SOUTH32 Illawarra Metallurgical Coal

DENDROBIUM AREA 3B SWAMP REHABILITATION RESEARCH PROGRAM

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DOCUMENT REVISION LOG

Persons authorising this Plan

NAME	TITLE	DATE
Gary Brassington	Manager Approvals	March 2022

Document Revisions

Revision	Description of Changes	Date
IMC Document		
Draft	Original Document – draft for consultation	03/10/2013
Rev A	Draft incorporating agency feedback	19/11/2013
Rev 1.0	Submitted to DPIE	04/06/2014
Rev 1.1	Updated based on DPIE feedback 19/12/2014 and discussions	20/07/2015
Rev 1.2	Updated based on DPIE feedback 29/06/2014 and discussions	03/08/2016
Rev 2.0	Updated to address Condition 21 of the 3B SMP Approval	01/03/2022

Persons involved in the review of this Plan

Name	Title	Company	Exp (yrs)	Date
Cody Brady	Principal Approvals	South32	5	November 2021
Gary Brassington	Manager Approvals	South32	25	March 2022

1. INTRODUCTION

Dendrobium Coal Pty Ltd, a wholly owned subsidiary of South32 Ltd (South32), operates underground coal mining operations at Dendrobium Mine, located in the Southern Coalfield of New South Wales. The Dendrobium and Appin mines operate as Illawarra Metallurgical Coal (IMC). Longwalls from the Wongawilli Seam have been mined previously in Areas 1, 2 and 3A, with current operations in 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 section 75W of the *Environmental Planning and Assessment Act 1979* (EP&A Act) and required the submission of a comprehensive Environmental Assessment (Cardno 2007).

Conditional Approval for the modified project was granted 8 December 2008. The Dendrobium Development Consent requires a Swamp Impact Monitoring, Management and Contingency Plan (SIMMCP) subject to Schedule 3 Condition 6 and a Subsidence Management Plan (SMP) subject to Schedule 3 Condition 7.

Since the initial SMP and SIMMCP approval in February 2013, IMC have submitted several SMP applications and maintained a consolidated Area 3B SIMMCP to cover swamp impacts across the Area 3B mining area. The latest Area 3B SMP Approval for Longwall 18 (the final longwall proposed to be extracted in Area 3B at this time) is a consolidated document which contains conditions specific to each longwall in the Area 3B domain as well as general conditions.

Longwall 18 SMP Approval was granted by the Secretary 8 December 2020. Condition 21 of this Approval requires IMC to review its Swamp Rehabilitation Research Program (SRRP) and submit a report of the Program to the Secretary. The SRRP has been updated to address this condition and Table 1 below provides details of the updates.

Table 1 Swamp Rehabilitation Research Approval Conditions

Area 3B SMP Approval Conditions	SRRP Reference
20. The Applicant must prepare and implement a Swamp Rehabilitation Research Program to the satisfaction of the Secretary. This program must: a) be prepared in consultation with BCD, WaterNSW and DRE;	Section 3
b) be submitted by 31 October 2013 to the Secretary for approval;	
c) investigate methods to rehabilitate swamps subject to subsidence impacts and environmental consequences within Areas 3A and 3B, with the aim of restoring groundwater levels and groundwater recharge response behaviour to pre-mining levels;	Section 5

Area 3B SMP Approval Conditions	SRRP Reference
d) establish a staged field trial (for a 5-year duration or longer) for rehabilitation techniques at swamps that have been impacted by subsidence, commencing with Swamp 1b, including: • drilling a series of piezometers adjacent to targeted swamps to characterise groundwater levels and the bedrock fracture network; • undertaking electrical resistivity tomography surveys; and • undertaking a detailed evaluation of the success of the first stage of the trial, prior to the commencement of further stages;	Section 5.5 and Section 5.7
e) include the engagement of a suitably qualified, experienced and independent expert, who is approved by the Secretary in consultation with BCD, to prepare and submit a report to the Department and BCD on the local and regional impacts of mining at the mine on the Giant Dragonfly and the Littlejohns Tree Frog;	Section 5.8 & Section 5.9
f) include a trial of electrical resistivity tomography before and after the extraction of Longwalls 14 and 15 to detect changes in groundwater near the surface (including Swamps 13 and 14) and at deeper levels, with calibration against piezometer data over time;	Section 5.7
g) provide for the expenditure of at least $3.5 million over this period; and	Section 6
h) include a schedule for subsequent trials, development of work plans and ongoing reporting.	Appendix A
21. By 31 December 2021, the Applicant must review its Swamp Rehabilitation Research Program and submit a report of the Program to the Secretary which includes a) full reconciliation of funds invested;	Section 6
b) discussion of field trials and other activities undertaken;	Section 5
c) review of lessons learnt and summary of key findings; and	Section 5
d) consideration and discussion of any ongoing or additional research opportunities and commitments.	Section 5

2. OBJECTIVES

The purpose of this SRRP is to provide the framework of IMC's swamp research program and comply with Conditions 20 and 21 of the Area 3B SMP Approval.

The objectives of the SRRP are to:

- investigate methods to rehabilitate swamps subject to subsidence impacts and environmental consequences within Areas 3A and 3B, with the aim of restoring groundwater levels and groundwater recharge response behaviour to pre-mining levels;
- establish a staged field trial (for a 5-year duration or longer) for rehabilitation techniques at swamps that have been impacted by subsidence, commencing with Swamp 1b, including:
  - drilling a series of piezometers adjacent to targeted swamps to characterise groundwater levels and the bedrock fracture network;
  - undertaking electrical resistivity tomography surveys; and
  - undertaking a detailed evaluation of the success of the first stage of the trial, prior to the commencement of further stages;
- to prepare and submit a report to the Department and BCD on the local and regional impacts of mining at the mine on the Giant Dragonfly and the Littlejohns Tree Frog;
- include a trial of electrical resistivity tomography before and after the extraction of Longwalls 14 and 15 to detect changes in groundwater near the surface (including Swamps 13 and 14) and at deeper levels, with calibration against piezometer data over time;
- provide for the expenditure of at least $3.5 million over this period; and
- include a schedule for subsequent trials, development of work plans and ongoing reporting.

3. CONSULTATION

The Area 3B SMP Approval conditions require the SRRP to be prepared in consultation with the Biodiversity and Conservation Division (BCD) within the Department of Planning, Industry and Environment (DPIE), WaterNSW and the Resources Regulator. The SRRP is to be implemented to the satisfaction of the Secretary. A draft SRRP was provided to key Government Agencies (including BCD, WaterNSW and then Trade and Investment (T&I)) 3 October 2013 for comment. Submissions on the draft SRRP were provided by DPIE, T&I, BCD and WaterNSW. The Wollongong Office of T&I hosted a joint Agency workshop with IMC to discuss the SRRP. The workshop was held 16 December 2013 with the following agencies attending DPIE, BCD, WaterNSW and T&I.

This SRRP has been revised on the basis of the agreed outcomes from the workshop and taking the submissions into account as outlined in **Table 2**.

Table 2 Consultation for Dendrobium Area 3B Swamp Rehabilitation Research Program

Agency	Issue	Response	SRRP Reference
DPIE BCD WaterNSW	- No evidence of consultation	- A draft SRRP was provided to Government Agencies (including BCD, WaterNSW and T&I) 3 October 2013 for comment - Submissions on the draft SRRP have been provided (DPIE, BCD, T&I and WaterNSW) - Joint Agency workshop 16 December 2013 with DoPI, OEH, WaterNSW and T&I - Issues raised are addressed in the SRRP as outlined in Table 1	
DPIE WaterNSW	- A very basic overview of sealing rock fractures, injection grouting, knick point control and water spreading is provided - The program states that monitoring will be installed to assess rehabilitation results against pre- mining levels – monitoring should already be installed	- Detailed descriptions of the installed monitoring and proposed rehabilitation methods are provided in the SIMMCP - Additional detail has been included in the SRRP	Section 5
DPIE WaterNSW T&I	- The research program should outline a field trial and schedule where the methods are scientifically tested - Further detail needs to be provided with regard to either investigation of new techniques or the development of current techniques for swamp rehabilitation	- Field trials are proposed for Swamps 1A, 1B, 5 and 15B - Field trails will investigate sealing of rock fractures, injection grouting, knick point control, water spreading and restoring groundwater levels in swamps	Sections 5.5
DPIE	- The research program should lead to a peer-reviewed journal paper	- The research conducted by IMC can be published subject to South32 publishing rules	

