in the northern slopes of the Native Dog Tributary 1 valley.
- The BACS, a regionally important aquitard, is not completely offset and maintains continuity across the fault. The major stratigraphic units (Hawkesbury Sandstone [HBSS] and CVSS) are largely continuous across the fault with minor displacement relative to their thickness. Minor offsets of lithology would result in the fault representing a weak barrier to transverse (north-south) groundwater flow.
- Narrow-spaced packer testing across the Elouera Fault shows a highly variable permeability structure (and overall average permeability) between drill sites and between closely adjacent holes at the same site. The data indicate that permeable zones are discontinuous on a scale of tens of metres and the fault does not form a continuous conduit to groundwater flow (along the fault).

- The highest average permeability was observed at the shallowest fault intersection (upper CVSS) and therefore the fault may form a zone of enhanced permeability near the surface associated with increased fracturing of the HBSS. However, the fault does not form a continuous conduit or connection to deeper stratigraphic levels. Groundwater levels within the HBSS beneath Swamp 35b are within metres of the ground surface despite the projected fault trace subcropping beneath the swamp and significant depressurisation of the lower CVSS (which is also intersected by the fault).

4.7.5 Lineament Investigation

The Panel Report Part 1 (2019a) on specific mining activities at Metropolitan and Dendrobium Mines recommended that "*all applications to extract coal within Special Areas should be supported by independently facilitated and robust risk assessments that conform to ISO 31000 (the international standard for risk management subscribed to Australia)*".

The Panel also recommended that the potential implications for water quantity of faulting, bedding plane shears and lineaments need to be very carefully considered and risk assessed at all mining operations in the Special Areas.

The Department of Planning, Industry and Environment (DPIE) have previously provided correspondence to IMC that the Panel have raised concerns regarding mining operations near or under lineaments in special areas of the catchment of the Southern Coalfield. The Panel stated, "*specific regard to the potential impacts on surface water features, including swamps and waterfalls, of mining near and under lineaments*".

A risk assessment has been carried out to identify the existing controls associated with mining operations of Dendrobium's Longwall 18 in Special Areas of the catchment and to make recommendations for further controls where appropriate (Axys 2020).

SRK (2020) assessed the presence of surface structures, including lineaments, and the role these might play in enhancing subsidence and environmental impacts around mining areas at Dendrobium. SRK noted that the conditions at Dendrobium (Southern Coalfield) are different to those in the Western Coalfield (e.g. at Springvale Mine) where lineaments around mining areas enhanced subsidence effects to significant distances, leading the transmission of effects out to hundreds of metres or a kilometre or so from Springvale workings. Based on analysis of repeated Lidar surveys, SRK concluded that "longwall mining activities to date at Dendrobium appear to have had little or no effect in the reactivation of surface lineaments" and "minor [apparent] movement is mostly restricted to areas above individual longwall panels. The potential for reactivation of surface lineaments extending outside the planned longwall areas was assessed as low.

MSEC1034 (2019) has indicated that subsidence anomalies along or around lineaments are obvious at Springvale Mine (in the Western Coalfield), with LiDAR mapping showing up to 30% more subsidence along these features, but that this behaviour is not evident at Dendrobium.

At Dendrobium Mine, lineaments are rarely successfully correlated with a structure feature (fault, dyke) at seam level. Further, they have not caused difficulties to mine operations at Dendrobium, nor are mapped lineaments known to interact with water features (e.g. swamps, waterfalls) in a manner that suggest they exacerbate the risk of mining to such features or exacerbate the distance to which impacts manifest themselves (Axys 20190.

Therefore, based on current data, a series of groundwater deterministic scenarios, as per the IESC Uncertainty Guidelines (Middlemis and Peeters, 2019) have been carried out to assess the uncertainty associated with particular predictions. These scenarios consider potential changes to hydraulic conductivity associated with valley-bulging and reactivation of the Elouera Fault, and focus on predictions of mine inflow, losses from the reservoirs and effects on watercourses that might be caused by mining at Dendrobium. These scenarios and assumptions are detailed in the groundwater assessment (Watershed Hydrogeo 2020).

4.7.6 Review of Experience of Inflows Adjacent to Lineaments and Fault Structures

IMC commissioned overcore measurements adjacent to the Elouera Fault to determine the magnitude of stress relief across the fault associated with previous longwall mining at Elouera Mine and the likely additional stress relief associated with extracting Longwall 17 and 18. The geotechnical detail of that work is presented in (SCT 2020a).

SCT (2020b) undertook a review of the experience of inflows adjacent to lineaments and fault structures in the context of stress relief. A key conclusion of this investigation states "*types of interactions observed at the Western Coalfield site are not expected along the Elouera Fault. If such interactions were to occur, they would have occurred already and there is no evidence of any such interaction. Longwalls 7 and 8 at Elouera Colliery has already significantly relieved the horizontal stress in the vicinity of the Elouera Fault with causing any perceptible inflows in any of the multiple boreholes and mine entries that penetrate the fault plane.*"

5 PREDICTED IMPACTS

Subsidence has the potential to affect watercourses overlying and adjacent to the proposed longwalls due to either transient or relatively permanent changes in porosity and permeability of the soil matrix and bedrock. Sandstone is likely to fracture as a result of the differential subsidence movements predicted.

If a watercourse overlies a longwall panel it is likely to undergo temporary extensional “face line” cracking (perpendicular to the long axis of the panel) as the panel retreats, followed by re-compression as the maximum subsidence occurs at any one location.

In addition, where a watercourse overlies a longwall, it is likely to undergo both longer-term extensional “rib line” cracking (parallel to the long axis of the panel) along the outer edge and compression within the central portion of the subsidence trough.

Predicted impacts were assessed for Wongawilli Creek (third order) and all other drainage lines (first and second order) within Area 3B.

In accordance with the findings of the Southern Coalfield Inquiry and IEP (2019a and b):

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

Impact predictions have been completed within the Study Area in order to record potential and likely impacts from the proposed mining. The predictions are based on mathematical and empirical models and utilise the best available information for the Southern Coalfield and in particular Dendrobium Mine conditions. The impact predictions have been compared with previous predictions for Dendrobium Mine and the Conditions of Consent to ensure compliance of the proposed mining. This comprehensive impact assessment is provided in the Dendrobium Area Longwall 18 SMP (South32, 2020)).

Monitoring is conducted in the area potentially affected by subsidence and in reference areas. Data collected in the impact zone will be compared to baseline and reference sites to determine any impacts from subsidence.

5.1 Subsidence Effects

The maximum predicted subsidence parameters resulting from the extraction of Longwall 18 are provided in MSEC (2020). The predicted subsidence parameters including; vertical subsidence, tilt and curvature have been used in the impact assessment for Dendrobium Area 3B.

The predicted strains were determined by analysing the strains measured at Dendrobium Mine and other NSW Collieries, where the longwall width-to depth ratios and extraction heights were similar to Longwalls 9 to 18. The prediction of strain is more difficult than the predictions of subsidence, tilt and curvature. The reason for this is that strain is affected by many factors, including ground curvature and horizontal movement, as well as local variations in the near surface geology, the locations of joints in bedrock, and the depth of bedrock. Survey tolerance can also represent a substantial portion of the measured strain, in cases where the strains are of a low order of magnitude. The profiles of observed strain, therefore, can be irregular even when the profiles of observed subsidence, tilt and curvature are relatively smooth.

Adopting a linear relationship between curvature and strain provides a reasonable prediction for the conventional tensile and compressive strains. The locations that are predicted to experience hogging or convex curvature are expected to be net tensile strain zones and locations that are predicted to experience sagging or concave curvature are expected to be net compressive strain zones. In the Southern Coalfield, it has been found that a factor of 15 provides a reasonable relationship between the predicted maximum curvatures and the predicted maximum conventional strains.

The maximum predicted conventional strains resulting from the extraction of Longwall 18, based on applying a factor of 15 to the maximum predicted curvatures, are both 8 mm/m tensile and compressive. These predicted levels of strain are likely to result in fracturing of the surface bedrock.

5.1.1 Wongawilli Creek

Wongawilli Creek is located 1 km east of the proposed Longwall 18, at its closest point. At this distance, the predicted incremental vertical subsidence, upsidence and closure for the creek, due to the mining of Longwall 18, are all less than 20 mm. While the creek could experience very low levels of these subsidence effects, it is not expected to experience measurable tilts, curvatures or strains. It is unlikely, therefore, that adverse impacts would occur along Wongawilli Creek due to the mining of Longwall 18.

The waterfall (WC-WF54) on Wongawilli Creek is predicted to experience less than 20 mm subsidence as a result of the extraction of the Longwall 17. While it is possible that the waterfall could experience subsidence slightly greater than 20 mm, it would not be expected to experience any significant conventional tilts, curvatures or strains. Longwall 18 is located over 1 km from the waterfall. At this distance, the waterfall is not expected to experience measurable conventional or valley related effects. It is unlikely, therefore, that adverse impacts would occur at the waterfall due to the mining of Longwall 18.

5.1.2 Native Dog Creek

Native Dog Creek is located outside the Study Area based on the 35° angle of draw line and predicted 20 mm subsidence contour for Longwall 18. However, it is partially located within the Study Area based on the 600 m boundary. The total length of creek within the Study Area based on the 600 m boundary is 0.6 km. **Table 6** provides a summary of the maximum predicted values of total subsidence, upsidence and closure at Native Dog Creek following completion of Longwall 18 (MSEC 2020).

Table 6 Maximum Predicted Total Subsidence, Valley Related Upsidence and Closure at Native Dog Creek within the Longwall 18 Study Area Resulting from the Extraction of the Longwalls

Longwall	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
Longwall 18	<20	20	30

The section of Wongawilli Creek located within the Study Area is predicted to experience less than 20 mm vertical subsidence. Whilst the creek could experience very low levels of vertical subsidence, it is not expected to experience measurable conventional tilts, curvatures or strains.

The maximum predicted total valley related movements for the section of creek located within the Study Area are <20 mm upsidence and 30 mm closure.

5.1.3 Drainage Lines

The drainage lines that are located directly or partially above Longwall 18 include ND1, ND1C and their tributaries. Other drainage lines that are located within the Study Area based on the 600 m boundary include LA1, LA2, ND1A, ND1B, ND2, ND2A, WC7 and WC12. These drainage lines are first and second order streams that form tributaries to Lake Avon and Wongawilli Creek.. A summary of the maximum predicted values of total subsidence, upsidence and closure at undermined drainage lines, after the extraction of the Longwall 18 is provided in **Table 7** (MSEC 2020).

Table 7: Maximum Predicted Total Subsidence, Valley Related Upsidence and Closure at the Drainage Lines Following the Extraction of Longwall 18

Name	Maximum Predicted Subsidence (mm)	Maximum Predicted Upsidence (mm)	Maximum Predicted Closure (mm)
LA2	3175	600	600
ND1	< 20	125	200
ND1C	2675	325	350

5.2 Environmental Consequences

Ground subsidence and depressurisation of groundwater systems associated with underground mining can result in a range of effects on surface water and shallow groundwater systems. In this section, potential impacts are identified, and their likelihood and severity assessed in relation to the proposed mining activities.

In relation to Longwall 18 the most likely effects are summarised in HGEO (2020):

1. Altered drainage and flooding. Mine subsidence can lead to changes in gradient within a watercourse which in turn may lead to a change in the likelihood of ponding, flooding and erosion.
2. Flow diversions. The development of fractures in a stream bed may result in diversion of flow from the stream channel to the sub-surface and a measurable reduction in stream flow at monitoring gauges. This effect has the potential to be long-lasting and possibly permanent.
3. Groundwater drawdown and reduction in baseflow. Where stream flow is partly sustained by the discharge of groundwater from adjacent aquifers (baseflow), groundwater drawdown or depressurisation due to mining can lead to a reduction in baseflow and additional cease to flow/pool dry days. This effect is likely to be long-lasting (i.e. decades), but not permanent.
4. Altered surface water quality. Fracturing of the stream substrate can result in the development of ferruginous springs (iron staining), alteration of water quality parameters and the mobilisation of trace metals which may in turn affect the health of aquatic ecosystems.
5. Altered swamp hydrology. Near-surface fracturing can result in a decline in shallow groundwater levels which may in turn affect soil moisture content, swamp vegetation and dependent ecosystems. Effects on swamp hydrology (water retention and groundwater drainage rates) can be long-lasting and possibly permanent. Potential effects on swamp vegetation is described in the ecological assessment (Niche, 2020) accompanying this surface water assessment.

These environmental consequences are further defined below and quantified in the TARP (**Appendix A**).

5.2.1 Streambed Fracturing

Fractures and joints in bedrock and rockbars occur naturally from erosion and weathering processes and from natural valley bulging movements. Where longwall mining occurs in the vicinity of streams, mine subsidence movements can result in additional fracturing or the reactivation of the existing joints. The main mining-related mechanisms for these impacts are conventional subsidence and valley related upsidence and closure movements.

Diversions of surface water flows also occur naturally from erosion and weathering processes and from natural valley bulging movements. Mining-induced surface water flow diversions into the strata occur where there is an upwards thrust of bedrock, resulting in a redirection of some water flows into the dilated strata beneath the creek beds. At higher depths of cover, where a constrained zone exists or where the creek is not directly mined beneath, surface water flows generally reappear further downstream of the fractured zone as the surface flow is only redirected below the creek bed where the fractured zone exists.

MSEC (2020) predicts that maximum tensile strains greater than 0.5 mm/m may be of sufficient magnitude to result in fracturing of the beds of drainage lines in Area 3B. Compressive strains greater than 2 mm/m may be of sufficient magnitude to result in the bedrock buckling and fracturing, which can induce fractures in the beds of watercourses. Streambed fracturing as a result of longwall mining is most likely to occur within incised and rock bedded streams that have been directly mined beneath.

Impacts have been observed along the drainage lines above and adjacent to the previously extracted Longwalls 9 to 15 in Area 3B, including fracturing in the rockbars and exposed bedrock, dilation and uplift of the bedrock, iron staining, surface water flow diversions and reduction in pool water levels. These impacts predominately occurred directly above the extracted longwalls. However, fracturing was also observed up to 300 m from the extracted longwalls in Area 3B.

It is expected that fracturing of the bedrock would occur along the sections of the drainage lines that are located directly above the proposed Longwall 18 and the adjacent Longwalls 16 and 17. Fracturing can also occur outside the extents of the longwalls, with minor and isolated fracturing occurring at distances up to approximately 400 m.

The mining-induced compression due to valley closure effects can also result in dilation and the development of bed separation in the topmost bedrock, as it is less confined. This valley closure related dilation is expected to develop predominately within the top 10 m to 20 m of the bedrock. Compression can also result in buckling of the topmost bedrock resulting in heaving in the overlying surface soils. Surface water flow diversions are likely to occur along the sections of drainage lines that are located directly above and adjacent to the longwalls.

Further assessments of the potential impacts on surface water are provided in the report by HGEO (2020).

If impacts are greater than predicted, a range of mitigation and rehabilitation techniques may be applicable and will be implemented in consultation with and the approval of relevant agencies.

These techniques are described in **Section 6**. Rehabilitation of the fracturing within Donalds Castle Creek below Swamp 5 is proposed as part of the Swamp Rehabilitation Research Plan and the WC21 and Donalds Castle Creek Rehabilitation Plan.

5.2.2 Sites of Highest Risk of Impact

In most cases where pool water levels are observed to drop by more than expected after considering rainfall conditions, this has occurred after the streams were directly mined beneath. Longwalls 9 to 17 have been setback from Wongawilli Creek resulting in minimisation of the potential for these types of impacts along this creek.

5.2.3 Ferruginous Springs

No ferruginous springs have been observed to date, however, iron staining within and downstream of watercourse fractures have been observed (Longwall 9 to 15 EoP Reports).

Observational, water quality as well as aquatic and terrestrial ecology monitoring as outlined in the TARP (**Appendix A**) will be implemented. If impacts are greater than those predicted, a range of mitigation and rehabilitation techniques and environmental offsets may be applicable and will be implemented in consultation with and the approval of relevant agencies. These techniques are described in **Section 6**.

5.2.4 Watercourse Gradient and Alignment

Subsidence can change the gradient and alignment of streams and the outflow characteristics of pools. If these changes are significant when compared to existing landscape alignment and stream gradients there can be changes to flows, stream powers and pool water levels.

The maximum predicted tilt for the drainage lines within the Study Area is 40 mm/m (i.e. 4.0 % or 1 in 25). The predicted mining-induced tilts are less than the natural gradients of the drainage lines that typically vary between 50 mm/m and 200 mm/m (i.e. 5 % to 20 %).

There are predicted reversals in grade along LA2 directly above Longwall 17 (**Figure 5-1**). There is potential for minor and localised increased ponding upstream of these locations. However, this drainage line is located above the previous Longwall 17 and, therefore, the potential for increased ponding occurs due to this previous longwall rather than the proposed Longwall 18.

There are no predicted reversals of stream grade along the remaining drainage lines within the Study Area. There are slight reductions in grades along drainage lines ND1C and WC12, upstream of the chain pillars and the edges of the mining area. There is potential for minor and localised increased ponding upstream of these locations. However, drainage line WC12 is located above the existing Longwall 16 and Longwall 17 and, therefore, the potential for increased ponding occurs due to these previous longwalls rather than the proposed Longwall 18.

Elsewhere, the predicted post-mining grades are similar to the natural grades. It is unlikely, therefore, that there would be large-scale adverse changes in the levels of ponding or scouring of the banks along these drainage lines due to the mining-induced tilt. It is possible that localised increased ponding could develop in some isolated locations, where the natural grades are small, and upstream of the chain pillars and the edges of the mining area.

The potential impacts of increased ponding and scouring of the drainage lines, therefore, are expected to be minor and localised. Impacts resulting from changes in surface water flows due to mining-induced tilt are expected to be small in comparison with those which occur during natural flooding conditions.

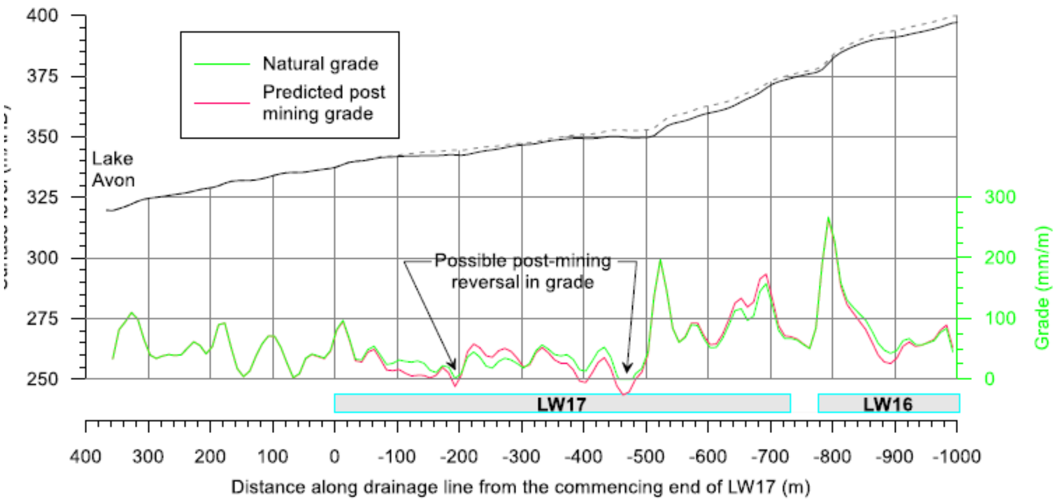

Figure 5-1: Natural and predicted post-mining surface levels along Drainage Line LA2 (MSEC 2020)

The changes in the levels of ponding, flooding and scouring of the banks of the drainage lines would be expected to be very localised in the locations of the predicted maximum tilts, or where the existing natural gradients are relatively flat. The impacts due to the mining-induced tilts on surface water flows are expected to be small in comparison with those which occur during natural flooding conditions.

The average natural gradient of Wongawilli Creek, excluding Waterfall WC-WF54, is approximately 10 mm/m (i.e. 1%, or 1 in 100). The predicted changes in grade due to the extraction of Longwall 17, therefore, are considerably less than the average natural grade. It is unlikely, therefore, that there would be adverse changes in the potential for ponding, flooding or scouring of the banks along the creek due to the mining-induced tilt.

5.2.5 Surface Water Flows

Mining directly under or close to surface watercourses can result in diversion of flow from the watercourse and/or loss of surface flow from the catchment. Water diverted from surface channels can be directed through fracture networks to the water table and may re-emerge downstream, as is commonly observed in the Southern Coalfield. If surface fractures intersect deeper (vertically connected) mining induced fracture networks, there is potential for water to be directed into those deeper fracture storages, or to the mine itself. In the latter case, surface flow would be lost from the catchment. Significant losses would be detected as a decrease in flow (and catchment yield) at downstream gauges (see **Sections 3.4 and 4.2**). This would occur at the limit of subsidence induced fracturing downstream within the watercourses.

Based on the subsidence assessment by MSEC (2020), and previous experience at Dendrobium as discussed above, the following effects are expected as a result of Longwall 18 extraction:

- Wongawilli Creek: At a distance of 1 km from the proposed longwall the main channel of Wongawilli Creek, including Waterfall 54 is unlikely to experience adverse impacts such as stream bed fracturing and significant flow diversion.
- LA2 will be partially mined under by the preceding Longwall 17 and will likely experience stream bed fracturing and flow diversions associated with that longwall. Flow reductions will likely be observed at the downstream gauge LA2S1. Additional fracturing and flow diversions may result from subsidence associated with Longwall 18; however, those effects are likely to be minor compared with those of Longwall 17.
- The main 2nd order channel of ND1 and the lower reaches of NDC (including ND2) are within 400 m of Longwall 18. Valley-related closure is likely to result in minor and localised fracturing of the ND1 creek bed and potential flow diversion. Minor fracturing is possible in NDC and ND2 although effects will be minor compared with those associated with the Elouera Mine.
- Other watercourses (WC6, WC7, WC12, WC15 and LA1) are located more than 400 m from the proposed longwall. It is unlikely that those watercourses will experience significant fracturing and flow diversion.

One impact has been identified in Wongawilli Creek at the base of WC_Pool 43a (Longwall 9 EoP Report). The fracture has a length of approximately 2 m and a width of up to 0.02 m.

Based on previous experience at the mine it is expected that fracturing and surface water flow diversion would occur along the drainage lines which are directly mined beneath.

This is supported by the fracturing and diversion of flow from Longwalls 9 to 15 which can be observed in Donalds Castle Creek and in drainage lines DC13, LA4 and WC21.Section of drainage lines which support Upland Swamps have soil accumulations and alluvial deposits and it is likely that fracturing in the bedrock of the swamps would not be seen at the surface.

Baseflow depletion via groundwater drawdown or depressurisation can occur in watercourses located further from longwall panels, such as along the reach of Wongawilli Creek between Areas 3A and 3B.

The most recent estimates of surface water losses are summarised in **Table 8** (Watershed Hydrogeo, 2020). The range in the following table represents the minimum to maximum loss. Maximum loss accounts for potential permanency of effects. Estimates from catchments other than those listed here can be extracted from model results as required.

Table 8 Predicted surface water losses (from Longwall 18 Groundwater Assessment by Watershed Hydrogeo 2020)

5 Year Interval	LA2	LA3	ND1	Native Dog Ck (inc. ND1)	Wongawilli Creek (to WWL)	Lake Avon catchment (inc tribs)*	Lake Cordeaux catchment (inc tribs)*
2016-20	0	0	0	0	0	-3 to -11	-91 to -318
2021-25	0.000 - - 0.002	0.000 - - 0.002	-0.020 - - 0.069	-0.031 - - 0.108	-0.002 - - 0.011	-39 to -137	-102 to -357
2026-30	0.000 - - 0.002	0.000 - - 0.002	-0.043 - - 0.149	-0.065 - - 0.229	-0.005 - - 0.017	-120 to -419	-147 to -515
2031-35	0.000 - - 0.002	0.000 - - 0.002	-0.039 - - 0.149	-0.063 - - 0.229	-0.005 - - 0.019	-155 to -542	-174 to -609
2036-40	-0.002 - - 0.006	0.000 - - 0.002	-0.034 - - 0.149	-0.055 - - 0.229	-0.017 - - 0.059	-155 to -544	-177 to -618
2041-45	-0.002 - - 0.008	0.000 - - 0.002	-0.025 - - 0.149	-0.044 - - 0.229	-0.020 - - 0.069	-128 to -446	-151 to -529
2046-50	-0.003 - - 0.009	0.000 - - 0.002	-0.018 - - 0.149	-0.039 - - 0.229	-0.021 - - 0.072	-75 to -264	-89 to -311
2051-55	-0.003 - - 0.009	0.000 - - 0.002	-0.013 - - 0.149	-0.038 - - 0.229	-0.021 - - 0.074	-35 to -123	-36 to -127
Note: impacts assessed in the future need to be compared against actual mine/longwall development							

* predicted surface water losses due Dendrobium as a whole.

5.2.6 Water Quality

Mine subsidence can impact the quality of water in streams due to leaching of minerals from freshly fractured bedrock and from increased inputs from groundwater to surface water flow. Such impacts tend to be temporary, localised and associated with low flow conditions. An investigation into the potential impacts of mine subsidence on water quality in watercourses has been undertaken and described in the report by HGEO (2020) and is summarised below.

Watercourses that have been directly mined under typically show one or more of the following water quality effects compared with baseline conditions:

- A transient increase in EC, evident at one or more monitoring sites, but not always detectable at downstream locations.
- An increase in water pH from baseline mildly acidic conditions to near neutral conditions. By contrast mining under Native Dog Creek by Elouera Longwalls resulted in a decrease in water pH which lasted several years.
- Transient increases in dissolved Fe and Mn (+/- Zn and Al) at sampling locations immediately down-stream of the affected area.

Water quality impacts have not been detected in watercourses that are not directly mined under.

Based on previous observations, it is expected that water quality influence due to the extraction of Longwall 18 would be minor or undetectable in stream reaches within subsidence affected areas (LA2, ND1 and NDC). Impacts may be observed in the first order tributary ND1C which crosses Longwall 18; however, those impacts are not expected to significantly influence water quality at the ND1 outlet. Local discolouration of streambeds and rock faces by iron hydroxide precipitation can continue for a number of years but is a temporary impact. Water quality effects on stored waters of the reservoirs are expected to be negligible and undetectable.

The Area 3B longwalls have mined directly under the upper reaches of Donalds Castle Creek and as expected fracturing and sub-bed flow diversions and water quality impacts have occurred (Longwall 9 and 10 EoP Reports). Due to the substantial distance downstream there has been no measurable reduction in the quality or quantity of surface water inflow to the Cordeaux River at its confluence with Donalds Castle Creek (Longwall 9 to 15 EoP Reports).

As the Area 3B longwalls will mine directly under the first and second order streams it is expected that fracturing and sub-bed flow diversions will occur and this is likely to alter flows and water quality in these areas. Monitoring of past mining impacts where streams were directly mined under indicate that these effects are naturally attenuated within approximately 600 m of downstream flow. Given the distances between the first and second order streams that are mined under and Wongawilli Creek it is predicted that some attenuation of these impacts will occur.

With the substantial distance downstream to Cordeaux River it is predicted there will be no measurable reduction in the quality or quantity of surface water inflow to the River. Observation and monitoring during and after the extraction of Longwalls 9 to 15 support this prediction (Longwall 9 to 15 EoP Reports).

5.2.7 Water Supply Reservoirs and the Cordeaux River

Condition 3 Schedule 3 of the Dendrobium Development Consent requires a review of potential water quality and quantity impacts. There has been no significant effect in the short or long term on either bulk raw water quality or drinking water quality in the Native Dog Creek arm of Lake Avon, despite Native Dog Creek being directly mined under by Elouera Colliery longwalls, causing creek bedrock fracturing. Similarly, monitoring undertaken at Dendrobium Areas 1 and 2 indicated there was no effect in the short or long term on bulk raw water (used for drinking water) quality in Lake Cordeaux.

Any water-borne inputs to Lake Avon from Dendrobium Area 3B will likely be restricted to a possible erosive export of fine sands and clays and/or ferruginous precipitates near the mouths of minor stream designated LA2, LA3, LA4 and LA5. Due to the localised areas of influence any impact on freshwater ecology is considered unlikely and the remoteness of these areas from water off-takes from the dam ensures any impact in water supply quality would be undetectable.

Estimates of loss of surface water within the water supply catchments to Lake Avon and Lake Cordeaux are summarised in **Section 5.2.5**. Estimates of leakage from the reservoirs are calculated via a number of methods and are compared to Dam Safety NSW's Tolerable Limit of < 1ML/day. Current estimates are below these limits.

It is unlikely that fracturing resulting in sub-bed flow diversion and pool water level loss will occur in Wongawilli Creek (Watershed Hydrogeo 2018). Fracturing and diversion of surface water flows has occurred at Donalds Castle Creek at DC-RB33. Any diverted surface water flow which is not captured into deeper storage is likely to re-emerge at the surface. This would occur at the limit of subsidence induced fracturing downstream within Donalds Castle Creek.

Area 3B is located upstream of the junction of Wongawilli Creek and Cordeaux River. At the junction, any change in water quality in Cordeaux River is predicted to be negligible. This is on the basis that the majority of flow in the Cordeaux River results from dam release, environmental flows and/or overflow from Cordeaux Reservoir. As demonstrated above, inflow and quality impacts to the reservoir from Dendrobium Mine are predicted to be negligible. Water quality impacts within Wongawilli Creek are predicted to be minor within the reach of the Creek adjacent to Area 3B. Wongawilli Creek extends a further 4.5 km to the confluence of the Cordeaux River. Additional catchment inflows to Wongawilli Creek occur in this reach and will mitigate any minor water quality impacts that do occur. For this reason, any minor water quality impacts in Wongawilli Creek will give rise to no more than negligible change in water quality or flow at Cordeaux River.

5.2.8 Surface Slopes and Gradient

For the purposes of this Plan a steep slope has been defined as an area of land having a natural gradient greater than 1 in 3 (i.e. a grade of 33%, or an angle to the horizontal of 18°). The steepest slopes within Area 3B, not including the cliffs and rock outcrops, were identified within the valley of Wongawilli Creek. These slopes have grades of up to 1 in 1, or angles to the horizontal of 45°.

Steep slopes were also identified directly above the proposed longwalls in Area 3B, along Donalds Castle Creek and the other major drainage lines, which have grades of up to 1 in 1.5, or angles to the horizontal of 34°.

The maximum predicted tilt at the steep slopes, resulting from the extraction of the proposed longwalls, is 40 mm/m (i.e. 4 %). The predicted changes in grade are small when compared to the natural grades of the steep slopes, which are greater than 1 in 3 and, therefore, the predicted tilts are unlikely to result in any significant impact on the stability of the steep slopes.

5.2.9 Erodibility

Ground movements caused by mine subsidence may increase erosion and loss of soil materials through rock falls and cracking of the surface. Rock falls and soil cracking has occurred as a result of mining Dendrobium Areas 1, 2, 3A and 3B.

Monitoring and inspections show there has been no evidence of sustained subsidence-induced erosion of the valley slopes of previous mining areas in Dendrobium. Based on that experience, no significant erosive effects or consequences such as changes to water quality from the mining of Area 3B are expected.

5.2.10 Aquatic Flora and Fauna

Monitoring is undertaken within Wongawilli Creek, WC21 and Donalds Castle Creek, and at comparable control sites established on Wongawilli, Sandy, Donalds Castle and Kentish creeks. Univariate and multivariate statistical analyses of data obtained from the AUSRIVAS sampling and artificial collectors were used to examine changes to aquatic ecology that may have occurred and to assess whether such changes are associated with mining. Surveys were undertaken in 2010, 2011, 2013, 2014, 2015, 2017 and 2019.

5.2.11 Threatened Species

Twenty-five threatened plant species and seventy-one threatened animal species have been recorded within a 10 km radius of Dendrobium Area 3B. Of these, eleven plant species and fifty-three animal species are considered to have a moderate to known likelihood of occurrence in the study area. Seven-Part tests undertaken by Niche (2012) concluded that the proposed activities are unlikely to cause a significant impact to any threatened plant species, however significant impact on local populations of Littlejohn's Tree Frog, Giant Burrowing Frog, Red-crowned Toadlet and Giant Dragonfly was likely. The possible mechanisms and physical effects of subsidence was determined to have a direct impact on known and potential habitat for the species, as these species are reliant upon Donalds Castle Creek and drainage lines (Niche 2012).

As part of the Longwall 18 Terrestrial Ecology Assessment, Niche (2020) conducted a review of the SIS predictions with regard to subsidence impacts on threatened biodiversity along with other relevant studies and surveys conducted as part of the Longwall 18 assessment support the findings of the Dendrobium Area 3 Species Impact Statement (Biosis 2007) with few departures.

Assessments of Significance were undertaken for the threatened aquatic species the Adams Emerald Dragonfly, the Sydney Hawk Dragonfly and the Macquarie Perch and these assessments concluded that it is unlikely that the proposed project will have a significant impact on the species as they would only be subject to temporary, localised and minor impacts.

6 MANAGEMENT AND CONTINGENCY PLAN

The potential impacts of mine subsidence to watercourses and associated features in Area 3B are provided below, together with a summary of the avoidance, minimising, mitigation and remediation measures proposed.

6.1 Objectives

The aims and objectives of the Plan include:

- Avoiding and minimising impacts to significant environmental values where possible.
- Implementing TARPs and reporting to identify, assess and responding to impacts to watercourses.
- Carrying out mitigation and remediation works in a manner that protects to the greatest practicable extent the environmental values of the area.
- Achieving the Performance Measures outlined in the Area 3B SMP Approval, to the satisfaction of the Secretary.
- Implementing environmental offsets where applicable.
- Monitoring and reporting effectiveness of the Plan.

To achieve these aims, monitoring, management, mitigation, remediation and offsetting has been incorporated into the mining activity proposed by IMC.

6.2 Trigger Action Response Plan

The TARPs relate to identifying, reporting, assessing and responding to potential impacts to watercourses (including impacts greater than predicted) from subsidence in Dendrobium Area 3B. These TARPs have been prepared using knowledge gained from previous mining in other areas of Dendrobium. The TARPs for Area 3B watercourses are included in **Appendix A**.

The TARPs represent actions (including reporting) to be taken upon reaching each defined trigger level. If required, a Corrective Management Action (CMA) is developed in consultation with stakeholders to manage an observed impact in accordance with relevant approvals. The WIMMCP provides a basis for the design and implementation of any mitigation and remediation. Generic CMAs are developed as required, in consultation with WaterNSW, to provide for a prompt response to a specific impact that requires a specific CMA. If appropriate these discussions will consider whether pre-approvals for the CMA can be obtained where immediate implementation is required.

Monitoring of environmental aspects provides key data when determining any requirement for a CMA, including mitigation or rehabilitation. The triggers are based on comparison of baseline and impact monitoring results. Specific triggers will continue to be reviewed and developed in consultation with key stakeholders. Where required the triggers will be reviewed and changes proposed in impact assessment reports provided to government agencies or in EoP Reports.

Level 1 TARPs typically relate to the routine impacts from mining and/or natural (non-mining) variability in the monitoring data. TARP level 1 impacts are reported to key stakeholders via a variety or mechanisms, including an Impact Update Report provided to Government Agencies.

Level 2 and 3 TARPs result in further investigations and reporting. Impact assessment reports include:

- Study scope and objectives;
- Consideration of relevant aspect from this Plan;
- Analysis of trends and assessment of any impacts compared to prediction;
- Root cause analysis of any change or impact;
- Assessment of the need for contingent measures and management options;
- Any recommended changes to this Plan; and
- Appropriate consultation.

The Level 2 and 3 TARPs may require the development of site specific CMAs which include:

- A description of the impact to be managed;

- Results of specific investigations;
- Aims and objectives for any corrective actions;
- Specific actions required to mitigate/manage and timeframes for implementation;
- Environmental offsetting;
- Roles and responsibilities;
- Gaining appropriate approvals from landholders and government agencies; and
- Reporting, consultation and communication.

6.3 Avoiding and Minimising

Mine layouts for Dendrobium Area 3B have been developed using IMC's Integrated Mine Planning Process (IMPP). This process considers mining and surface impacts when designing mine layouts.

IMC has assessed mining layout options for Dendrobium Area 3B against the following criteria:

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

Several layout alternatives for Area 3B were assessed by IMC using a multi-disciplinary team including environment, community, mining and exploration expertise. These included variations in the number of longwalls and orientations, lengths, and setbacks of the longwalls from key surface features. These options were reviewed, analysed and modified until an optimised longwall layout in Area 3B was achieved.

Area 3B is part of the overall mining schedule for Dendrobium Mine and has been designed to flow on from Areas 1, 2 and 3A to provide a continuous mining operation. There are a number of surface and subsurface constraints within the vicinity of Area 3B including major surface water features such as Lake Avon, and Wongawilli Creek; and a number of geological constraints such as dykes, faults, and particularly the Dendrobium Nepheline Syenite Intrusion. The process of developing the layout for Area 3B has considered predicted impacts on major natural features and aimed to minimise these impacts within geological and other mining constraints.

The layouts at Dendrobium Mine have been modified to reduce the potential for impacts to surface features, including limiting the maximum extraction height to 3.9 m. Changes to a mine layout have significant flow-on impacts to mine planning and scheduling as well as economic viability. These issues need to be taken into account when optimising mine layouts. The process adopted in designing the Dendrobium Area 3B mine layout incorporated the hierarchy of avoid/minimise/mitigate as requested by the DPIE and BCD during the consultation process. Mine plan changes result in significant business and economic impact, including:

- Reduction in coal extracted;
- Reduction in royalties to the State;
- Additional costs to the business;
- Risks to longwall production due to additional roadway development requirements; and
- Constraints on blending which can disrupt the supply of coal to meet customer requirements.

Restricting mine layout flexibility can also have the following consequences:

- Additional energy used to ventilate the mine;
- Increased safety risks such as risk of frictional ignition on the longwall due to less than optimal ventilation;
- Increased power usage, reduced fan lifespan and a requirement to install booster fans;
- Requirement for heavy secondary support density;

- Potential for horizontal stress and vertical abutment concentrations;
- The risk of strata control associated with increased roadway development and longwall install and take-off faces;
- Exposes the workforce to higher risk environments more frequently;
- Results in a large number of equipment movements and interaction with workers and infrastructure; and
- Requires specialised equipment and skilled personnel with limited availability.

Area 3B longwalls have been setback between 130 m and 680 m from Wongawilli Creek and minimum of 300 m from Lake Avon. This reduction in extraction also reduces subsidence movements at surface features in proximity to Wongawilli Creek and Lake Avon, including the streams LA2, LA3, LA4, LA5, WC7, WC9, WC12, WC15, WC16, WC18, and Swamps 23 and 11.

A Wongawilli Creek Waterfall 54 Management Strategy (South32 2020) has been developed to ensure the performance measures required by the SMP Approval for WC-WF54 are met. The Wongawilli Creek Waterfall Management Strategy is similar to the successful Sandy Creek Waterfall Management Plan for Dendrobium Area 3A.

The mining layout of Longwall 18 is designed to avoid Lake Avon, Wongawilli Creek, the Nepheline Syenite Intrusion as well as other geological constraints. The length of Longwall 18 has been reduced at the eastern end to avoid an in seam geological feature. Longwall 18 contains a significant structurally disturbed zone along MG18 between cut-throughts 7-8 which also extends into the longwall block (South32, 2020). This zone appears to consist of a series of three faults with displacements 10 – 15 m, downthrown to the south and middle and has been investigated via a variety of exploration methods. A summary of the geology of Longwall 18 is available in Attachment G. Inseam drilling data suggests that conditions for the shortened Longwall 18 block are likely similar to those previously experienced in Area 3B with only minor impacts from geological features expected.

Wongawilli Creek is situated on the eastern side of the longwalls in Area 3B. The thalweg (i.e. base or centreline) of the creek is greater than 1 km from the finishing (i.e. eastern) end of Longwall 18, at its closest point. The creek is therefore located outside the Study Area based on the 600 m boundary. The minimum distances between the thalweg of the creek and the completed longwalls are 110 m for Longwall 6 in Area 3A and 290 m for Longwall 9 in Area 3B.