Agency	Issue	Response	SRRP Reference
DPIE BCD WaterNSW	- The program should include an itemised budget of costs - Data collection to meet approval conditions should not be included unless such monitoring is directly informing a project under the SRRP - DP&E will advise the company of research expenditure protocols	- Indicative costs of the research program are provided - Data collection costs will only be included where such monitoring is directly informing a project under the SRRP	Section 5.2 Section 6
DPIE BCD WaterNSW	- Appendix 1 does not include a specific swamp rehab project - Suitable sites include: Swamps 12, 15B, 1A, 1B, and 5	- Specific projects have been included for Swamps 1A, 1B, 5 and 15B	Sections 5.2, 5.5, 5.6, 5.7, 5.8 and 5.9.
BCD	- OEH does not believe the research on Isotopic Assessment of Swamp Ecohydrology is relevant to swamp rehabilitation - Research on Height of Connective Fracturing has little ability to rehabilitate or restore impacted swamps - Pre-mining hydrology research to develop a water balance for a swamp has occurred - Much of the work on swamp geomorphology has already been done - If the research does not address fracturing under swamps it will not be successful – consider what techniques can be used to understand fracture networks under swamps	- The assessment of swamp ecohydrology has been removed from the SRRP. - Investigation into connected fracturing in strata above mining is critical for swamp rehabilitation. This program identifies the height of fracturing from the seam toward the surface and from the surface down to the constrained zone. - The design of any grouting must take the dimensions and conductance of these fracture networks into account otherwise rehabilitation of swamps will not be able to restore groundwater levels - Heights of connective fracturing from the seam to the constrained zone and from the surface to the constrained zone are being investigated. The most appropriate technology	Section 5.3 – 5.5

Agency	Issue	Response	SRRP Reference
		for these assessments will be researched - The assessment of pre-mining hydrology has been removed from the SRRP - The swamp geomorphology research has been removed from the SRRP	
BCD	- The SRRP should identify who is to undertake the trial	- The responsibilities under the SRRP are outlined in Section 9	Section 5 outlines parties engaged to undertake research
BCD	- Auditing and review of the SRRP should go through an external peer review process to ensure scientific rigour - Public access should be provided to ensure findings are available to inform and guide future mining	- The SRRP is subject to Independent Audit every 3 years, in accordance with Condition 6, Schedule 8, of the Consent - Reporting of SRRP results will be undertaken in accordance with Condition 5, Schedule 8 of the Consent	Sections 8 and 10
BCD WaterNSW	- Recommend establishment of a Research Program Steering Committee from the company, experts, government agencies and researchers - Consider other research and/or literature reviews e.g. Department of Environment	- The SRRP will be implemented as required by Condition 15 of the Area 3B SMP Approval - IMC will work cooperatively with research and industry partners, including Government Agencies	Section 7
DPIE	- SRRP to state that a minimum of $3.5 million dollars will be expended on the Program over a 5 year period	- Commitment to $3.5 million expenditure over the period of the SRRP	Section 6

4. STATUTORY REQUIREMENTS

IMC operates under a number of statutory approvals, licences, leases and permits granted under NSW and Commonwealth Legislation. The Area 3B SMP Approval requires the development and implementation of several Management Plans, including a SIMMCP under Condition 1 of the SMP Approval. Rehabilitation and research activities described in the SRRP will be undertaken in accordance with the Area 3B SMP Approval.

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

- Dendrobium Mining Lease CCL 768, Mining Lease 1510 and 1566;
- Environmental Protection Licence (EPL) 3241;
- Dendrobium Mining Operations Plan (MOP);
- Relevant Work Health and Safety approvals; and
- Any additional leases, licences or approvals resulting from the Dendrobium Approval.

In addition, supplementary approvals may be required from WaterNSW to access some areas and undertake works for activities within the Metropolitan Special Area.

5. SWAMP REHABILITATION RESEARCH PROGRAM

Detailed monitoring programs have been implemented to provide a basis for the design and implementation of any mitigation or remediation required. Monitoring provides key data when determining any requirements for mitigation or rehabilitation. Baseline data is compared with monitoring results during and following mining to determine any remediation that may be required.

A detailed description of the monitoring program installed in Area 3B is provided in the SIMMCP.

The preferred rehabilitation options are outlined in the SIMMCP. These options have been developed from rehabilitation programs in the Georges River and from swamp rehabilitation techniques used for non-mining related impacts in the Blue Mountains and other areas. The techniques proposed in the SIMMCP will be refined and/or modified to improve the likelihood of success based on the results of research proposed in the SRRP.

A program of research has commenced and will continue through the mining of Area 3B and be adaptive to results as the program is implemented. Previous research will support the proposed research initiatives into swamp rehabilitation (Sections 5.2 to 5.12 and Appendix 1). Research programs and projects undertaken by IMC will develop further understanding of the factors which influence swamp health and function, and how swamps have been changed due to mining and what rehabilitation methods may be required for swamp restoration.

Since the previous iteration of the SRRP, The Independent Expert Panel for Mining in the Catchment (IEPMC) noted that currently there is no proven method to rehabilitate swamps or evidence that swamps can be remediated (IEPMC 2019).

In line with correspondence from WaterNSW to DPIE (27 September 2019), the LW18 SMP Approval notes; previous requirements to implement a trial of directional drilling and grouting underneath targeted swamps have been removed from paragraph (d) of this condition. Therefore, research contributing to the SRRP has been focussed on quantifying impacts.

5.1 Subsidence Effects on Swamps

Subsidence is an unavoidable consequence of the longwall mining technique 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 streams and groundwater dependent ecosystems such as upland swamps.

There are two broad mechanisms by which subsidence could cause changes in swamp hydrology:

- The bedrock below the swamp cracks as a consequence of strains and water drains into the fracture zone. The extent and permanence of these changes relate to the size of the fracture zone (increase in porosity/storage) and whether the fractures are connected to a deeper aquifer, the mine workings or bedding shear pathway to the surface lower in the catchment.
- Tilting, cracking, desiccation and/or changes in vegetation health result in concentration of runoff and erosion which alters water distribution in the swamp.

The SRRP will investigate rehabilitation methodologies which mitigate the above two mechanisms.

Changes to swamp hydrology can result in environmental consequences. The likelihood and timing of these consequences relate to the size and duration of the effect. The environmental consequences which could relate to changes in hydrology include:

- Increased rates or frequency of erosion events.
- Increased frequency and extent of the organic components of the swamp soil burning during intense bushfires.
- Increased rates of species composition change and/or changes in vegetation communities.

5.2 Monitoring and Data Collection

Detailed monitoring programs have been implemented as described in the SIMMCP. The data collected from this program is to provide a basis for the management of swamp impacts, including the design and implementation of any mitigation or remediation required. IMC monitors upland swamps in and around mining operations. Three types of sites are currently monitored:

- “Swamp sites” – measured data include groundwater level, soil moisture; observations; photo points and vegetation health.
- “Water sites” – measured data include water quality parameters, pool water levels; photo sites; observations and surface water flow.

- “Ecology sites” – measured data include swamp size, flora and fauna abundance and diversity as well as the presence or absence of listed species; observations and photo points.

Comparison of data from post-mining and during mining to baseline conditions provides key data when determining any requirements for mitigation or rehabilitation. The costs of data collection to meet approval conditions will not be included in the costs of implementing the SRRP unless such monitoring is directly informing research for the SRRP, including the Water Balance Study (Section 5.6) and the Swamp Resistivity Research Project (Section 5.7).

Monitoring of shallow groundwater levels allows for the indirect measurement of water storage and transmission within the saturated part of hill-slope/upland swamp complexes. Shallow groundwater piezometers have been installed in a number of swamps within and around Area 3 (Figure 1 and Figure 2). Swamps 2, 7, 15a, 22, 24, 25, 33, 84, 85, 86, 87 and 88 have been instrumented as reference sites for shallow groundwater (Figure 3). Note that, Swamps 7 and 15a will be designated as impact monitoring swamps upon the extraction of Longwall 21 and Longwall 19 respectively.

This data is used to compare differences in shallow groundwater levels within swamps and hill-slope aquifers before and after mining. The shallow groundwater piezometer data is also compared with the Cumulative Monthly Rainfall Residuals (a key parameter for interpreting temporal soil and shallow groundwater data).

The piezometric monitoring directed at shallow groundwater levels is supplemented with monitoring of soil moisture profiles obtained by moisture probes. Probes are installed to a depth of 1.5 m with data loggers. The soil moisture probe data is compared with the Cumulative Monthly Rainfall Residuals. Comparisons of the Cumulative Monthly Rainfall Residuals against 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).

Pool water levels in swamps and associated streams are measured using installed benchmarks in impact sites and reference sites. Water level/flow gauges and data loggers are installed at key stream flow monitoring sites. Data has been collected since 2003 and has been compiled within monitoring and field inspection reports, End of Panel 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 as well as to measure the success of any rehabilitation aimed at re-establishing groundwater levels within swamps.