6.4 Mitigation and Rehabilitation

If the performance measures in the Development Consent and Area 3B SMP Approval are not met, then following consultation with BCD, WaterNSW and Mining, Exploration and Geosciences (MEG), the Secretary of DPIE may issue a direction in writing to undertake actions or measures to mitigate or remediate subsidence impacts and/or associated environmental consequences. The direction must be implemented in accordance with its terms and requirements, in consultation with the Secretary and affected agencies.

As indicated in Schedule 2 Conditions 1 and 14 of the Dendrobium Development Consent (Minister for Planning 2008) and Schedule 3 Condition 14 of the Area 3B SMP Approval (DPIE 2019), the mitigation and rehabilitation described in this Plan is required for the development and is an integral component of the proposed mining activity. To the extent these activities are required for the development approved under the Dendrobium Development Consent no other licence under the *Biodiversity Conservation Act 2016* (BC Act) is required in respect of those activities.

At the time of grant of the Dendrobium Development Consent there was no requirement for concurrence in respect of threatened species or ecological communities. The requirement for concurrence was, at that time, governed by section 79B of the EPA Act. At the time of grant of the Dendrobium Development Consent there was a requirement for consultation with the Minister administering the then *Threatened Species Conservation Act 1995*, (repealed by the BC Act) and this consultation was undertaken.

6.4.1 Sealing of Rock Fractures

Where the bedrock base of any significant permanent pool or controlling rockbar within Wongawilli Creek or Donalds Castle Creeks are impacted from subsidence and where there is limited ability for these fractures to seal naturally they will be sealed with an appropriate and approved cementitious (or alternative) grout. Grouting will be focused where fractures result in diversion of flow from pools or through the controlling rockbar. Significant success has been achieved in the remediation of the Georges River where four West Cliff longwalls directly mined under the river and pool water level loss was observed.

A number of grouts are available for use including cement and Poly-urethane Resin (PUR), with various additives. These grouts can be used with or without fillers such as clean sand. Grouts can be mixed on-site and injected into a fracture network or placed by hand. Hand-placed and injection grouting of large fractures were successfully implemented in the Georges River near Appin.

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

6.4.2 Injection Grouting

Injection grouting involves the delivery of grout through holes drilled into the bedrock targeted for rehabilitation.

A variety of grouts and filler materials can be injected to fill the voids in the fractured strata intercepted by the drill holes. The intention of this grouting is to achieve a low permeability 'layer' below any affected pool as well as the full depth of any controlling rockbar.

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

Grouting holes are drilled in a pattern, usually commencing at a grid spacing of 1m x 1m to 2m x 2m. The most efficient way to drill the holes taking into account potential environmental impact is by using handheld drills. The drills are powered by compressed air which is distributed to the work area from a compressor. The necessary equipment will be sited on cleared seismic lines or other clear areas wherever possible with hoses run out to target areas.

Grout is delivered from a small tank into the ground via mechanical packers installed at the surface. All equipment can be transported with vehicles capable of travelling on tracks similar to seismic lines. If necessary, equipment or materials can be flown to nearby tracks or open spaces by helicopter. Helicopter staging has previously occurred from Cordeaux Mine where there is appropriate logistical support. The grout is mixed and pumped according to a grout design. A grout of high viscosity will be used if vertical fracturing is believed to be present since it has a shorter setting time. A low viscosity grout will be used if cross-linking is noted during grouting. Once the grout has been installed the packers are removed and the area cleaned.

After sufficient time for the product to set the area may be in-filled with additional grouting holes that target areas of significant grout take from the previous pass. The grouting program can normally be completed with hand held equipment. Wherever possible the setup and mixing areas will be restricted to cleared seismic lines and other open areas. Bunds are used to contain any local spillage at mixing points.

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

If flow diversion through a large rockbar occurs it may be more appropriate to implement alternative grouting techniques such as a deeper grout curtain which can be delivered via traditional or directional drilling technologies. Grouting should preferentially be undertaken at the completion of subsidence movements in the area to reduce the risk of the area being re-impacted. **Figure 6-1** shows grouting operations in progress within the Georges River.


(A)


(B)

(C)

Figure 6-1: Rockbar Grouting in the Georges River - (A) Drilling into the bedrock, (B) Grout pump station setup, (C) Injecting grout into bedrock via a specially designed packer system.

6.4.3 Erosion Control

Erosion can occur along preferred flow paths where subsidence induced tilts increase a catchment area. To arrest this type of erosion, 'coir log dams' are installed at knick points in the channelised flow paths or at the inception of tunnel/void spaces (**Figure 6-2**).

Figure 6-2 Square Coir Logs for Knick Point Control

As the coir log dams silt up they are regularly added to by the placement of additional layers of logs until the pooled water behind the 'dams' is at or above the level of the bank of the eroded channel. The coir logs are held in place by 50mm x 50mm wooden stakes and bound together with wire (**Figure 6-3**).

The coir log dam slows the flows in the eroding drainage line such that the drainage line will silt up.

Figure 6-3 Installation of Square Coir Logs

The most important aspect of these coir dams is the positioning of the first layer of coir logs. A trench is cut into the soil so the first layer sits on the underlying substrate or so the top of the first coir log is at ground level (**Figure 6-4**).

Figure 6-4 Trenching and Positioning of the First Layer of Coir Logs and Construction of a Small Dam in a Channel

The coir log dams are constructed at intervals down the eroding flow line, the intervals being calculated on the depth of erosion and predicted peak flows and added to until the pooled water behind the 'dams' is at or above the level of the bank of the erosion. Where increased filtering of flows is required the coir logs are wrapped in fibre matting (**Figure 6-5**).

Figure 6-5 Small Coir Log Dams with Fibre Matting

6.4.4 Surface Treatments

Where cracking develops in significant areas and natural infilling is not occurring, the cracks may require forking over and compacting to prevent erosion. Larger cracks may require more work to repair them, for example, mulch or other protection to prevent the development of erosion channels. Surface protection will remain in place until revegetation covers the disturbed area. In some cases, if the cracks are wider they may require gravel or sand filling up to surface level and revegetation using brush matting. Maintenance of moisture in rehabilitation areas can be enhanced by additional water spreading techniques, involving long lengths of coir logs and hessian 'sausages' linked together across the contour such that water flow builds up behind them and slowly seeps through the water spreaders (**Figure 6-6**).

Figure 6-6 Round Coir Logs Installed to Spread Water

Erosion control and water spreading involves soft-engineering materials that are biodegradable and become integrated into the soil profile. This approach is ecologically sustainable in that all the materials used can breakdown and become part of the organic component of the soil. This also removes the requirement for any post-rehabilitation removal of structures or materials. However, rehabilitation measures have the potential to cause impact through the materials used and the disturbance associated with access. Relevant approvals will be obtained to ensure the protection of the environment as works are implemented.

6.4.5 Gas Release

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

Very few gas releases have been observed within the Dendrobium mining area.

6.4.6 Water Quality

Ecoengineers (2012) outline mitigation measures that would be considered if unpredicted water quality impacts were detected. Any works on WaterNSW land requires prior approval from WaterNSW to access the land and there is a requirement for compliance with the Access Agreement between WaterNSW and IMC. These requirements ensure strict limits are placed on any impacts associated with undertaking rehabilitation works on WaterNSW land.

6.4.7 Alternative Remediation Approaches

IMC has successfully implemented a subsidence rehabilitation program in the Georges River where there were impacts associated with mining directly under streams. This rehabilitation focused on grouting of mining induced fractures and strata dilation to reinstate the structural integrity and water holding capacity of the bedrock. Metropolitan Colliery is currently undertaking work aimed at rehabilitating areas impacted by subsidence using PUR and other grouting materials. IMC is consulting with Metropolitan Colliery in relation to these technologies. Should rehabilitation be necessary in Dendrobium Area 3B, the best option available at the time of the rehabilitation work will be identified and with appropriate approval, implemented by IMC.

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

6.4.8 Monitoring Remediation Success

Baseline studies have been completed within the Study Area to record biophysical characteristics of the mining area. Monitoring is conducted in the area potentially affected by subsidence from the Area 3B extraction as well as areas away from mining to act as control sites. The studies in these areas are based on the BACI design criteria.

A comprehensive monitoring program is in place for watercourses identified in this Plan. A summary of watercourse monitoring within Dendrobium Area 3B is provided in **Section 2**. In the event monitoring reveals impacts greater than what is authorised by the approval, modifications to the project, mitigation measures and environmental offsets would be considered to minimise impacts.

The monitoring program would remain in place prior to, during and following the implementation of any mitigation measures in Area 3B. The monitoring program is based on the BACI design with sampling undertaken at impact and control locations prior to the commencement of mitigation, during mitigation and after the completion of the mitigation actions. The monitoring locations/points for watercourses within Dendrobium Area 3B will be reviewed as required and can be modified (with agreement) accordingly.

Data will be analysed according to the BACI design. Statistical analyses between control, impact and mitigation sites will be used to determine whether there are statistically significant differences between these sites. This analysis will assist in determining the success of any mitigation or natural reduction of mining impacts over time.

Observation data will also be collected as part of the monitoring program and be used to provide contextual information to the above assessment approach. Monitoring data and observations will be mapped, documented and reported.

6.5 Biodiversity Offset Strategy

Where impacts are greater than predicted or not within approved levels, compensatory measures (environmental offsets) will be considered. Any compensatory measure will consider the level of impact requiring compensation, the compensatory measures available and the practicality and cost of implementing the measure.

Subject to Condition 14 of Schedule 3 of the Dendrobium Development Consent:

The Applicant shall provide suitable offsets for loss of water quality or loss of water flows to WaterNSW storages, clearing and other ground disturbance (including cliff falls) caused by its mining operations and/or surface activities within the mining area, unless otherwise addressed by the conditions of the Dendrobium Development Consent, to the satisfaction of the Secretary. These offsets must:

(a) be submitted to the Secretary for approval by 30 April 2009;

(b) be prepared in consultation with WaterNSW;

(c) provide measures that result in a beneficial effect on water quality, water quantity, aquatic ecosystems and/or ecological integrity of WaterNSW's Special Areas or water catchments.

IMC transferred 33 ha of land adjacent to the Cataract River to WaterNSW to meet the above condition.

A biodiversity offset strategy has been developed in consultation with OEH and WaterNSW for the approval of the Secretary of DPE. The Secretary DPE approved the Strategic Biodiversity Offset in accordance with Condition 15 of Schedule 2 of the Dendrobium Development Consent for the Dendrobium Coal Mine 16th December 2016. The Secretary also expressed satisfaction that the Strategy fulfils the requirements of Condition 9 of the SMP for Area 3B.

6.6 Research

To assist in further understanding the impacts of subsidence and rehabilitation of swamps IMC will undertake research to the satisfaction of the Secretary. The research will be directed to improving the prediction, assessment, remediation and/or avoidance of subsidence impacts and environmental consequences to swamps. The knowledge and techniques developed through this research will assist with any requirement for rehabilitation within watercourses.

6.7 Contingency and Response Plan

In the event the TARP parameters are considered to have been exceeded, or are likely to be exceeded, IMC will implement a Contingency Plan to manage any unpredicted impacts and their consequences.

This would involve the following actions:

- Identify and record the event.
- Notify government agencies and specialists as soon as practicable.
- Conduct site visits with stakeholders as required.
- Contract specialists to investigate and report on changes identified.
- Provide incident report to relevant agencies.
- Establish weekly monitoring frequency for the site until stabilised.
- Updates from specialists on investigation process.
- Inform relevant government agencies of investigation results.
- Develop site CMA in consultation with key stakeholders and seek approvals.
- Implement CMA as agreed with stakeholders following approvals.
- Conduct initial follow up monitoring and reporting following CMA completion.
- Review the WIMMCP in consultation with key government agencies and seek approval for any modifications.
- Report in EoP Report and AEMR.

A site-specific rehabilitation action plan detailing the location and specific works to be implemented will be prepared following the identification of mining induced degradation that exceeds the trigger levels specified in the TARPs.

The site-specific rehabilitation action plan will be circulated to relevant stakeholders for comment prior to finalisation. Authority to access the land to conduct works and implement environmental controls will be approved by WaterNSW.

Table 9 provides a summary of the avoidance, mitigation and contingency measures proposed to manage impacts where predicted impacts are exceeded.

Table 9 Performance Measures, Predicted Impacts, Mitigation and Contingent Measures for Watercourses

Feature	Performance Measure	Predicted Impacts	How Monitored	How Managed	Exceeding Prediction	Contingent Measures
Wongawilli Creek	**Minor environmental consequences** including: minor fracturing, gas release and iron staining; and minor impacts on water flows, water levels and water quality	Minor environmental consequences including: minor fracturing, gas release and iron staining; and minor impacts on water flows, water levels and water quality	• Observation of Wongawilli Creek for fracturing, gas release and iron staining • Measurement of pool water levels • Measurement of surface water flow • Measurement of surface water quality	The Longwall is located 1 km from Wongawilli Creek Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period	Mining results in more than minor environmental consequences in Wongawilli Creek, including: • fracturing within Wongawilli Creek resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period • measured surface water flow reduction in Wongawilli Creek at its confluence with Cordeaux River that is greater than predicted by modelling (to the satisfaction of the Secretary) that cannot be attributed to natural variation • gas release results in vegetation dieback that does not revegetate • gas release results in mortality of threatened species or ongoing loss of aquatic habitat • iron staining and associated increases in dissolved iron resulting from the mining is observed in water at Wongawilli Creek downstream monitoring site Wongawilli Ck (FR6) • ±3 standard deviation change (positive for EC, negative for pH and DO) from the baseline mean, for a minimum of two consecutive monitoring events that cannot be attributed to natural variation	Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period Provide residual environmental offset for any mining impact as required by Condition 14 Schedule 3 of the Development Consent

Feature	Performance Measure	Predicted Impacts	How Monitored	How Managed	Exceeding Prediction	Contingent Measures
Donalds Castle Creek	**Minor environmental consequences** including: minor fracturing, gas release and iron staining; and minor impacts on water flows, water levels and water quality	Minor environmental consequences including: minor fracturing, gas release and iron staining; and minor impacts on water flows, water levels and water quality	• Observation of Donalds Castle Creek for fracturing, gas release and iron staining • Measurement of pool water levels • Measurement of surface water flow • Measurement of surface water quality	The longwalls mine under the first and second order upper reaches of Donalds Castle Creek only (Longwall 18 is not predicted to impact DCC) Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period	Mining results in more than minor environmental consequences in Donalds Castle Creek, including: • fracturing within Donalds Castle Creek resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period • measured surface water flow reduction in Donalds Castle Creek at its confluence with Cordeaux River that is greater than predicted by modelling (to the satisfaction of the Secretary) that cannot be attributed to natural variation • gas release results in vegetation dieback that does not revegetate • gas release results in mortality of threatened species or ongoing loss of aquatic habitat • iron staining and associated increases in dissolved iron resulting from the mining is observed in water at the Donalds Castle Creek downstream monitoring site Donalds Castle Ck (FR6) • ±3 standard deviation change (positive for EC, negative for pH and DO) from the baseline mean, for a minimum of two consecutive	Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period Provide residual environmental offset for any mining impact as required by Condition 14 Schedule 3 of the Development Consent

Feature	Performance Measure	Predicted Impacts	How Monitored	How Managed	Exceeding Prediction	Contingent Measures
					monitoring events that cannot be attributed to natural variation	
Waterfall WC-WF54	Negligible environmental consequences including: no rock fall occurs at the waterfall or from its overhang; no impacts on the structural integrity of the waterfall, its overhang and its pool; negligible cracking in Wongawilli Creek within 30m of the waterfall; and negligible diversion of water from the lip of the waterfall	Negligible environmental consequences including: no rock fall occurs at the waterfall or from its overhang; no impacts on the structural integrity of the waterfall, its overhang and its pool; negligible cracking in Wongawilli Creek within 30m of the waterfall; and negligible diversion of water from the lip of the waterfall	• Observation of Waterfall WC-WF54 for rock falls, impacts on structural integrity and cracking • Measurement of pool water levels	Implementation of the Wongawilli Creek WF54 Management Plan	Mining results in more than negligible environmental consequences including: • rock fall at the waterfall or its overhang • impacts on the structural integrity of the waterfall, its overhang or its pool • cracking in Wongawilli Creek within 30m of the waterfall which results in observable flow diversion • cracking in Wongawilli Creek which results in observable flow diversion from the lip of the waterfall	Grouting of fractures within 30m of the waterfall where flow diversion is observed (where it is safe to do so) Provide residual environmental offset for any mining impact as required by Condition 14 Schedule 3 of the Development Consent
Lake Avon	Negligible environmental consequences including: negligible reduction in the quality or quantity of surface water inflows to the reservoir; negligible reduction in the quality or quantity of groundwater inflows	Negligible reduction in the quality and quantity of surface water and groundwater inflows to Lake Avon	• Measurement of surface water flow • Measurement of water quality • Groundwater model calibrated to groundwater levels, surface water flows and mine water budget	The longwalls have been setback a minimum of 300 m from the full supply level of Lake Avon	Mining results in more than negligible reduction in the quality or quantity of surface water or groundwater inflows to Lake Avon, including: • surface water flow reduction into Lake Avon is greater than predicted by modelling (to the satisfaction of the Secretary) that cannot be attributed to natural variation • ±3 standard deviation change (positive for EC, negative for pH and	Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period Provide residual environmental offset

Feature	Performance Measure	Predicted Impacts	How Monitored	How Managed	Exceeding Prediction	Contingent Measures
	to the reservoir and negligible leakage from the reservoir to underground mine workings.				DO) from the baseline mean of the Lake Avon inflows, for a minimum of two consecutive monitoring events that cannot be attributed to natural variation	for any mining impact as required by Condition 14 Schedule 3 of the Development Consent
Cordeaux River	Operations do not result in reduction (other than **negligible reduction**) in the quality or quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek	Negligible reduction in the quality and quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek	• Observation of Wongawilli Creek for iron staining • Measurement of surface water flow • Measurement of surface water quality	The Longwall is located 1 km from Wongawilli Creek	Mining results in more than negligible reduction in the quality or quantity of surface water inflows to the Cordeaux River at its confluence with Wongawilli Creek, including: • measured surface water flow reduction in Wongawilli Creek at its confluence with Cordeaux River is greater than predicted by modelling (to the satisfaction of the Secretary) that cannot be attributed to natural variation • ±3 standard deviation change (positive for EC, negative for pH and DO) from the baseline mean of Wongawilli Creek at its confluence with Cordeaux River, for a minimum of two consecutive monitoring events that cannot be attributed to natural variation	Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period Provide residual environmental offset for any mining impact as required by Condition 14 Schedule 3 of the Development Consent

Note: The mitigation measures will be assessed for appropriateness (in consultation with key stakeholders), as the need arises, on the individual watercourses being impacted to ensure significant additional impacts to the watercourses are not created by the carrying out of these mitigation measures. The provision of residual environmental offsets will be considered where the potential impacts of mitigation measures are greater than the impacts of mining or where the mitigation measures are not successful. Additional actions are required as per the TARPs, including informing stakeholders, review of monitoring and further assessments as required.

7 INCIDENTS, COMPLAINTS, EXCEEDANCES AND NON-CONFORMANCES

7.1 Incidents

IMC will notify DPIE and other relevant agencies of any incident associated with Area 3B operations as soon as practicable after IMC becomes aware of the incident. IMC will provide DPIE and any relevant agencies with a report on the incident within seven days of confirmation of any event.

7.2 Complaints Handling

IMC will:

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

7.3 Non-Conformance Protocol

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

Non-conformities, corrective actions and preventative actions are managed in accordance with the following process:

- Identification and recording of non-conformance and/or non-compliance.
- Evaluation of the non-conformance and/or non-compliance to determine specific corrective and preventative actions.
- Corrective and preventative actions to be assigned to the responsible person.
- Management review of corrective actions to ensure the status and effectiveness of the actions.

An Annual Review will be undertaken to assess IMC's compliance with all conditions of the Dendrobium Development Consent, Mining Leases and other approvals and licenses.

An independent environmental audit will also be undertaken (Condition 6 Schedule 8) to review the adequacy of strategies, plans or programs under these approvals and if appropriate, recommend actions to improve environmental performance. The independent environmental audit will be undertaken by a suitably qualified, experienced and independent team of experts whose appointment has been endorsed by the Secretary of DPIE.

8 PLAN ADMINISTRATION

This WIMMCP will be administered in accordance with the requirements of the Dendrobium Environmental Management System (EMS) and the Dendrobium Development Consent Conditions. A summary of the administrative requirements is provided below.

8.1 Roles and Responsibilities

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

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

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

Responsibilities for environmental management in Dendrobium Area 3 and the implementation of the WIMMCP include:

Manager Approvals

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

Principal Approvals

- Authorise the WIMMCP and any amendments thereto.
- To document any approved changes to the WIMMCP.
- Provide regular updates to IMC on the results of the WIMMCP.
- Arrange information forums for key stakeholders as required.
- Prepare any report and maintain records required by the WIMMCP.
- Organise and participate in assessment meetings called to review mining impacts.
- Respond to any queries or complaints made by members of the public in relation to aspects of the WIMMCP.
- Organise audits and reviews of the WIMMCP.
- Address any identified non-conformances, assess improvement ideas and implement if appropriate.
- Arrange implementation of any agreed actions, responses or remedial measures.
- Ensure surveys required by this WIMMCP are conducted and record details of instances where circumstances prevent these from taking place.

Coordinator Environment

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

Survey Team Coordinator

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

Technical Experts

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

Person(s) Performing Inspections

- Inform the Coordinator Environment of any non-conformances identified with the Plan, or ideas aimed at improving the WIMMCP.
- Conduct inspections in a safe manner.

8.2 Resources Required

The Approvals Manager provides resources sufficient to implement this WIMMCP.

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

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

8.3 Training

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

- An initial site induction (including all relevant aspects of environment, health, safety and community).
- Safe Work Method Statements and Job Safety Analyses, Toolbox Talks and pre-shift communications.
- On-going job specific training and re-training (where required).

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

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

8.4 Record Keeping and Control

Environmental Records are maintained in accordance with the IMC document control requirements.

IMC document control requirements include:

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

The WIMMCP and other relevant documentation will be made available on the South32 website in accordance with Condition 11, Schedule 2 of the Development Consent.

8.5 Management Plan Review

A review of the objectives and targets associated with the Dendrobium Area 3 operations is undertaken on an annual basis via the IMC planning process. These reviews, which include involvement from senior management and other key site personnel, assess the performance of the mine over the previous year and develop goals and targets for the following period.

An annual review of the environmental performance of Dendrobium Area 3 operations will also be undertaken in accordance with Condition 5 Schedule 8 of the Dendrobium Development Consent. More specifically this WIMMCP will be subject to review (and revision if necessary, to the satisfaction of the Secretary) following:

- The submission of an annual review under Condition 5 Schedule 8.
- The submission of an incident report under Condition 3 Schedule 8.
- The submission of an audit report under Condition 6 Schedule 8.

- Any modification to the conditions of the Dendrobium Development Consent or SMP approval.

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

9 REFERENCES AND SUPPORTING DOCUMENTATION

ACARP, 2009. Damage Criteria and Practical Solutions for Protecting River Channels. Project Number C12016. Ken Mills SCT May 2009.

Axys, 2019. Risk Assessment: Review of Dendrobium Longwall 17 Subsidence Management Plan. AR2573 (Revision 3) 4 March 2019.

Axys, 2020. Risk Assessment: Review of Dendrobium Longwall 18 Subsidence Management Plan, Risk Assessment Report. AR2944 (Revision E) 4 March 2019.

BHP Billiton Illawarra Coal, 2006. Georges River Report: Assessment of Georges River Remediation Longwalls 5A1-4. November 2006.

BHP Billiton Illawarra Coal, 2011. Understanding Swamp Conditions - Field Inspection Report - September 2010 to November 2010. BHP Billiton Illawarra Coal, April, 2011.

Biosis Research 2007. Dendrobium Area 3 Species Impact Statement, Prepared for BHP Billiton Illawarra Coal, Biosis Research Pty Ltd.

Biosis Research 2007. Dendrobium Coal Mine and Elouera Colliery Flora and Fauna Environmental Management Program, Annual Monitoring Report – Spring 2003 to Winter 2006, Biosis Research Pty Ltd.

Biosis Research, 2009. Revision of the Dendrobium Coal Mine Flora and Fauna Monitoring Program. February 2009.

Biosis Research, 2012(a). Elouera and Dendrobium Ecological Monitoring Program. Annual Monitoring Report Financial Year 2010/2011. August 2012.

Biosis Research, 2012(b). Swamp 15b TARP Assessment – Ecology. Ref:15462, 10 October 2012.

Biosis, 2014. Dendrobium Ecological Monitoring Program, Annual Report for 2012/2013 Financial Year. February 2014. Prepared for Illawarra Coal.

Biosis, 2015. Dendrobium Terrestrial Ecology Monitoring Program, Annual Report for 2014. September 2015. Prepared for Illawarra Coal.

Biosis, 2019. Dendrobium Areas 2, 3A and 3B: Terrestrial Ecology Monitoring Program Annual Report 2018, Final Report, Prepared for Illawarra Coal, 21 June 2019.

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

Cardno, 2020. Aquatic Flora and Fauna Review. Illawarra Coal Holdings Pty Ltd, August 2020.

Cardno, 2018. Dendrobium Area 3B Aquatic Ecology Monitoring 2010 to 2017. 8 December 2019.

Cardno Ecology Lab, 2012. Aquatic Flora and Fauna Assessment. Prepared for BHPBIC, February 2012.

Cardno Ecology Lab, 2012. Swamp 15b and SC10C Aquatic Flora and Fauna Review. Ref: NA49913032, 5 October 2012.

Cardno Ecology Lab, 2013. Dendrobium Area 3A Aquatic Ecology Monitoring 2008-2012. Job Number: EL1112073 Prepared for BHP Billiton – Illawarra Coal, February 2013.

Cardno Ecology Lab, 2013. Review of Sandy Creek Pools Aquatic Flora and Fauna. 25 February 2013.

Cardno Ecology Lab, 2013. SC10C Level 3 Aquatic Ecology Trigger Assessment. 11 June 2013.

Cardno Ecology Lab, 2015. Dendrobium Area 3A Aquatic Ecology Monitoring 2008 to 2014. 30 March 2015.

Cardno Forbes Rigby, 2007. Landscape Impact Assessment and Monitoring Site Optimisation. Prepared for BHPBIC.

Cardno Forbes Rigby, 2007. Area 3A Subsidence Management Plan Longwalls 6 to 10. Prepared for BHPBIC.

Cardno Forbes Rigby, 2007. Dendrobium Area 3 Environmental Assessment. Prepared for BHPBIC.

Chafer, C., Noonan, M and Macnaught, E. 2004. The Post-Fire Measurement of Fire Severity and Intensity in the Christmas 2001 Sydney Wildfires. International Journal of Wildland Fire Vol. 13; pp. 227-240.

Chiew, F, Wang, Q. J., McConachy, F., James, R., Wright, W, and deHoedt, G. 2002. Evapotranspiration Maps for Australia. Hydrology and Water Resources Symposium, Melbourne, 20-23 May, 2002, Institution of Engineers, Australia.

Coffey, 2012. Groundwater Study Area 3B Dendrobium Coal Mine: Numerical Modelling. GEOTLCOV24507AA-AB2 2 October 2012.

Ditton, S., and Merrick, N.P. 2014. A new sub-surface fracture height prediction model for longwall mines in the NSW coalfields. Paper presented at the Australian Earth Science Convention, Newcastle, NSW.

Doherty, J. 2010. PEST: Model-Independent Parameter Estimation User Manual (5th ed.): Watermark Numerical Computing, Brisbane, Queensland, Australia.

EarthTech Engineering Pty Ltd, 2005. Thresholds for Swamp Stability. Prepared for BHPBIC, January 2005.

The Ecology Lab, 2007. Dendrobium Area 3 Assessment of Mine Subsidence Impacts on Aquatic Habitat and Biota. October 2007.

Ecoengineers, 2006. Assessment of Surface Water Chemical Effects of Mining by Elouera Colliery. January - December 2005. February 2006.

Ecoengineers, 2006. Assessment of Catchment Hydrological Effects by Mining by Elouera Colliery Stage 1: Establishment of a Practical and Theoretical Framework. August 2006.

EcoEngineers, 2007. Surface Water Quality and Hydrology Assessment to Support SMP Application for Dendrobium Area 3.

EcoEngineers, 2010. End of Panel Surface and Shallow Groundwater Impacts Assessment Dendrobium Area 2 Longwall 5. Document Reference No. 2010/01A. April 2010.

Ecoengineers, 2012. Surface Water Quality and Hydrological Assessment: Dendrobium Area 3B Subsidence Management Plan Surface and Shallow Groundwater Assessment.

Ecoengineers, 2012. Level 2 TARP Independent Review and Recommendations Swamp 15b Dendrobium Area 3A. 25 September 2012.

Ecoengineers, 2013. Level 3 TARP Independent Review and Recommendations Sandy Creek Catchment Pool 7 (Dendrobium Area 3A). 12 February 2013.

Ecoengineers, 2013. Level 2 TARP Specialist Review and Recommendations Donalds Castle Creek. 22 May 2013.

Ecoengineers, 2014. End of Panel Surface and Shallow Groundwater Impacts Assessment, Dendrobium Area 3B Longwall 9. June 2014.

Ecoengineers, 2015. End of Panel Surface and Shallow Groundwater Impacts Assessment, Dendrobium Area 3B Longwall 10. February 2015.

Eco Logical Australia, 2004. The Impacts of Longwall Mining on the Upper Georges River Catchment: Report to Total Environment Centre, 2004.

Forster, 1995. Impact of Underground Mining on the Hydrogeological Regime, Central Coast NSW. Engineering Geology of the Newcastle-Gosford Region. Australian Geomechanics Society. Newcastle, February 1995.

GHD, 2007. Dendrobium Area 3A Predicted Hydrogeologic Performance. Report for BHP Billiton, Illawarra Coal. November 2007.

GSS Environmental, 2013. Baseline and Pre-Mining Land Capability Survey. Dendrobium Mine, Area 3B. February 2013.

Hazelton P.A. and Tille P.J. 1990. Soil Landscapes of the Wollongong-Port Hacking 1:100,000 Sheet map and report, Soil Conservation Service of NSW, Sydney.

Hebblewhite, 2010. BHP Billiton Illawarra Coal: Bulli Seam Operations Project – Independent Review. 31 March 2010.

Helensburgh Coal Pty Ltd, 2007. Submission to: Independent Expert Panel - Inquiry into NSW Southern Coalfield July 2007, Helensburgh Coal Pty Ltd.

Heritage Computing, 2009. Dendrobium Colliery Groundwater Assessment: Mine Inflow Review, Conceptualisation and Preliminary Groundwater Modelling. Merrick, N.P., Heritage Computing Report HC2009/2, February 2009.

Heritage Computing, October 2011. Recalibration of the Dendrobium Local Area Groundwater Model after Completion of Longwall 6 (Area 3A). Report prepared for Illawarra Coal. Report HC2011/13.

HGEO, 2019. Dendrobium Mine End of Panel Surface Water and Shallow Groundwater Assessment: Longwall 14 (Area 3B), September 2019, Project number: J21474, Report: D19327.

HGEO, 2019. Dendrobium Mine Estimates of seepage from Lake Avon following redrilling of holes at AD3, AD4 and AD8. September 2019. Project number: J21476. Report: D19337.

HGEO, 2020. Assessment of surface water flow and quality effects of proposed Dendrobium Longwall 18. Report: D18301. August 2020.

HGEO, 2020. Structure and hydrogeology of the Elouera Fault (No. D20365), Report by HGEO Pty Ltd for South32 Illawarra Metallurgical Coal.

HGEO, 2020. Investigation into the height of fracturing above extracted longwalls in Area 3, Dendrobium (No. D19341), Report by HGEO Pty Ltd for Illawarra Metallurgical Coal.

HGEO, 2020. Dendrobium Mine End of Panel surface water and shallow groundwater assessment: Longwall 15 (Area 3B) (No. D20358), Report by HGEO Pty Ltd for South32 Illawarra Coal.

HydroSimulations, 2014. Dendrobium Area 3B Groundwater Model Revision: Swamps, Stream Flows and Shallow Groundwater Sata. Report: HC2014/4 March 2014.

HydroSimulations, 2019. Dendrobium Area 3B Longwall 17 Groundwater Assessment. Report: HC2018 March 2019.

Illawarra Coal, 2014. Longwall 9 End of Panel Report.

Illawarra Coal, 2015. Longwall 10 End of Panel Report.

Illawarra Coal, 2016. Longwall 11 End of Panel Report.

Illawarra Coal, 2017. Longwall 12 End of Panel Report.

Illawarra Coal, 2018. Longwall 13 End of Panel Report.

Illawarra Metallurgical Coal, 2019. Longwall 14 End of Panel Report.

Independent Expert Panel for Mining in the Catchment, 2018. Initial report on specific mining activities at the Metropolitan and Dendrobium coal mines. 12 November 2018.

Independent Expert Panel for Mining in the Catchment, 2019a, Independent Expert Panel for Mining in the Catchment Report: Part 1. Review of specific mining activities at the Metropolitan and Dendrobium coal mines, Prepared for the NSW Department of Planning, Industry and Environment.

Independent Expert Panel for Mining in the Catchment, 2019b, Independent Expert Panel for Mining in the Catchment Report: Part 2. Coal Mining Impacts in the Special Areas of the Greater Sydney Water Catchment, Prepared for the NSW Department of Planning, Industry and Environment.

Kirchner, J. W. 2009. Catchments as simple dynamical systems: Catchment characterization, rainfall-runoff modelling, and doing hydrology backwards. Res., W02429.

Manly Hydraulics Laboratory, 2006. BHP Billiton Dendrobium Mine Area 2 Subsidence Environmental Management Plan Water Monitoring and Management Program. Prepared for BHPBIC. Version 1.4 January 2006.

McMahon, 2014. Dendrobium Community Consultative Committee Report: Review of Surface Water Study. An independent review of surface water hydrological modelling associated with Illawarra Coal's Dendrobium Area 3, conducted by Emeritus Professor Thomas McMahon, University of Melbourne. 4 June 2014.

MSEC, 2007. Dendrobium Mine Area 3A Longwalls 6 to 10. Report on The Prediction of Subsidence Parameters and the Assessment of Mine Subsidence Impacts on Natural Features and Surface Infrastructure Resulting from the Extraction of proposed Longwalls 6 to 10 in Area 3A at Dendrobium Mine in Support of the SMP and SEMP Applications. September 2007.

MSEC, 2012. Dendrobium Area 3B Subsidence Predictions and Assessments for Natural Features and Surface Infrastructure in Support of the SMP Application.

MSEC, 2015. Dendrobium Area 3B – Longwalls 12 to 18 Review of the Subsidence Predictions and Impact Assessments for Natural and Built Features in Dendrobium Area 3B based on Observed Movements and Impacts during Longwalls 9 and 10.

MSEC, 2017. Dendrobium mine – Area 3B. The Effects of the Proposed Modified Commencing Ends of Longwalls 15 to 18 in Area 3B at Dendrobium Mine on the Subsidence Predictions and Impact Assessments. MSEC914 August 2017.

MSEC, 2018. Dendrobium – Longwalls 17 and 18. Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of Longwalls 17 and 18 in Area 3B at Dendrobium Mine. MSEC992 November 2018.

MSEC, 2019. Report on the effects of surface lineaments on the measured ground movements at Dendrobium Area 3B based on the measured LiDAR contours. Report No. MSEC1034.

MSEC, 2020. Dendrobium – Longwall 18 Subsidence Predictions and Impact Assessments for the Natural and Built Features due to the Extraction of the Proposed Longwall 18 in Area 3B at Dendrobium Mine. MSEC1103 Rev C. July 2020.

Niche Environment and Heritage, 2012. Terrestrial Ecological Assessment. Prepared for BHP Billiton Illawarra Coal. February, 2012.

Niche Environment and Heritage, 2020. Dendrobium Longwall 18 Terrestrial Ecological Assessment. South 32 Illawarra Metallurgical Coal. August 2020.

NPWS, 2003. The Native Vegetation of the Woronora, O'Hares and Metropolitan Catchments. Central Conservation Programs and Planning Division NSW National Parks and Wildlife Service; August 2003.

OEC, 2001. Environmental Impact Statement Dendrobium Coal Project. Olsen Environmental Consulting, Figtree, N.S.W.

Parkhurst. D.L., and Appelo, C.A.J. 2012. Description of Input and Examples for PHREEQC Version 3 – A Computer Program for Speciation, Batch-Reaction, One- Dimensional Transport and Inverse Geochemical Calculations. US Department of Interior/US Geological Survey.

Parson Brinckerhoff, 2012. Independent Review of Dendrobium Area 2 and 3A Hydrochemical Data. August 20012.

Parsons Brinckerhoff, 2015. Connected fracturing above longwall mining operations, Part 2: Post-longwall investigation. For BHP Billiton Illawarra Coal. Document number 2172268F-WAT-REP-002 RevB. 6 March 2015.

Petersen, 1992. The RCE: a Riparian, Channel, and Environmental Inventory for small streams in the agricultural landscape. Freshwater Biology Vol 27, Issue 2, April 1992.

Resource Strategies, 2009. Bulli Seam Operations Environmental Assessment. Report in support of an application for the continued operations of the Appin and West Cliff Mines.

SCT ,2020a. Updated Review of Overcore Measurements Adjacent to Elouera Fault. SCT Letter Report DEN4968A to Richard Walsh dated 23 June 2020.

SCT, 2020b. Review of Experience of Inflows Adjacent to Lineaments and Fault Structures in the context of Stress Relief. SCT Letter Report DEN5125A to Cody Brady dated 11 August 2020.

Singh & Kendorski, 1981. Strata Disturbance Prediction for Mining Beneath Surface Water and Waste Impoundments, Proc. First Conference on Ground Control in Mining, West Virginia University, PP 76-89.

SLR, 2020. Dendrobium Area 3A Longwall 19 Groundwater Assessment. Report: 665.10009-R02_v2.0. Jan 2020.

South32, 2020. Wongawilli Creek Waterfall 54 Management Strategy. August 2020.

SRK, 2020. Geological structures comparison investigation (No. STH055 RevE), Report by SRK Consulting for Illawarra Metallurgical Coal.

Tammetta, P. (2013). Estimation of the height of complete groundwater drainage above mined longwall panels. Groundwater, 51(5), 723-734.

Tomkins, K.M. and Humphries, G.S. 2006. Technical report 2: Upland Swamp development and erosion on the Woronora Plateau during the Holocene. January 2006. Sydney Catchment Authority – Macquarie Collaborative Research Project.

Tozer, M. et el 2002. Native Vegetation Maps of the Cumberland Plain Western Sydney. NSW National Parks and Wildlife Service 2002.

Waddington, A.A. and Kay, D.R. 2001. Research into the Impacts of Mine Subsidence on the Strata and Hydrology of River Valleys and Development of Management Guidelines for Undermining Cliffs. Gorges and River Systems. Final Report on ACARP Research Project C8005, March 2001.

Waddington, A.A. and Kay, D.R. 2002. Management Information handbook on the Undermining of Cliffs, Gorges and River Systems. ACARP Research Projects Nos. C8005 and C9067, September 2002.

Watershed Hydrogeo, 2018. Analysis of low flow and pool levels on Wongawilli Creek. Report r003i2, October 2018.

Watershed Hydrogeo, 2019. Discussion of Surface Water Flow TARPs. Report r011i5, December 2019.

Watershed Hydrogeo, 2020. Dendrobium Mine Longwall 18 Groundwater Assessment. Prepared for Illawarra Coal Pty Ltd. August 2020.

Zhang, L. Dawes, W.R. and Walker, G.R. 1999. Predicting the effect of Vegetation Changes on Catchment Average Water Balance. Technical Report No. 99/12, Cooperative Research Centre for Catchment Hydrology.

Appendix A – Watercourse Monitoring and Trigger Action Response Plan

Appendix A – Watercourse Monitoring and Trigger Action Response Plan

Watercourse monitoring within Dendrobium Area 3 will be installed ahead of mining to achieve 2 years baseline data (subject to timing and approval timeframes of any request to install additional monitoring). Monitoring will be conducted throughout the mining period and for at least 2 years following active subsidence or until the consequences of mining have stabilised. A review of post mining monitoring will be carried out in consultation with DPIE, WaterNSW and other relevant agencies where required. Where impacts are observed, the monitoring period will be extended and this will be reported in Impact Assessment Reports and End of Panel Reports. For Level 2 and 3 Triggers and for impacts exceeding prediction this review will be conducted in consultation with key agencies. The location of monitoring sites is indicated on the figures of the relevant areas WIMMCP.