The installed monitoring program for the key research sites consists of:

Swamp 1A

- Piezometers - 01a_04ii, 01a_04iii

Swamp 1B

- Piezometers - 01b_02iii, 01b_02iv
- Soil moisture meter - S01b_02iii, S01b_02iv

- Flow monitoring site - DC13S1

Swamp 5

- Piezometers - 05_01, 05_04
- Soil moisture meter - S05_01, S05_08
- Flow monitoring site DCS2

Swamp 13

- Piezometers - 13_01
- Soil Moisture - S13_S01, S13_S02, S13_S03

Swamp 14

- Piezometers - 14_01, 14_02
- Soil Moisture - 14_01, 14_02

Swamp 15B

- Piezometers 15b-H1, 15b-H2, 15b-H3, 15b_39
- Soil moisture meter – S15b-H1, S15b-H2, S15b-H3, S15b_39
- Flow monitoring site SC10CS1

Reference sites

- Piezometers 02_01, 07_05, 07_06, 15a_03, 15a_04, 15a_07, 15a_12, 15a_15, 15a_18, 22_01, 22_02, 24_01, 25_01, 33_01, 33_02, 84_02, 85_01, 85_02, 86_01, 86_02, 87_01, 87_02, 88_01, 88_02
- Soil moisture meter S02_01, S07_05, S07_06, S15a_03, S15a_07, S15a_12, S15a_15, S15a_18 , 22_01, 22_02, S24_01, S25_01, S33_01, S33_03, S84_S02, S85_01, S85_02, S85_03 S86_01, S86_02, S86_03, S87_01, S87_02, S88_01, S88_02
- Flow monitoring sites C1, SCU

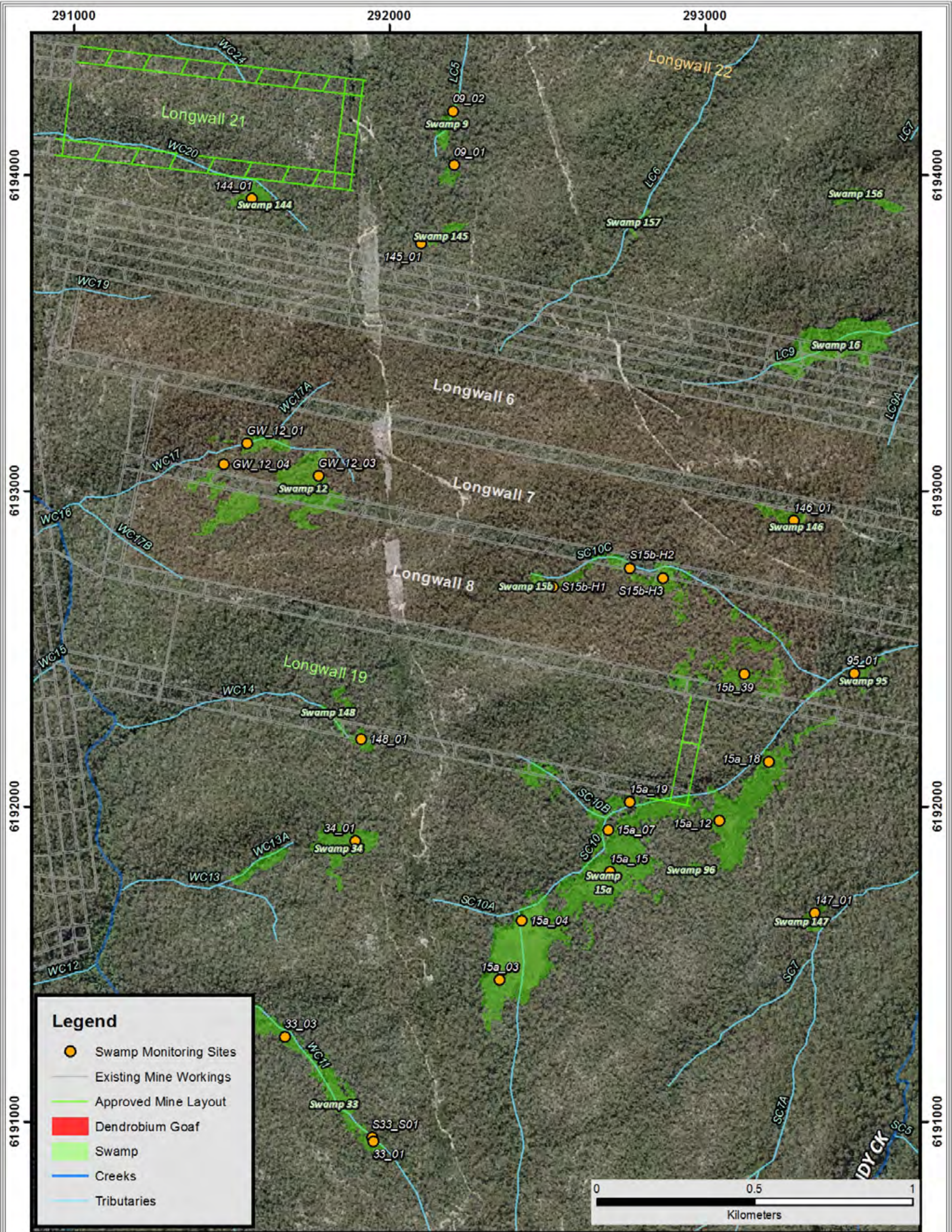


Figure 1
Area 3A - Swamp Monitoring Overview

Date: February, 2022
Author: B.Agland
Horizontal Datum
MGA - Zone 56

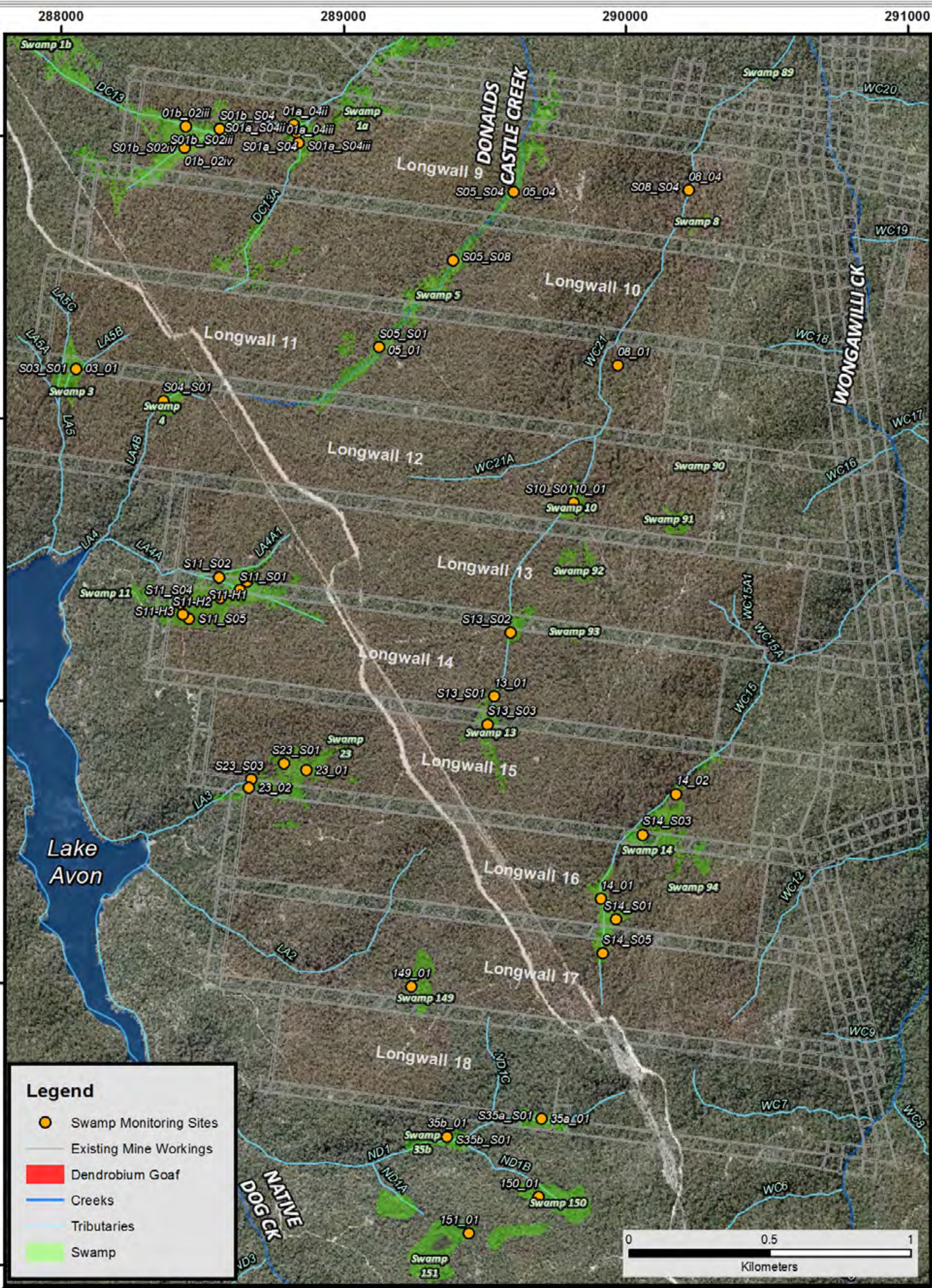
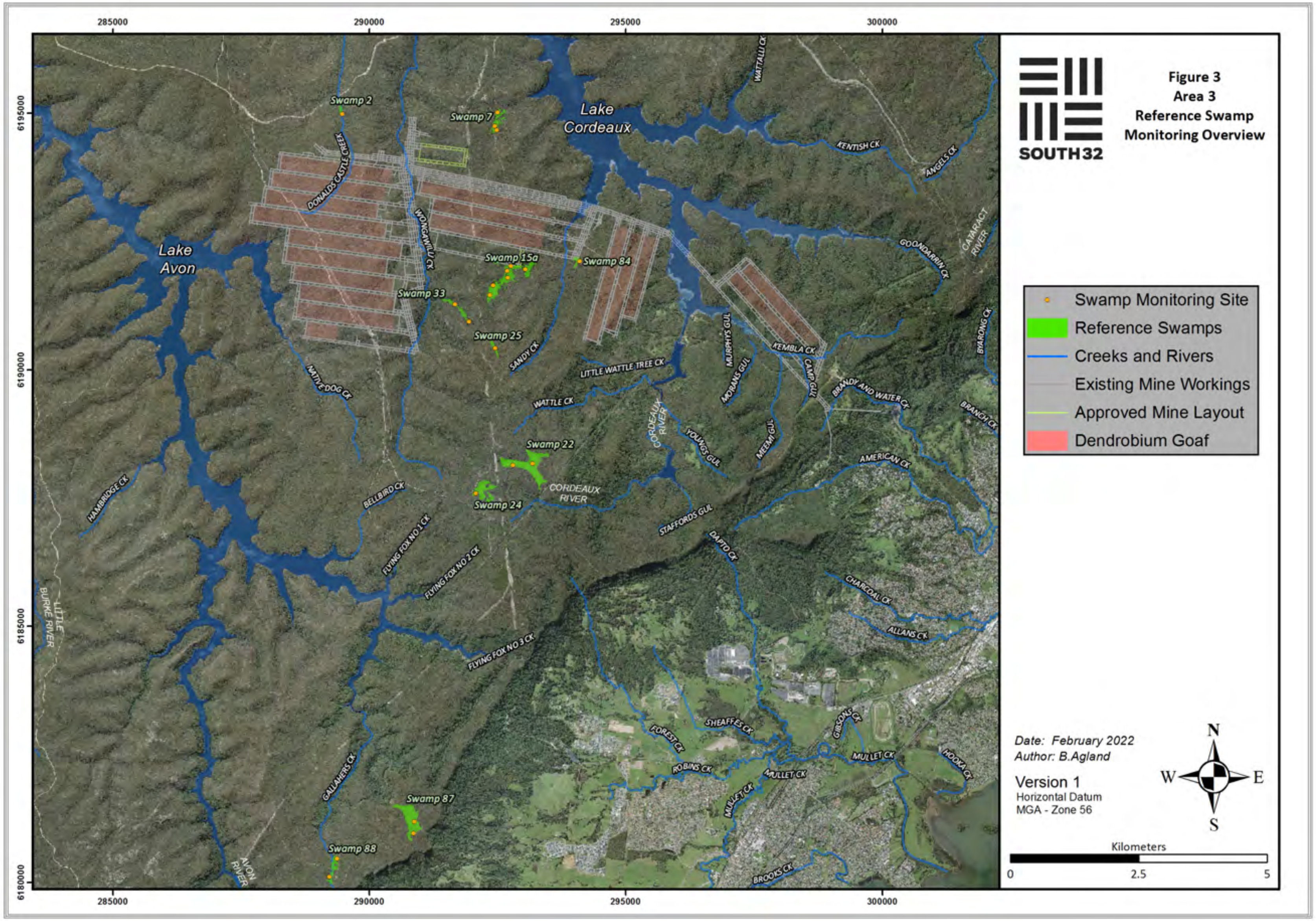


Figure 2
Area 3B - Swamp Monitoring Overview

Date: February, 2022
Author: B Agland
Horizontal Datum
MGA - Zone 56



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5.3 Height and Depth of Connective Fracturing

The project aims to investigate the connective fracturing above proposed longwall panels and the potential impacts on connected water systems, including swamps. This project researched the impact of Longwall 9 in Dendrobium Mine, Area 3B and has involved diamond core holes drilled at key locations to provide information on the following:

- Pre-mining hydraulic characteristics;
- Hydraulic conductivity of the fractured rock mass and connectivity of fractures using packer testing, down hole flow testing and cross-hole tracer tests.

The overall objective of this study is to characterise the groundwater system in the Triassic strata above proposed longwall mining operations, and specifically to identify inherent horizontal and vertical flow paths related to connected fractures and other flow paths, prior to mining. The study included repeat investigations after the longwall passed through the area, in the post-mining environment.

Understanding of the pre-mining, post-mining and after rehabilitation subsurface hydraulic behaviour and hydrogeologic conditions will be beneficial to determine if rehabilitation of a swamp is to be considered and the success of the rehabilitation.

5.4 Sealing of Rock Fractures

The sealing of rock fractures resulting from mine subsidence is addressed in the SIMMCP and the Area 3B SMP Approval Conditions. Where the bedrock base of any significant permanent pool or controlling rockbar within swamps is impacted by subsidence and there is limited ability for these fractures to seal naturally there is a requirement to seal them with an appropriate and approved 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 and a grouting trial is currently underway at Dendrobium Mine within WC21.

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.

5.5 Swamp 1b Hydrogeological Investigation

During 2018, IMC commissioned HGEO to conduct a hydrogeological investigation at Swamp 1b in accordance with Condition 20(d) of the Longwall 18 SMP Approval (formerly Condition 19(d) of the Area 3B SMP Approval).

Swamp 1b was partially mined under during extraction of Longwall 9 and Longwall 10 from March 2013. In order to characterise groundwater levels and the bedrock fracture network of Swamp 1b, six investigation boreholes were drilled outside the margin of the swamp to depths ranging from 59 m to 119.8 m. All holes were diamond cored, logged, tested and equipped with vibrating wire piezometers (VWPs) for ongoing groundwater. These works were completed in May 2018.

Key Findings

The swamp comprises up to 1.9 m of swamp sediment (unconsolidated sands and clays, organic - rich towards the surface) overlying weathered Hawkesbury Sandstone. Prior to mining at Area 3B, the swamp sediments were saturated most of the time, but may have desaturated during prolonged dry periods.

Shallow groundwater within the swamp was perched above groundwater in the underlying Hawkesbury Sandstone, but may have been feed by interflow from the regolith or perched horizons in the Hawkesbury Sandstone for days to weeks after rain events.

The extraction of Longwalls 9 and 10 resulted in ground subsidence of up to 2 m on the eastern and central part of Swamp 1b with the greatest subsidence observed near the swamp outlet.

Following the passage of Longwall 9 in March 2013, a piezometer located in the central part of the swamp shows a marked reduction in wetting frequency and an increase in groundwater recession rate, consistent with increased permeability and drainage in the swamp substrate.

Drilling investigations show that the swamp is underlain by Hawkesbury Sandstone, comprising mostly bedded and cross-bedded, fine- to coarse-grained sandstone with lenses of siltstone and claystone. Claystone horizons typically cannot be correlated with confidence between bores. Iron staining and banding is a common feature of the oxidised zone of weathering in the upper Hawkesbury Sandstone and reflects long-term groundwater movement and iron oxide precipitation in more permeable sandstone units and fractures.

Structural logging identifies two main populations of joints: those parallel to bedding, and inclined joints with an average dip of 63° to the northeast. Bores located above extracted longwalls show abundant open fractures, both parallel and inclined to bedding. Down-hole video surveys indicate water ingress via open fractures and drainage of water down the bore walls some 10 m to 20 m above the measured standing water levels.

All boreholes located above the goaf footprints of Longwalls 9 and 10 show evidence for enhanced strata permeability compared with pre-mining conditions, with some or all tests from each bore plotting outside the P10-P90 range. However, permeability of strata is not significantly enhanced beyond the goaf margin at these locations, with the permeability of strata at S2401 and S2406 (540 m and 34 m outside the Longwall 9 goaf footprint) plotting within the P10-P90 range for pre-mining Hawkesbury Sandstone.