Table 1.1 – Dendrobium Area 3 Watercourse Monitoring

<table>
<tr><th colspan="2">Monitoring Site</th><th>Site Type</th><th>Monitoring Frequency</th><th>Parameters</th></tr>
<tr><td colspan="5">OBSERVATIONAL MONITORING</td></tr>
<tr><td>AREA 3A</td><td>Sandy Creek and tributaries (including SC7 and SC10)
Wongawilli Creek and tributaries
Refer to Figure 3-1 of 3A WIMMCP</td>
<td rowspan="3">Observation and photo point monitoring:
• Sites based on an assessment of risk
• Streams and swamps
• Pools and rockbars
• Previously observed impacts that warrant follow-up inspection</td>
<td rowspan="3">• Monthly 2 years pre- and post-mining, weekly when longwall is within 400 m of monitoring site
• Reference sites 6 monthly</td>
<td rowspan="3">Visual signs of impacts to creeks and drainage lines (i.e. cracking, vegetation changes, increased erosion, changes in water colour, soil moisture etc.) determined by comparing baseline photos with photos during the mining period

Manual Field Testing:
Key water quality parameters in pools analysed to identify any changes resulting from mining including pH, Temp, EC, DO and ORP

Pool water levels to identify any changes resulting from mining. At suitable sites, pool water levels will be measured with a pressure transducer and continuous logger. A benchmark for manual readings will be installed at sites that are not suitable for a logger</td></tr>
<tr><td>AREA 3B</td><td>Impact Sites
Native Dog, Wongawilli and Donalds Castle Creeks, WC21, WC18, WC16, WC15, WC12, WC9, WC7, LA5, LA4, LA3, LA2, LA1, ND1, ND2 and DC13
Swamps 5, 10, 11, 13, 14, 23, 35a, 35b, 1a, 1b, 8, 3 and 4
Refer to Figures 2-2 to 2-11 and 2-25 to 2-32 of 3B WIMMCP
Reference Sites
Wongawilli Creek, Sandy Creek, Gallaghers Creek, LC5(1), WC11, DC10, SC9A, CR36 and D10
Swamps 2(1), 7(1), 15a, 22, 24, 25, 33, 84, 85, 86, 87 and 88
Refer to Figures 2-12 to 2-25, 2-28 to 2-30 and 2-33 to 2-35</td></tr>
<tr><td>AREA 3C</td><td>Impact Sites (2, 3)
Wongawilli Creek, , WC20, WC21, WC22, WC23, WC24, , LC5(1)
Swamps), ,), 9, , , 144 and 145
Reference Sites
CR36 (Cordeaux River tributary)</td></tr>
<tr><td colspan="5">WATER CHEMISTRY</td></tr>
<tr><td>AREA 3A</td><td>Wongawilli Creek
WWU1, WWU4, WC_Pool 46, WWM2, WC_Pool 43b and Wongawilli Creek (FR6)
WC17_S1 (Wongawilli Creek tributary)
WC14_S1 (Wongawilli Creek tributary)
WC13_S1 (Wongawilli Creek tributary)
Sandy Creek
SCk_Rockbar 5 (Sandy Creek adjacent to LW7)
SC10_Rockbar 3 (Sandy Creek tributary)
SC10C_Pool 1 (SC10 tributary)
SC7_S1 (Sandy Creek tributary)</td>
<td>• Collect sample
• Field water quality</td>
<td>• Monthly monitoring pre, during and post mining for two years</td>
<td>Lab. Analytes:
• (incl. lab checks of pH, lab. check of EC, DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si)</td></tr>
</table>

	Lake Cordeaux Sandy Creek Arm (lake site) *Refer to Figure 3-2 of 3A WIMMCP*			
AREA 3B	**Wongawilli Creek** WWU1 (Wongawilli Creek headwaters) WWU4 (Wongawilli Creek upstream) WC_Rockbar 39 (Wongawilli Creek adjacent to LW17) WC Pool 49 (Wongawilli Creek adjacent to LW15) WC_Pool 46 (Wongawilli Creek adjacent to LW12) WWM2 (Wongawilli Creek adjacent to LW11) WC_Pool 43b (Wongawilli Creek downstream of LW9) Wongawilli Creek (FR6) (Wongawilli Creek downstream) WC21_Pool 5 (Wongawilli Creek tributary downstream of mining) WC21 Pools 30 and 53 (Wongawilli Creek tributaries over mining) WC15_Pool 28 (Wongawilli Creek tributary downstream of mining) WC15_Pool 9 (Wongawilli Creek tributary downstream of mining) WC15_Pool 2 (Wongawilli Creek tributary downstream of mining) WC7_Pool 1(Wongawilli Creek tributary downstream of mining) WC12_Pool 1 (Wongawilli Creek tributary downstream of mining) **Lake Avon** LA4_S1, LA4_S2, LA5_S1, LA5_S2, LA3 Pool 4, LA2 Pool 5, LA1 and LA_1 (Lake Avon tributaries downstream of mining) NDC_Pool 1 (Native Dog Creek downstream of mining) NDC_Pool 3 (Native Dog Creek downstream of mining) ND1_Pool 2 (tributary to Native Dog Creek downstream of mining) **Donalds Castle Creek** Donalds Castle Creek (FR6) (Donalds Castle Creek lower) DCL3 (Donalds Castle Creek Upstream approx. 1km from Cordeaux River) DC_Pool 22 (Donalds Castle Creek downstream of mining) DC13_Pool 2b (Donalds Castle Creek tributary downstream of mining) **Lake Cordeaux** *LC5_S1 (Reference Site)* *Refer to Figure 2-35* **Cordeaux River** CR36_S1 (Cordeaux River tributary Reference Site)			

AREA 3C	**Wongawilli Creek** WWU1 (headwaters; upstream of Area 3C) WWU4 (upstream of Area 3C) WC_S3 (adjacent to Longwall 20) Wongawilli Creek (FR6) (Wongawilli Creek downstream) WC_Pool 43b (adjacent to Longwall 20) WC_S1 (downstream of Longwall 21) WC20_S1 (downstream of Longwall 20) [(4)] WC24_S1 (downstream of Longwall 20) [(4)] WC26_S1 (downstream of Longwall 20) [(4)] WC21_Pool 5 (Wongawilli Creek tributary within the study area) **Donalds Castle Creek** Donalds Castle Creek (FR6) (Donalds Castle Creek lower) DCL3 (Donalds Castle Creek upstream of Cordeaux River confluence) **Lake Cordeaux** LC5_S1[1] (downstream of Longwall 20) **Cordeaux River** CR36_S1 (Reference site northeast of Area 3C)			
WATER FLOW				
Ref Sites	**O'Hares Creek** [NSW govt site] 213200 (O'Hares Creek @ Wedderburn) **Wongawilli Creek** WWU (Wongawilli Creek upstream)	• Some data (for reference sites) is provided by Water NSW		Other reference sites may be used depending on data availability and quality (e.g. Woronora River 2132101 and Bomaderry Creek 215016)
AREA 3A	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WC14S1 (Wongawilli Creek tributary) **Sandy Creek** SCL2(Sandy Creek at downstream) SC10S1 and SC10CS1 (Sandy Creek tributary) *Refer to Figures 3-5 of 3A WIMMCP*	• Pressure transducer with data logger • Flow gauging site (volumetric or flow meter). Low-profile weir or suitable natural rockbar control	• Continuous 1-hour logging intervals	Automatic pool water level measurements which are converted to flows by calculation of rating curves using measured creek cross sections/measured flows at the monitoring point. Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from similar reference sites (that are not impacted by mining).
AREA 3B	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WC21S1 (Wongawilli Creek tributary downstream of mining) WC15S1 (Wongawilli Creek tributary downstream of mining) WC12S1 (Wongawilli Creek tributary downstream of mining) **Donalds Castle Creek** DCU (Donalds Castle Creek @ FR6) DC13S1 (Donalds Castle Creek tributary downstream of mining) DCS2 (Donalds Castle Creek downstream of mining)			

	Lake Avon LA4S1 (Lake Avon tributary downstream of mining) LA3S1 (Lake Avon tributary downstream of mining) LA2S1 (Native Dog Creek tributary downstream of mining) NDCS1 (Lake Avon tributary downstream of mining) NDTS1 (Native Dog Tributary downstream of mining) **Lake Cordeaux** LC5S1 (Reference Site) **Cordeaux River** CR36S1 (Cordeaux River tributary Reference Site) *Refer to Figure 2-36 of 3B WIMMCP*			
AREA 3C	**Wongawilli Creek** WWU (Wongawilli Creek upstream) WWL_A (Wongawilli Creek downstream) WWL (Wongawilli Creek downstream) WCS1 (Wongawilli Creek downstream) WC20S1 (Wongawilli Creek tributary downstream of mining) WC24S1 (Wongawilli Creek tributary downstream of mining) WC26S1 (Wongawilli Creek tributary within the study area) WC21S1 (Wongawilli Creek tributary within the study area) **Donalds Castle Creek** DCU (Donalds Castle Creek downstream of mining) DCS2 (Donalds Castle Creek within study area) **Lake Cordeaux** LC5S1[1] (Downstream of LW20) **Cordeaux River** CR36S1 (Cordeaux River tributary Reference Site)			
AQUATIC ECOLOGY				
AREAS 3A, 3B and 3C	**Impact Sites:** Sites 2, 3, 4, X4, X5 and X6 (Wongawilli Creek) Sites X2 and X3 (WC21) Site X1 (Donalds Castle Creek) Sites 8, 9, 11, 12 and 13 (Sandy Creek Catchment) *Refer to Figure 2-57 of 3B WIMMCP* **Reference Sites:** Site 1 (Wongawilli Creek – until LW15) Site 5 (Wongawilli Creek) Site 14 (Donalds Castle Creek) Site 6 (WC21) Site 7 (Sandy Creek)	• Quantitative and observational monitoring	• Two baseline monitoring campaigns prior to mining during autumn and spring • Biennial monitoring during mining in autumn and spring • Biennial monitoring post mining for two years or as otherwise required • Biennial monitoring targets sites as mining progresses through the domain	Macroinvertebrate sampling and assessment using the AUSRIVAS protocol and quantitative sampling using artificial collectors In consideration of Adams Emerald Dragonfly, Giant Dragonfly and Sydney Hawk Dragonfly, individuals of the genus Austrocorduliidae and Gomphomacromiidae, Petalura are identified to species level if possible

	Sites 15 and 16 (Kentish Creek) *Refer to Figure 2-57 of 3B WIMMCP*			Fish are sampled by visual observations and dip netting in Area 3A, and sampled using baited traps in Area 3B
TERRESTRIAL ECOLOGY				
AREAS 3A, 3B and 3C	**Impact Sites:** DC13 (Donalds Castle Creek tributary) DC(1) (Donalds Castle Creek) WC15 and 21 (Wongawilli Creek tributaries) LA4A (Lake Avon tributary) ND1 (Native Dog Creek tributary) **Reference Sites:** WC10 and 11 (Wongawilli Creek tributaries) SC6, SC7-1, SC7-2, SC7A and SC8 (Sandy Creek tributaries) DC8 (Donalds Castle Creek tributary) NDC (Native Dog Creek)	• Standardised transects in potential breeding habitat for two threatened frog species, Littlejohn's Tree Frog and Giant Burrowing Frog	• Surveys are undertaken in optimal periods over the season (i.e. when frogs are calling and/or active at known sites)	Frog surveys are conducted along creeks with a focus on features susceptible to impacts e.g. breeding pools. Potential breeding habitat for Littlejohn's Tree Frog and Giant Burrowing Frog will be targeted. Standardised transects have been established to record numbers of individuals at each site from one year to the next. Tadpole counts will also be undertaken as part of the breeding habitat monitoring transects. These transects are surveyed by walking down the creekline and counting all amphibians seen or heard on either side of the line

(1) *Reference site for Area 3B; impact site when mining commences in Area 3C.*

(2) *The proposed sites are designed to monitor each mapped pool/rockbar complex within the Study Area reach of Wongawilli Creek. Based on site inspections (August 2019), continuous monitoring will be implemented at suitable sites. A benchmark for manual readings will be installed at sites that are not suitable for continuous monitoring.*

(3) *Proposed sites within the Wongawilli Creek tributaries are subject to change based on further field inspections. The sites will target pool/rockbar complexes and steps.*

(4) *The proposed water chemistry monitoring sites are designed to detect changes to water quality, due to mining in Area 3C, within Wongawilli Creek. The proposed tributary sites (WC26, WC24 and WC20) aim to detect surface water inputs into Wongawilli Creek. Based on field observations, the Wongawilli Creek tributaries WC28, WC27, WC25, WC23 and WC22 were deemed as unsuitable for water chemistry sites due to a lack of site flows and the morphology of the tributaries.*

Table 1.2 – Dendrobium Area 3B Watercourse Impacts, Triggers and Response

OBSERVATIONAL-MONITORING		
Wongawilli Creek, Donalds Castle Creek and WC-WF54 **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences • Waterfall WC-WF54 – negligible environmental consequences	***Level 1*** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area • Observation that a pool on a subject Creek is dry • Observation that the subject Creek has ceased to flow	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
General observation of streams in active mining areas when longwall is within 400m	***Level 2*** • Observation that a single pool on a subject Creek is dry in consecutive monitoring events • Observation that two or more pools on a subject Creek are dry in a single monitoring event • Observation that the subject Creek has ceased to flow in consecutive monitoring event	• *Actions as stated for Level 1* • Carry out Water Flow Assessment Method D • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	• Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion • Crack or fracture between 10 and 50m length • Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention • Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Crack or fracture over 300mm width at its widest point • Crack or fracture over 50m length • Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water • Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced

	• Gas release results in vegetation dieback, mortality or loss of aquatic habitat • Observable increase in iron staining within the mining area continues more than 600m from the longwall	movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
	Exceeding Prediction • Structural integrity of the bedrock base of any significant permanent pool or controlling rockbar cannot be restored i.e. pool water level within the pool after CMAs continues to be lower than baseline period • Gas release results in vegetation dieback that does not revegetate • Gas release results in mortality of threatened species or ongoing loss of aquatic habitat • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at Wongawilli Creek downstream monitoring site Wongawilli Creek (FR6) • Iron staining and associated increases in dissolved iron resulting from the mining is observed in water at the Donalds Castle Creek downstream monitoring site Donalds Castle Creek (FR6) • Rock fall at WC-WF54 or its overhang • Impacts on the structural integrity of WC-WF54, its overhang or its pool	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Native Dog Creek, ND1, ND2, WC15, WC12, WC7, LA1 and LA2 General observation of streams in active mining areas when longwall is within 400m	***Level 1*** • Crack or fracture up to 100mm width at its widest point with no observable loss of surface water or erosion • Crack or fracture up to 10m length with no observable loss of surface water or erosion • Erosion in a localised area (not associated with cracking or fracturing) which would be expected to naturally stabilise without CMA and within the period of monitoring • Observable release of strata gas at the surface • Observable increase in iron staining within the mining area	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR

	Level 2 • Crack or fracture between 100 and 300mm width at its widest point or any fracture which results in observable loss of surface water or erosion • Crack or fracture between 10 and 50m length • Soil surface crack that causes erosion that is likely to stabilise within the monitoring period without intervention • Observable increase in iron staining within the mining area continues to outside the mining area i.e. 400m from the longwall	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Crack or fracture over 300mm width at its widest point • Crack or fracture over 50m length • Fracturing observed in the bedrock base of any significant permanent pool which results in observable loss of surface water • Soil surface crack that causes erosion that is unlikely to stabilise within the monitoring period without intervention • Gas release results in vegetation dieback, mortality or loss of aquatic habitat • Observable increase in iron staining within the mining area continues more than 600m from the longwall	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success • Review relevant TARP and Management Plan in consultation with key agencies
WATER QUALITY		
Wongawilli Creek **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences Wongawilli Creek (FR6) Baseline means: • pH 5.98 • EC 98.8 uS/cm • DO 89.5%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)

	Level 3 • Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.45 – EC 154.1 uS/cm – DO 50.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Donalds Castle Creek **Relevant Performance Measure(s):** • Donalds Castle Creek - minor environmental consequences Donalds Castle Creek (FR6) Baseline means: • pH 5.41 • EC 116.0 uS/cm • DO 85.6%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required

	• Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• Review relevant TARP and Management Plan in consultation with key agencies • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al – Filterable suite of metals • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 3.60 – EC 185.8 uS/cm – DO 40.1%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Lake Avon **Relevant Performance Measure(s):** • Lake Avon - negligible reduction in the quality of surface water inflows to Lake Avon Lake Avon tributary (LA4_S1) Baseline means: • pH 5.38 • EC 90.8 uS/cm • DO 89.9%	***Level 1*** • One exceedance of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Two non-consecutive exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required

	• Three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• Review relevant TARP and Management Plan in consultation with key agencies • Collect laboratory samples and analyse for: – pH, EC, major cations, major anions, Total Fe, Mn & Al – Filterable suite of metals • Develop site CMA (subject to agency feedback). This may include: – Limestone emplacement to raise pH where it is appropriate to do so – Grouting of fractures in rockbar and bedrock base of any significant pool where flow diversion results in pool water level lower than baseline period • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Mining results in two consecutive exceedances or three exceedances of the ±3 standard deviation level (positive for EC, negative for pH and DO) from the baseline mean within six months: – pH 4.90 – EC 129.8 uS/cm – DO 69.5%	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
POOL WATER LEVEL		
Wongawilli Creek and Donalds Castle Creek **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	***Level 1*** • Single pool on a subject Creek is observed as dry	• Continue monitoring program • Carry out Water Flow Assessment Method D. • Submit letter report to DPIE, MEG and Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Single pool on a subject Creek is observed as dry in consecutive monitoring events • Two or more pools on a subject Creek are observed as dry in a single monitoring event	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)

	Level 3 • Fracturing resulting in diversion of flow such that <10% of the pools have water levels lower than baseline period	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BD, DPIE, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
	Exceeding Prediction • Fracturing resulting in diversion of flow such that >10% of the pools have water levels lower than baseline period	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent
Waterfall WC-WF54 **Relevant Performance Measure(s):** • Waterfall WC-WF54 – negligible environmental consequences	***Exceeding Prediction*** • Fracturing in Wongawilli Creek within 30m of the waterfall which results in observable flow diversion • Fracturing in Wongawilli Creek which results in observable flow diversion from the lip of the waterfall	• *Actions as stated for Level 3* • Investigate reasons for the exceedance • Update future predictions based on the outcomes of the investigation • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent

Monitoring	Trigger	Action
SURFACE WATER FLOW		
Wongawilli Creek and Donalds Castle Creek **Lake Avon and Cordeaux River** **Relevant Performance Measure(s):**	***Level 1*** • A) Lower flow than expected (additional 10-15% of days where Q% lower than Reference Q%) • B) 5-10% increase in cease-to-flow frequency beyond natural) • C) Reduction in Q50 (10-15% beyond natural)	• Continue monitoring program. • Submit an Impact Report to BCD, DPIE, MEG, WaterNSW. • Report in the End of Panel Report. • Summarise actions and monitoring in AEMR.

• Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences • Lake Avon - negligible reduction in the quantity of surface water inflows to Lake Avon[1] • Cordeaux River - negligible reduction in the quantity of surface water inflow to the Cordeaux River at its confluence with Wongawilli Creek[2] **Surface water flow Reference sites** (as in Table 1.1)**:** • Wongawilli Creek - WWU (Wongawilli Creek upstream); • O'Hares Creek at Wedderburn (213200); • (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016) NB. This section of the TARP contains four Water Flow Assessment Methods, labelled A, B, C and D, which are specified in detail in Watershed HydroGeo (2019). Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites. *Natural variability ('NV') will be defined as the 'average' change at the selected reference sites. Triggers may occur when the apparent impact at a site (NV + x% change) could be less than maximum observed variability at one of the reference sites.*	***Level 2*** • A) Lower flow than expected (additional 15-20% of days where Q% lower than Reference Q%). • B) 10-20% increase in cease-to-flow frequency (beyond natural) • C) 15-20% reduction in Q50 (beyond natural) • D) Observation that the subject Creek has ceased to flow at spatially consecutive monitoring sites.	• *Actions as stated for Level 1* • Review monitoring frequency. • D) → carry out Water Flow Assessment Method D. • Submit letter report to DPIE, MEG and WaterNSW and seek advice on any CMA required. • Implement agreed CMAs as approved (subject to agency feedback).
	Level 3 • A) Lower flow than expected (additional >20% of days where Q% lower than Reference Q%) • B) >20% increase in cease-to-flow frequency (beyond natural) • C) >20% reduction in Q50 (beyond natural)	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, WaterNSW. • Implement additional monitoring or increase frequency if required. • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, MEG, WaterNSW. • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success. • Review relevant TARP and Management Plan in consultation with key agencies.
	Exceeding Prediction Measured surface water flow reduction, based on Assessment Methods C, D, to be compared against predictions made in contemporary groundwater modelling conducted to the satisfaction of the Secretary to assess whether effects that cannot be explained by natural variability "exceed prediction".	• *Actions as stated for Level 3* • Investigate reasons for the exceedance. • Update future predictions based on the outcomes of the investigation. • Provide residual environmental offset for any mining impact where CMAs are unsuccessful as required by Condition 14 Schedule 3 of the Development Consent.

[1] Surface water inflows calculation = [Impacts at gauged catchments (LA1 + LA2 + LA3 + LA4 + LA6+ NDT1 + ND2) + estimated impacts at ungauged but undermined catchments (e.g. LA5)] / [total inflow to LA].
[2] Flow reduction as determined from measured at flow gauging station WWL_A.

Tributaries of Wongawilli Creek and Donalds Castle Creek and other affected watercourses not subject to performance measures **Surface water flow Reference sites** (as in Table 1.1)**:** • Wongawilli Creek - WWU (Wongawilli Creek upstream); • O'Hares Creek and Wedderburn (213200); • (other such sites, if necessary, include Woronora River 2132101 and Bomaderry Creek 215016) NB. This section of the TARP contains four Water Flow Assessment Methods, labelled A, B, C and D, which are specified in detail in Watershed HydroGeo (2019). Hydrological changes are assessed by comparing pre- and post-mining observed flows from impact or assessment sites to flow data from the reference sites. *Natural variability ('NV') will be defined as the 'average' change at the selected reference sites. Triggers may occur when the apparent impact at a site (NV + x% change) could be less than maximum observed variability at one of the reference sites.*	***Level 1*** • A) Lower flow than expected (additional 10-20% of days where Q% lower than Reference Q%) • B) 5-10% increase in cease-to-flow frequency (beyond natural) • C) 10-20% reduction in Q50 (beyond natural)	• Continue monitoring program. • Submit an Impact Report to BCD, DPIE, MEG, WaterNSW. • Report in the End of Panel Report. • Summarise actions and monitoring in AEMR.
	Level 2 • A) Lower flow than expected (additional 20-30% of days where Q% lower than Reference Q%) • B) 10-20% increase in cease-to-flow frequency (beyond natural) • C) 20-30% reduction in Q50 (beyond natural)	• *Actions as stated for Level 1* • Review monitoring frequency. • Submit letter report to DPIE, MEG and WaterNSW and seek advice on any CMA required. • Implement agreed CMAs as approved (subject to agency feedback).
	Level 3 • A) Lower flow than expected (additional >30% of days where Q% lower than Reference Q%) • B) >20% increase in cease-to-flow frequency (beyond natural) • C) >30% reduction in Q50 (beyond natural)	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, WaterNSW. • Implement additional monitoring or increase frequency if required • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, MEG, WaterNSW. • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and WaterNSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success. • Review relevant TARP and Management Plan in consultation with key agencies.
AQUATIC ECOLOGY		
Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat • Wongawilli Creek catchment – 8 sites • Donalds Castle Creek catchment – 1 site	***Level 1*** • Reduction in aquatic habitat for 1 year	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2	• *Actions as stated for Level 1*

Relevant Performance Measure(s): • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	• Reduction in aquatic habitat for 2 years following the active subsidence period	• Review monitoring frequency • Submit letter report to DPIE, BCD, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Reduction in aquatic habitat for >2 years following the active subsidence period	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced movements and impacts are complete), including monitoring and reporting on success
TERRESTRIAL FAUNA – THREATENED FROG SPECIES		
Pool water level, interconnectivity between pools and loss of connectivity, noticeable alteration of habitat • Wongawilli Creek catchment – 2 sites • Donalds Castle Creek catchment – 2 sites • Lake Avon tributary – 1 site • Native Dog tributary – 1 site **Relevant Performance Measure(s):** • Wongawilli Creek - minor environmental consequences • Donalds Castle Creek - minor environmental consequences	***Level 1*** • Reduction in habitat for 1 year	• Continue monitoring program • Submit an Impact Report to BCD, DPIE, MEG, Water NSW • Report in the End of Panel Report • Summarise actions and monitoring in AEMR
	Level 2 • Reduction in habitat for 2 years following the active subsidence period	• *Actions as stated for Level 1* • Review monitoring frequency • Submit letter report to DPIE, BCD, MEG and Water NSW and seek advice on any CMA required • Implement agreed CMAs as approved (subject to agency feedback)
	Level 3 • Reduction in habitat for > 2 years following the active subsidence period	• *Actions as stated for Level 2* • Offer site visit with BCD, DPIE, MEG, Water NSW • Implement additional monitoring or increase frequency if required • Review relevant TARP and Management Plan in consultation with key agencies • Develop site CMA (subject to agency feedback). This may include: grouting of rockbar and bedrock base of any significant pool where it is appropriate to do so in consultation with BCD, DPIE, MEG, Water NSW • Completion of works following approvals and at a time agreed between S32, DPIE, MEG and Water NSW (i.e. may be after mining induced

		movements and impacts are complete), including monitoring and reporting on success

Department of Planning, Industry and Environment (DPIE)

Biodiversity and Conservation Division (BCD)

Department of Mining, Exploration and Geosciences (MEG)

WaterNSW

Appendix B – Dendrobium Long Term Groundwater Monitoring Program

DENDROBIUM LONG-TERM GROUNDWATER MONITORING PROGRAM

Areas 3A, 3B and 3C

Prepared for:

South32
Illawarra Metallurgical Coal
Innovation Campus Enterprise 1 Building
Level 3 Squires Way
North Wollongong, NSW 2500
Australia

SLR Ref: 665.10009-R03
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PREPARED BY

SLR Consulting Australia Pty Ltd
ABN 29 001 584 612
Level 1, The Central Building, UoW Innovation Campus
North Wollongong NSW 2500 Australia

T: +61 404 939 922
E: wollongong@slrconsulting.com www.slrconsulting.com

BASIS OF REPORT

DOCUMENT CONTROL

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665.10009-R03-v2.0	28 January 2020	Braiya White, Claire Stephenson	Claire Stephenson	Noel Merrick

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DOCUMENT REFERENCES

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FIGURES

APPENDICES

1 Introduction

Dendrobium mine is located approximately 12 kilometres (km) west of Wollongong (NSW) in the Southern Coalfield, and within the Metropolitan Special Catchment Area managed by WaterNSW. Longwall mining has been undertaken at Dendrobium since 2005 (IEPMC, 2019a) with the earliest multilevel piezometers installed in 2003 in Area 1 and from 2007 for Area 3. Dendrobium Mine is divided into six mining domains with Area 3 being further divided into Areas A, B and C.

SLR Consulting Pty Ltd (SLR) has been engaged to develop a long-term groundwater monitoring program for Areas 3A, 3B, and Longwall (LW) 20 – 21 (Area 3C) for the Dendrobium Mine operated by Illawarra Metallurgical Coal (IMC), a subsidiary of South32.

A long-term groundwater monitoring network is required to be developed to satisfy Condition 5(a), Schedule 4 of the Subsidence Management Plan Approval, granted 11th July 2019 (Development Consent DA 60-03-2001). This condition states that prior to the extraction of Longwall 16 (extraction proposed to commence in February 2020) the applicant must review and revise the Watercourse Impact Monitoring, Management and Contingency Plan for Area 3B to include a *"program of long-term groundwater monitoring, to be developed in consultation with WaterNSW, to monitor **groundwater levels** at specific locations and depths until post-mining groundwater levels have stabilised"*.

A recent investigation conducted by the Independent Expert Panel on Mining in the Catchment (IEPMC 2019a) has recommended that monitoring is increased at mine sites within the Greater Sydney Water Catchment Special Areas, to improve early identification of negative effects to features of environmental value. The IEPMC identified that large investigative efforts and monitoring programs have been undertaken at Dendrobium (and other mines within the Greater Sydney Water Catchment Special Areas). However, the IEPMC concluded the 'scale and complexity' of groundwater responses to mining in the region required more extensive monitoring to be undertaken by mines (IEPMC, 2019a).

This report presents a synthesis of the existing groundwater monitoring network and provides details of a recommended long-term groundwater monitoring program for Dendrobium mine areas 3A, 3B and 3C. This includes recommendations on monitoring frequency, annual reporting and data management requirements, along with groundwater model review requirements.

2 Existing Groundwater Monitoring Network

The following sections outline the various components and details of the current site groundwater monitoring network installed for Areas 3A, 3B and 3C. The monitoring network comprises a substantial number of multilevel vibrating wire piezometers (VWPs) positioned in various geologic units. Groundwater quality measurements are taken using pumps installed at selected VWP sites.

2.1 Groundwater Levels -VWPs

Groundwater levels are measured at Dendrobium using the extensive network of VWPs. These VWPs are positioned over the longwall footprint (including along longwall panel centrelines), within the off-goaf area and adjacent to major reservoirs (i.e. Lake Avon and Lake Cordeaux) in order to assess the impacts of depressurisation on the regional groundwater system. In all, 149 VWPs with 615 sensors have been installed as part of the monitoring network for Areas 3A, 3B and 3C. From this, a total of 101 VWPs with 394 individual sensors remain active. The Hawkesbury Sandstone is the most intensely monitored geologic unit, with 241 sensors positioned within 85 active VWPs.

Currently, measurements are collected at the VWPs on a daily to sub-daily basis and downloaded by field staff periodically for reporting. This data is collected and collated by Dendrobium Mine and uploaded and managed in an online database controlled by Geosensing Solutions.

The construction details of the VWPs and the monitored geology are shown in **Table 2-1** and locations shown in **Figure 1**.

Table 2-1 Groundwater Monitoring Network – VWPs

Area	S-Index	Status	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/ BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
3A	S1096	AD	AIS Kemira DDH 19	292699.6	6191120.9	435.1		1								1	
3A	S1099	AD	AIS Kemira DDH 22	292040.9	6191530.9	429.9		1								1	
3A	S1106	AD	AIS Kemira DDH 24	293904.7	6192602.4	335.2		1								1	
3A	S1388	AD	AIS Dend. DDH 29	292128.9	6192392.9	427.6		1								1	
3A	S1587	AD	DC Dend.DDH 41	292934.4	6193080.4	412.0		1								1	
3A	S1719	AD	DC Dend. DDH 56	291202.0	6193277.0	413.6	429.0	1								1	
3A	S1720	AD	DC Dend. DDH 57	291636.7	6192468.7	373.4	369.1	1								1	
3A	S1738	AD	DC Dend. DDH 61	292124.2	6191861.0	421.7	361.8	1								1	
3A	S1845	AD	Dend. DDH 77	291464.0	6193770.0	399.7		2							1	1	
3A	S1867	EX	ED Dend. DDH 84	293792.6	6192912.5	346.0		11	2		3	2	1	1	1	1	
3A	S1870	EX	ED Dend. DDH 85	293593.2	6192648.2	351.5	159.5	12	3		3	2	1	1	1	1	
3A	S1871	AD	ED Dend. DDH 86	293525.0	6193287.1	375.6		12	3		3	2	1	1	1	1	
3A	S1878	EXP	ED Dend. DDH 91	293842.3	6191994.3	337.1	309.3	11		1	3	3	1	1	1	1	
3A	S1879	EX	ED Dend. DDH 92	291440.3	6192133.4	379.7	368.5	12	3		3	3	1		1	1	
3A	S1885	EX	ED Dend. DDH 93	291504.4	6192667.9	420.0	420.4	12	3		3	3	1		1	1	
3A	S1888	EX	ED Dend. DDH 96	292486.5	6191987.4	381.3	320.5	8	2		2	2			1	1	
3A	S1889	AD	ED Dend. DDH 97	292244.8	6192980.4	435.4	386.3	8	2		2	2			1	1	
3A	S1890	AD	ED Dend. DDH 98	292637.3	6192490.5	407.1	347.5	8	2		2	2			1	1	
3A	S1892	EX	ED Dend. DDH 99	291014.1	6193952.0	356.1	389.2	8	2		2	2			1	1	
3A	S1907	EXP	ED Dend. DDH 103	293212.2	6191943.1	371.9	371.9	8	2		2	2			1	1	
3A	S1934	AD	ED Dend. DDH 115	292128.0	6192398.0	427.5	114.2	4	2		2						
3A	S1992	EX	EDEN119	293732.1	6192706.8	339.1	250.0	8	1		4	2			1		
3A	S1994	EX	EDEN120	293865.2	6192982.4	345.5	258.0	8	1		3	3			1		
3A	S2143C	AD	S2143C	293984.0	6192803.4	335.8		1	1								
3A	S2442A	EX	SC1-A	292788.5	6193213.2	407.6		6	3	1	2						
3A	S2443	EX	SC4	292176.0	6193027.4	426.7	227.0	6	3	1	2						
3B	S1579	EX	Dend. DDH 40	289061.3	6192056.3	423.1	446.4	1								1	
3B	S1739	AD	DC Dend. DDH 62	289683.6	6191798.7	423.7	438.4	1								1	
3B	S1755	EX	DC Dend. DDH64	289475.4	6191380.2	433.3		2							1	1	
3B	S1758	AD	Dend. DDH 65	288586.6	6193106.9	408.8		2							1	1	
3B	S1796	EX	Dend. DDH 69	289946.6	6194587.4	398.6	471.3	2							1	1	

Area	S-Index	Status	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/ BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
3B	S1800	AD	Dend. DDH 70	289933.4	6193996.5	392.5	452.8	2							1	1	
3B	S1855	EX	Dend. DDH 82	289746.5	6192833.2	366.6		2							1	1	
3B	S1908	AD	ED Dend. DDH 104	288925.9	6193601.4	405.7	460.5	8	2		3	1			1	1	
3B	S1910	EXP	EDEN105	289387.4	6194176.3	377.2		8	2		2	2			1	1	
3B	S1911	AD	EDEN106	288802.8	6192549.4	405.2	437.4	12	3		3	2	1	2		1	
3B	S1914	AD	EDEN107	289370.0	6192511.9	414.5	442.7	8	2		2	2			1	1	
3B	S1925	EXP	ED Dend. DDH 108	289251.6	6193041.1	416.7	463.6	8	2		2	2			1	1	
3B	S1926	AD	ED Dend. DDH 109	289660.4	6193444.9	409.0	458.0	8	2		2	2			1	1	
3B	S1927	EXP	ED Dend. DDH 110	290066.0	6192211.0	414.8	437.2	8	2		2	2			1	1	
3B	S1929	AD	ED Dend. DDH 111	290010.6	6193398.1	337.7	381.0	8	2		2	2			1	1	
3B	S1930	EXP	ED Dend. DDH 112	290367.3	6193582.9	353.1	401.4	12	3		3	3	1		1	1	
3B	S1931	EXP	ED Dend. DDH 113	290335.6	6192889.9	396.4		10	2	1	3	2			1	1	
3B	S1932	EXP	ED Dend. DDH 114	288863.3	6191505.4	396.1	400.2	12	4		3	3		1		1	
3B	S1995	AD	EDEN121	288212.4	6193662.3	404.5		2							1	1	
3B	S1998	EX	EDEN122	287750.6	6194273.1	410.5	479.3	2							1	1	
3B	S1999	EX	EDEN123	289232.8	6190843.7	406.4		2							1	1	
3B	S2000	EX	EDEN124	290161.4	6191011.2	442.0		2							1	1	
3B	S2001	EX	EDEN125	288462.6	6192020.0	413.9	431.2	10	3		3	2			1	1	
3B	S2002	AD	EDEN126	288633.4	6194222.1	400.0	466.0	2							1	1	
3B	S2003	AD	EDEN127	290571.1	6192478.0	409.4		2							1	1	
3B	S2004	EX	EDEN128	290538.5	6190794.8	443.5		2							1	1	
3B	S2006	EX	EDEN129	287263.2	6194204.3	409.1	464.0	10	3		3	2			1	1	
3B	S2007	EX	EDEN130	287590.8	6193718.9	405.8		2							1	1	
3B	S2009	AD	EDEN131	287828.2	6193092.0	402.5		10	3		3	2			1	1	
3B	S2013	EX	EDEN134	290857.7	6191198.2	399.7		2							1	1	
3B	S2070	EX	EDEN150	287619.3	6192813.2	414.7		2							1	1	
3B	S2071	AD	EDEN151	287027.2	6193200.9	443.1		2							1	1	
3B	S2078	AD	EDEN154	288190.0	6192451.9	342.0		2							1	1	
3B	S2126	AD	S2126	288536.6	6193897.9	397.6		2							1	1	
3B	S2192	AD	S2192	289826.7	6193848.7	389.3	288.0	6	3		3						
3B	S2193	EX	S2193	288523.4	6190985.9	370.8		2							1	1	
3B	S2194	EX	S2194	288514.9	6190978.8	371.1		11	3		3	2			1	1	1
3B	S2220	EXP	S2220 (AQ5)	289827.2	6193830.7	388.1	287.5	6	3		3						
3B	S2288	EX	Dend S2288 and S2208	292821.1	6195048.6	343.8		1								1	

Area	S-Index	Status	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/ BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
3B	S2303	EXP	Dend S2303	287109.8	6196268.1	411.7		9	3		3	1			1	1	
3B	S2306	EX	Swamp Bore 3 (adjacent)	288643.3	6192483.7	395.5	70.0	4	4								
3B	S2307	EX	Swamp Bore 4	288665.9	6192424.6	394.5	50.0	4	4								
3B	S2313	EX	Avon 1	287609.0	6192815.5	415.3		3	2		1						
3B	S2314	EX	Avon 2	288193.5	6192470.3	342.4		1	1								
3B	S2314A	EX	Avon 2 Redrill	288194.6	6192455.6	342.6		3	2		1						
3B	S2335	EX	WC21Project Hole1Site 2	289725.4	6192748.7	372.6	51.0	6	6								
3B	S2335A	EX	WC21Project Hole1Site 2	289727.0	6192755.0	370.1		6	6								
3B	S2336	EX	WC21Hole2,Site2	289721.9	6192758.1	372.4	35.0	1	1								
3B	S2337	EX	WC21Project Hole1Site 5	290021.0	6193411.9	336.1	51.0	4	4								
3B	S2338	EX	WC21Hole2,Site5	290012.2	6193406.7	336.1	51.0	3	3								
3B	S2351	EX	S14-04	290049.6	6191178.2	402.8		1	1								
3B	S2351A	EX	S14-03	290054.3	6191175.2	403.6		1	1								
3B	S2354	EX	S14-05	289730.9	6191413.7	424.6		1	1								
3B	S2376	EX	Avon6	288400.4	6192527.0	367.8		3	2		1						
3B	S2377	EX	Avon3	288333.4	6192020.4	408.2		3	2		1						
3B	S2378	EX	Avon4	288407.4	6191770.9	379.3		3	2		1						
3B	S2379	EX	Avon5	288312.9	6191140.5	356.6		3	2		1						
3B	S2398	EX	LW14-1	289073.2	6192164.3	420.2	335.0	7	4	1	2						
3B	S2398A	EX	LW14-1A	289072.9	6192156.9	420.5	11.0	1	1								
3B	S2398B	EX	LW14-1 post extraction Redrill	289070.9	6192172.6	418.0	335.5	7	4	1	2						
3B	S2399	EX	LW12-1	289810.5	6192965.1	355.1	350.0	6	3	1	2						
3B	S2399A	EX	S2399A	289815.6	6192967.8	354.6		2	2								
3B	S2401	EX	Den01b_R1	287752.2	6194264.9	411.1	119.0	6	6								
3B	S2402	EX	Den01b_R2	288207.8	6193666.6	403.4	92.0	6	6								
3B	S2403	EX	Den01b_R3	288345.1	6193761.1	400.7	60.0	6	6								
3B	S2404	EX	Den01b_R4	288528.6	6193896.8	396.2	59.0	6	6								
3B	S2405	EX	Den01b_R5	288729.5	6194087.6	386.1	71.0	6	6								
3B	S2406	EX	Den01b_R6	288669.1	6194176.5	396.6	86.0	6	6								
3B	S2408	EX	GW14-2	289552.1	6192193.4	398.1		7	7								
3B	S2409	EX	GW14-3	289546.1	6192269.7	394.6	120.0	6	6								
3B	S2409A	EX	GW14-3	289546.1	6192269.7	394.6	11.0	1	1								
3B	S2411	EX	LW12-2	289761.1	6192837.7	364.0	285.0	7	4	1	2						
3B	S2411A	EX	LW12-2a	289761.6	6192839.3	363.8	12.0	1	1								