Monitoring of groundwater levels (piezometric head) indicate depressurised conditions at the lower-most sensor in three out of four holes located above longwall goaf footprints, indicating a decline in groundwater levels in the upper Hawkesbury sandstone since prior to mining in Area 3B. There is no evidence for a significant decline in groundwater levels at S2401, located 540 m from the goaf footprint, compared with pre-mining groundwater levels. The groundwater level at S2406, located 34 m from the Longwall 9 goaf footprint is likely to have declined since mining.

5.6 Water Balance Study

IMC is sponsoring a four-year upland swamp water balance study, conducted by University of New South Wales Water Research Lab (UNSW WRL), within the Metropolitan Special Area. Potential Temperate highland peat swamps on sandstone (THPSS) sites were inspected via onsite investigations to determine if they would be suitable sites for future investigations. Sites were analysed based on proximity to historical, current and future longwall extractions, climatic variability (rainfall, evaporation), access, and physical characteristics (e.g., slope, shape, size, catchment location, etc.). Field reconnaissance was undertaken to visually inspect each nominated site. Three swamps within the Metropolitan Special Area (Avon and Cordeaux catchments) were chosen to be included in the study:

- Swamp 14
- Swamp 7
- Swamp 87.

The primary aim of this study is to calculate the water balance within the surficial sediments of multiple THPSS before and after longwall mining, employing a Before-After-Control-Impact (BACI) design. The project has commenced with reporting scheduled to be completed in the fourth year.

5.7 Swamp Resistivity Research Project

The swamp resistivity tomography research project is an ongoing study that commenced in 2018, that addresses Condition 20(f) of the Longwall 18 SMP approval (**Table 1**). The aim of using repeated surveys was to understand the changes in moisture content in the swamp and shallow sandstone as a result of underground mining. This was undertaken by tracking the soil and rock resistivity changes on the same transects across and along the swamp extent.

Electrical Resistivity Imaging (ERI) technique

The electrical resistivity imaging (ERI) technique used in this study is based on the measurements of physical rock and soil properties, and electrical resistivity. The measured apparent electrical resistivity (as measured by potential difference between sets of electrodes for a known current) depends on soil moisture content, salinity, porosity and temperature. Changes in soil moisture can therefore be tracked by undertaking several resistivity measurements if there is a good calibration between the electrical resistivity and the measured soil moisture. Soil moisture and saturation are considered key parameters for this study.

Key Findings

Swamp 1B

A total of ten resistivity transects were surveyed along and across Swamp 1B. One longitudinal and transversal transect perpendicular to the drainage direction of the swamp were completed both upstream and at the western edge of the swamp. Within the central part of the swamp, the transects were set such that they passed near the location of existing moisture probes and piezometers.

Ten resistivity surveys were completed at upgradient, western, central and downgradient parts of the Swamp 1B. All surveys were undertaken in June/July 2019 approximately 6 years after the swamp was mined beneath.

The changing climate conditions are observed in the response of soil moisture and shallow swamp piezometers, with a quick increase in saturation and rise in groundwater levels with rainfall events. However, the decline in groundwater levels is much faster compared to the reduction in soil moisture. This is particularly observed in the central part of the swamp.

Typically, the deeper layers have resistivity exceeding 1600 Ohm.m indicating dry conditions. The exceptions in Swamp 1B are the upgradient transect R21 and downgradient transect R17. At R21 the resistivity results point to a saturated zone at around 8 m depth with resistivity in the range from 0-800 Ohm.m. This is in agreement with 6 m of saturation and groundwater level at 402 mAHD observed in the uppermost sensor of S2401. Similarly, at R17, located over the surface expression of the channel, a wetter zone was identified at 5-15 m chainage along the transect, which correlates with the location of the channel. The wetter zone is modelled at 5-10 m depth. There was no water ponding or flow in the channel at the time of the survey.

The longwall mining under the swamp likely resulted in a decrease of groundwater levels and loss of saturation in the central and downgradient part of the swamp, which is supported by multiple measurements and resistivity survey. However, the upgradient part of the swamp remains partially saturated as confirmed by ongoing wetting of the surface layer, identified wetter zones between 5-10 m depth and presence of groundwater in shallow sandstone. It is recommended that one additional survey in similar climate conditions is undertaken to ensure that the results are consistent.

Swamp 13

A total of six resistivity transects were surveyed along and across Swamp 13. Three longitudinal transects (two adjoining) and three transects perpendicular to the drainage direction of the swamp were completed both upstream, across the central part and at the downstream part of the swamp.

Four resistivity surveys were completed at different time periods over the same transects in Swamp 13. All surveys are considered to be post mining given that they were completed when the longwall was within 400 m distance from the swamp (DoP, 2008). However, two surveys were completed before the swamp was directly mined under and two were completed after. The resistivity transects targeted upper, central and lower parts of the swamp. The climate conditions for all surveys were characterised by dry weather, with the exception of the third survey where above average rainfall was recorded prior to the survey. Although this does not allow direct comparison with other surveys, it enables the assessment of change and tracking of moisture following rainfall periods.

Two distinct layers are evident in the resistivity data: a surficial layer several metres thick sharply overlying a layer with different physical properties (sandstone).

There is no standing groundwater within the swamp, and the groundwater level in sandstone downgradient of Swamp 13 is below at least 386 mAHD. This interpretation is based on the hydraulic gradient from VWPs at S2408 and S2409 in shallow sandstone. This suggests that the swamp and the upper sandstone horizons are now unsaturated.

The surficial layer within the swamp responds to soil moisture changes with resistivity increasing as saturation decreases and is directly related to rainfall and evaporation. This is further supported by the change in soil moisture content with the average of 20% volumetric water content /10 cm soil. The effect of rainfall following wetter periods and evaporation following drier weather periods within the top 2 m is observed in all transects.

Based on the survey results the lower (downgradient) part of the swamp is drier compared to the upper and central areas. This is also supported by the faster soil response to wetting and drying conditions compared to the upgradient and central parts of the swamp.

The change from first to fourth survey within 2-5 m of the surface indicates that wetting has occurred as indicated by a decrease in resistivity. This wetting is possibly due to the rainfall in March 2019. However, beneath this shallow zone drying has occurred as inferred by an increase in resistivity, likely due to longwall induced fracturing.

This change in moisture distribution with depth reflects the pattern of percolating moisture from past rainfall events. As a result, it can be inferred that rainfall continues to have an important role in swamp soil moisture, irrespective of the fracturing resulting from longwall mining impacts.

It is also possible that the decrease in resistivity is due to lateral moisture distribution promoted by sub-horizontal layering of strata.

Swamp 14

A total of eleven resistivity transects were surveyed along and across Swamp 14. Six longitudinal transects (two adjoining) and six transects perpendicular to the drainage direction of the swamp were completed both upstream, across the central part, and at the downstream part of the swamp.

Eleven resistivity surveys were completed in Swamp 14 over the same transects before and after Swamp 14 was mined beneath (the upgradient section of Swamp 14 was not yet mined beneath during the second post-mining survey) in the period from 2018 to 2021. Considering the longitudinal north-south extent of the swamp, the undermining of the lower northern part occurred from late 2019 to 2020, while the undermining of the central part occurred in second half of 2020 and early 2021. The proximity of Longwall 17 to the upgradient part of the swamp indicates that during mid to late 2021 the mining beneath this part of the swamp and relevant impacts are likely to be observed.

Two surveys were completed before the swamp was directly mined beneath. The third survey was completed within the 400 m distance from Longwall 15 passing under the downgradient (northern) part of the swamp. The fourth was undertaken at the approach of Longwall 17 extraction and within the 400 m Risk Management Zone (RMZ) from Longwall 17 undermining the upper (southern) part of the swamp. The resistivity transects targeted upper, central and lower parts of the swamp. The climate conditions for pre-mining surveys were characterised by a wetter first survey and drier second survey. The first post-mining survey was undertaken after a 6 month dry period followed by significant rainfall in February 2020 and the second post-mining survey was undertaken after a wetter period during the first half of 2021. The post mining survey enables the assessment of change and tracking of moisture following rainfall periods. Soil moisture and piezometer reading data was used to verify the findings.

Two distinct horizons are evident in Swamp 14 as observed from the resistivity data: a surficial layer several metres (up to 2 m generally) thick sharply overlying a sandstone layer with different physical properties.

The resistivity of sandstone as observed at the outcrop was around 1000 Ohm.m. The deeper swamp horizons and layers beneath the swamp were verified on this basis.

The differentiation between the upper and lower part of SW14 identified in the previous survey (2020) is now further confirmed based on the most recent survey. The differentiation based on saturation is due to undermining of the downgradient part of the swamp in 2019/2020 and undermining of the central part during 2020/2021.