Area	S-Index	Status	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/ BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
3B	S2412	AD	LW15-1	289201.1	6191807.4	427.3	341.4	7	4	1	2						
3B	S2412A	AD	LW15-1A	289201.1	6191807.4	427.3	12.0	1	1								
3B	S2420	EX	LW12-3	289738.4	6192780.0	367.8	272.8	7	4	1	2						
3B	S2420A	EX	LW12-3A	289738.4	6192780.0		272.8	1	1								
3B	S2421	EX	LW13-1	289590.4	6192492.2	381.8		7	4	1	2						
3B	S2421A	EX	LW13-1A	289590.4	6192492.2			1	1								
3B	S2433	EX	Elouera2-1	289082.0	6190172.9	375.7		1	1								
3B	S2435	EX	AD7	288080.8	6192411.6	328.2	108.2	3	2		1						
3B	S2436	EX	AD8	288313.8	6191499.7	320.3	108.2	3	1	1	1						
3B	S2436B	EX	AD8B	288313.8	6191499.7	320.5	39.3	1	1								
3B	S2436C	EX	AD8C (angle hole)	288319.6	6191500.8	320.7	70.0	1	1								
3B	S2441	EX	Elouera1-1	288752.5	6190268.4	347.6		1	1								
3B	S2441A	EX	Elouera1-2	288754.5	6190253.8	349.0		1	1								
3B	S2441B	EX	Elouera1-3	288760.7	6190260.9	348.4		1	1								
3B	S2444	EX	Elouera2-2	289077.9	6190167.7	376.3	324.8	1	1								
3C	S1390	EX	AIS Dend. DDH 31	292469.3	6194395.7	375.2		1								1	
3C	S1779	AD	Dend. DDH 67	292381.4	6195550.6	368.7	403.0	2							1	1	
3C	S1844	EX	Dend. DDH 76	291391.1	6194868.8	375.6	408.6	2							1	1	
3C	S1969	AD	EDEN118	293998.1	6193985.7	368.5		11	3		3	3			1	1	
3C	S2010	AD	EDEN132	292273.2	6196658.1	374.2	441.8	1								1	
3C	S2011	AD	EDEN133	292055.1	6197166.1	371.7		2							1	1	
3C	S2017	AD	EDEN136	291384.8	6196706.4	351.3		2							1	1	
3C	S2018	AD	EDEN137	291154.4	6195520.3	369.0		2							1	1	
3C	S2019	EX	EDEN138	291897.6	6195913.7	361.8		2							1	1	
3C	S2059	EXP	EDEN148	293245.7	6194795.1	380.8	401.3	12	3	1	3	3			1	1	
3C	S2207	EX	S2207	291807.6	6195324.3	416.8		2							1	1	
3C	S2208	AD	S2208	292801.1	6195037.3	344.1		7	2		2	2				1	
3C	S2211	AD	S2211	293247.0	6194106.0	397.7		2							1	1	
3C	S2212	AD	S2212	293534.8	6194402.9	369.2		10	1		3	3			1	1	1
3C	S2333	EX	D-A3C-14-12	290697.1	6197087.4	310.9		10	3		3	2			1	1	
3C	S2333A	AD	D-A3C-14-12A	290688.1	6197088.0	311.2		10	3		3	2			1	1	
3C	S2341A	EX	D-A5-28A	287489.0	6195138.2	402.6		4	4								
3C	S2352	EX	D-A5-6	286264.6	6195393.3	408.8	425.8	10	3		3	2			1	1	
3C	S2355	EX	A5_S85_DBH	288136.2	6194877.8	396.6	70.6	4	4								

Area	S-Index	Status	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/ BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
3C	S2355A	EX		288135.3	6194879.2	396.5	10.5	1	1								
3C	S2357	EX	A5-S100_DBH	286809.6	6196991.8	394.0	71.0	4	4								
3C	S2358	EX	A5-S97_DBH	286859.6	6197664.4	385.7	71.0	4	4								
3C	S2359	EX	D-A5-5	285354.6	6195547.7	403.6		10	3		3	2			1	1	
3C	S2361	EX	A5_S109_DBH	286277.9	6195810.7	402.4	70.0	4	4								
3C	S2362	EX	A5_S110_DBH	285772.9	6195823.0	399.9	70.0	4	4								
3C	S2364	EX	A5_S103_DBH	285982.8	6196782.1	395.0	70.0	4	4								
3C	S2365	EX	A5_101/102_DBH	286042.3	6196448.9	399.2	75.0	4	4								
3C	S2365A	EX		286041.9	6196442.6	399.1	70.0	1	1								
3C	S2370	EX	D-A5-2	285554.8	6196642.7	375.6		10	3		3	2			1	1	
3C	S2371	EX	A6_S116_DBH	291977.5	6199135.2	351.2	70.0	4	4								
3C	S2372	EX	A6_S115_DBH	291576.9	6198891.4	373.5	70.0	4	4								
3C	S2372A	EX		291572.2	6198894.4	373.6	17.0	1	1								
3C	S2373	EX	A6_S112_DBH	292043.2	6200899.2	359.0	70.0	4	4								
3C	S2374	EX	A6_S83_DBH	291114.8	6201461.1	324.4	70.0	4	4								
3C	S2438	EXP		287944.9	6197535.1	399.3	444.3	9	3		3	2			1		

Note: mbgl – metres below ground level
Coordinates are for GDA94 MGA56
HBSS – Hawkesbury Sandstone
BHCS/BACS – Bald Hill Claystone
BGSS – Bulgo Sandstone
SBSS – Scarborough Sandstone
WBCS – Wombarra Shale
CCSS – Coalcliff Sandstone
BUSM – Bulli Coal Seam
WWSM – Wongawilli Coal Seam
TGSM – Tongarra Coal Seam
Dend. – Dendrobium
EX – Existing
AD – Currently abandoned and destroyed
EXP – Existing – but with only a subset of original sensors

2.2 Water Quality

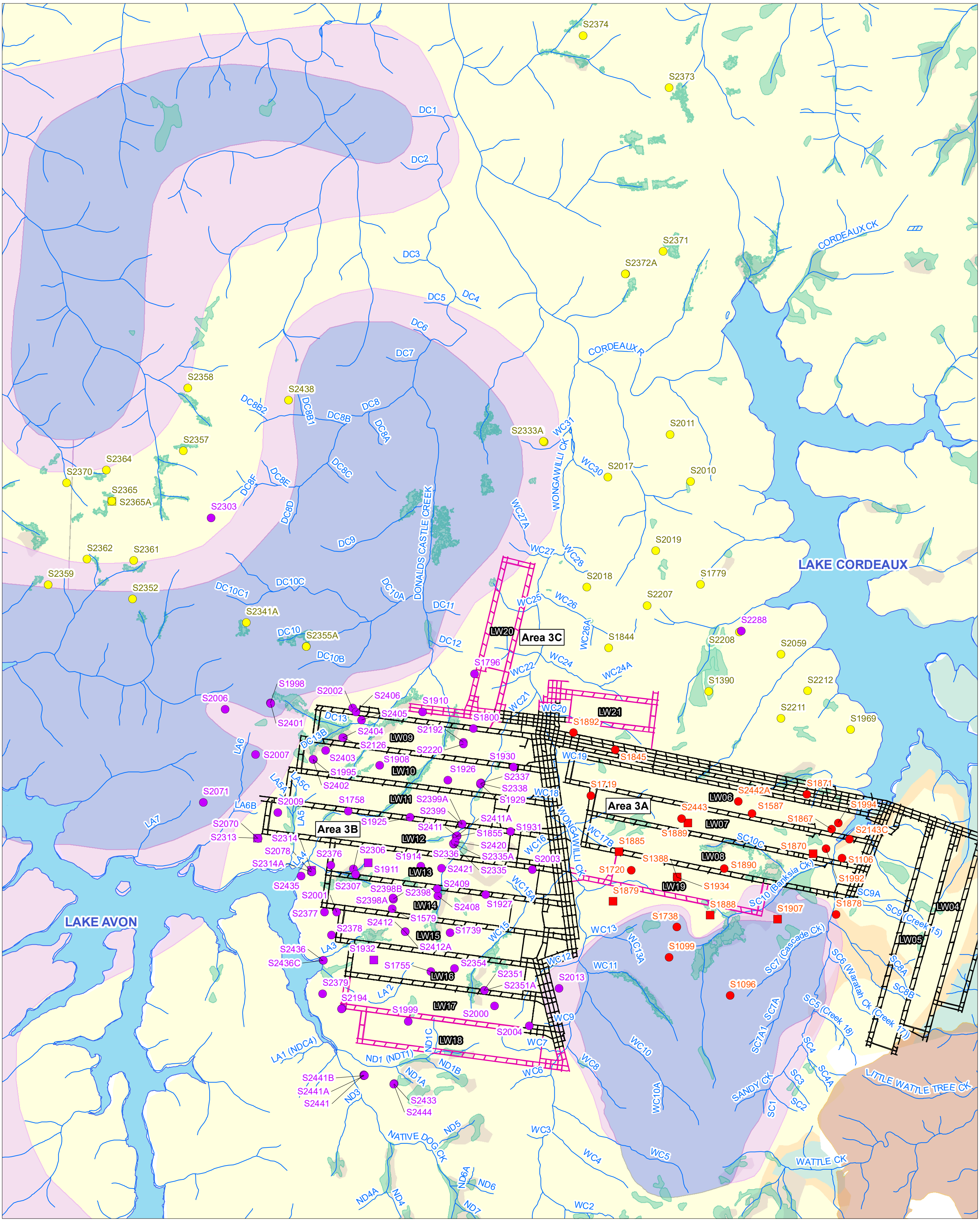
Groundwater quality is sampled at selected VWPs in Areas 3A, 3B and 3C via pumps fixed within the VWP borehole. Currently, 22 of the site VWPs are equipped for water quality sampling at multiple vertical intervals. Each borehole has up to three pumps, with the Hawkesbury Sandstone, Bulgo Sandstone or Scarborough Sandstone being the key lithologies monitored at Areas 3A, 3B and 3C. Details of these bores and the number of pumps per geologic unit are outlined in **Table 2-2**, and also presented on **Figure 1**.

Groundwater quality measurements are taken from the in-built pumps. Groundwater is currently assessed for salinity (as EC), pH, major ion compositions (e.g. HCO_3, Na), minor ion composition, and metals (e.g. Ba, Sr, Li) as well as a range of isotopes (e.g. tritium). Sampling of water quality has been undertaken at the mine since 2004.

Table 2-2 Groundwater Monitoring Network – water quality

Area	S-Index	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Pumps	No. Pumps by Geology		
								HBSS	BGSS	SBSS
3A	S1870	ED Dendrobium DDH 85	293593.2	6192648.2	351.5	159.5	2	2	1	
3A	S1879	ED Dendrobium DDH 92	291440.3	6192133.4	379.7	368.5	2	2	1	
3A	S1885	ED Dendrobium DDH 93	291504.4	6192667.9	420.0	420.4	2	2	1	
3A	S1888	ED Dendrobium DDH 96	292486.5	6191987.4	381.3	320.5	2	2	1	
3A	S1889	ED Dendrobium DDH 97	292244.8	6192980.4	435.4	386.3	2	2	1	
3A	S1907	ED Dendrobium DDH 103	293212.2	6191943.1	371.9	371.9	3	2	1	
3A	S1934	ED Dendrobium DDH 115	292128.0	6192398.0	427.5	114.2	2	2		
3B	S1911	EDEN106	288802.8	6192549.4	405.2	437.4	3	2	1	
3B	S1932	ED Dendrobium DDH 114	288863.3	6191505.4	396.1	400.2	2	3		
3B	S2001a	EDEN125a	288358.0	6191952.0	-	466.0	3	2	1	
3B	S2313	Avon 1	287609.0	6192815.5	415.3		3	2	1	
3B	S2314	Avon 2	288193.5	6192470.3	342.4		3	2	1	
3B	S2376A	Avon6A	288395.1	6192516.8	367.6		3	2	1	
3B	S2377A	Avon3A	288342.0	6192013.1	408.1		3			
3B	S2378A	Avon4A	288416.5	6191767.5	379.2		3	2	1	
3B	S2379A	Avon5A	288306.5	6191149.3	356.2		3	2	1	
3B	S2436A	AD8A	288313.8	6191499.7	320.3	90.0	2	1	1	
3C	S1970	EDEN118a	294014.0	6193981.0	-		3	1	1	1
3C	S2332A		290404.9	6196320.3	366.9		3	2	1	
3C	S2341B	D-A5-28B	287489.0	6195138.2	-		1	2	1	
3C	S2361A		286277.9	6195810.7	402.4	70.0	1	1		
3C	S2365A		286041.9	6196442.6	399.1	70.0	1	1		

Note: mbgl – metres below ground level
HBSS – Hawkesbury Sandstone
SBSS – Scarborough Sandstone
Coordinates are for GDA94 MGA56
BGSS – Bulgo Sandstone



DENDROBIUM LONG-TERM GROUNDWATER MONITORING PLAN

FIGURE 1

Existing Groundwater Monitoring Network

0 — 1 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:55,000

Project No.:	665.10009
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Monitoring bore area (VWP)
- 3A
- 3B
- 3C

Monitoring bore area (VWP & WQ)
- 3A
- 3B
- 3C

- Proposed mine workings
- Current/Completed mine workings
- Watercourses
- Lakes
- Upland swamp (IC/OEH)
- Cinder above seam
- Cinder in seam
- Qs/Qal – alluvium
- Qs – swamp sediments
- Qt – talus
- Rh – HBSS
- Rnz – BHCS (BACS)
- Rnbu – BUSS/CVSS

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3 Long-Term Groundwater Monitoring Program

3.1 Groundwater Levels

In order to identify bores within the existing network to be maintained as part of the long-term groundwater monitoring program, a series of criteria were set to identify bores that will provide beneficial data and insights into the behaviour over the life of the mine and post closure.

Four categories defining features of importance and areas of interest were used to select bores from the existing groundwater monitoring network that should be used as part of the long-term monitoring program. These categories are:

- longwall panel monitoring locations;
- Lake Avon shoreline monitoring locations;
- Lake Cordeaux monitoring locations; and
- locations associated with watercourses of interest (i.e. Wongawilli Creek, Donalds Castle Creek and Sandy Creek. See **Figure 1** for locations).

From these categories, a total of 48 existing bores have been identified to be retained as part of the long-term monitoring program for Dendrobium Areas 3A, 3B and 3C. Each of these bores is currently utilised to monitor groundwater level in several geologic units at various locations around the mine. Nine open standpipe bores have also been selected based on available information. Further verification of the construction and condition of the bores may be required prior to establishing the network, where issues are identified alternative locations will be proposed.

Table 3-1 provides a summary of these bores based on mine area and the monitoring groups identified above. A map of the location of each bore defined by monitoring group is provided on **Figure 2**. Several recommendations have been made for the modification of existing monitoring locations to enhance the monitoring network.

The proposed updates to the existing network include:

- The installation of sensors in the shallow geologic units (i.e. Hawkesbury Sandstone and Bald Hill Claystone) at monitoring bore S1796. This bore is adjacent to the western margin of Longwall 20 and currently has sensors in the Bulli and Wongawilli Coal Seams. The addition of shallow sensors at this location would provide a mining-affected dataset to compare to other bores that monitor groundwater levels adjacent to Donalds Castle and Wongawilli Creek (located either side of this longwall panel).
- The installation of sensors in the shallow geologic units (i.e. Hawkesbury Sandstone and Bald Hill Claystone) at monitoring bores S2013 and S2019 to monitor shallow groundwater levels adjacent to Donalds Castle Creek and Wongawilli Creek. It is also proposed that the abandoned bore S2018 be reinstated for this purpose.

Further discussion on the long-term monitoring network is included in **Section 3.1.1** to **Section 3.1.4**.

Table 3-1 Bores to be included in Long-term Monitoring Program

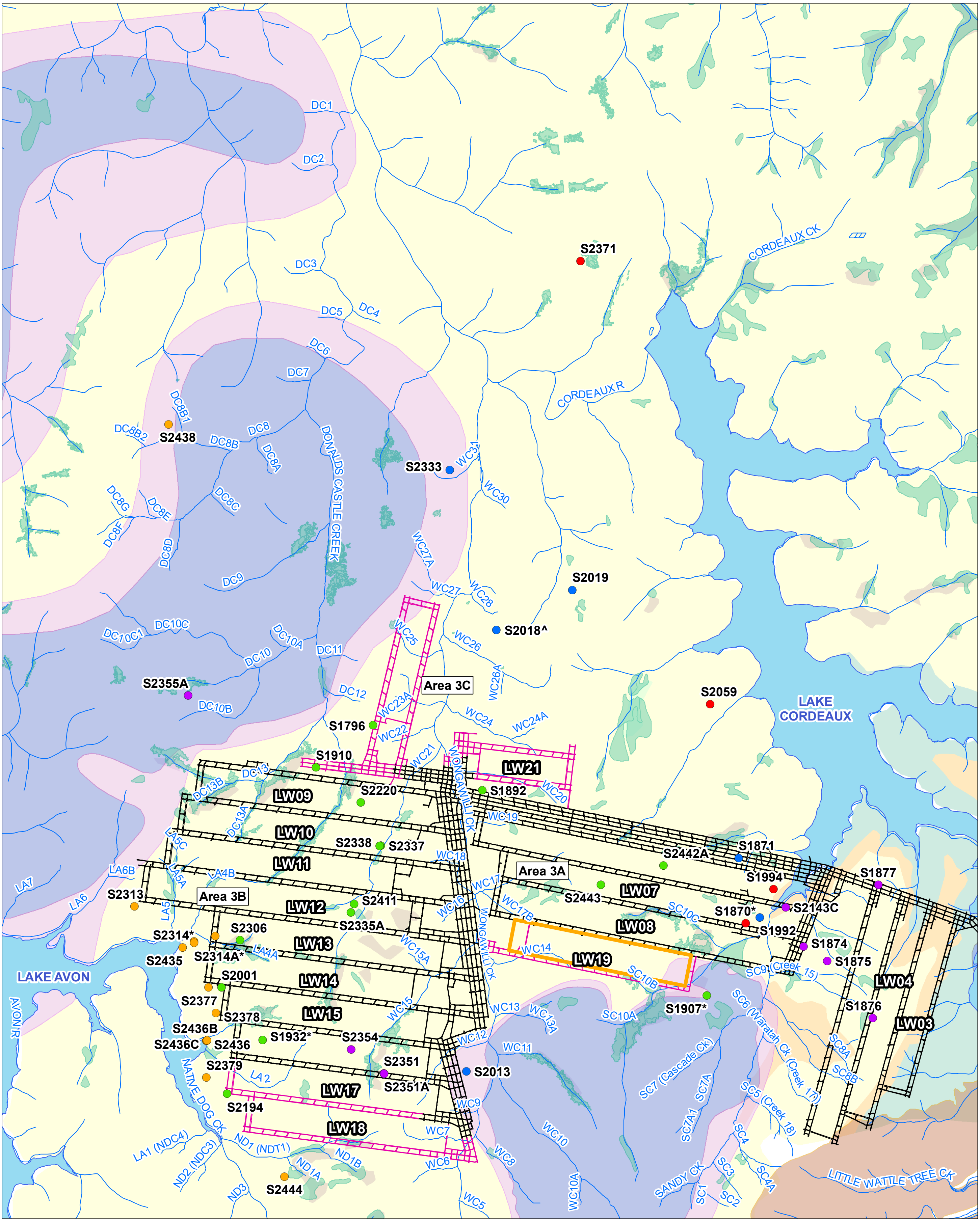
Monitoring Group	Area	S-Index	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
Longwall	3A	S1892	ED Dendrobium DDH 99	291014.1	6193952.0	356.1	389.2	8	2		2	2			1	1	
	3A	S1907	ED Dendrobium DDH 103	293212.2	6191943.1	371.9	371.9	8	2*		2*	2			1	1	
	3A	S2442A	SC1-A	292788.5	6193213.2	407.6	-	6	3	1	2						
	3A	S2443	SC4	292176.0	6193027.4	426.7	227.0	6	3	1	2						
	3B	S1910	EDEN105	289387.4	6194176.3	377.2	-	8	2		2	2			1	1	
	3B	S1932	ED Dendrobium DDH 114	288863.3	6191505.4	396.1	400.2	12	4*		3	3		1		1	
	3B	S2001	EDEN125	288462.6	6192020.0	413.9	431.2	10	3		3	2			1	1	
	3B	S2194	S2194	288514.9	6190978.8	371.1	-	11	3		3	2			1	1	1
	3B	S2220	S2220 (AQ5)	289827.2	6193830.7	388.1	287.5	6	3		3						
	3B	S2306	Swamp Bore 3 (adjacent)	288643.3	6192483.7	395.5	70.0	4	4								
	3B	S2335A	WC21Project Hole1Site 2	289727.0	6192755.0	370.1	-	6	6								
	3B	S2337	WC21Project Hole1Site 5	290021.0	6193411.9	336.1	51.0	4	4								
	3B	S2338	WC21Hole2,Site5	290012.2	6193406.7	336.1	51.0	3	3								
	3B	S2411	LW12-2	289761.1	6192837.7	364.0	285.0	7	4	1	2						
	3B	S1796	Dend. DDH 69	289946.6	6194587.4	398.6	471.3	2	P	P					1	1	
	3B	S2351#	-	290049.6	6191178.2		15.0	OSP	1								
	3B	S2351A#	-	290054.3	6191175.2	-	30.1	OSP	1								
	3B	S2354#	-	289730.9	6191413.7	-	50.0	OSP	1								
Avon	3B	S2313	Avon 1	287609.0	6192815.5	415.3	-	3	2		1						
	3B	S2314	Avon 2	288193.5	6192470.3	342.4	-	1	1								
	3B	S2314A	Avon 2 Redrill	288194.6	6192455.6	342.6	-	3	2		1						
	3B	S2376	Avon6	288400.4	6192527.0	367.8	-	3	2		1						
	3B	S2377	Avon3	288333.4	6192020.4	408.2	-	3	2		1						
	3B	S2378	Avon4	288407.4	6191770.9	379.3	-	3	2		1						
	3B	S2379	Avon5	288312.9	6191140.5	356.6	-	3	2		1						
	3B	S2435	AD7	288080.8	6192411.6	328.2	108.2	3	2		1						
	3B	S2436	AD8	288313.8	6191499.7	320.3	108.2	3	1	1	1						
	3B	S2436B	AD8B	288313.8	6191499.7	320.5	39.3	1	1								
	3B	S2436C	AD8C (angle hole)	288319.6	6191500.8	320.7	70.0	1	1								
	3B	S2444	Elouera2-2	289077.9	6190167.7	376.3	324.8	1	1								
	3C	S2438	-	287944.9	6197535.1	399.3	444.3	9	3		3	2			1		
Cordeaux	3A	S1870	ED Dendrobium DDH 85	293593.2	6192648.2	351.5	159.5	12	3		3	2	1	1	1	1	
	3A	S1994	EDEN120	293865.2	6192982.4	345.5	258.0	8	1		3	3			1		
	3C	S2059	EDEN148	293245.7	6194795.1	380.8	401.3	12	3	1	3	3			1	1	

Monitoring Group	Area	S-Index	Bore Name	Easting	Northing	Collar RL (mAHD)	Total depth (mbgl)	No. Sensors	No. Piezometers by Geology								
									HBSS	BHCS/BACS	BGSS	SBSS	WBCS	CCSS	BUSM	WWSM	TGSM
	3C	S2371	A6_S116_DBH	291977.5	6199135.2	351.2	70.0	4	4								
	3A	S2143C[#]	-	293984.0	6192803.4	-	12.5	OSP	1								
	3A	S1874[#]	EDEN87b	294158.5	6192420.5	-	26.0	OSP	1								
	3A	S1875[#]	EDEN88b	294392.2	6192279.2	-	28.0	OSP	1								
	2	S1876[#]	EDEN89b	294836.8	6191719.2	-	41.5	OSP	1								
	2	S1877[#]	EDEN90b	294891.3	6193024.3	-	11.0	OSP	1								
Watercourses	3A	S1871	ED Dendrobium DDH 86	293525.0	6193287.1	375.6	-	12	3		3	2	1	1	1	1	
	3A	S1992	EDEN119	293732.1	6192706.8	339.1	250.0	8	1		4	2			1		
	3C	S2333	D-A3C-14-12	290697.1	6197087.4	310.9	-	10	3		3	2			1	1	
	3B	S2013	EDEN134	290857.7	6191198.2	399.7	-	4	P	P					1	1	
	3C	S2018^	EDEN137	291154.4	6195520.3	369.0	-	4	P	P					1	1	
	3B	S2019	EDEN138	291897.6	6195913.7	361.8	-	4	P	P					1	1	
	3B	S2355	A5_S85_DBH	288136.2	6194877.8	396.6	70.6	4	4								
	3B	S2355A[#]	-	288135.3	6194879.2	-	18.0	OSP	1								

OSP – Open Standpipe (bore constructed as PVC monitoring bore with one screened interval to enable manual groundwater monitoring)

\# - bore condition and construction to be verified

^ - currently abandoned, proposed to be re-established for monitoring purposes.



0 — 1 km

Projection: GDA 1994 MGA Zone 56
Scale: 1:50,000

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Monitoring Group

- Lake Avon monitoring locations
- Lake Cordeaux monitoring locations
- Longwall panel monitoring locations
- Watercourse monitoring locations
- Open standpipe locations
- LW19 longwall panel
- Proposed mine workings
- Current/Completed mine workings
- Watercourses
- Lakes
- Upland swamp (IC/OEH)
- Cinder above seam
- Cinder in seam
- Qs/Qal – alluvium
- Qs – swamp sediments
- Qt – talus
- Rh – HBSS
- Rnz – BHCS (BACS)
- Rnbu – BUSS/CVSS

DENDROBIUM LONG-TERM GROUNDWATER MONITORING PLAN

FIGURE 2

Proposed Monitoring Locations

3.1.1 Longwall Panel Monitoring Locations

As part of current monitoring, several bores have been installed above and around longwall panels to monitor changes in permeability before and after mining has occurred in the area. As described in the LW14 End of Panel Report (HGEO, 2019a), bores installed above longwall panels are often destroyed due to shearing after the longwall passes. Therefore, bores installed over the longwall panel are either discretely collecting data prior to or following mining. As part of the long-term monitoring program, the latter will be required to assess the change in groundwater levels over the mine workings to understand the response to goaf properties and subsidence with time after mining.

Based on this, 16 existing VWPs were proposed to be included in the long-term monitoring program to monitor groundwater levels in the strata above the longwall panels. If any of these bores are destroyed or removed during the course of mining, it is recommended that a new bore be redrilled to replace the lost bore once ground conditions have stabilised to allow data continuity.

Three existing OSP bores have also been included in the monitoring network. S2351 and S2351A are located adjacent to one another and monitor the Hawkesbury Sandstone at depths of 14 m and 29 m respectively. S2354 is also located in the Hawkesbury Sandstone at 42 m depth. Each of these bores overly the footprint of Longwall 16. It is recommended that manual groundwater levels be recorded for comparison to nearby VWP's (e.g. 1932) to verify sensor data.

A hydrograph of modelled groundwater levels, based on the results presented in SLR (2020), is presented for a representative location in **Figure 3**. A full set of recorded and simulated hydrographs is included in **Appendix A**.

S2443 is located above Longwall 7 (Area 3A) which was mined between 2011 and 2012. During active mining, aquifers overlying the mined coal seam experience depressurisation. Such an event can be observed at S2443 in sensors monitoring the lower Hawkesbury Sandstone aquifer (113.5 HBSS) and down to the lower Bulgo Sandstone (225 BGSS) following the start of mining in Area 3A (Longwall 6 in early 2010). As mining moves away from this location and into Area 3B (2015-2022), mining related drawdown and depressurisation is observed. Drawdown in the range of 5-10 m is typically observed in the upper Hawkesbury Sandstone aquifer, with recovery generally occurring faster (stabilisation of groundwater levels within 15 to 30 years post-mining). The lower units (Bulgo Sandstone, Scarborough Sandstone and coal seams) experience the greatest drawdown and may take a period of longer than 50 years for groundwater levels to stabilise post-mining.

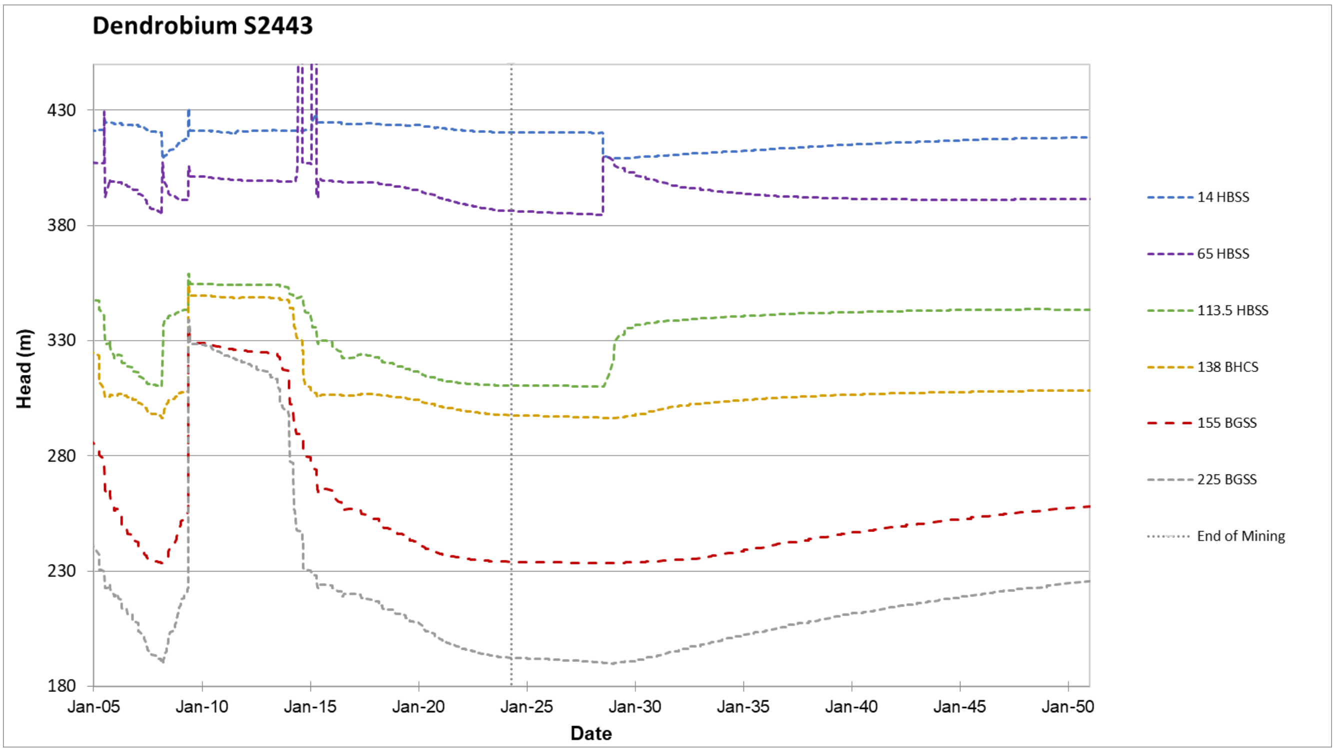


Figure 3 Modelled Groundwater Levels for Bore S2443

3.1.2 Lake Avon Shoreline Monitoring Locations

As tabulated in **Table 3-1**, 13 existing bores have been proposed to monitor groundwater levels adjacent to Lake Avon as part of the long-term monitoring program. These bores are located on the western margin of the Area 3B between the longwall panel and the eastern arm of Lake Avon that is fed by Native Dog Creek (see **Figure 2**).

Monitoring at these locations is primarily concentrated in the upper stratigraphic units (i.e. Hawkesbury Sandstone and Bald Hill Claystone) as Lake Avon is set within this geology. In addition to being used for groundwater level monitoring, these bores have recently been assessed for changes in strata permeability that have resulted from mining activity as part of a recent investigation undertaken by HGEO (2019b).

A hydrograph of modelled groundwater levels, based on the results presented in SLR (2020), is presented for a representative location in **Figure 4**.

S2314 is located approximately 140 m from the Lake Avon Shoreline and 160 m from the western end of Longwall 13. Monitoring is undertaken at three depths within the Hawkesbury Sandstone and Bulgo Sandstone aquifers, which is typical of the other Lake Avon monitoring bores. The lower stratigraphic units experience the greatest drawdown due to their proximity to the coal seam. At S2314, approximately 90 m of mining related drawdown is predicted to occur in the Bulgo Sandstone aquifer, with recovery predicted to begin approximately 65 years after mining is completed. Mining related impacts are less for the Hawkesbury Sandstone with the lower sensor predicted to experience a water level reduction of ~25 m, and the upper sensor ~5 m. Groundwater levels are predicted to stabilise within 5 years and 15 years of the completion of mining, in the upper and lower Hawkesbury Sandstone respectively.

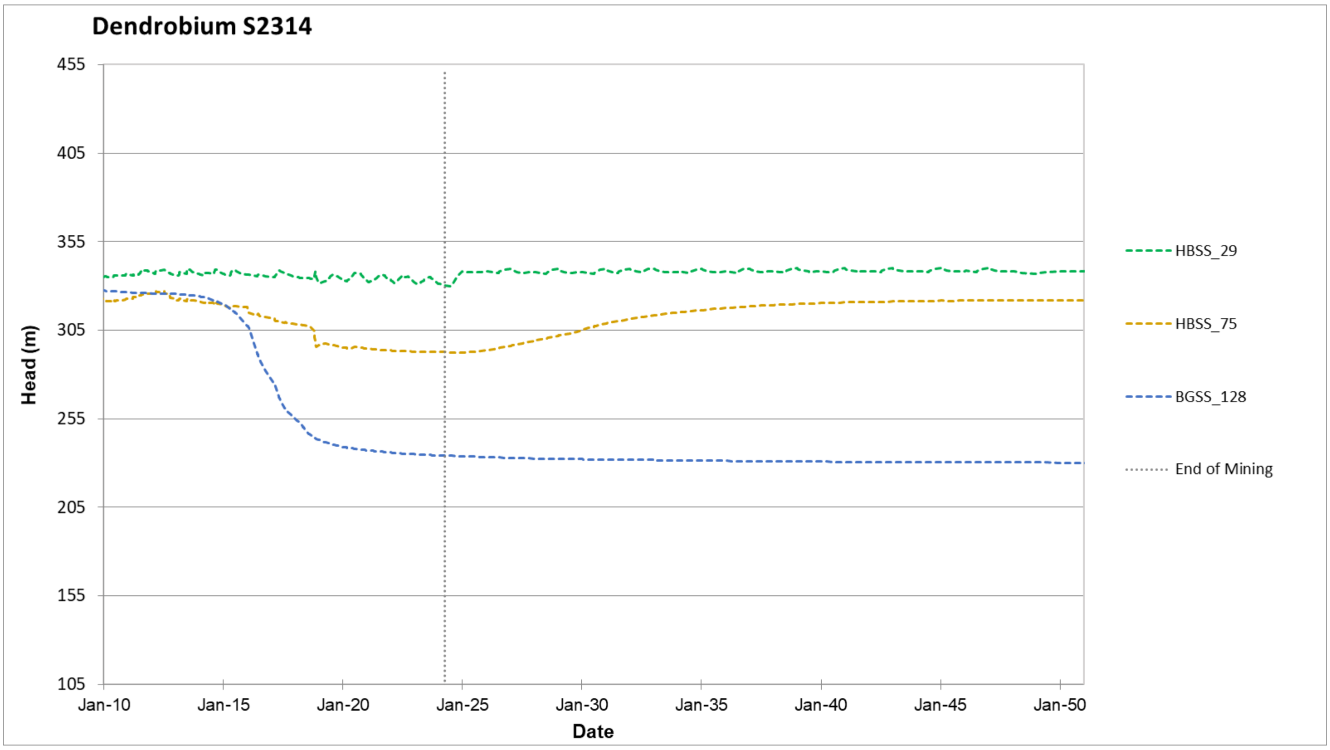


Figure 4 Modelled Groundwater Levels for Bore S2314

3.1.3 Lake Cordeaux Monitoring Locations

Three bores from the existing monitoring network have been proposed to be included as part of the long-term monitoring program (see **Figure 2** for locations) to monitor groundwater levels at Lake Cordeaux. S1994 and S1870 overlie Longwalls 6 and 7 (Area 3A) and are adjacent to Sandy Creek which flows into Lake Cordeaux. S1870 also has groundwater quality sampling capabilities. S2059 is located approximately 1.3 km north of Area 3A and approximately 345 m from the nearest point of Lake Cordeaux. S2371 is located to the north a further 4.5 km from bore S2059 and is approximately 900 m Lake Cordeaux. This location has been included as a far-field reference point for comparison against the monitoring bores positioned closer to the mine.

As with the Lake Avon bores, these bores have sensors primarily located in the upper stratigraphic units (i.e. Hawkesbury Sandstone and Bald Hill Claystone) in order to monitor any mining related impacts that may occur within these aquifers.

The following five existing OSP bores have also been included in the monitoring network, S2143C, S1874, S1875, S1876, S1877. Monitoring at these locations has not occurred since approximately 2012-2013, however, it is recommended that they be reinstated in order to monitor groundwater level recovery of the shallow aquifer adjacent to Lake Cordeaux. This includes review of the condition of the bores to ensure they are suitable to collect representative data. These bores are positioned within the Hawkesbury Sandstone at depths between 11 m and 42 m. It is recommended that manual groundwater level readings be taken from these bores and the data collected be used to verify water levels collected at shallow sensors in the adjacent VWPs S1870, S1992 and S1994.

A hydrograph of modelled groundwater levels, based on the results presented in SLR (2020), is presented for a representative location in **Figure 5**.

S1870 is located over the footprint of Longwall 7 (Area 3A) and adjacent to Sandy Creek and Lake Cordeaux. As with the hydrographs presented in **Sections 3.1.1** and **3.1.2**, the greatest mining related effects take place in the lower aquifers, with the degree of drawdown increasing with depth from the surface and proximity to the mined coal seam. Drawdown of 5-10 m is predicted to occur in the shallow Hawkesbury Sandstone aquifers with stabilisation of groundwater levels expected to occur within 5 years after the completion of mining. Drawdown of the Bulgo Sandstone aquifer is predicted to be in the range of 50-70 m, with recovery commencing around 5 years after the completion of mining. Groundwater levels are predicted to stabilise around 10 m lower than pre-mining groundwater levels approximately 100 to 150 years after the completion of mining.

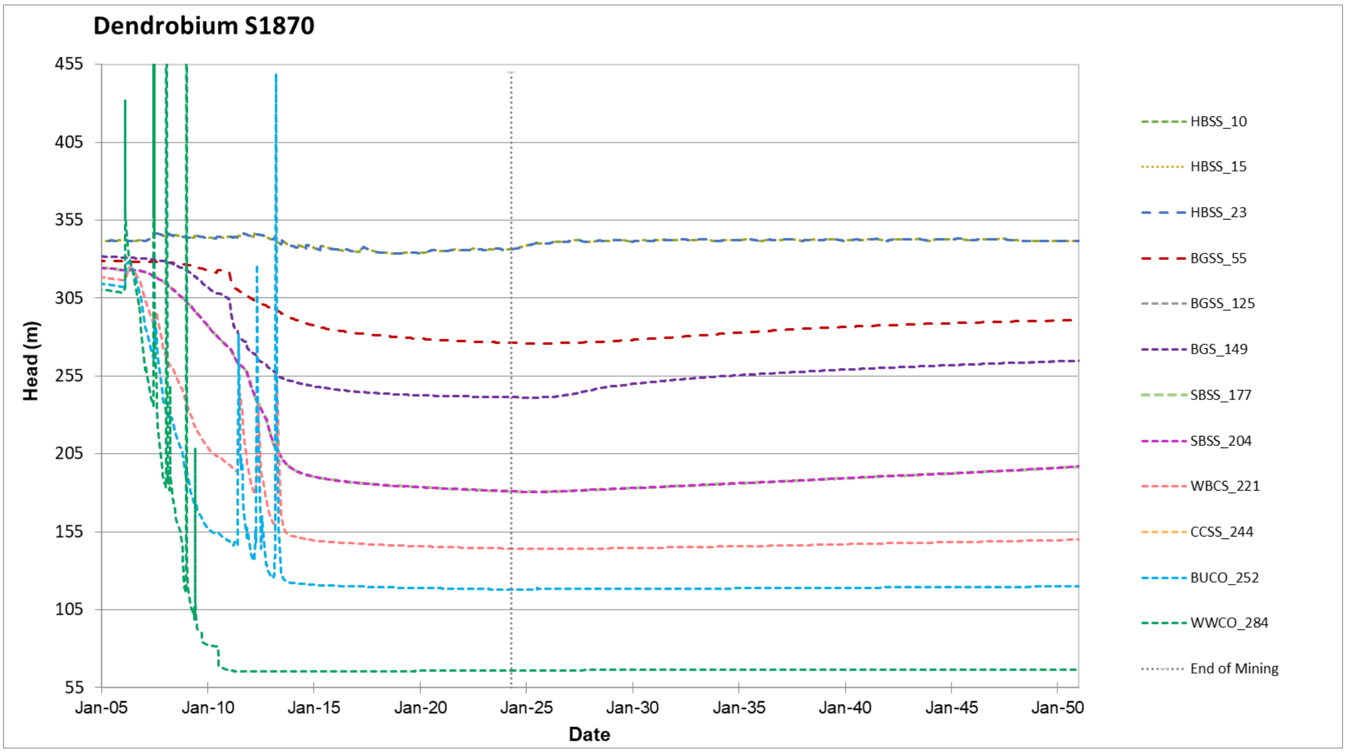


Figure 5 Modelled Groundwater Levels for Bore S1870

3.1.4 Monitoring Locations Associated with Watercourses

Seven bores from the existing monitoring network have been proposed to be included as part of the long-term monitoring program (see **Figure 2** for locations) to monitor groundwater levels along several watercourses associated with the mine. The watercourses of greatest interest are Donalds Castle Creek, Wongawilli Creek and Sandy Creek. Bores S1871 and S1992 are located adjacent to Sandy Creek and overlie the roadways and longwall panels (6 and 7) in Area 3A. The data provided by these bores will also support the data collected for S1870 and S1994 as part of the Lake Cordeaux Monitoring Group. Bore S2333/2333A is positioned to the north between Donalds Castle Creek and Wongawilli Creek at approximate distances of 1 km and 300 m respectively. S2355 is positioned within two tributaries, DC10 and DC10B, which flow into Donalds Castle Creek.

Bores S2013, S2018, and S2019 have been recommended to monitor groundwater levels near Wongawilli Creek. To do this, additional sensors have been recommended to be installed in the shallow geologic units (i.e. Hawkesbury Sandstone and Bald Hill Claystone) at these locations.

An existing OSP bore, S2355A, has been included in the monitoring network. It is positioned within two tributaries, DC10 and DC10B, which flow into Donalds Castle Creek. S2355A monitors the Hawkesbury Sandstone at a depth of 10.5 m. This open standpipe bore is adjacent to the VWP S2355, which also has a sensor positioned at 10.5 m depth. It is recommended that manual groundwater level measurements be taken from the OSP to verify VWP sensor readings.

A hydrograph of modelled groundwater levels, based on the results presented in SLR (2020), is presented for a representative location in **Figure 6**.

S2333 is located approximately 1.3 km from the northern end of Longwall 20, and approximately 300 m from Wongawilli Creek. At this location, mining related drawdown is not predicted to occur in the Hawkesbury Sandstone aquifer. Groundwater levels from the Bulgo Sandstone down to the Wongawilli Coal Seam are predicted to experience depressurisation in response to mining activities. The recovery of groundwater levels to pre-mining conditions is predicted to take more than 150 years to occur for these aquifers.

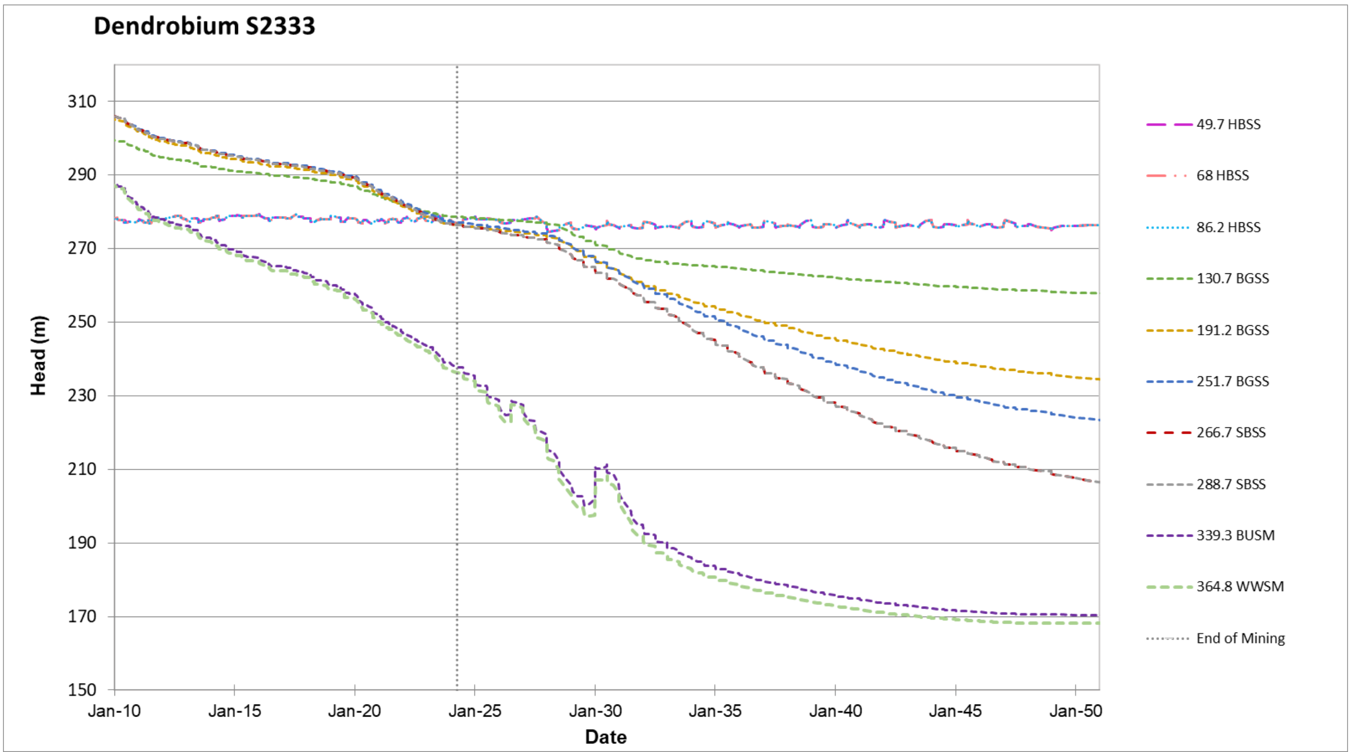


Figure 6 Modelled Groundwater Levels for Bore S2333

3.2 Groundwater Level Monitoring

3.2.1 Groundwater Levels

Consistent with the current monitoring program, groundwater level data should continue to be recorded at the VWPs on a daily basis. During active mining, data should be downloaded by field staff on a quarterly basis and stored on a central database. For the open standpipes, it is recommended that they be equipped with timeseries groundwater level loggers to obtain to assist with comparison to VWPs and for capturing seasonal responses. Post-closure groundwater level data should continue to be measured on a daily basis and downloaded on quarterly basis for a period of six years post-closure. After this time the monitoring frequency should be reviewed.

For OSP monitoring locations, groundwater levels should be manually dipped on a quarterly basis for comparison to trends recorded at nearby VWPs. This will allow for the identification of any potential deviations in measurements at these instruments. Dataloggers are also recommended to be installed at four locations (S1876, S2351A, S2354, and S2355A) to allow timeseries water level data to be collected at these locations.

3.3 Data Management and Reporting

During active mining, groundwater level data should be uploaded to the central database on a quarterly basis and QA/QC procedures put in place to ensure the accuracy of data entries. For the initial six years post closure data should be downloaded on a quarterly basis. Groundwater level data should be reviewed by a suitably qualified person on an annual basis, and analysis of the data assessment of potential for impacts reported in an annual review. After six years post closure data management and reporting requirements should be reviewed.

Groundwater trends should be compared to predicted groundwater trends based on current numerical groundwater model predictions. An assessment of observed groundwater levels against modelled predictions should be carried out during annual reporting by a suitably qualified person. This assessment should determine whether the observed data is consistent with observed and predicted trends and make recommendations for further investigations if a significant discrepancy is identified.

3.4 Future Modelling

It is recommended that the validity of model predictions be re-assessed regularly to ensure that estimates reflect observed environmental conditions and are capable of providing reliable predictions to allow for planning. This assessment should include, but not be limited to:

- Comparison of modelled and observed groundwater levels for the bores proposed to be monitored as part of the long-term monitoring program.
- Comparison of modelled and observed mine inflows.
- Comparison of modelled and observed vertical pressure head, particularly for longwall panel monitoring locations identified in **Section 3.1.1**.

As per **Section 3.2.1**, observed groundwater level trends should be compared to predicted levels from the current numerical groundwater model on an annual basis during active operations. This will enable early identification of any deviations in predictions and initiate review into the reasons for differences. In addition, in line with development consent conditions, a three-yearly independent review of the numerical groundwater model should be conducted.

4 Closing

SLR was engaged to review available information on the existing site groundwater monitoring network in consideration of predicted changes in groundwater conditions over the life of the mine. Based on the available information, a selection of key monitoring locations have been identified to be used in the long-term groundwater monitoring program for Areas 3A, 3B and 3C (LW20 – 21). The proposed network utilises existing monitoring points and includes nine open standpipe monitoring bores to assist in verifying VWP sensor trends.

Groundwater levels should continue to be recorded on a daily basis and downloaded quarterly during mining and post mining. Groundwater level trends should be compared to predicted and observed trends and reviewed and reported annually by a suitably qualified person. In addition to three-yearly independent reviews of the groundwater model, these assessments will enable regular review of the performance of the numerical groundwater model to replicate observed response to mining and recovery.

5 References

HGEO, 2019a. *Dendrobium Mine End of Panel Groundwater Assessment for Longwall 14 (Area 3B).* Report D19326, June 2019.

HGEO, 2019b. *Estimates of seepage from Lake Avon following redrilling of holes at AD3, AD4 and AD8.* Report D19337, September 2019.

IEPMC, 2019a. *Part 1 - Review of specific mining activities at the Metropolitan and Dendrobium coal mines*. https://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0004/281731/IEPMC-Part-1-Report.pdf

IEPMC, 2019b. *Part 2 - Coal mining impacts in the Special Areas of the Greater Sydney Water Catchment*. https://www.chiefscientist.nsw.gov.au/__data/assets/pdf_file/0005/281732/IEPMC-Part-2-Report.pdf

SLR, 2020. *Dendrobium Mine Longwall 19 Groundwater Assessment*. Prepared for South32, report 665.10009.R02, v2.0, January 2020.