The shallow groundwater level was recorded at all piezometer locations and the saturation was evident with the relatively high soil moisture content at around 1 m depth in the upgradient (southern) part of the swamp. This is supported by low resistivity measured at the upper horizon at most transects. This suggests that the upper swamp horizon is now partially saturated due to high rainfall events. High saturation is a reflection of higher rainfall conditions preceding the survey. However, the lower horizon is becoming increasingly drier (higher resistivity) in particular in the central and downgradient part of the swamp.

Pre-mining, the surficial layer in the central part of the swamp responded slowly to soil moisture changes with resistivity increasing as saturation decreased. This response was directly related to rainfall and evaporation. The first post mining survey (2020) indicated that the conditions in the central part of the swamp had not changed significantly after the downgradient part of the swamp was mined beneath by the progress of Longwall 15. This is evident in slow recharge following rainfall and slow recovery back to equilibrium and supports the understanding that there is shallow groundwater contribution in this area which maintains the water levels (in addition to rainfall). Further evidence for groundwater contribution in the upper part of the swamp is observed in the minor change in soil moisture content with the average of 35% volumetric water content at 1m to 1.2 m deep soil. However, during the second post mining survey further loss of swamp water retention capacity is observed in the upper part of the swamp. While the upper horizon was saturated during the last survey, the drying now occurs much quicker and the overall soil moisture content is lower. In the upgradient part of the swamp, lateral groundwater contribution promoted via sub-horizontal layering of strata remains the main contributor to the overall swamp moisture. However, in the downgradient part this lateral contribution no longer occurs with evidence of quick wetting and drying.

Groundwater in the downgradient part of the swamp responds very differently post-mining compared to the pre-mining period. The soil moisture saturation of around 30% volumetric soil water content (1 to 1.2 m depth) pre-mining appears to have stabilised at 8-18% volumetric soil water content (1-1.2 m depth) post-mining with sharp and quick response to rainfall. This indicates rapid recharge and drying with no retention of moisture during drier weather periods. Based on the survey results, the lower (downgradient) part of the swamp is now drier compared to the upper areas and compared to previous survey. This is supported by the faster soil response to wetting and drying conditions compared to the upgradient parts of the swamp and drier (higher resistivity) conditions at a depth of >2 m below surface.

This change in moisture distribution with depth reflects the pattern of percolating moisture from current and past rainfall events. As a result, it can be inferred that rainfall continues to have an important role in swamp soil moisture. However, the moisture is quickly lost from the surface to deeper horizons, exposing the upper layer to drier conditions.

The second post mining survey provides an important qualitative indication of the long-term groundwater contribution to the swamp compared to pre-mining conditions.

While the first post mining survey was undertaken after the downgradient part of the swamp was mined beneath and the second immediately after the upgradient part was mined beneath, the results do not provide the longer-term conditions in the swamp following mining. Given that the more recent survey was undertaken within the 400 m RMZ for Longwall 17 and just before the upgradient part of Swamp 14 was mined beneath, an additional survey is required and recommended (in 1-1.5 years' time) to understand the long-term impact given that new fractures may seal over time.

Monitoring data from soil moisture probes and piezometers in the swamp have enabled verification of the resistivity surveys and assisted in understanding the swamp system. Higher rainfall continues to provide moisture to the swamp sediments irrespective of the impact from mining. The swamp soil has demonstrated an ability to temporarily capture and perch rainfall runoff even if subsoil is unsaturated due to mining impacts. However, rapid drying conditions after rainfall, in particular at the downgradient part of the swamp, are significant and could lead to changes in vegetation and peat soil integrity resilience to future bushfires and drought and support for ecosystems. In addition, increased loss of moisture retention capacity in the upper horizons is presently significant in Swamp 14.

There is a need to confirm the long-term impact on Swamp 14 after conditions have stabilised and mining completed.

5.8 Littlejohn's Tree Frog Research Program

In 2017, the University of Newcastle's (UoN) Conservation Science Research Group was commissioned by IMC to undertake research to determine the impact longwall mine subsidence may be having on *L. littlejohni* populations occurring in the Dendrobium mine-lease areas. The project addresses Condition 20(e) of the Longwall 18 SMP approval (Table 1).

Prior to this program, little was known about *L. littlejohni*'s ecology. This lack of ecological baseline information, combined with the frog's rarity and potential for high variability in subsidence-caused habitat changes, made it difficult to predict the impacts that longwall mine subsidence will have on the population within the mining area or the species as a whole. Surveys were conducted within the Dendrobium mine-lease area on the Woronora Plateau and across the protected areas control sites, Dharawal National Park, Watagans National Park, and Parma Creek Nature Reserve.

Therefore, the key aims of the project was to:

1. Quantify the area of potential breeding habitat for the species across the Dendrobium mine lease and produce a predicted habitat model using species habitat and quantitative population viability models.
2. Identify the occupied area of breeding habitat within the Dendrobium mine lease.
3. Present pre-mining and post-mining data on presence, breeding status and abundance.
4. Based on existing information on impacts following mining, extrapolate outcomes for the remainder of frog habitat across the mining domain under future mining scenarios.
5. Consider the impact of water quality (e.g. iron staining) and drought (complete drying of potholes) on the local and regional frog populations under future mining scenarios.

Key Findings

This study identified a substantial amount of ecological and natural history data on *L. littlejohni*, which has helped shape an understanding of how this species is affected by longwall mine subsidence.

L. littlejohni breed in ponds or streams with little to no flow, in the absence of fish, with low salinity, and at a maximum pond size of 30,500 m2 and <2 m depth. They breed nearly year-round, with less breeding occurring in the peak of summer. *L. littlejohni's* genetic diversity is low with little geneflow or dispersal between survey populations identified by the research to date.

Low diversity may be driven by the species' low rates of dispersal, although individuals on occasion do move long distances across the mine-lease area. In terms of longwall mining impact, mined under streams contained fewer pools and fewer *L. littlejohni* adults.

Pools within mined-under sites were smaller and more ephemeral compared to control sites and contained fewer tadpoles. Consequently, while there was still evidence of some breeding and occupancy in mined-under streams – abundance was greatly reduced and breeding limited.

In sites where all pools had dried and there was no recovery in water retention, no *L. littlejohni* were observed.

No *L. littlejohni* tadpoles were observed in pools that were impacted with iron-flocculent staining, and controlled laboratory experiments showed that iron-flocculent is a readily absorbed source of damaging concentrations of metals such as iron and manganese.

5.9 Giant Dragonfly Research Project

IMC commissioned Invertebrate Identification Australia to conduct the Giant Dragonfly (*P. gigantea*) Research Project. The aim of the Project is to determine the local and regional impacts of mining at Dendrobium mine on *P. gigantea*, which is listed as endangered in NSW under the Biodiversity Conservation Act, 2016 (BC Act), with habitat loss and degradation identified as the main threats to the species. The Project addresses Condition 20(e) of the Longwall 18 SMP Approval (**Table 1**).

Since 2012 monitoring surveys for *P. gigantea* have been undertaken in Dendrobium Area 3B as part of the mining operations in this area. The work undertaken from late 2018 to the beginning of 2020 has contributed to identifying the distribution of local and regional populations of *P. gigantea* by correlating all records from online databases with all museum records, surveying new and existing locations, conducting the initial mark-recapture surveys, collecting samples for morphological analysis and collecting samples for DNA analysis and surveying new swamps. The study has also included the continuing monitoring and characterisation of impacted and non-impacted swamps of known populations.

Observations

The swamps considered to have suitable habitat for *P. gigantea* had the following characteristics:

- a high groundwater level with permanent wet areas that could include active soaks/seepage zones;
- exposed pools and streams evident during the dry periods and a deep, moist peat layer;
- usually contained characteristic saturated soil vegetation, such as Banksia robur, Melaleuca sp, Gahnia sp, Lomandra sp and the pouched Coral Fern (Gleichenia dicarpa); and

- typically have an associated population of burrowing crayfish.

The swamps where larger number of *P. gigantea* were observed, characteristically contained exposed pools that could be accessed aerially by the females. Females were usually located in close proximity to these pool and seepage zones whereas the males tended to move much greater distances away from these locations, presumably in search of females. Swamps that had overhanging vegetation covering the pools or streams usually recorded only single sightings and are likely fly-through animals only or no sightings were recorded; even at locations that had previously recorded large numbers of animals.

The swamps that had been impacted by mining operations appeared dry throughout the peat layer and lacked visible surface water, including deep pools, that intersected the wetlands and in the discharging watercourses below the swamps (Swamps 1a, 1b and 11). A number of these swamp streams originally contained deep pools and large populations of crayfish as demonstrated by the large number of burrows. The critical factor governing the presence of *P. gigantea* is the permanent shallow groundwater level. Once the groundwater level drops below the depth of the larval burrows (> 70 cm) and the peat dries the habitat and potentially population in a specific swamp is lost.

Project Plans for Year 3

- There are a number of swamps that have not been surveyed, particular around the southern area of the Woronora Plateau that will be included in the next round of survey.
- Targeted surveys in swamps of known *P. gigantea* presence to collect DNA samples and conduct a mark recapture program over the summer flying period.
- All other areas outside of the Dendrobium swamps could not be accessed due to the 2019-20 bushfires; no additional DNA samples could be collected in this fly season. The mark/recapture program will continue in swamps in the Dendrobium area.
- Identify swamps within the area of operations likely to have the highest conservation value for *P. gigantea*; and greatest resilience to groundwater impacts in order to prioritise swamps of positive occurrence for management.

6. EXPENDITURE

Research expenditure will be tracked and reported throughout the program as directed by DPIE. Detailed costing for the research detailed in Section 5 will be provided to DPIE. Cost estimates for the SRRP are provided below (see Table 3). In accordance with Condition 20(g) of the Longwall 18 SMP Approval, IMC will allocate the remaining funds, to a total of $3.5 million, once opportunities for future research have been identified and evaluated.

Table 3 Summary of SRRP expenditure.

Project Task	Cost
Connective Fracturing Research Project	
Core logging	$13,200.00
Drilling costs	$275,000.00
Drilling water and fines recovery	$68,020.00
Flow and tracer tests	$20,510.00
Geophysics	$33,500.00
Packer testing	$16,000.00
Research design, study, data analysis, interpretation, and reporting	$310,000.00
Sub total	**$736,230.00**
Monitoring and Data Collection	
Supply and install piezometers (refer to Section 5.2)	$111,000.00
Soil moisture installation (refer to Section 5.2)	$76,000.00
Data collection and maintenance (estimated at $4000 per month from 2016 to 2022)	$336,000.00
Sub total	**$523,000.00**
Swamp 1b Hydrogeological Investigation	
Drill rig mobilisation	$36,000.00
Drill rig cost	$86,400.00
Site access development for drill rig	$30,000.00
Environmental controls, site clean-up and restoration	$12,000.00
Supervision and site vehicle	$21,000.00
Geophysical, packer testing, core logging	$60,000.00
Supply and install piezometers	$24,000.00
Analysis and Reporting	$9,360.00
Sub total	**$278,760.00**
UNSW Swamp Water Balance Study	
Year 1	$25,000.00
Year 2	$100,000.00
Year 3	$125,000.00
Year 4	$125,000.00
Year 5	$125,000.00
Sub total	**$500,000.00**

Project Task	Cost
Swamp Resistivity Research Project	
Swamp 13	$32,400.00
Swamp 14	$65,440.00
Swamp 14 post mining	$66,590.00
Swamp 1B	$45,190.00
Swamp baseline surveys	$86,460.00
Sub total	**$296,080.00**
Littlejohns Tree Frog Research Project	
Year 1	$179,000.00
Year 2	$179,000.00
Year 3	$179,000.00
Sub total	**$537,000.00**
Giant Dragonfly Research Project	
Year 1	$62,470.00
Year 2	$134,300.00
Year 3	$78,000.00
Sub total	**$274,770.00**
Grand Total	**$3,145,840.00**

6.1 Height and Depth of Connective Fracturing

Research into the constrained and surface zones within the Hawkesbury Sandstone are of relevance to mining impacts and rehabilitation of swamp features. Research related to hydraulic conductivity of the fractured rock mass and connectivity of fractures (post mining) specifically within the Hawkesbury Sandstone (only) will be included within Condition 15 activities and expenditure requirements.

A number of novel approaches for assessing potential impacts to groundwater systems and connected ecosystems were researched as part of this program. IMC engaged Parsons Brinckerhoff to develop the research design, assist with field work and provide detailed interpretation of the results. The scope for Parsons Brinckerhoff includes best practice research design with outcomes capable of being published in appropriate peer reviewed journals.

The connective fracturing research expenditure can be categorised into the following work packages:

- Drilling costs - $275, 000
- Drilling water and fines recovery - $68,020
- Geophysics - $33,500
- Packer testing - $16,000
- Core logging - $13,200
- Flow and tracer tests - $20,510

- Research design, study, data analysis, interpretation and reporting - $310,000
- The cost specifically for the Hawkesbury Sandstone post mining components of the research only is $736,230.

6.2 Monitoring and Data Collection

The costs of data collection to meet approval conditions will not be included in the costs of implementing the SRRP unless such monitoring is directly informing research for the SRRP, including the Water Balance Study (Section 5.6) and the Swamp Resistivity Research Project (Section 5.7).

Monitoring has been installed to investigate whether rehabilitation would contribute to the restoration of groundwater levels and groundwater recharge behaviour. This monitoring data is a key component of the proposed research. The monitoring and data collection expenditure can be categorised into the following work packages:

- Supply and install piezometers into swamp sediments ($3,000 per piezometer) - $3,000 per site
- Supply and install soil moisture probe into swamp sediments ($2,000 per piezometer) - $2,000 per site
- Piezometer and soil moisture data collection, maintenance and data administration (37 piezometers and 38 soil moisture probes) - $4,000 per month

Piezometer and soil moisture sites relevant to the SRRP are noted in Section 5.2. Expenditure reporting in Table 3 has been calculated based on these sites and a monitoring period of 7 years (2016 through 2022).

6.3 Swamp 1b Hydrogeological Investigation

Cost for the Swamp 1b Hydrogeological Investigation are listed in Table 3. The expenditure can be categorised into the following work packages:

- Drill rig mobilisation - $6,000 per site
- Site access (for drill rigs only - if additional to grouting/erosion control sites) - $5,000 per site
- Environmental controls, site clean-up and restoration (for drill rigs only - if additional to grouting/erosion control sites) - $2,000 per site
- Supervision and site vehicle (for drill rigs only - $700 per day) - $3,500 per site
- Drilling to install piezometers (including drilling water and fines recovery) - $14,400 per site
- Geophysics, packer testing, core logging, flow and tracer tests - $10,000 per site
- Supply and install piezometers into Hawkesbury Sandstone ($2,000 per piezometer) - $4,000 per site

- Analysis and reporting - $9,360

6.4 Swamp Water Balance Study

IMC commenced funding a UNSW Swamp Water Balance Study in 2020. Funding for the project is summarised in Table 3.

6.5 Swamp Resistivity Research Program

IMC commenced funding the swamp resistivity tomography research project in 2018. Funding for the project is summarised in Table 3.

6.6 Littlejohn's Tree Frog Research Program

The Littlejohn's Tree Frog research program commenced in 2017. Funding for the project is summarised in Table 3.

6.7 Giant Dragonfly Research Program

Year 1 of the study included the collection of the following data:

- Counts of individuals and sexes from a single population.
- Define the physical characteristics of the preferred swamp habitats of the species including the natural/pre- development characteristics of the groundwater conditions through the monitoring of the swamp's groundwater levels, groundwater chemistry and vegetation communities.
- Conduct a morphological examination of variability of *P. gigantea* across its range using collected and museum specimens.
- Conduct initial genetic analysis of collected specimens.

7. RESEARCH AND INDUSTRY PARTNERS

IMC will work cooperatively with research and industry partners, including State and Commonwealth Government Agencies. This SRRP is to be prepared in consultation with BCD and WaterNSW. Related research and literature reviews on upland sandstone swamp rehabilitation will be considered in the design and implementation of the research included in the SRRP.

The Australian Coal Association Research Program (ACARP) was formed by the Australian Coal Association to develop and adopt technology and mining practices that improve the industry.

Industry funding for this program is reviewed and considered on a five-year cycle. Research programs are developed and prioritised by technical committees responsible for project selection. IMC is represented on the ACARP Underground Committee and actively supports research projects investigating the management of subsidence impacts in the Southern Coalfield. Research into the impacts of subsidence on upland swamps at Dendrobium Mine has received considerable funding through this program. IMC's investment in research will be leveraged with this and other sources of additional funding to optimise the results for IMC, the industry and other stakeholders.

8. REVISION AND REVIEW

The SRRP will be subject to regular auditing and review and be made available to relevant people within IMC.

The SRRP will be subject to an independent annual audit and the Independent Environmental Audit every 3 years from December 2011, in accordance with Condition 6, Schedule 8, of the Dendrobium Development Consent.

In accordance with Condition 8, Schedule 8, of the Dendrobium Development Consent, within three months of submitting the audit report to the Director-General, the review (and if necessary, revision) of the strategies/plans/programs required under the consent is to be undertaken.

9. ROLES AND RESPONSIBILITIES

Statutory obligations applicable to Dendrobium operations are identified and managed via an online compliance management system.

The overall responsibility for the implementation of this SRRP resides with the Principal Approvals. Responsibilities for environmental management in Dendrobium Area 3 and the implementation of the SRRP are outlined below.