APPENDIX A

Groundwater Level Hydrographs – Long-term monitoring locations

Longwall Panel Monitoring Locations

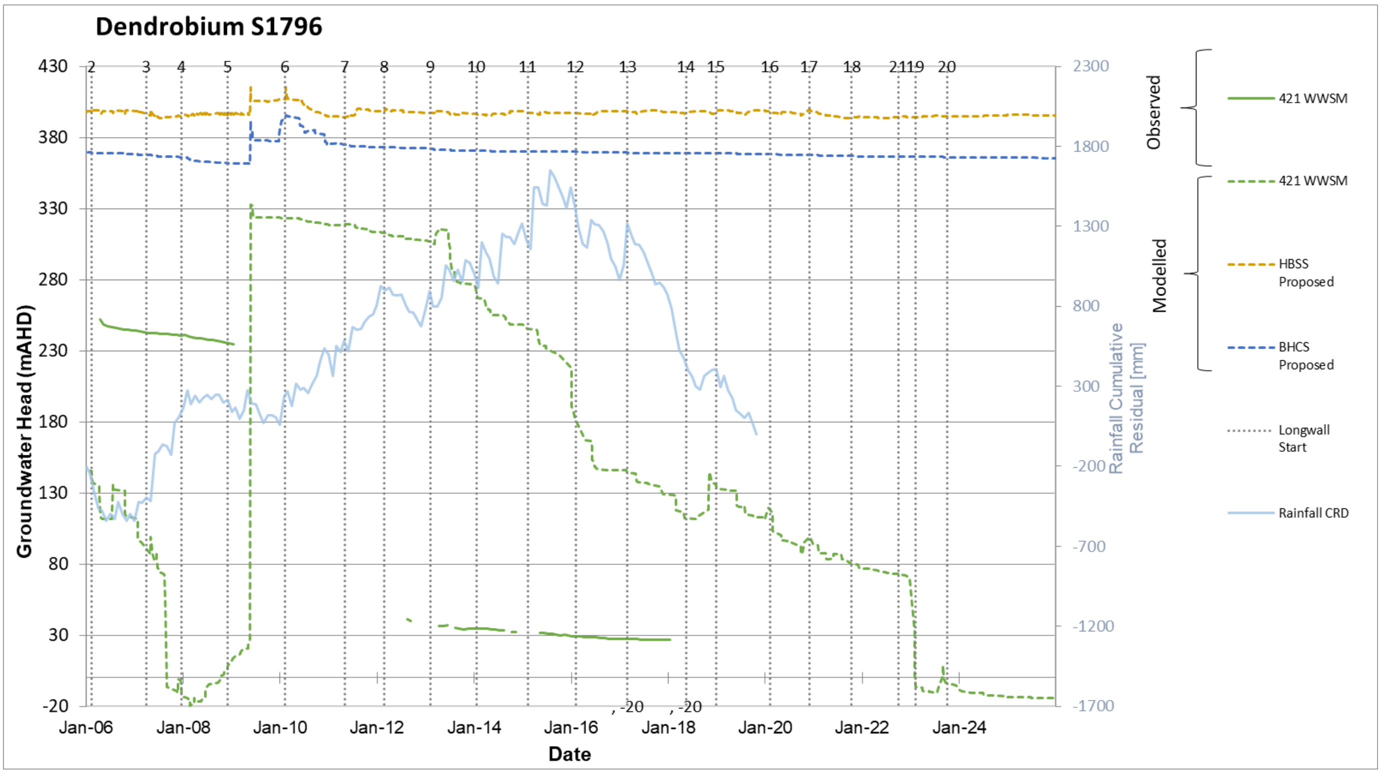


Figure A-1 Modelled and Observed Groundwater levels – S1796

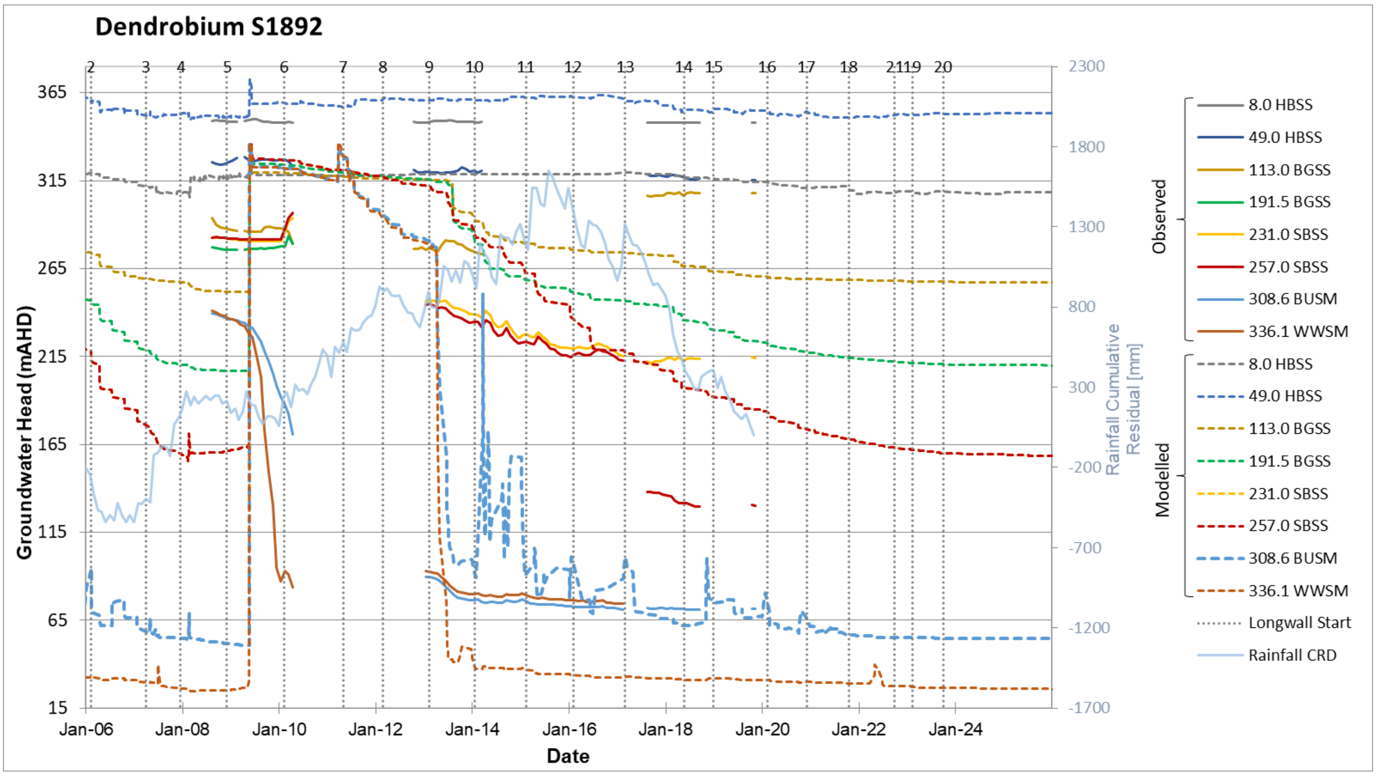


Figure A-2 Modelled and Observed Groundwater levels – S1892

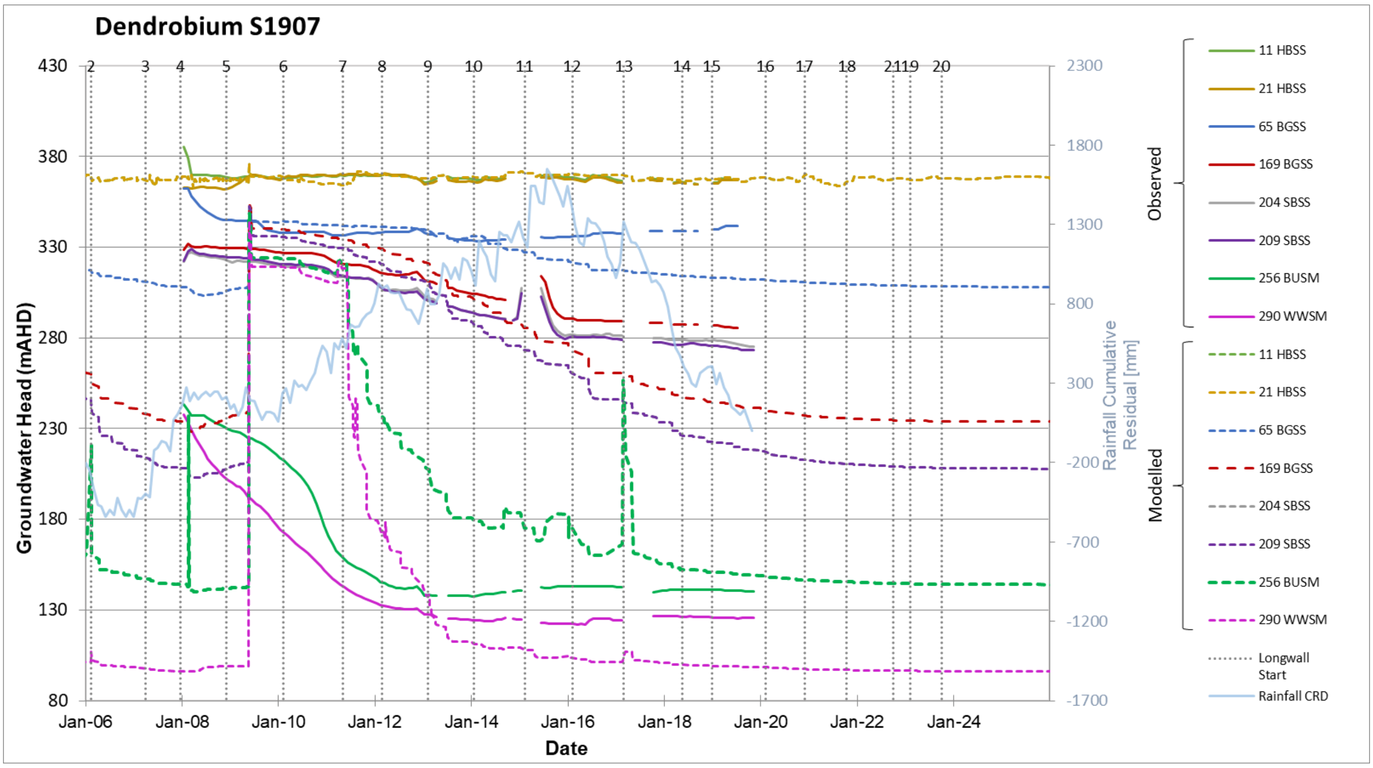


Figure A-3 Modelled and Observed Groundwater levels – S1907

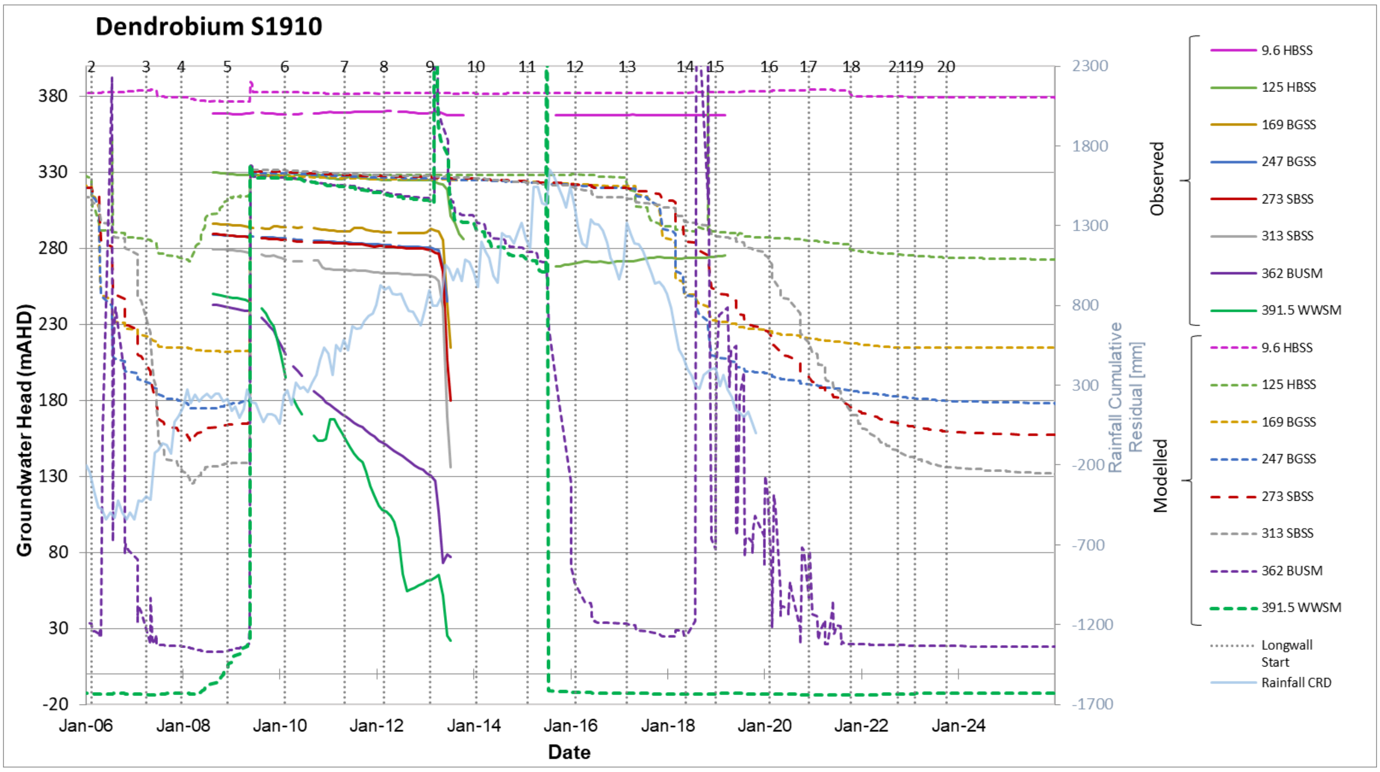


Figure A-4 Modelled and Observed Groundwater levels – S1910

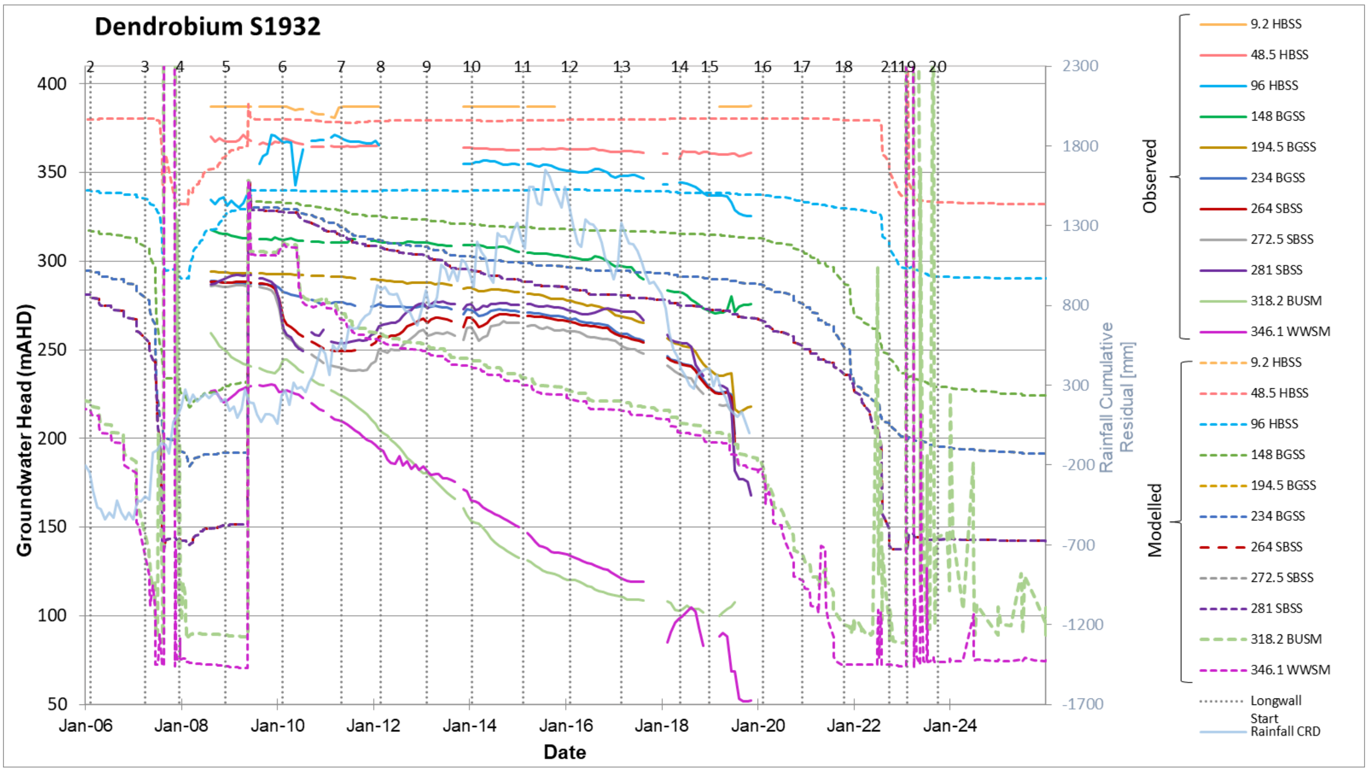


Figure A-5 Modelled and Observed Groundwater levels – S1932

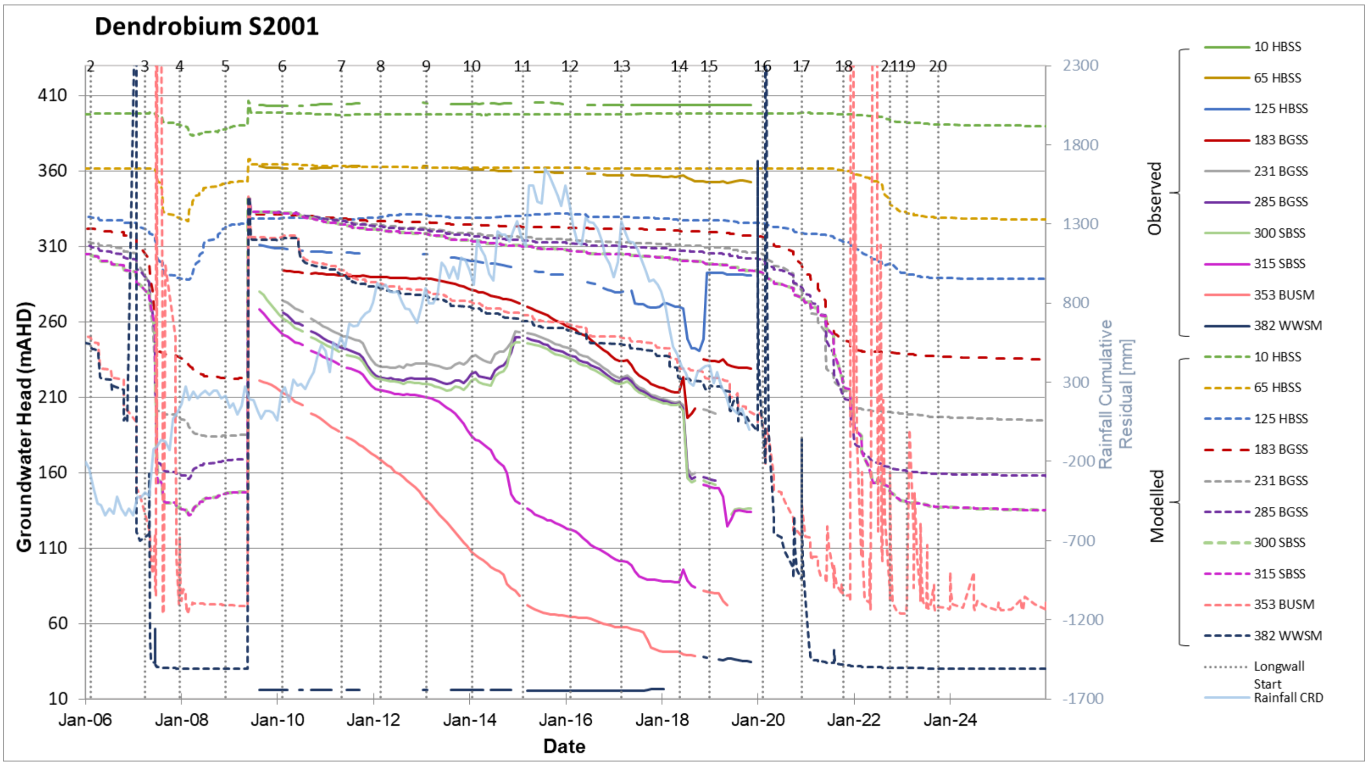


Figure A-6 Modelled and Observed Groundwater levels – S2001

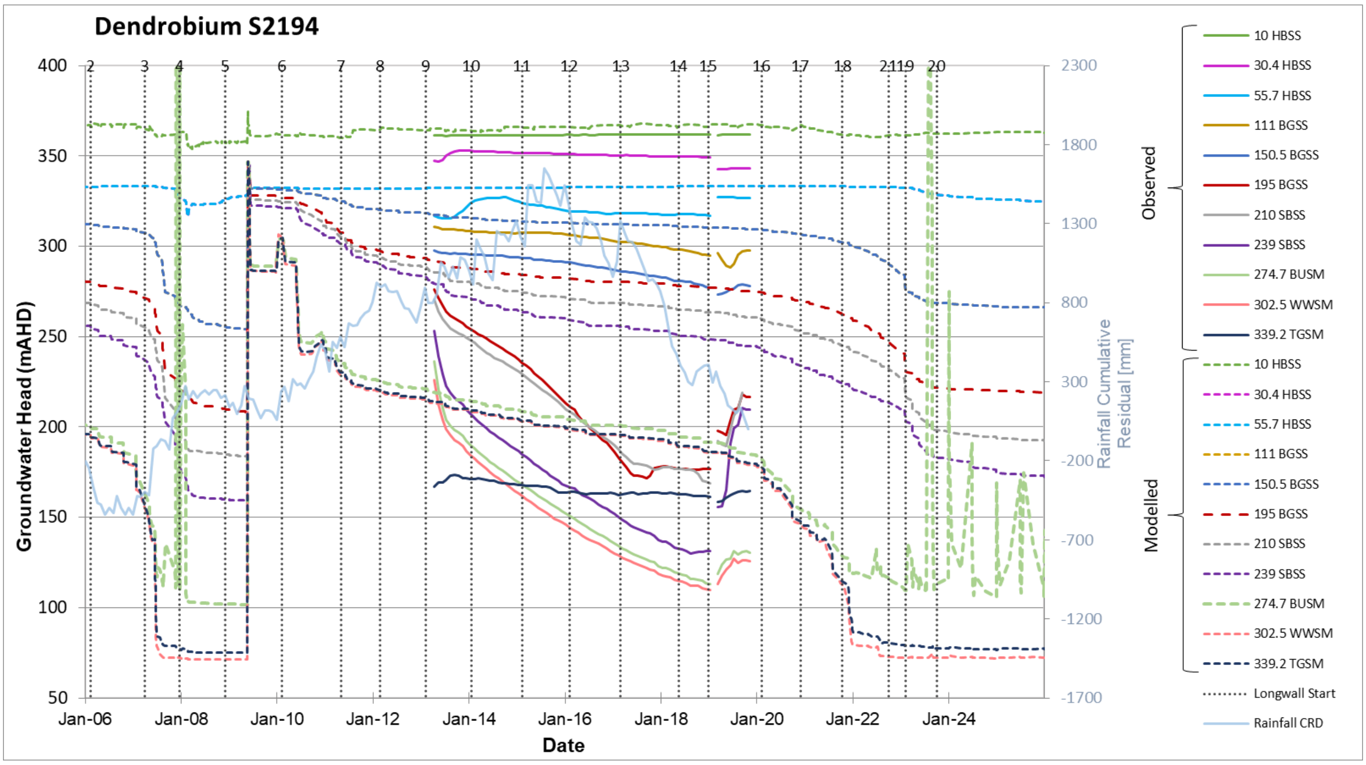


Figure A-7 Modelled and Observed Groundwater levels – S2194

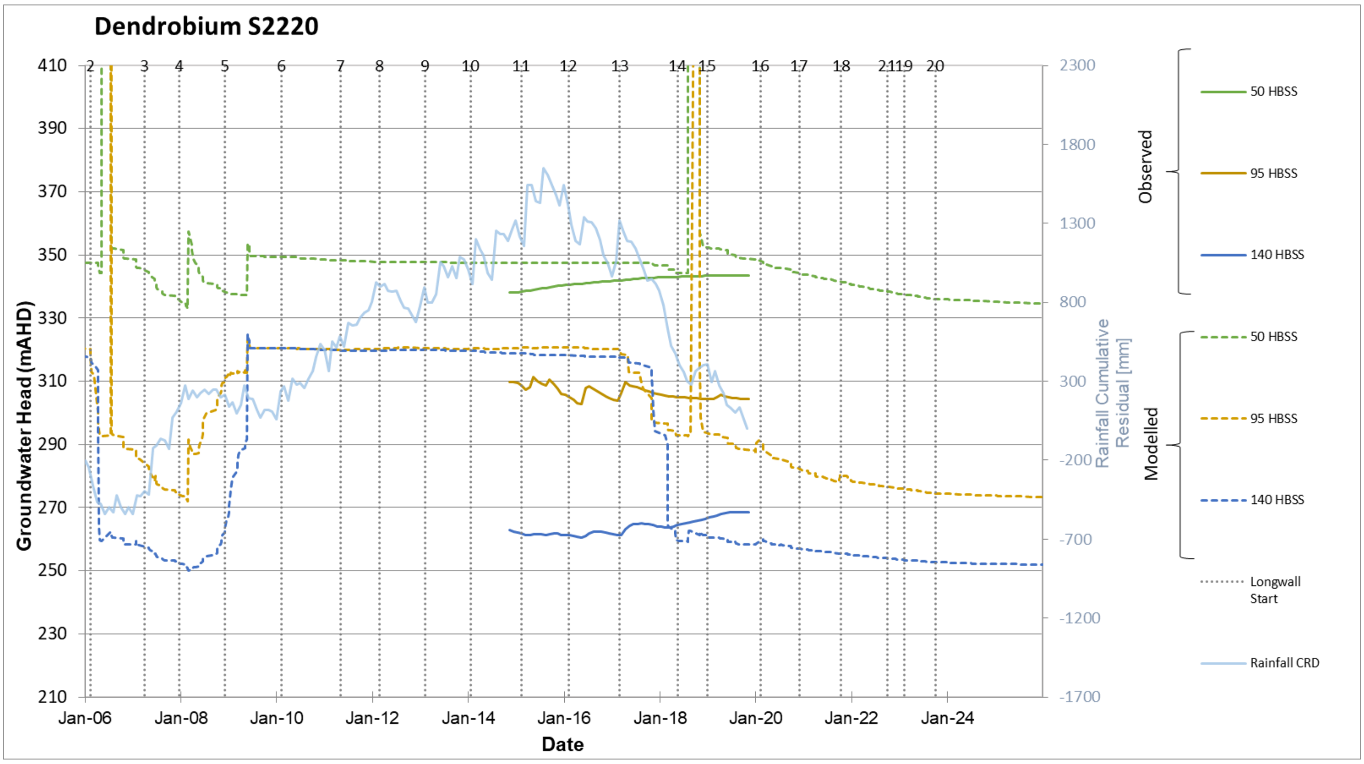


Figure A-8 Modelled and Observed Groundwater levels – S2220

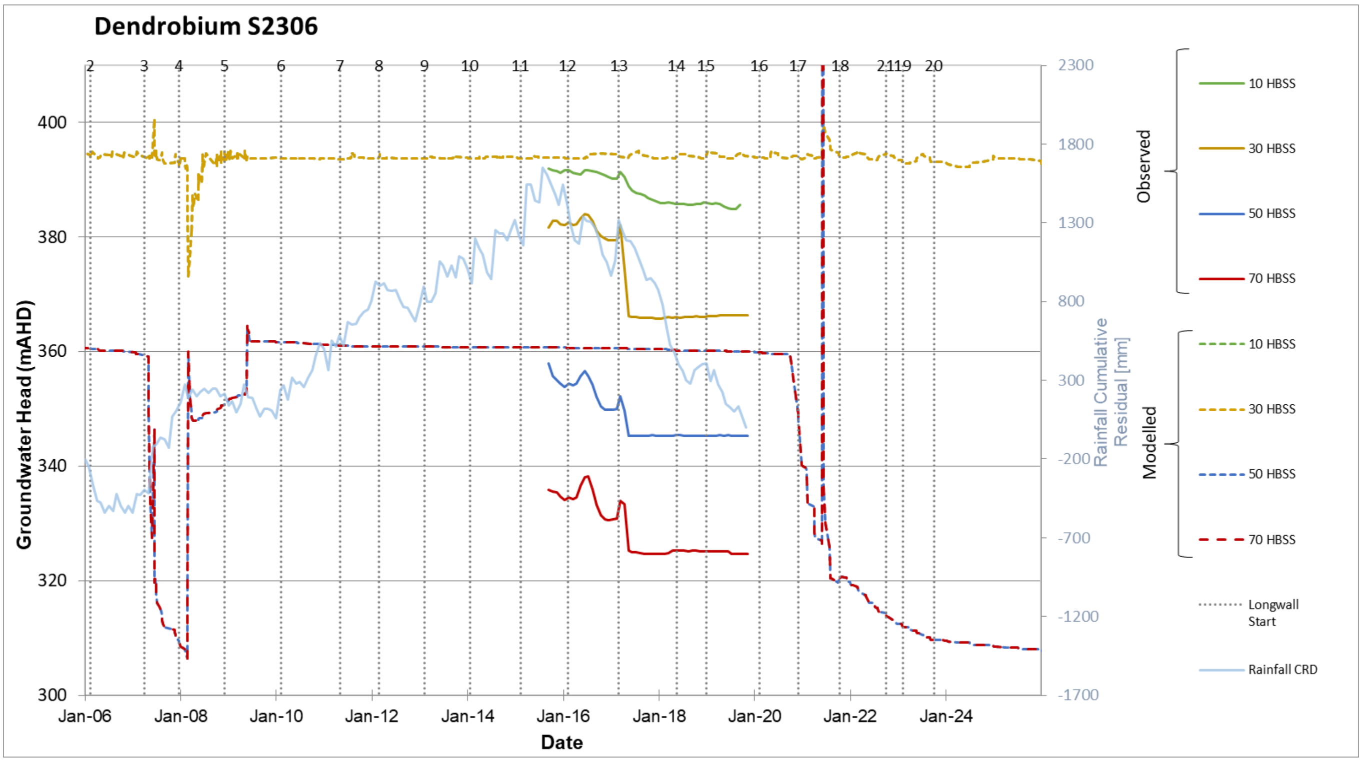


Figure A-9 Modelled and Observed Groundwater levels – S2306

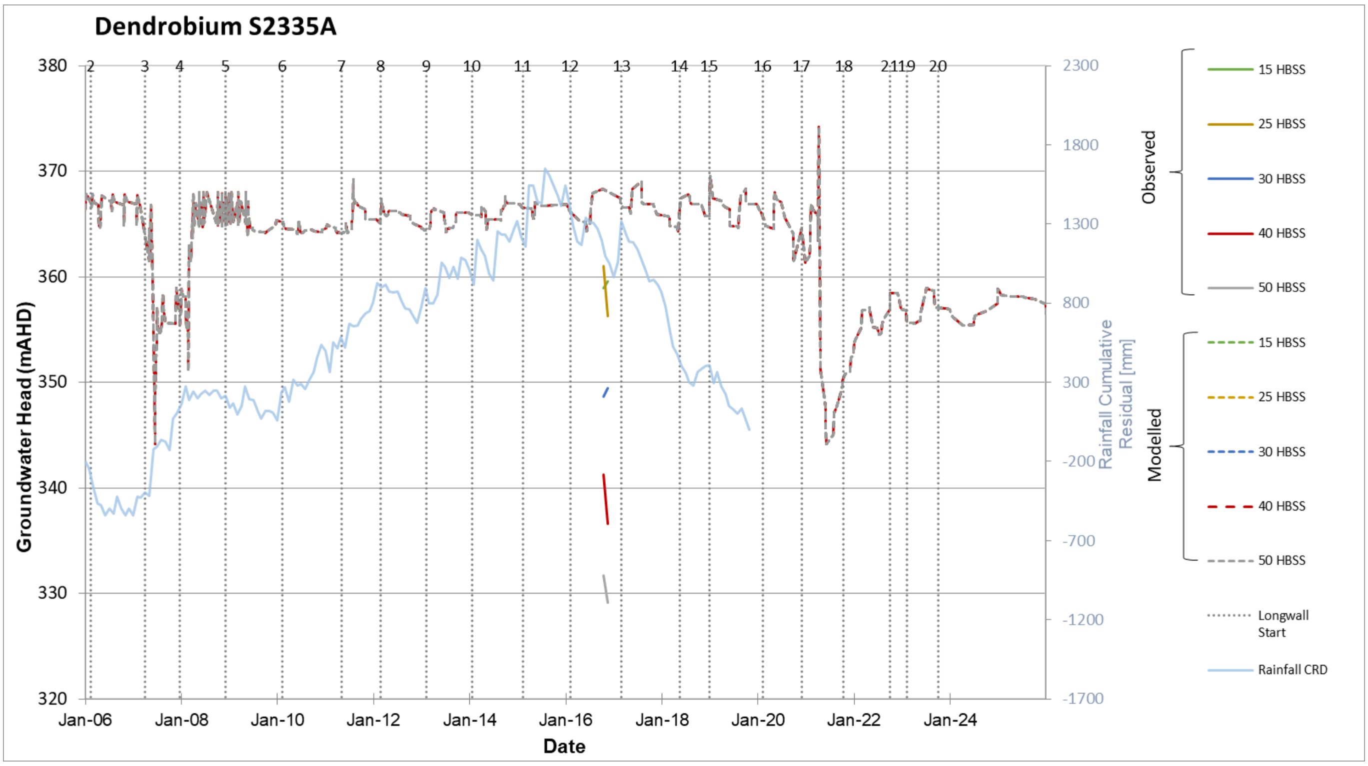


Figure A-10 Modelled and Observed Groundwater levels – S2335A

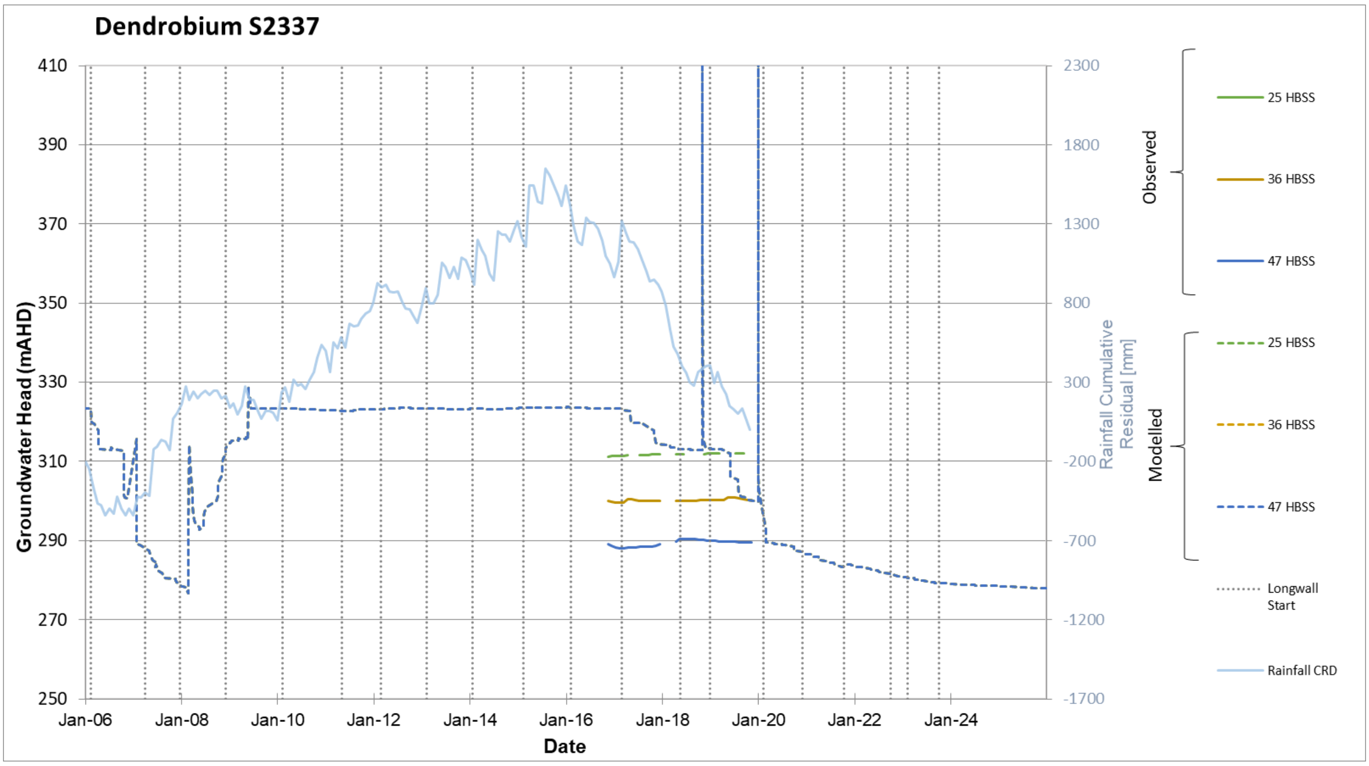


Figure A-11 Modelled and Observed Groundwater levels – S2337

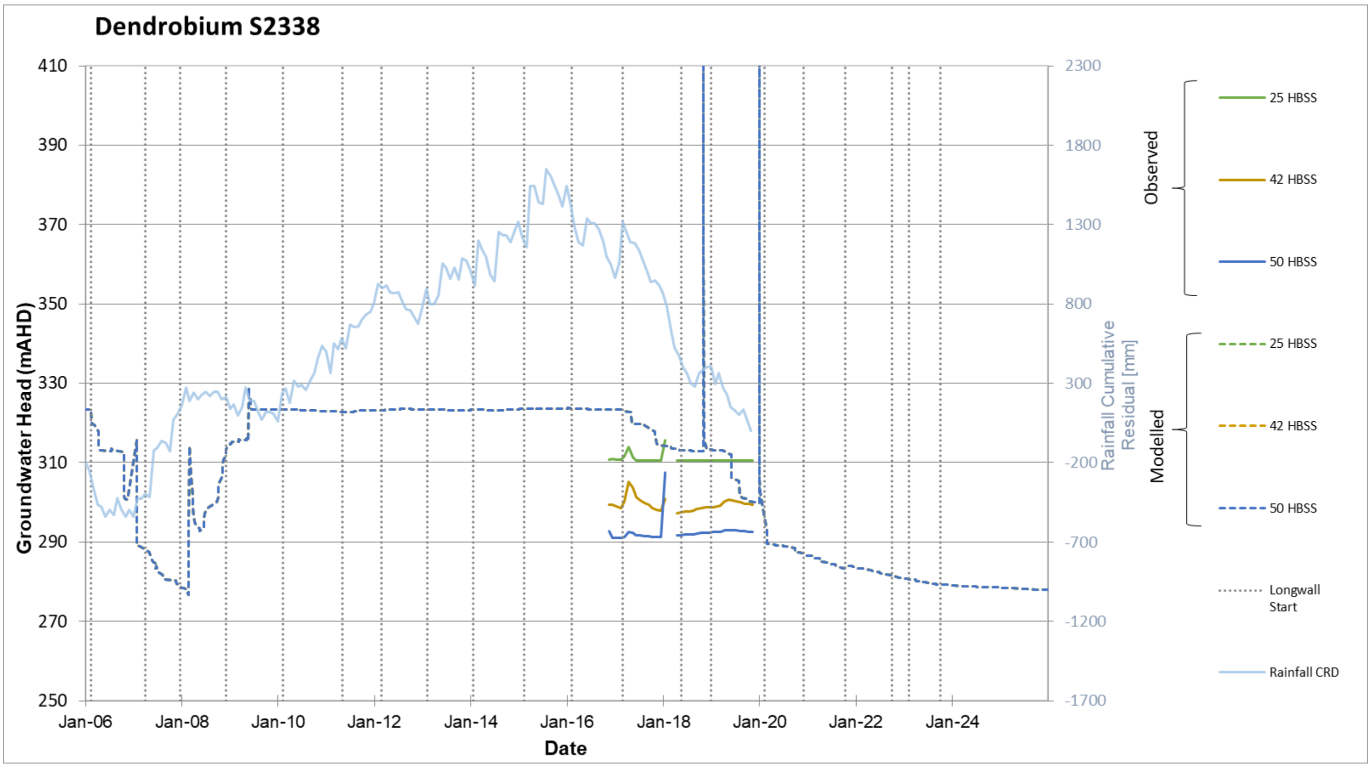


Figure A-12 Modelled and Observed Groundwater levels – S2338

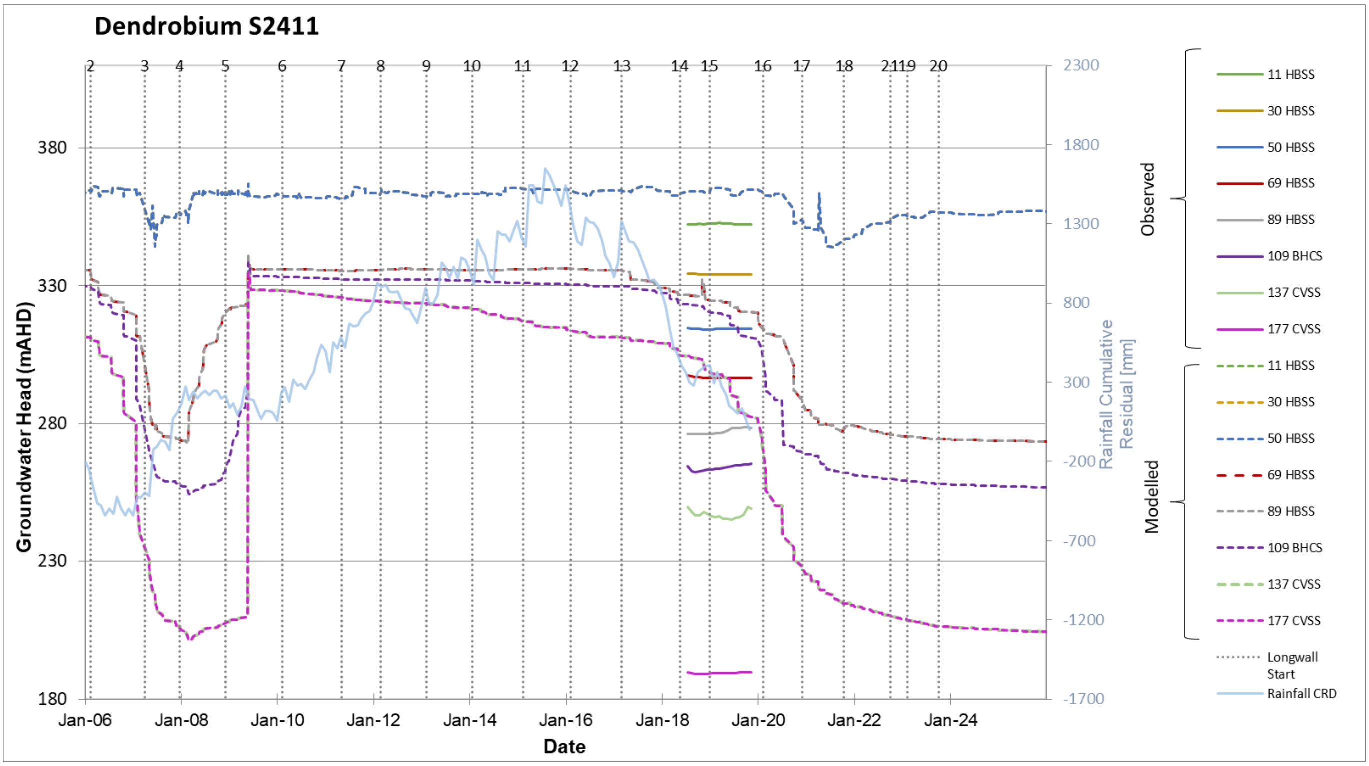


Figure A-13 Modelled and Observed Groundwater levels – S2411

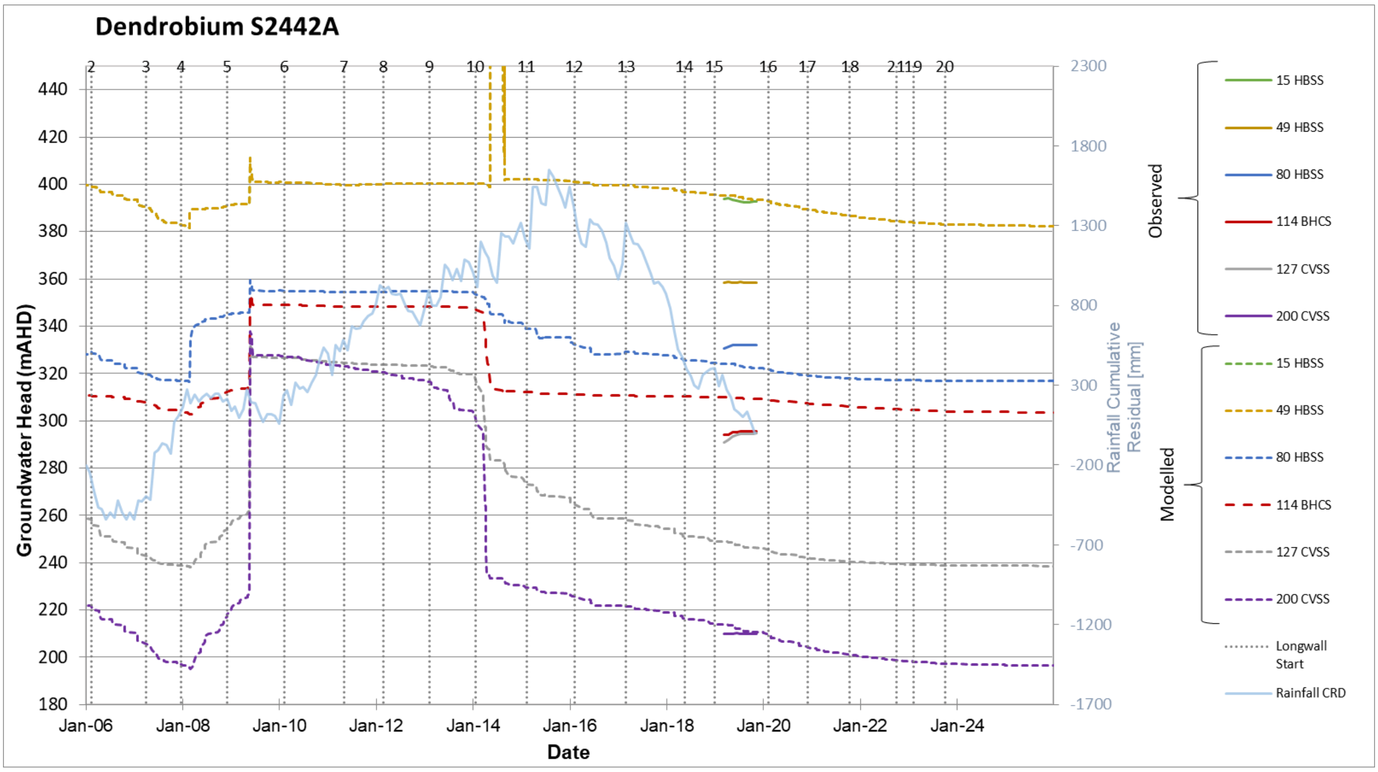


Figure A-14 Modelled and Observed Groundwater levels – S2442A

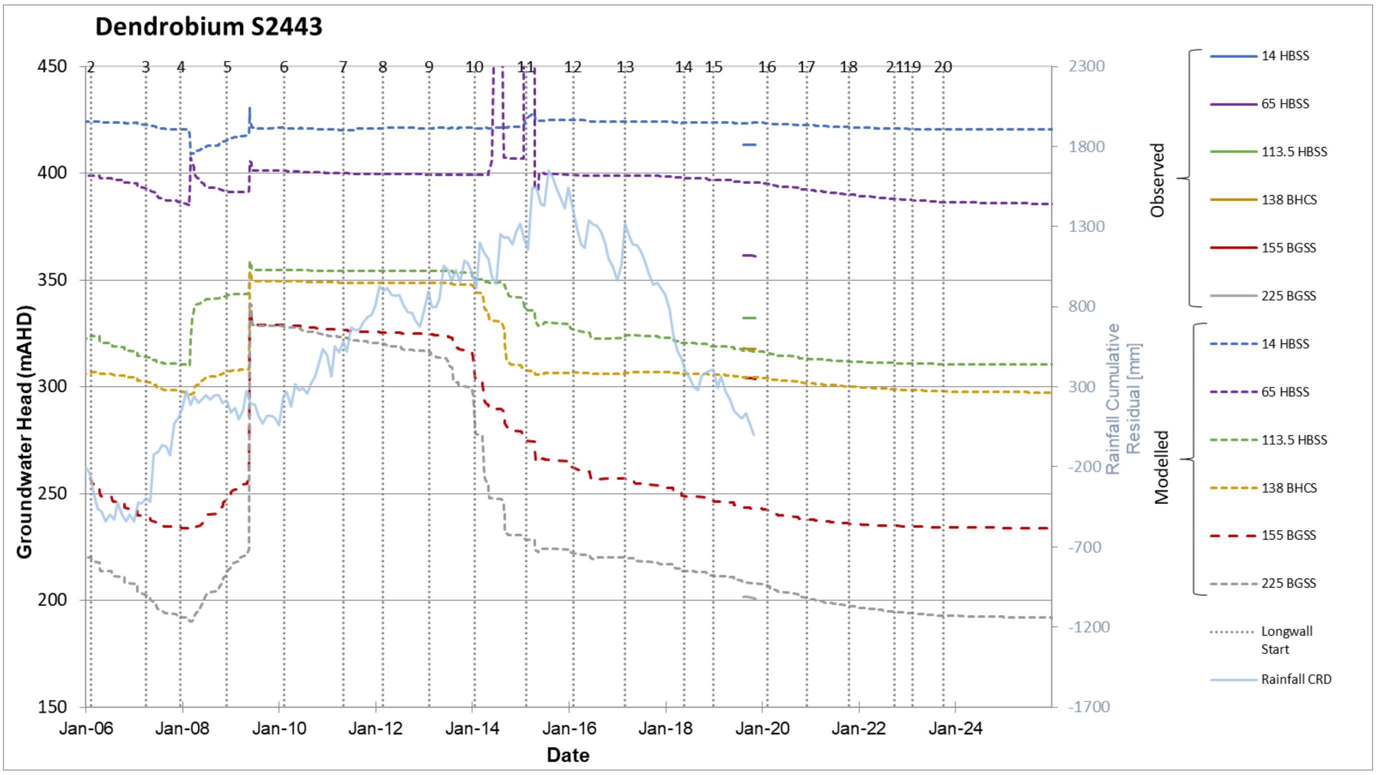


Figure A-15 Modelled and Observed Groundwater levels – S2443

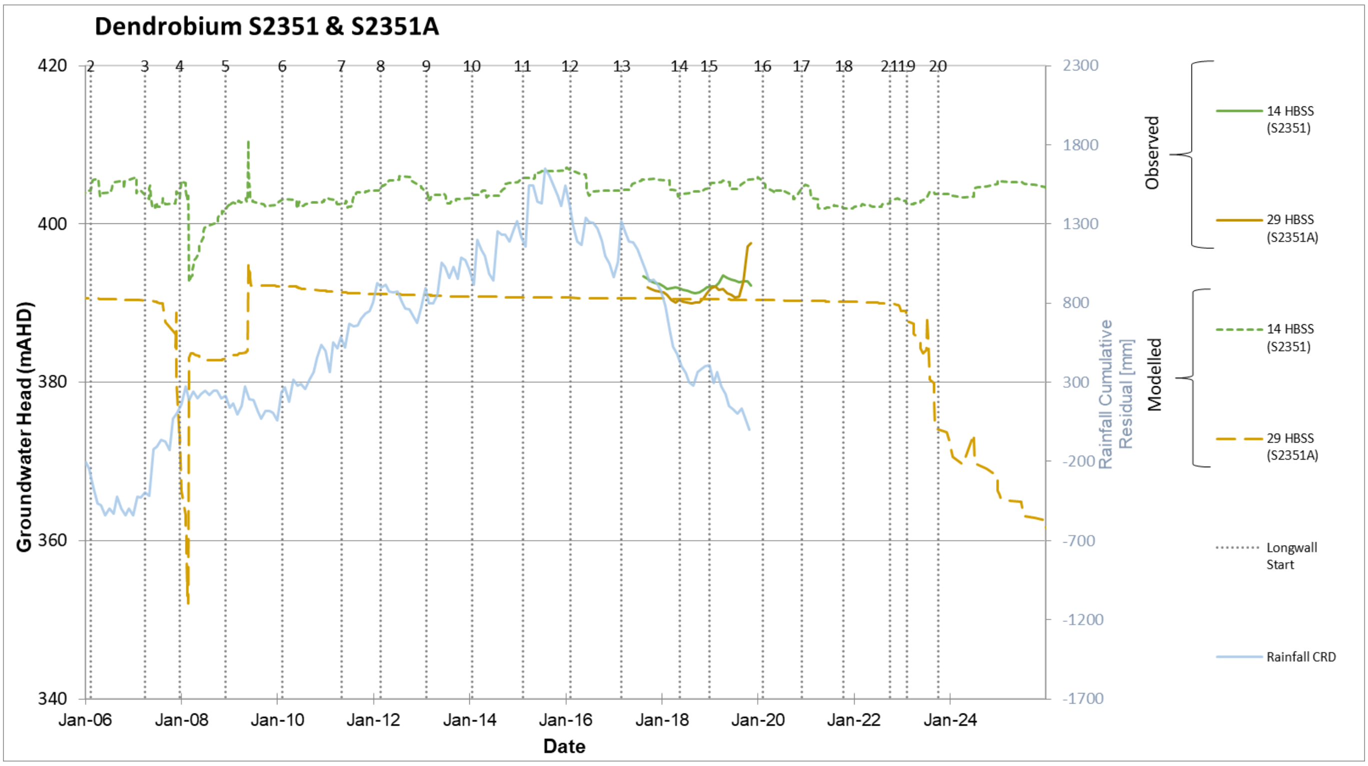


Figure A-16 Modelled and Observed Groundwater levels – S2351 and S2351A

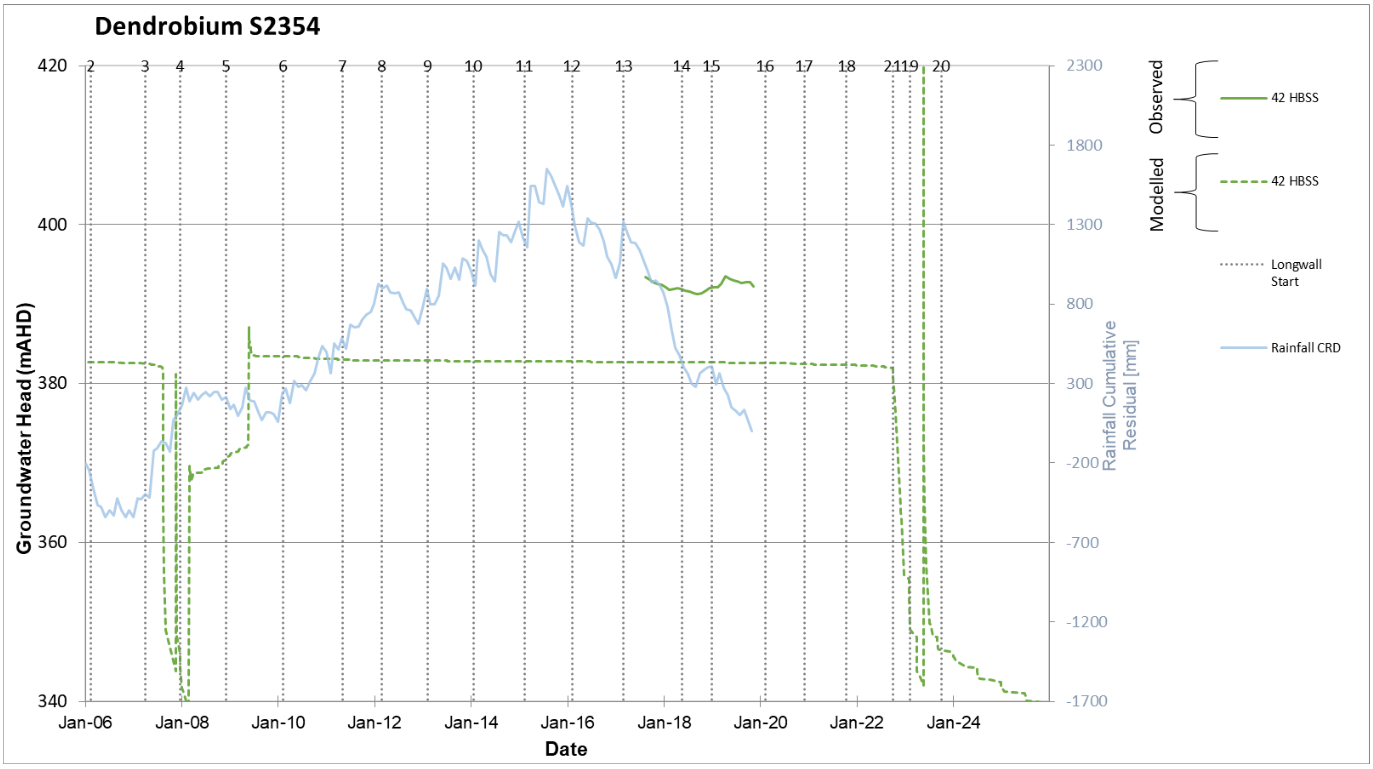


Figure A-17 Modelled and Observed Groundwater levels – S2354

Lake Avon Shoreline Monitoring Locations

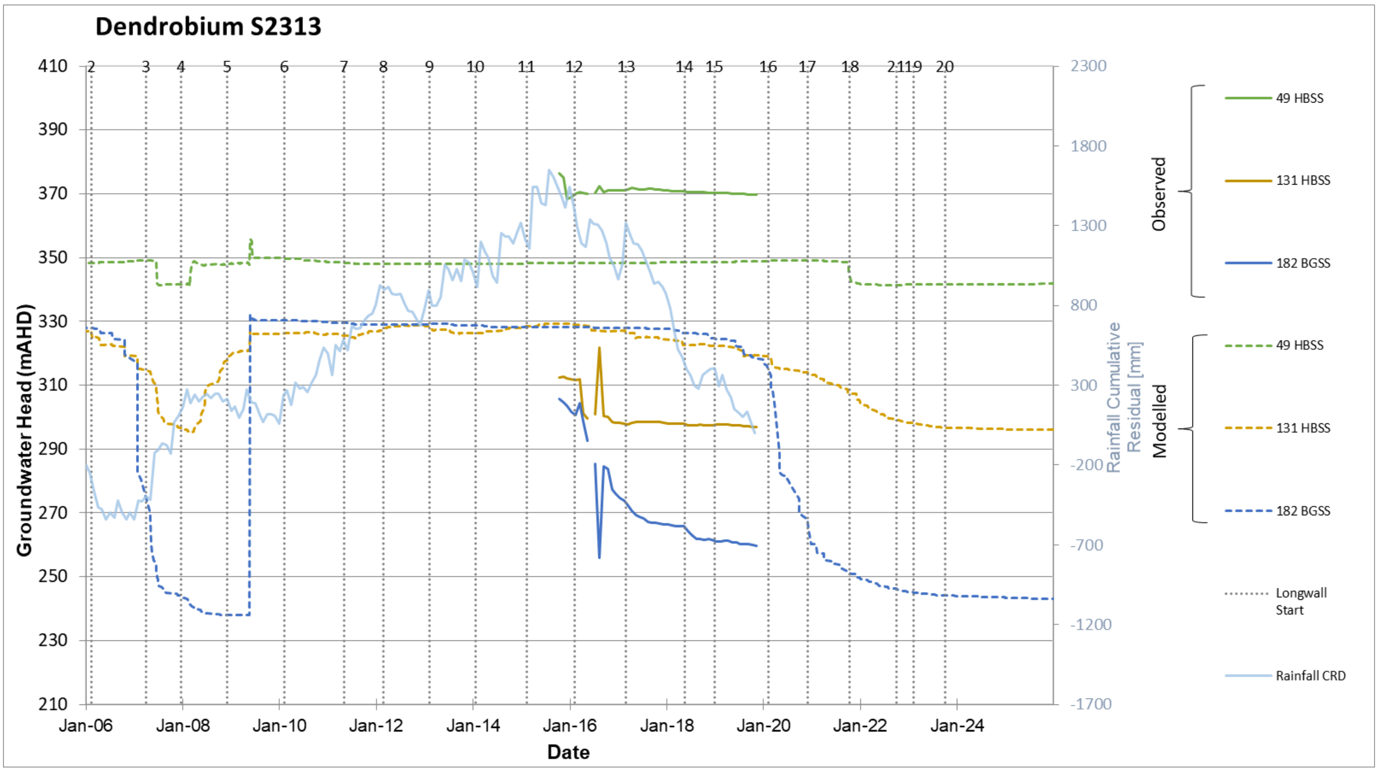


Figure A-18 Modelled and Observed Groundwater levels – S2313

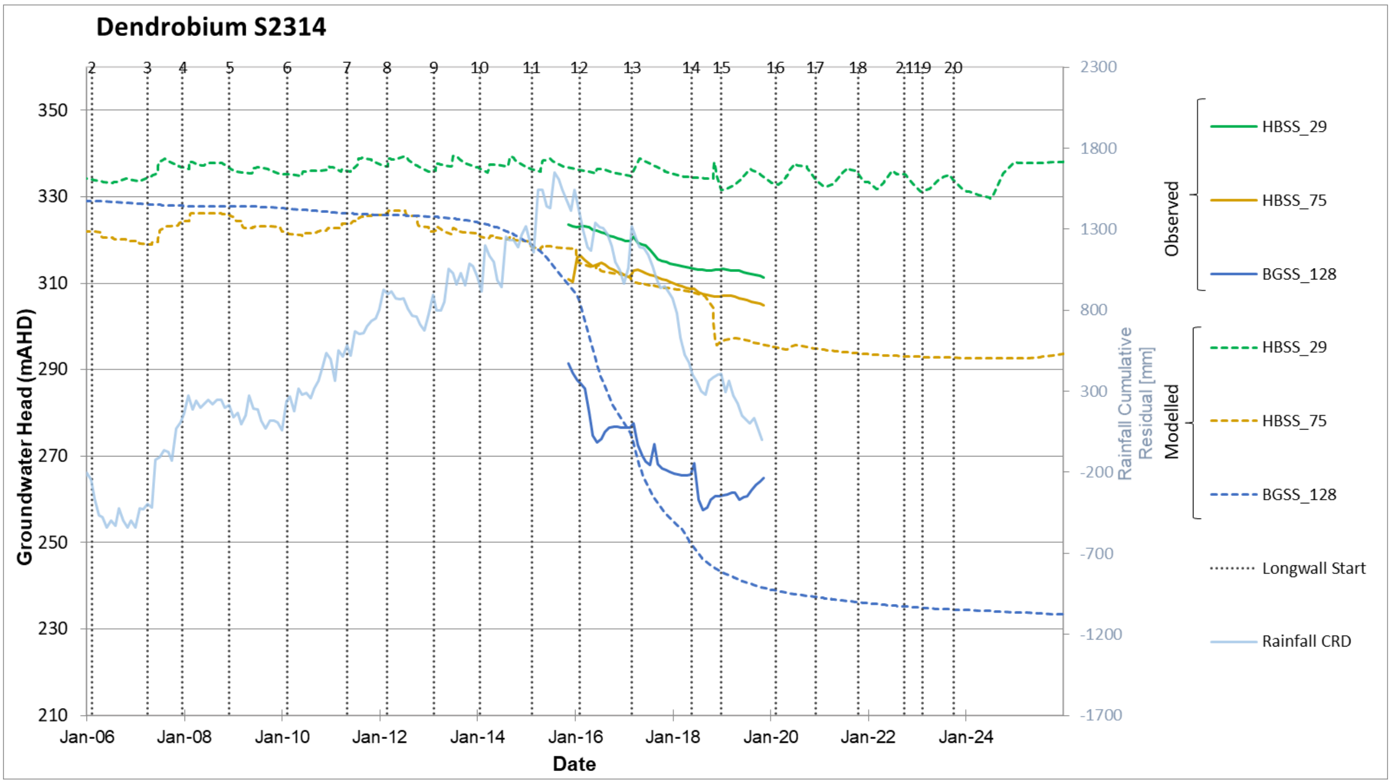


Figure A-19 Modelled and Observed Groundwater levels – S2314

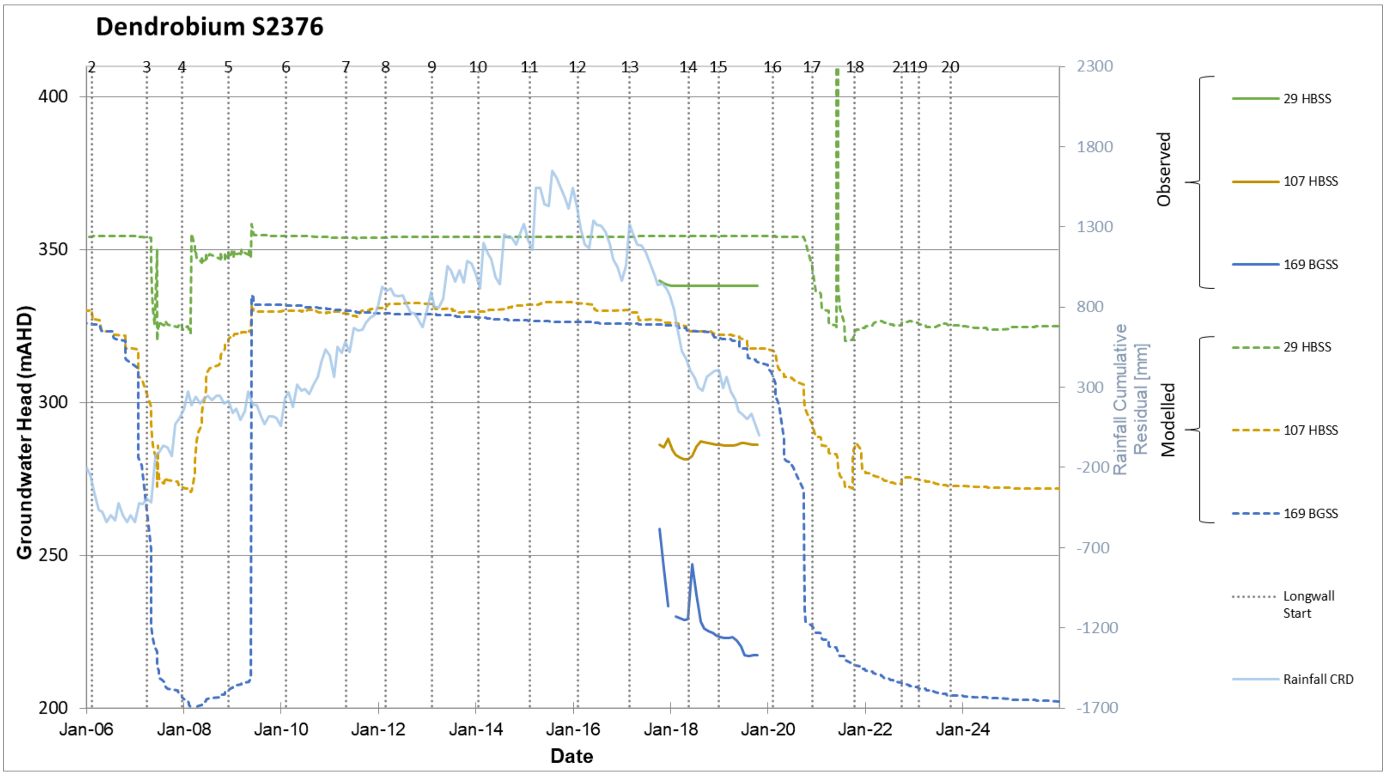


Figure A-20 Modelled and Observed Groundwater levels – S2376

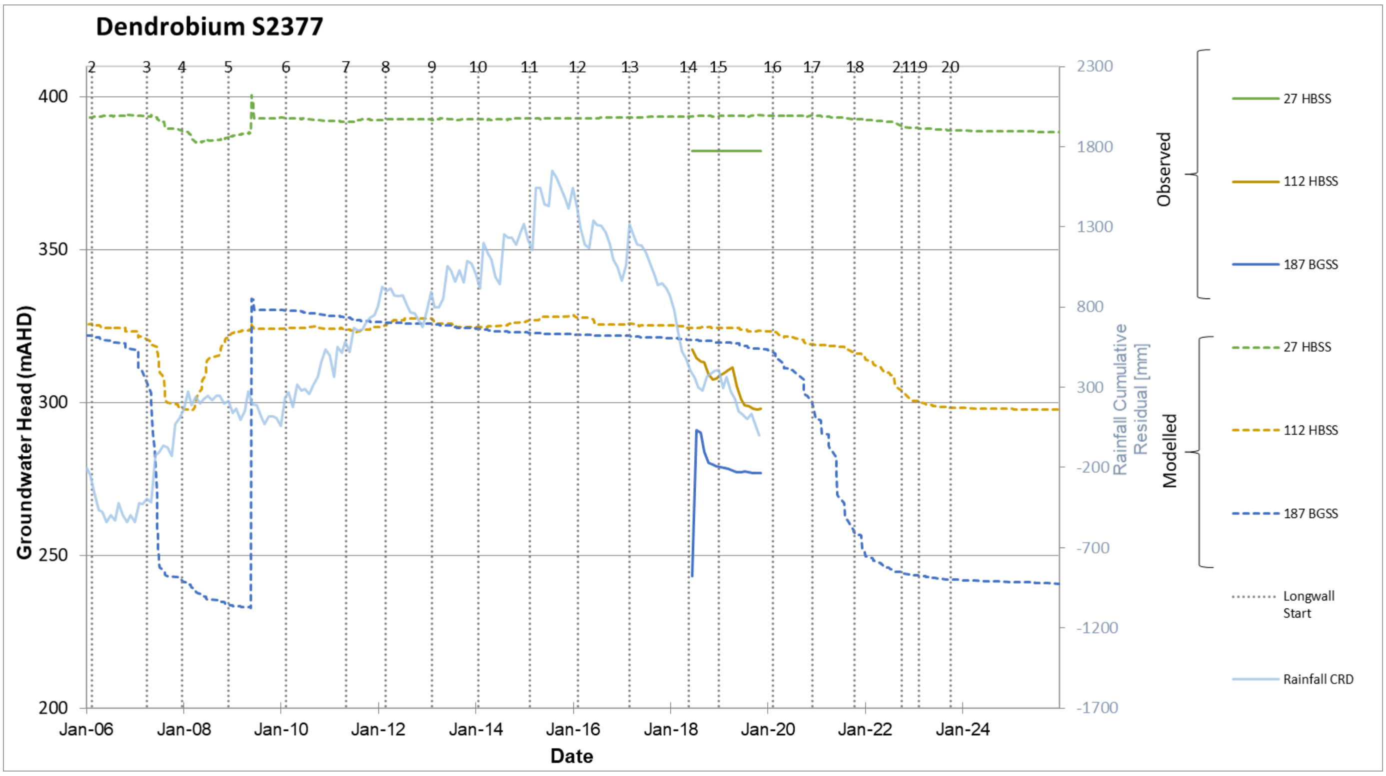


Figure A-21 Modelled and Observed Groundwater levels – S2377

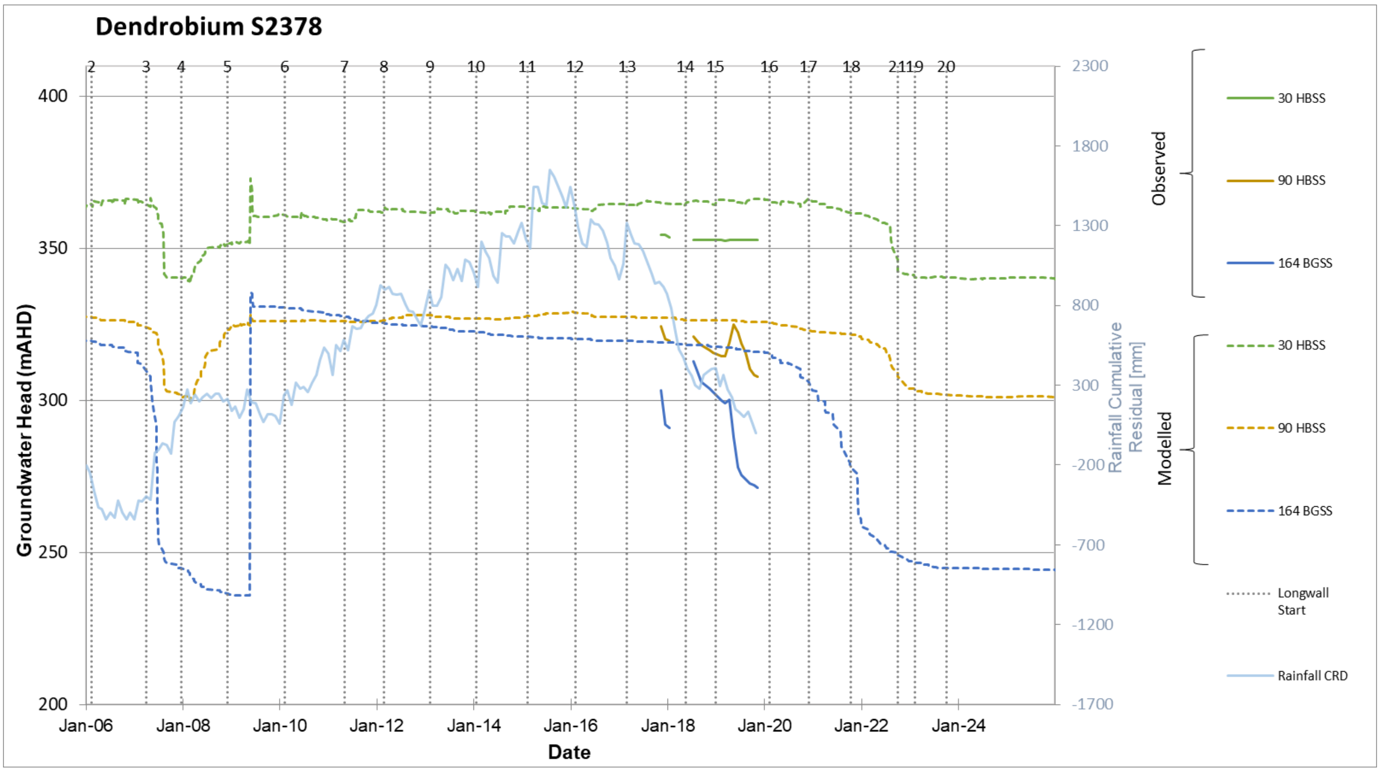


Figure A-22 Modelled and Observed Groundwater levels – S2378

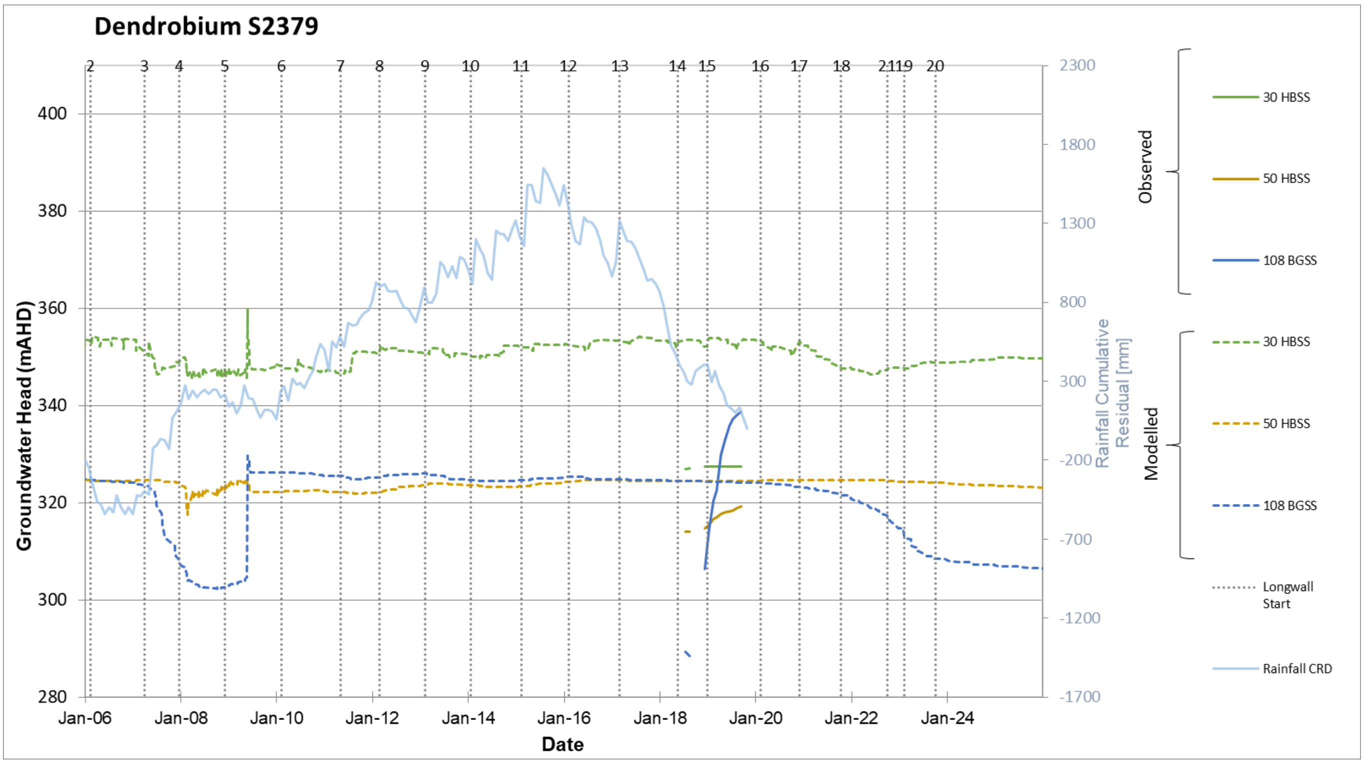


Figure A-23 Modelled and Observed Groundwater levels – S2379

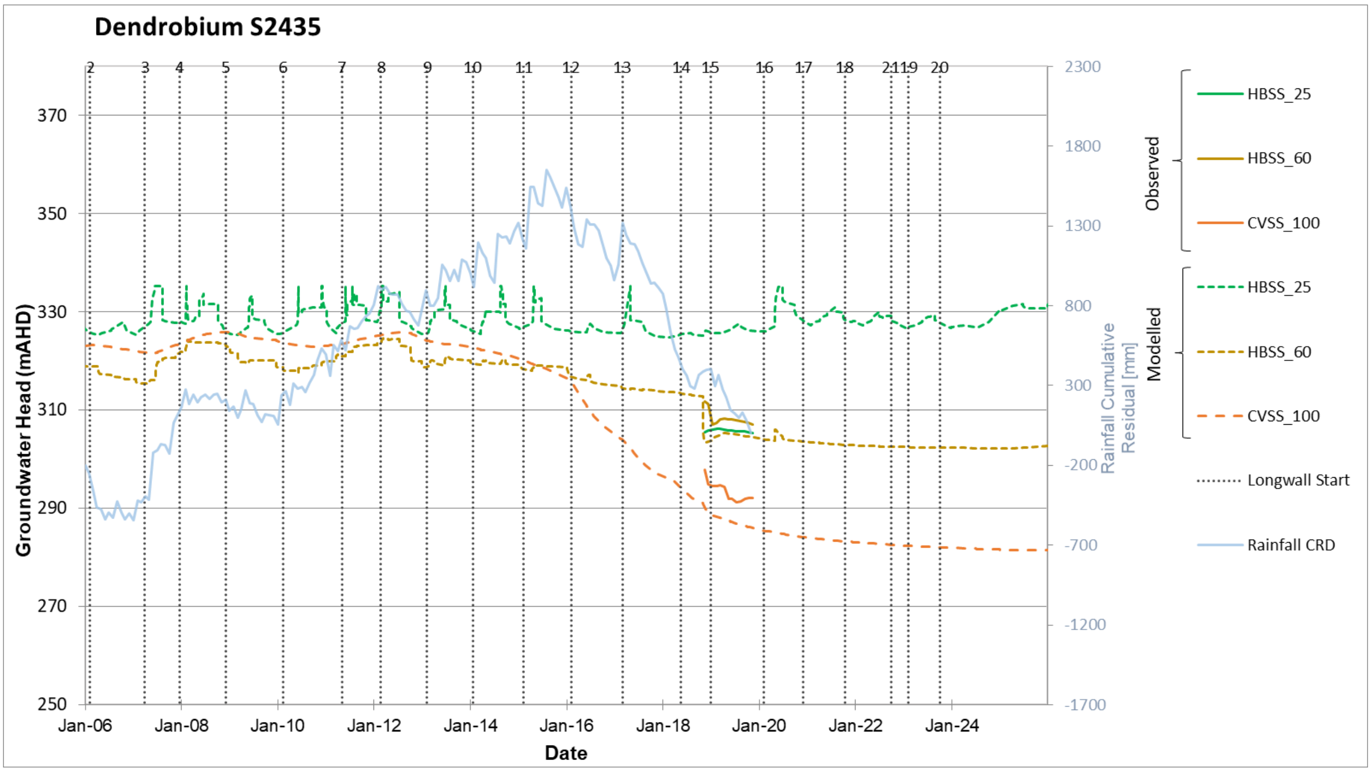


Figure A-24 Modelled and Observed Groundwater levels – S2435

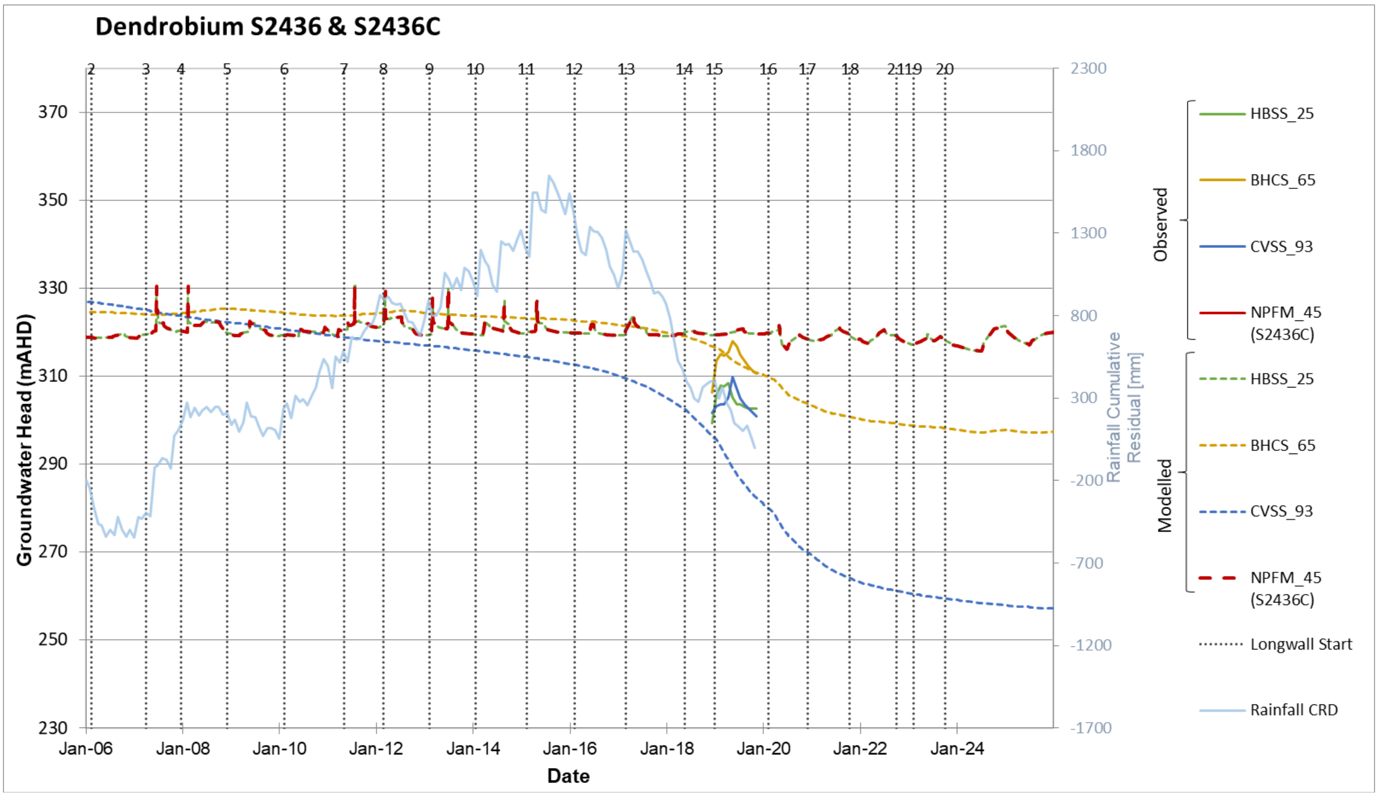


Figure A-25 Modelled and Observed Groundwater levels – S24367 & S2436C

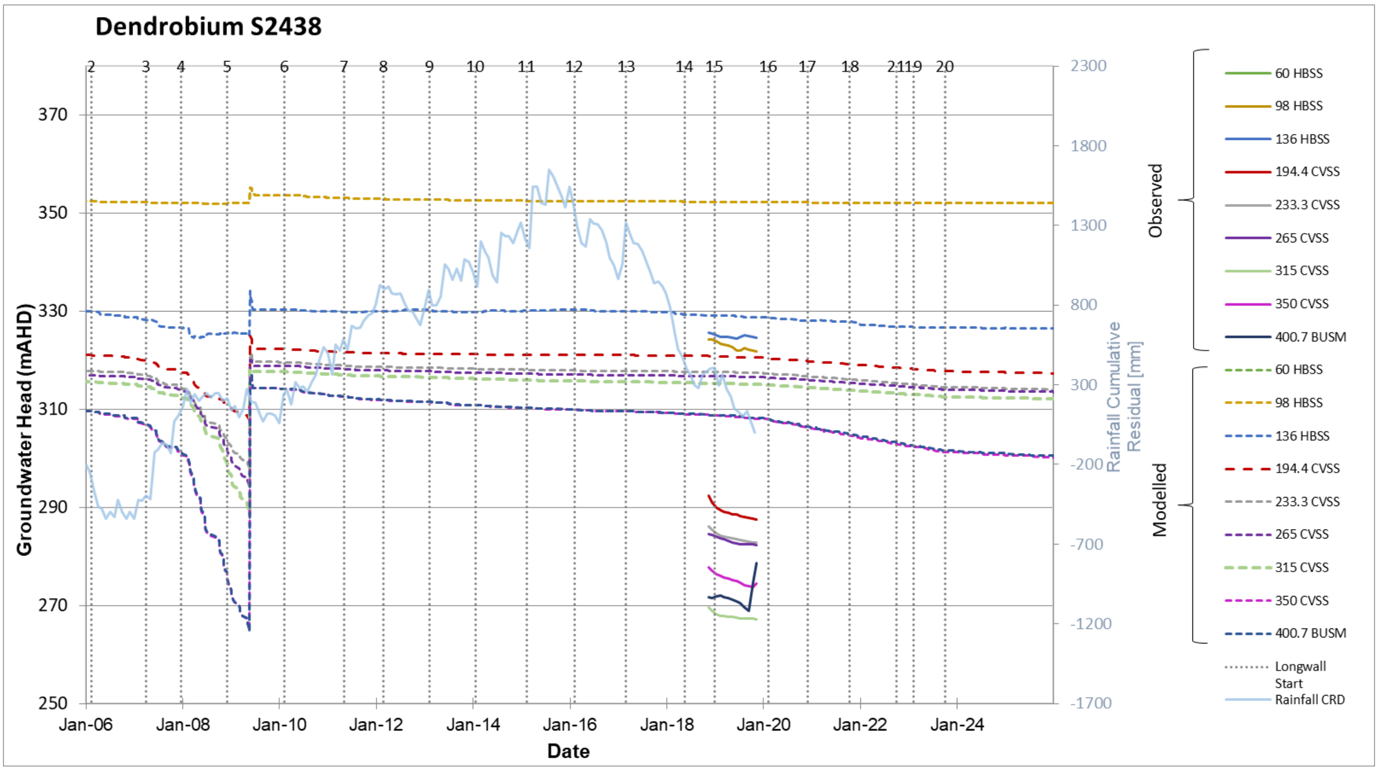


Figure A-26 Modelled and Observed Groundwater levels – S2438

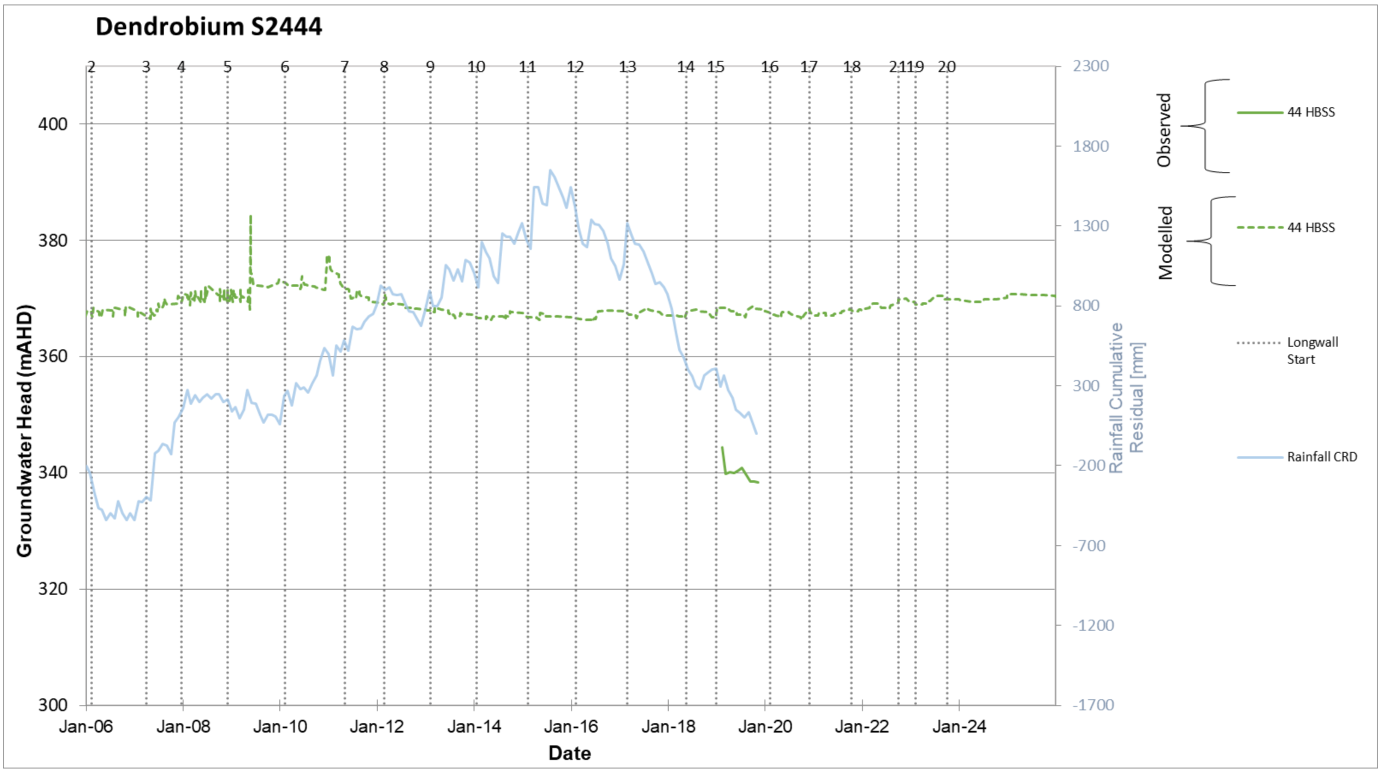


Figure A-27 Modelled and Observed Groundwater levels – S2444

Lake Cordeaux Monitoring Locations

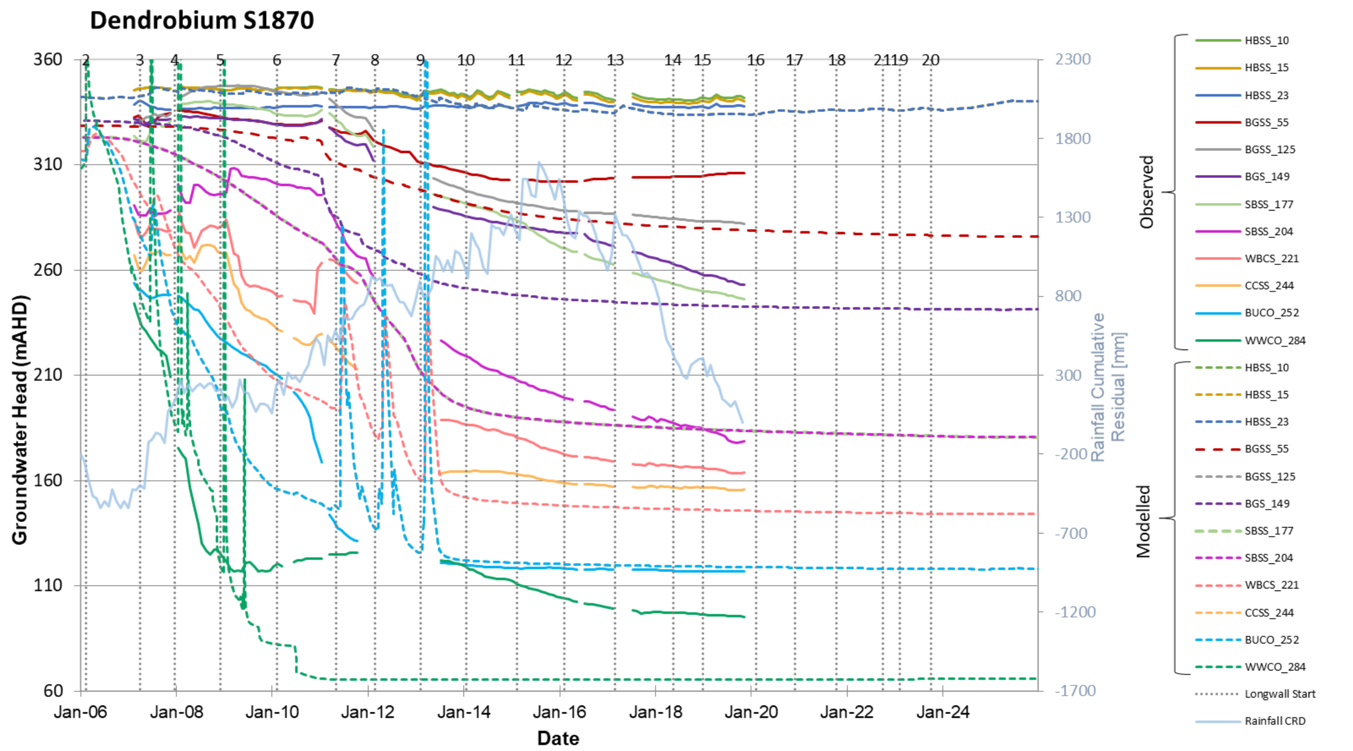


Figure A-28 Modelled and Observed Groundwater levels – S1870

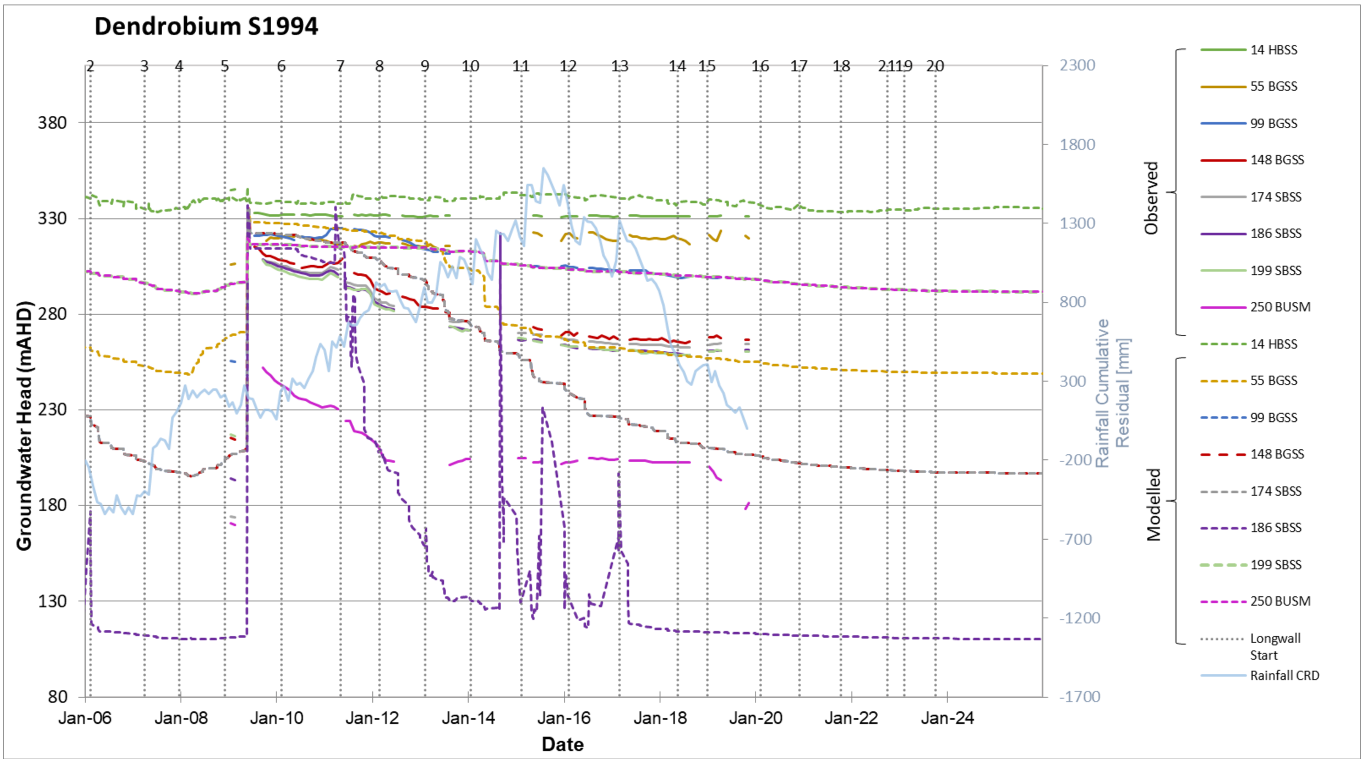


Figure A-29 Modelled and Observed Groundwater levels – S1994

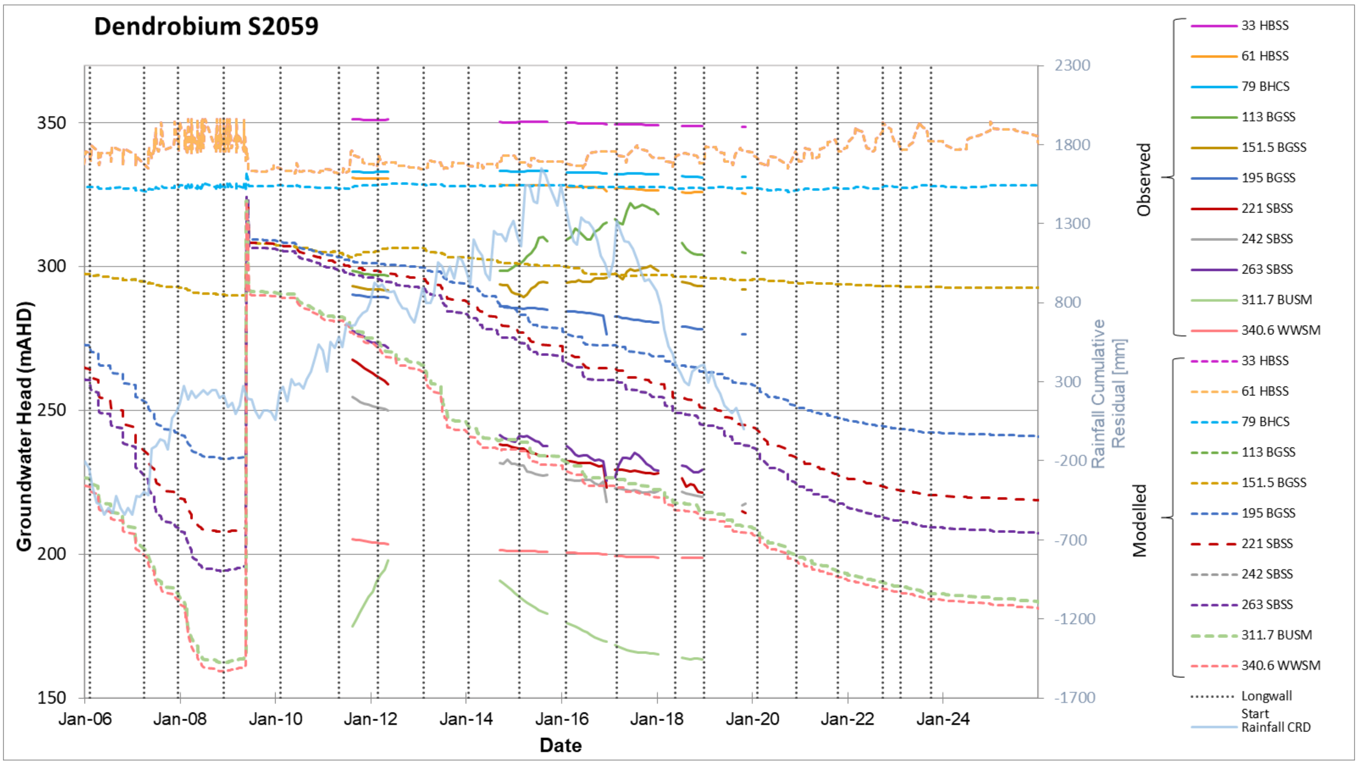


Figure A-30 Modelled and Observed Groundwater levels – S2059

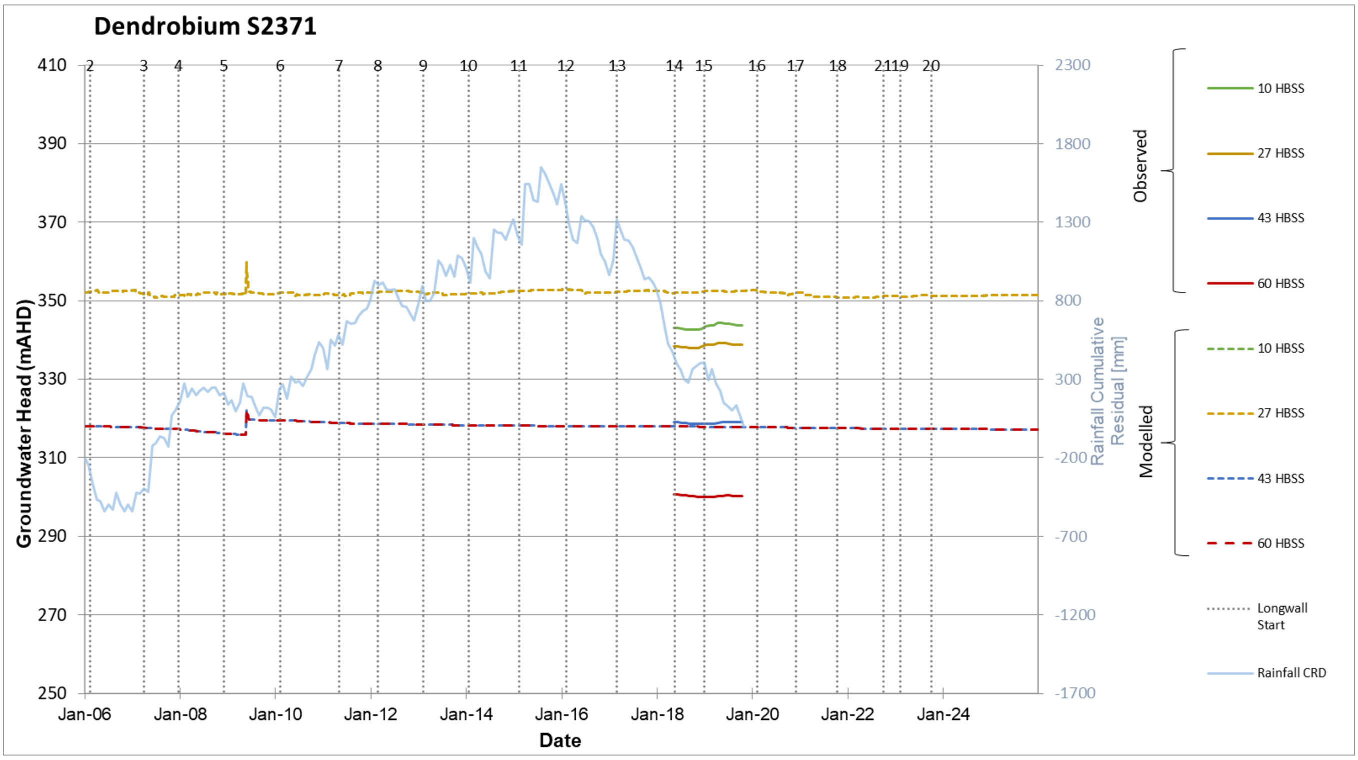


Figure A-31 Modelled and Observed Groundwater levels – S2371

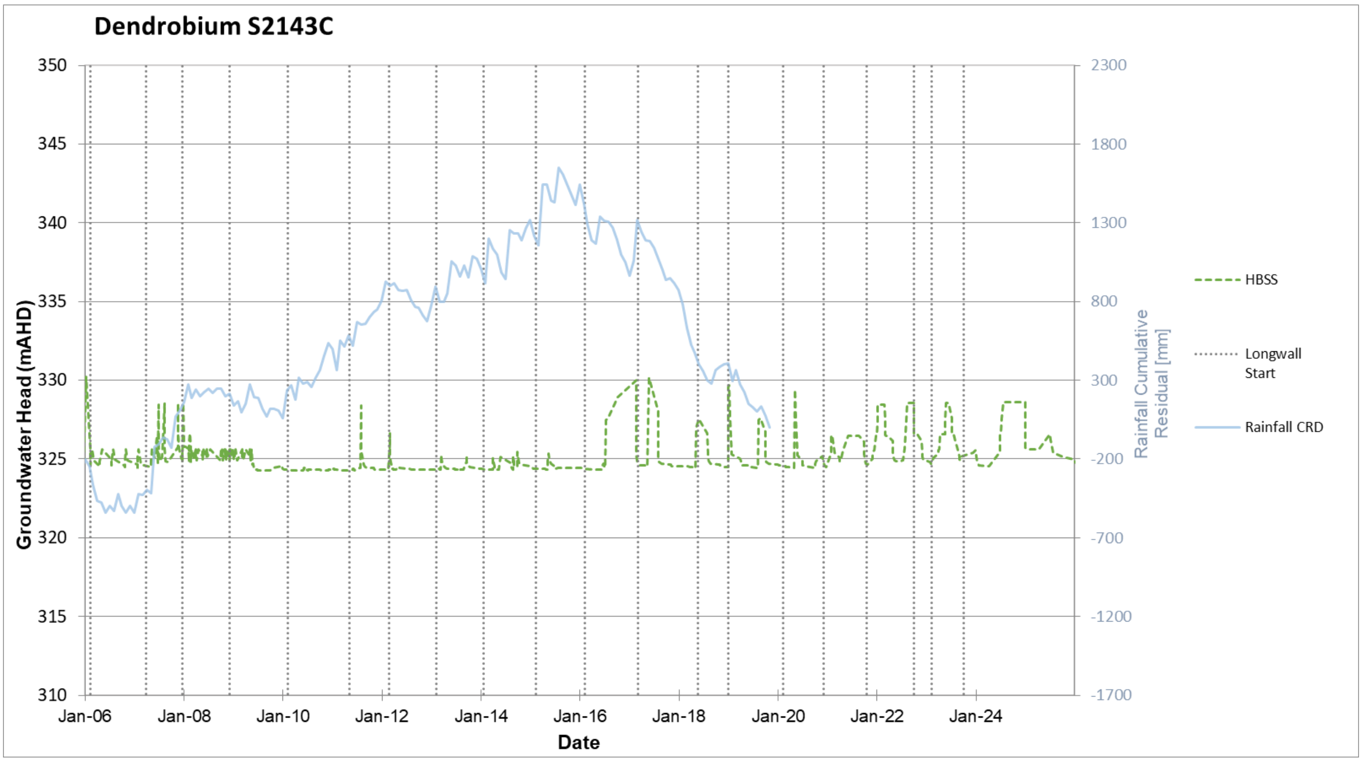


Figure A-32 Modelled Groundwater levels – S2143C

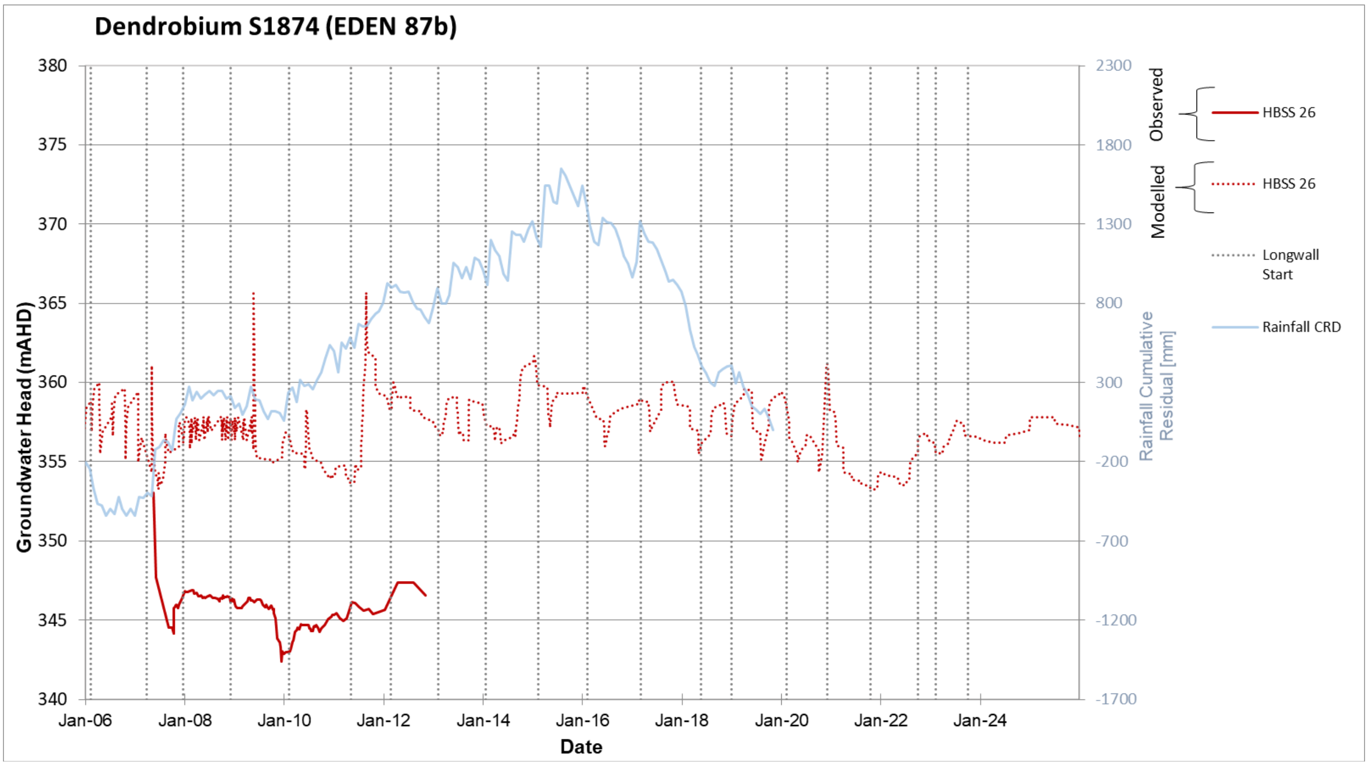


Figure A-33 Modelled and Observed Groundwater levels – S1874

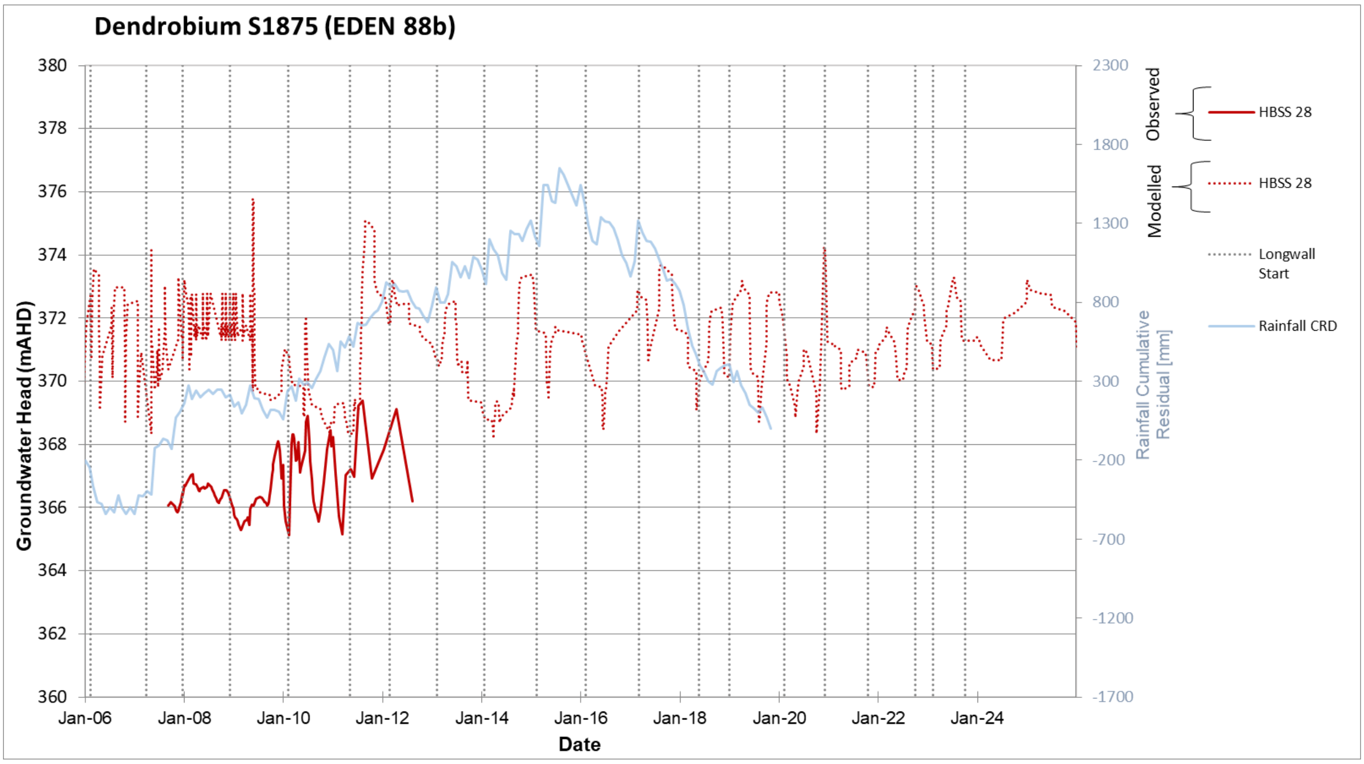
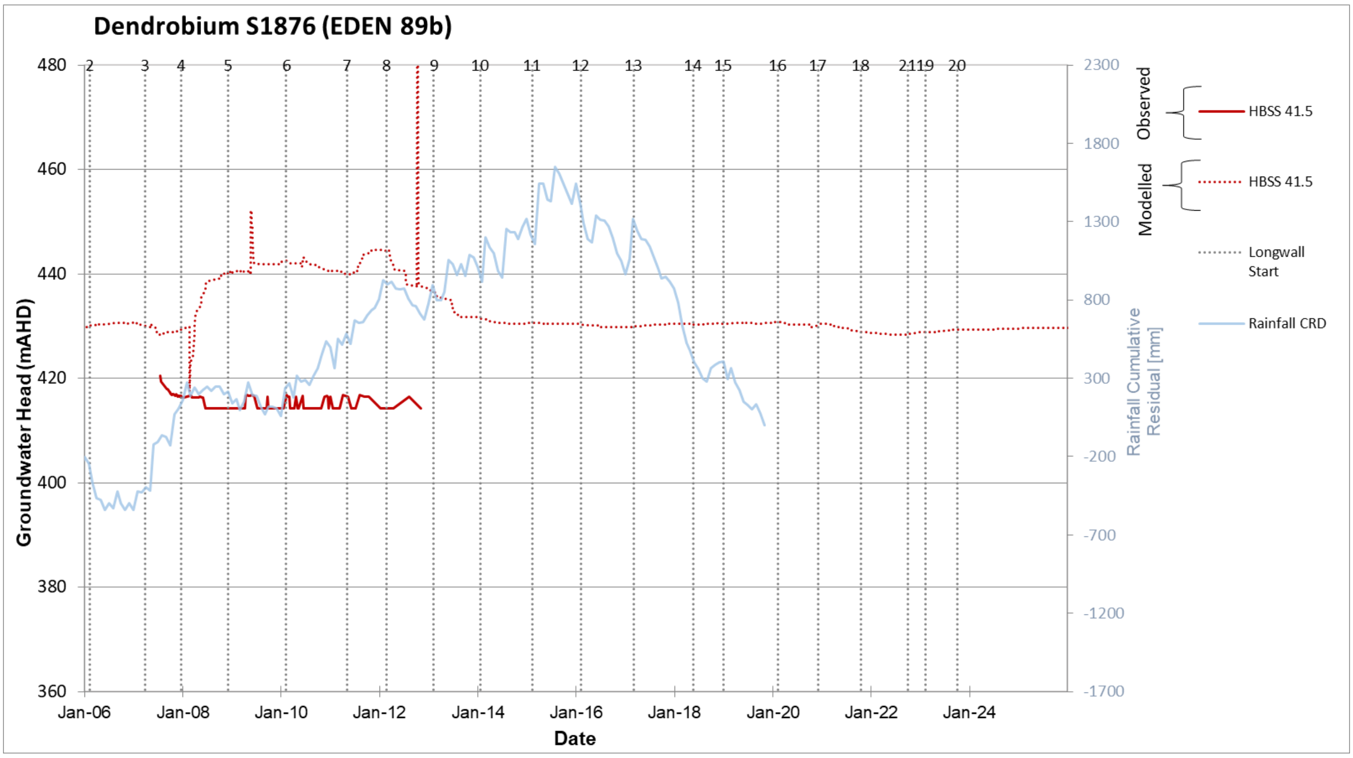


Figure A-34 Modelled and Observed Groundwater levels – S1875



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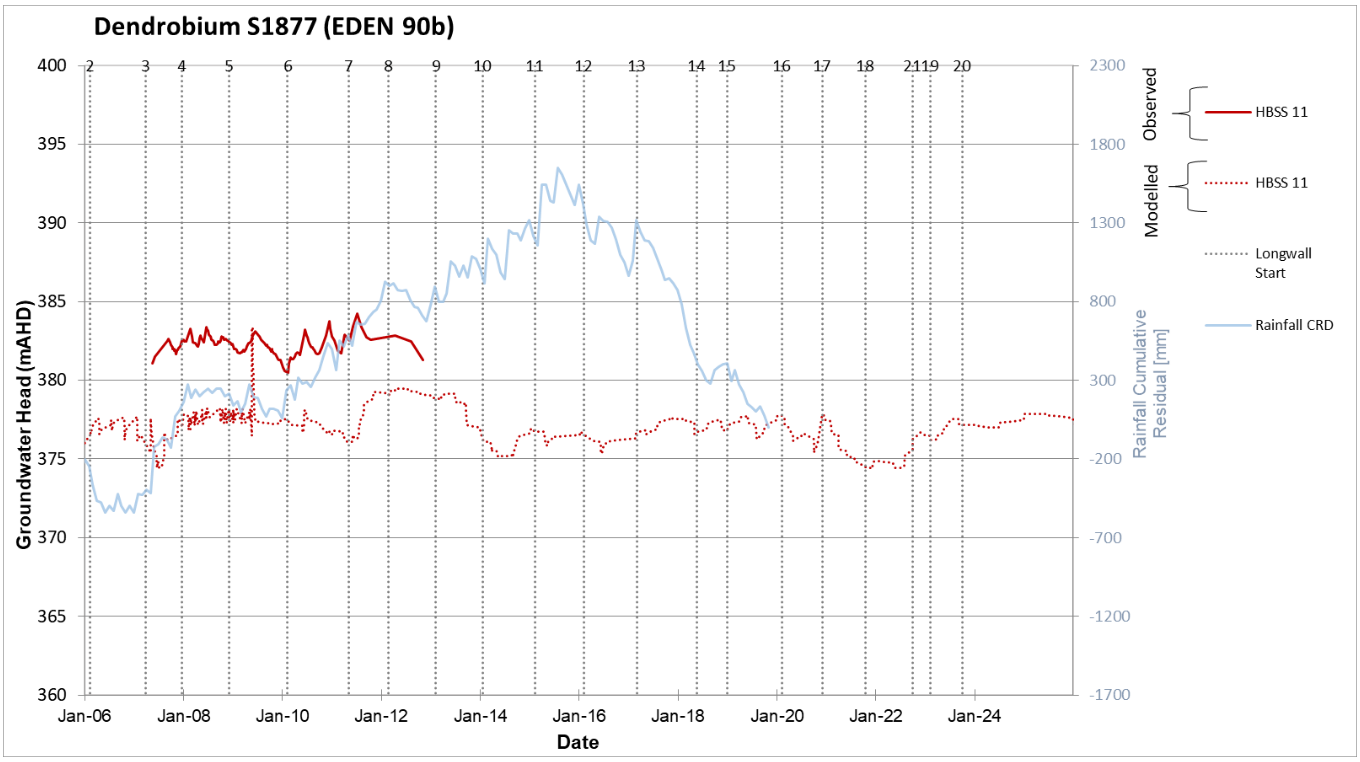

Figure A-35 Modelled and Observed Groundwater levels – S1877

Watercourse Monitoring Locations

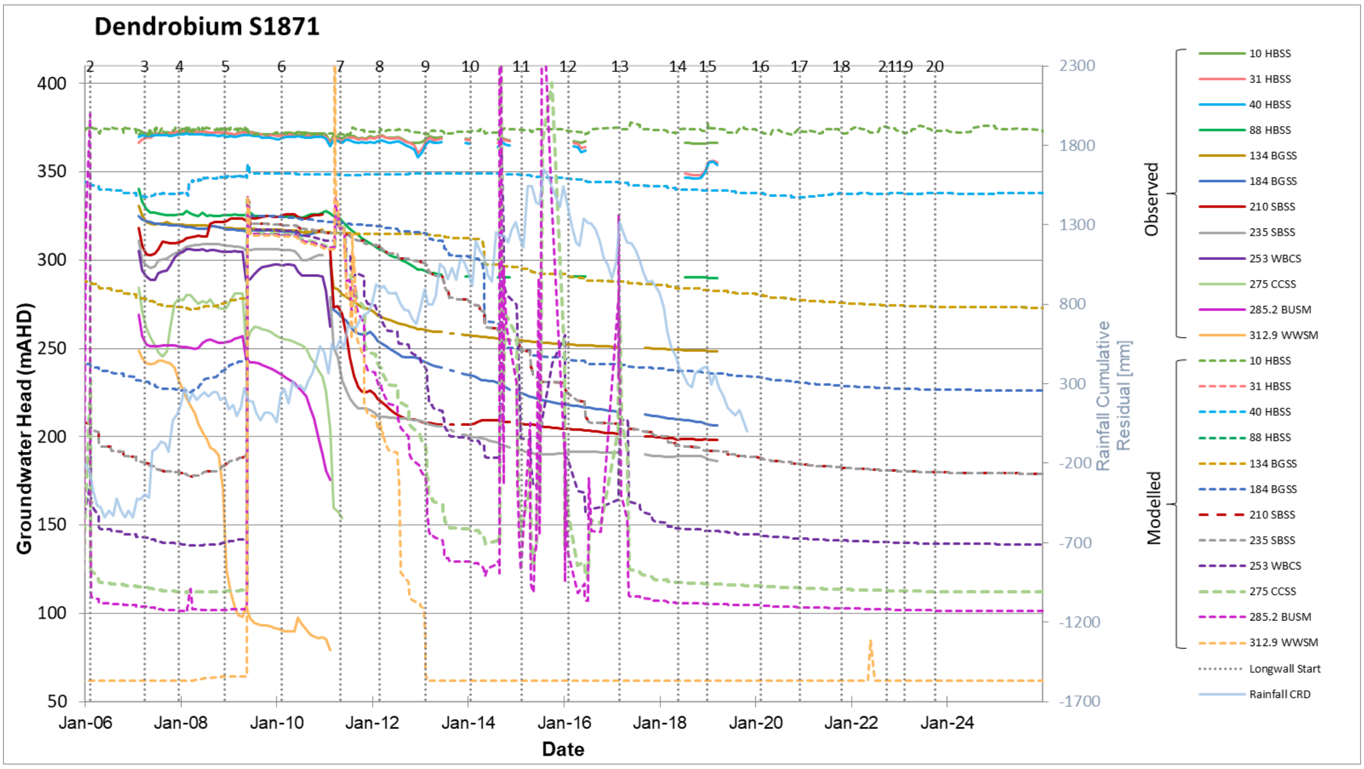