Table 4 Roles and Responsibilities for Dendrobium Area 3B Swamp Rehabilitation Research Program

Role	Responsibilities & Accountabilities	Authorities
Manager Approvals	• Ensure that the IMC Approvals Team is adequately resourced to effectively implement the SRRP	• Make or authorise changes to the SRRP to ensure compliance with the SMP Approval and/or Consent • Liaise with Government authorities in relation to the SRRP
Principal Approvals	• Implement research projects required by the SRRP to a high standard that is consistent with company and government expectations • Develop research projects related to swamp rehabilitation for inclusion in the SRRP • Measure success of rehabilitation methods and trials against the key	• Undertake Environmental Assessments and gain appropriate Approvals for research projects • Liaison with Government on the progress of research projects • Reporting on the implementation and

Role	Responsibilities & Accountabilities	Authorities
	objective of restoring groundwater levels and recharge response • Provide biannual updates of research expenditure to the Department • Coordinate independent annual audits of the SRRP with recommendations for subsequent trials and ongoing actions	management of the SRRP to Government authorities • Authorise persons as suitably qualified to undertake work under the SRRP
Superintendent Exploration	• Implement research projects required by the SRRP to a high standard that is consistent with company and government expectations • Develop research projects related to swamp rehabilitation for inclusion in the SRRP	• Undertake Environmental Assessments and gain appropriate Approvals for research projects • Liaison with Government on the progress of research projects • Reporting on the implementation and management of the SRRP to Government authorities
Technical Experts	• Conduct the roles assigned to them in a competent and timely manner to the satisfaction of the Principal Approvals and formally provide expert opinion as requested • Converting monitoring and research data into analytical documents that can be published for wider application	• Authorise technical reports

10. ACCESS TO INFORMATION

In accordance with Condition 11, Schedule 8 of the Development Consent, IMC will have the approved SRRP publicly available on its website: http://www.south32.net/home

Annual reporting of SRRP results will be through established mechanisms required by the Development Consent, including the AEMR (required under Condition 5, Schedule 8), which is available on the South32 website. The research conducted by IMC can be published subject to South32 publishing rules. This includes efforts to convert monitoring and research into analytical documents that can be published for wider application.

11. REFERENCES

Independent Expert Panel for Mining in the Catchment (IEPMC), 2019, 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

APPENDIX A: RESEARCH PROJECTS PREVIOUSLY SUPPORTED, CURRENTLY UNDERWAY AND PLANNED BY IMC

Table 5 Research projects previously supported, currently underway and planned by IMC

Research Project	Overview	Timing
Subsidence Modelling and Predictive Tools		
Incremental Subsidence Profile Model	The Incremental Subsidence Profile Model was developed by MSEC (formally Waddington Kay and Associates) for the Southern Coalfield. IMC contributed significant amounts of the empirical data to calibrate the model	Completed in the 1990's this model is routinely updated based on subsidence survey data provide
Upsidence and Closure Model	The ACARP Upsidence and Closure Model was developed by MSEC for the Southern Coalfield. IMC contributed significant amounts of the empirical data to calibrate the model	Completed in 2001 this model is routinely updated based on subsidence survey data provided by IMC
Effects of Geology on Upsidence and Closure Movements and Impacts in Valleys	This ACARP C18015 project aims to provide more appropriate upsidence and closure predictions and impact assessments near valleys, provide probabilistic predictions and improve the accuracy and level of confidence in predictions. IMC is a significant contributor to this project, supplying the majority of empirical data being analysed	Completed in 2014 this model is routinely updated based on subsidence survey data provided by IMC
Anomalous Subsidence Review	A review of known anomalous events over the last 20 years from IMC mining areas and research into the mechanisms contributing to these events	Completed in 2014
Groundwater Response to Mining		
Reducing the Impact of Longwall Extraction on Groundwater Systems	The objective of this project was to develop and demonstrate an integrated hydrogeological assessment approach with supporting tools, and to enhance industry's ability to predict the hydrogeological response to longwall mining.	Completed in 2012

<table>
<tr><th>Research Project</th><th>Overview</th><th>Timing</th></tr>
<tr><td></td><td>IMC contributed significantly to this project with Dendrobium Mine being one of the key case studies</td><td></td></tr>
<tr><td>Connective Fracturing Research Project</td><td>Project aims to investigate the connective fracturing above proposed longwall panels and the potential impacts on connected water systems, including swamps.

This project has been initiated for Longwall 9 in Area 3B and has involved diamond core holes drilled at key locations to provide information on the following:

• Pre-mining hydraulic characteristics;
• Hydraulic conductivity of the fractured rock mass and connectivity of fractures using packer testing, down hole flow testing and cross-hole tracer tests.

The overall objective of this study is to characterise the groundwater system in the Triassic strata above proposed longwall mining operations, and specifically to identify inherent horizontal and vertical flow paths related to connected fractures and other flow paths, prior to mining. The study will be repeated after Longwall 9 has passed through the area, in the post-mining environment.

Understanding of the pre-mining, post-mining and after rehabilitation subsurface hydraulic behaviour and hydrogeologic conditions will be beneficial to determine if rehabilitation of a swamp is to be considered and the success of the rehabilitation</td><td>2012 - 2015</td></tr>
<tr><td colspan="3">Impact Monitoring and Prediction Tools</td></tr>
<tr><td>GIS Methods for Subsidence Impact assessment</td><td>The objectives of this ACARP project (C14031) were to develop and demonstrate practical decision support methodology for the assessment of the impacts of mining subsidence on natural features. The decision support tools were developed within the flexibility of the Geographic Information</td><td>Completed May 2007 with continuing development of the techniques by IMC</td></tr>
</table>

Research Project	Overview	Timing
	System (GIS) environment and uses relevant case studies to demonstrate the usefulness of GIS tools. The project included analysis of a number of case studies, including Dendrobium and Appin Mines. This research led to the deployment of differential height analysis for mapping swamp boundaries in Dendrobium	
The Effect of Longwall Mining on Vegetated Environments	The aim of ACARP C15013 was to develop methods and tools to assist the coal mining industry to better monitor the consequences of longwall mine subsidence (LWMS) on surface environments. The project focus was to improve monitoring quality and potentially reduce costs through the incorporation of high-resolution remotely sensed data into LWMS monitoring programmes. A major component of this research was related to upland swamps within IMC mining areas	Completed January 2010 with continuing development of the techniques by IMC
Monitoring Surface Condition of Landscape Features Subject to Mining Subsidence with Very High Resolution Imagery	This ACARP C20046 project is researching the use of unmanned aerial vehicles to capture high resolution imagery of upland swamps with the intention of comparing and calibrating this data with traditional ground-based survey techniques	2012 - 2014
Subsidence Impact Mitigation and Rehabilitation		
Damage Criteria and Practical Solutions for Protecting River Channels	This ACARP Project C12016 investigated the nature of the disturbances that occur in the base of river channels, the potential impacts of these disturbances on water flow paths as well as the range of practical strategies available for the assessment, mitigation and remediation of these impacts. IMC provided substantial data to support this research, including the Georges River Grouting and Marhnyes Hole Slot case studies	Completed May 2009

Research Project	Overview	Timing
Effects of Surface Topography on Mining Subsidence Damage to River Channels	This ACARP Project C15025 investigated the potential to provide more effective solid coal barriers by better understanding the mechanics of the processes that cause horizontal subsidence movements. The report presents current understanding of the mechanics of mining induced horizontal ground movements and the opportunities available to reduce the size of protection barriers based on this understanding. IMC contributed significantly to this research, including provision of subsidence data for assessment of DinSAR monitoring	Completed April 2011 with IMC continuing to research DinSAR monitoring techniques
Additional Swamp Rehabilitation Research	Monitoring provides key data when determining any requirements for mitigation or rehabilitation. Baseline data is compared with monitoring results during and following mining to determine any remediation that may be required Monitoring has been installed to investigate whether the methods to rehabilitate swamps restore groundwater levels and groundwater recharge response behaviour. The monitoring data will be assessed against pre-mining, post mining and post rehabilitation levels. Additional monitoring will be installed as required for any specific rehabilitation research projects IMC will establish field trials whenever the requirement for rehabilitation is triggered by the SIMMCP TARP. A schedule for trials, development of work plans and ongoing reporting will be undertaken as required by the SMP Approval	Determined from any specific rehabilitation requirements
Swamp Water Balance Study	As described in Section 5.6.	2020 - present

Research Project	Overview	Timing
Swamp Resistivity Project	As described in Section 5.7.	2018 - present
Littlejohn's Tree Frog Research Program	As described in Section 5.8.	2019 - 2021
Giant Dragonfly Research Project	As described in Section 5.9.	2019 - present