Figure A-36 Modelled and Observed Groundwater levels – S1871

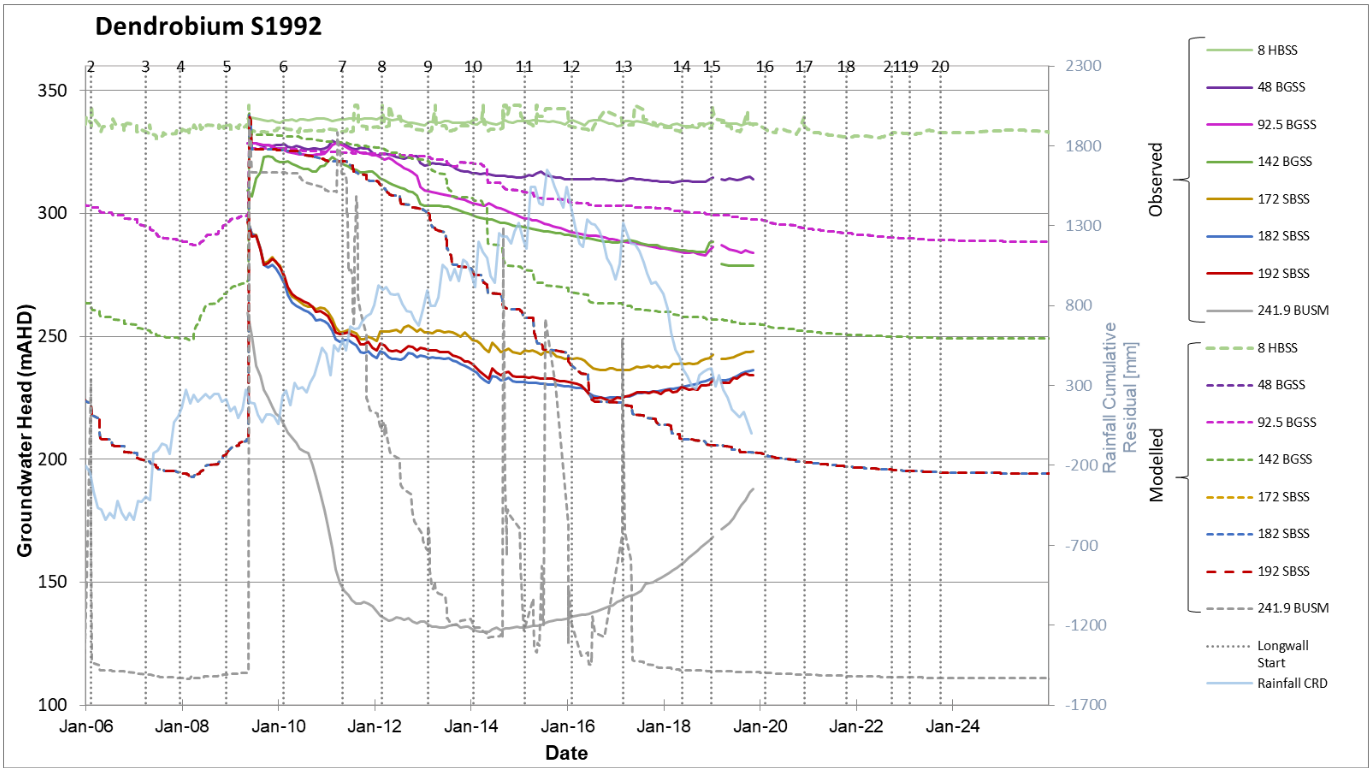

Figure A-37 Modelled and Observed Groundwater levels – S1992

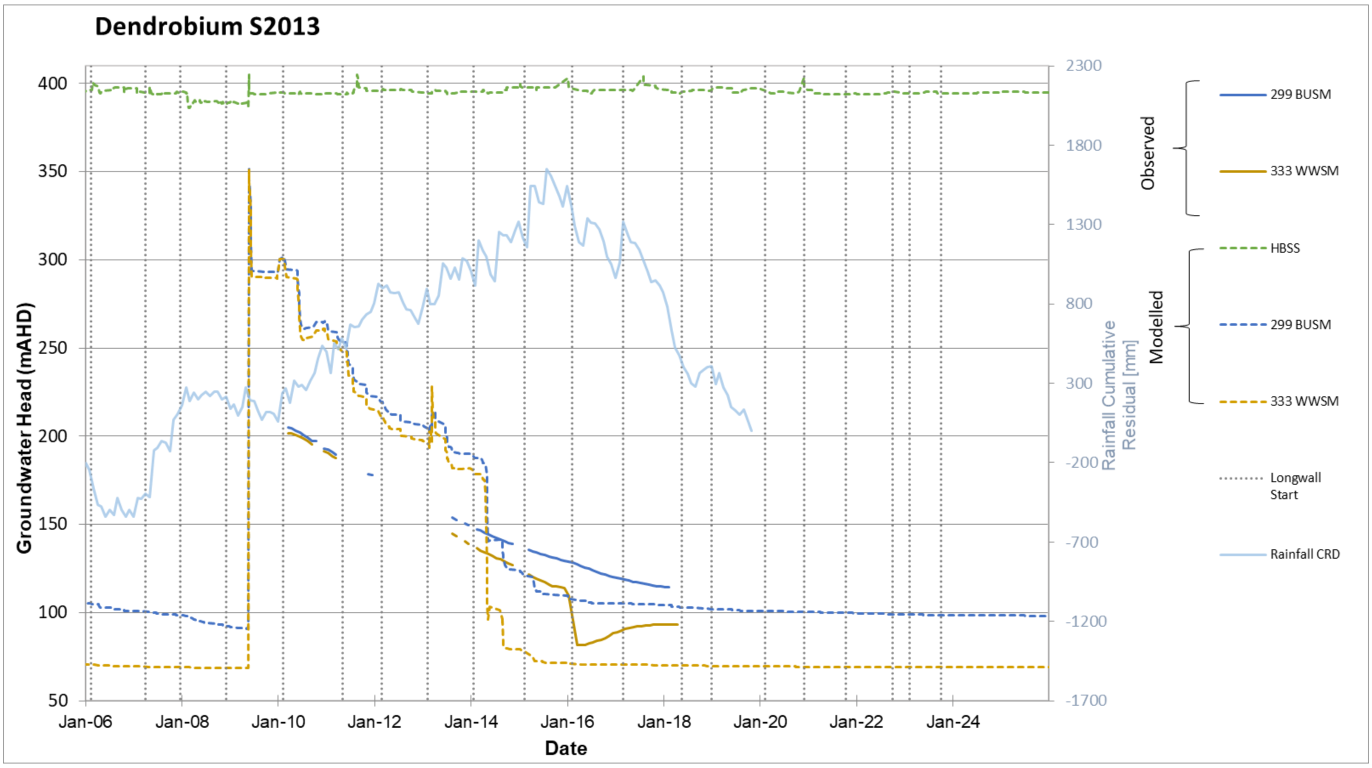

Figure A-38 Modelled and Observed Groundwater levels – S2013

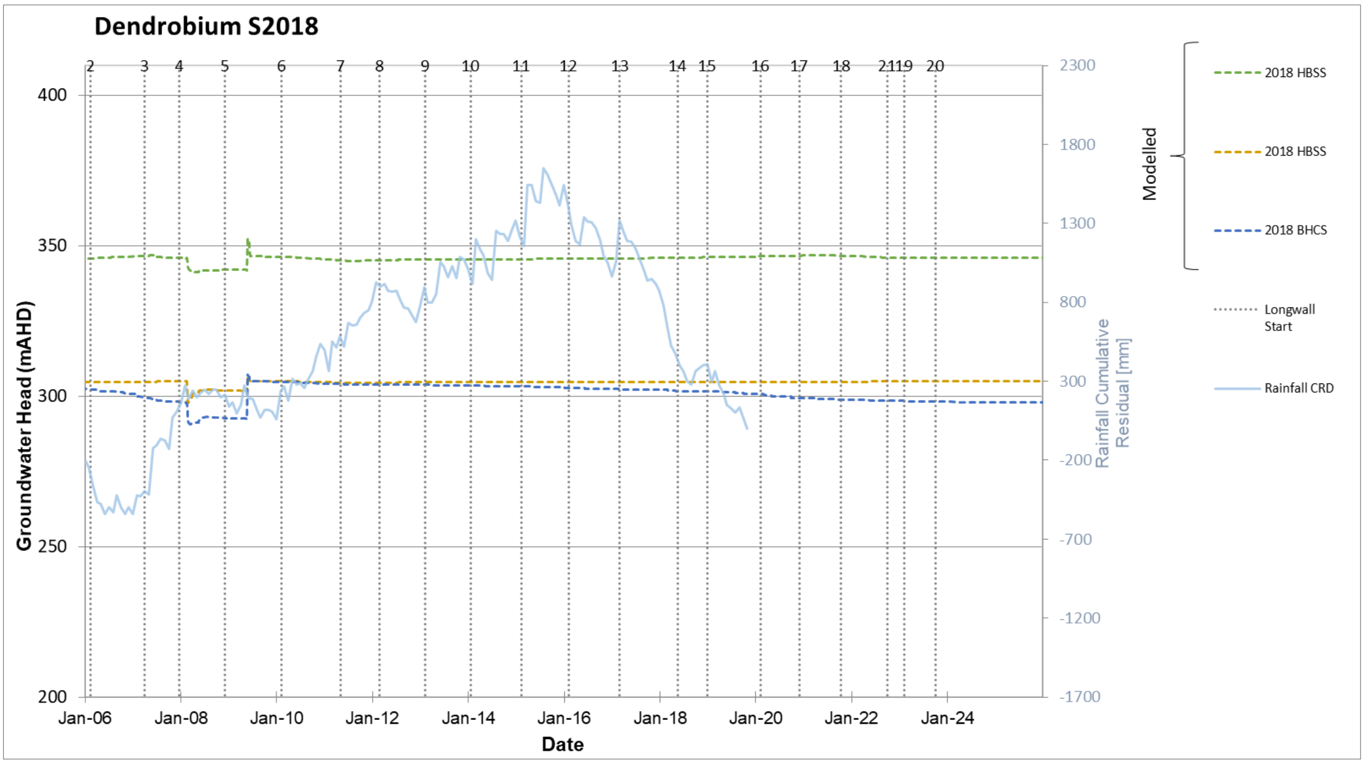

Figure A-39 Modelled Groundwater levels – S2018

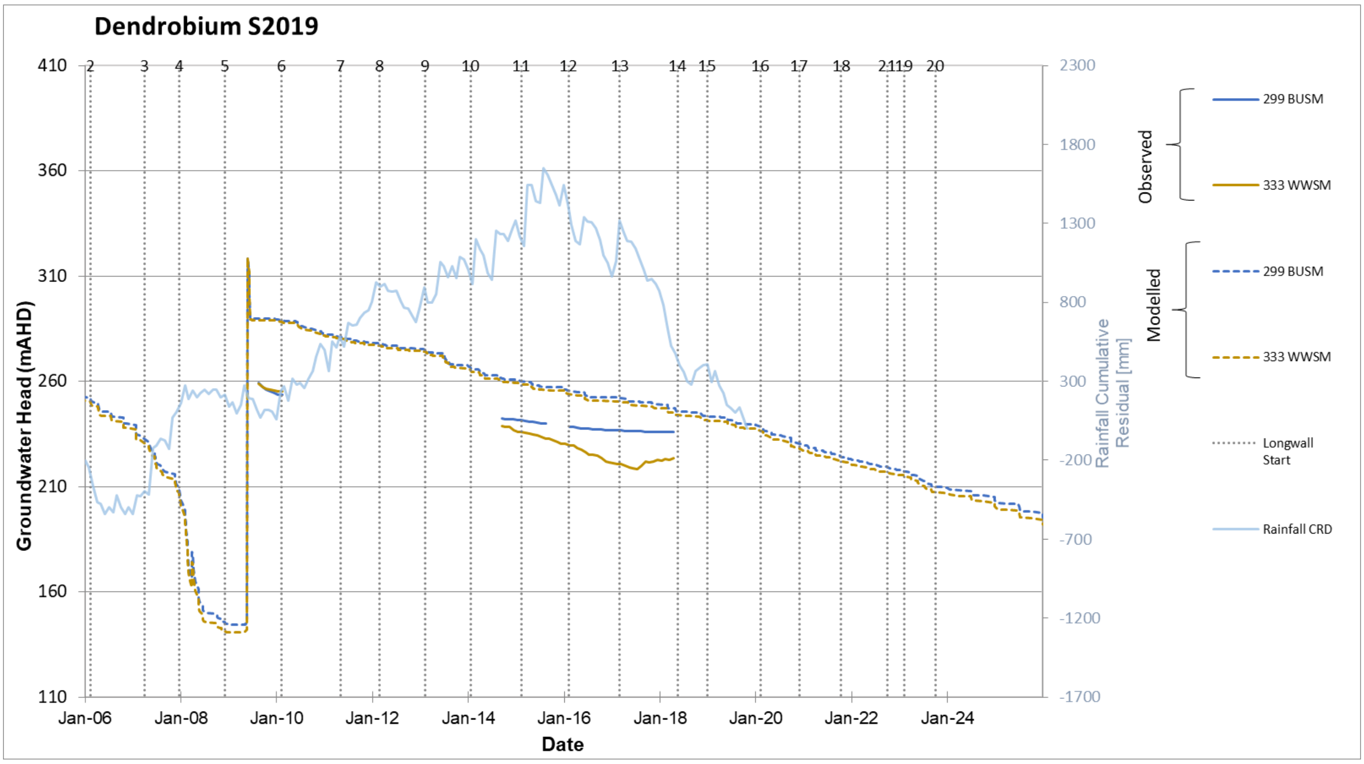

Figure A-40 Modelled and Observed Groundwater levels – S2019

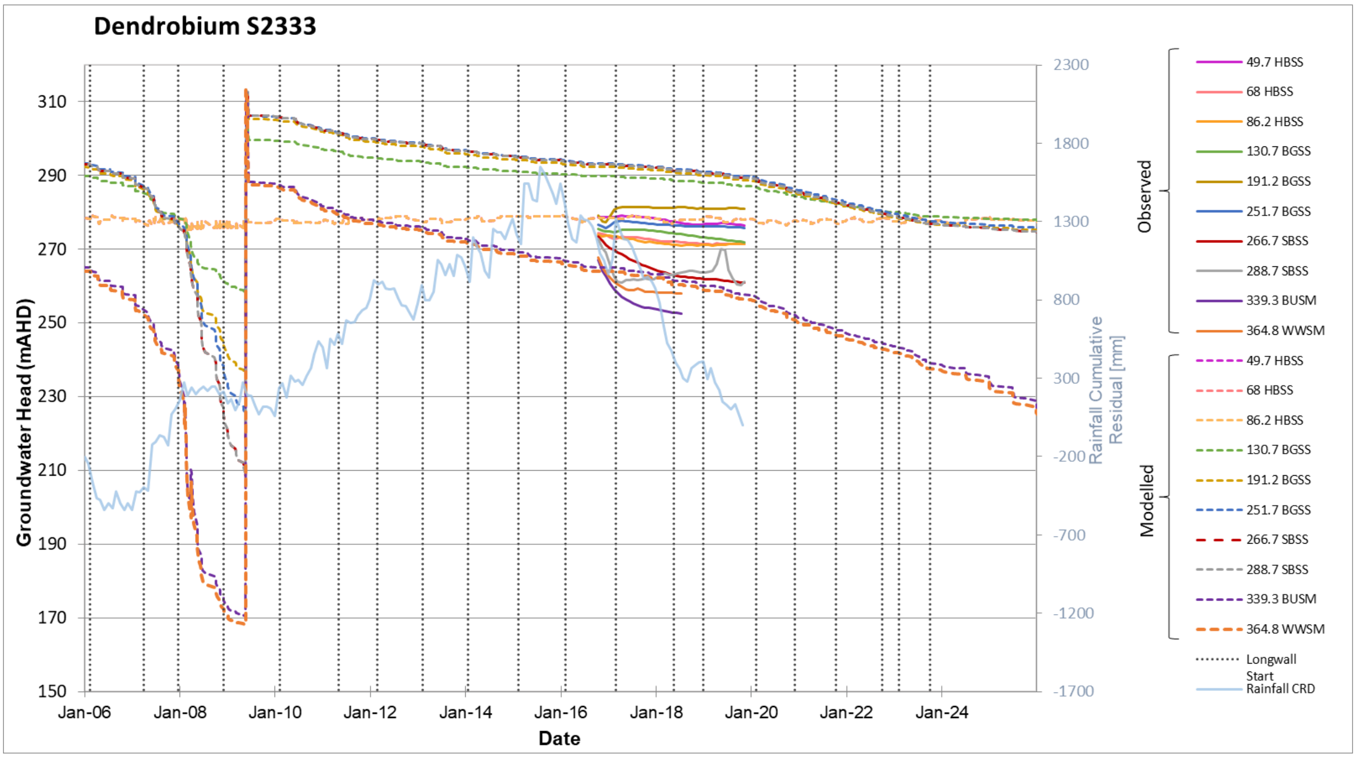

Figure A-41 Modelled and Observed Groundwater levels – S2333

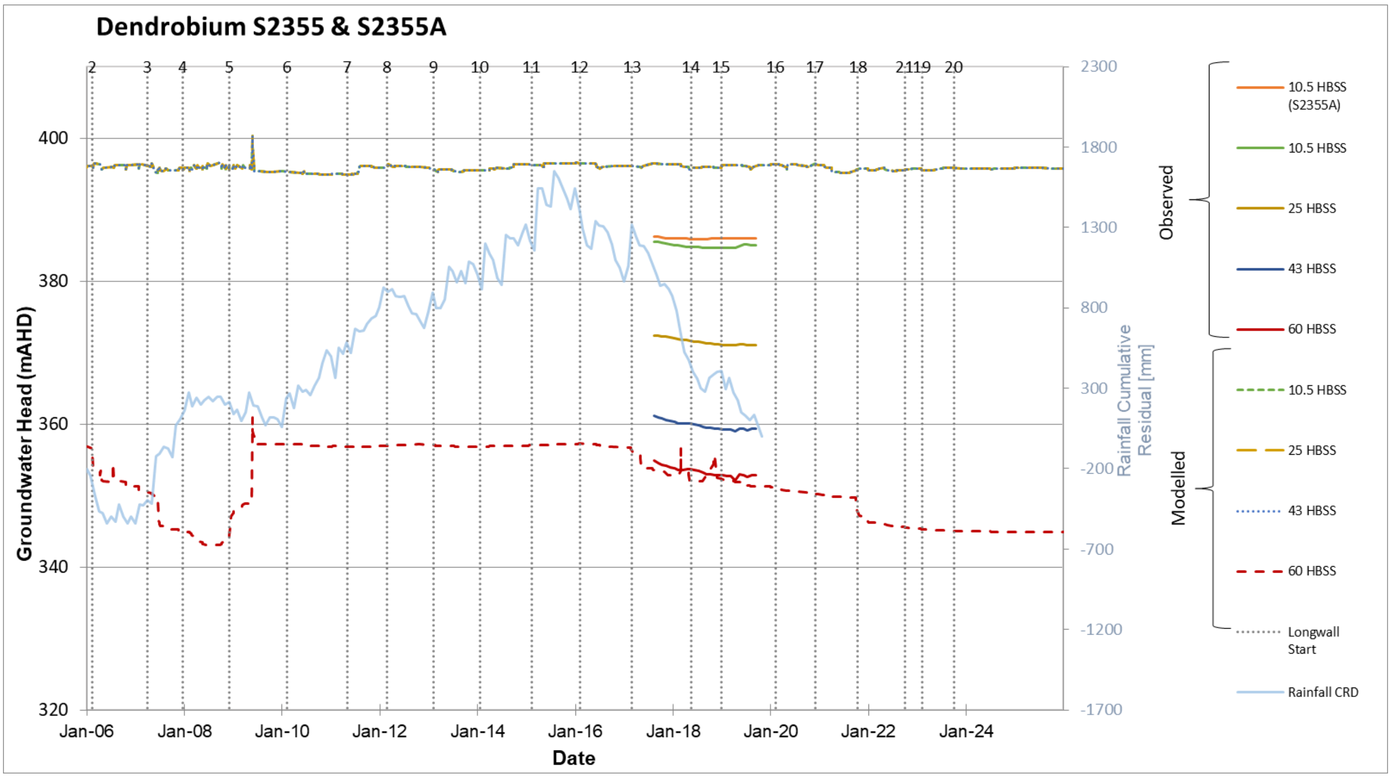

Figure A-42 Modelled and Observed Groundwater levels – S2355 and S2355A

ASIA PACIFIC OFFICES

BRISBANE
Level 2, 15 Astor Terrace
Spring Hill QLD 4000
Australia
T: +61 7 3858 4800
F: +61 7 3858 4801

CANBERRA
GPO 410
Canberra ACT 2600
Australia
T: +61 2 6287 0800
F: +61 2 9427 8200

DARWIN
Unit 5, 21 Parap Road
Parap NT 0820
Australia
T: +61 8 8998 0100
F: +61 8 9370 0101

GOLD COAST
Level 2, 194 Varsity Parade
Varsity Lakes QLD 4227
Australia
M: +61 438 763 516

MACKAY
21 River Street
Mackay QLD 4740
Australia
T: +61 7 3181 3300

MELBOURNE
Suite 2, 2 Domville Avenue
Hawthorn VIC 3122
Australia
T: +61 3 9249 9400
F: +61 3 9249 9499

NEWCASTLE
10 Kings Road
New Lambton NSW 2305
Australia
T: +61 2 4037 3200
F: +61 2 4037 3201

PERTH
Ground Floor, 503 Murray Street
Perth WA 6000
Australia
T: +61 8 9422 5900
F: +61 8 9422 5901

SYDNEY
2 Lincoln Street
Lane Cove NSW 2066
Australia
T: +61 2 9427 8100
F: +61 2 9427 8200

TOWNSVILLE
Level 1, 514 Sturt Street
Townsville QLD 4810
Australia
T: +61 7 4722 8000
F: +61 7 4722 8001

TOWNSVILLE SOUTH
12 Cannan Street
Townsville South QLD 4810
Australia
T: +61 7 4772 6500

WOLLONGONG
Level 1, The Central Building
UoW Innovation Campus
North Wollongong NSW 2500
Australia
T: +61 404 939 922

AUCKLAND
68 Beach Road
Auckland 1010
New Zealand
T: +64 27 441 7849

NELSON
6/A Cambridge Street
Richmond, Nelson 7020
New Zealand
T: +64 274 898 628