SWAMP REHABILITATION RESEARCH PROGRAM
REVIEW HISTORY

<table>
<thead>
<tr>
<th>Revision</th>
<th>Description of Changes</th>
<th>Date</th>
<th>Approved</th>
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<tr>
<td>Draft</td>
<td>Draft for consultation</td>
<td>03-10-13</td>
<td>GB</td>
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<td>Rev 1.0</td>
<td>For submission to Dept of Planning</td>
<td>04-06-14</td>
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<td>Rev 1.1</td>
<td>Updated based on Dept of Planning feedback 19-12-14 and discussions</td>
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<td>GB</td>
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<td>Rev 1.2</td>
<td>Updated based on Dept of Planning feedback 29-06-16 and discussions</td>
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<td>GB</td>
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1 INTRODUCTION

Dendrobium Mine is located in the NSW Southern Coalfield approximately 15km west of Wollongong. The mine is managed by South32 Illawarra Coal (IC). The mining is divided into Areas 1, 2 and 3. Extraction has occurred in Areas 1, 2, 3A and is currently in Area 3B.

Development Consent (DA 60-03-2001) for the mine was granted by the Department of Planning (now DP&E) on 20th November 2001. In 2007, IC applied to modify the consent and the footprint of Area 3. Conditional Approval for the modified project was granted 8th December 2008. The Dendrobium Mine revised Consent requires a Swamp Impact Monitoring and Management Plan (SIMMCP) subject to Schedule 3 Condition 6 and a Subsidence Management Plan (SMP) subject to Schedule 3 Condition 7.

On the 4th October 2012, IC submitted a SMP and SIMMCP for Dendrobium Area 3B for approval from the Director’s General of the Departments of Planning and Environment (DP&E) and Trade and Investment (T&I). The SMP (including the SIMMCP) was approved 5th February 2013 by the Director General T&I and 6th February 2013 by Director General DP&E.

Condition 15 of the Area 3B SMP Approval by DP&E requires the development of a Swamp Rehabilitation Research Program (SRRP). The Dendrobium Area 3B SMP Area is provided as Figure 1.

2 OBJECTIVES

The purpose of this SRRP is to provide the framework of IC’s swamp research program and comply with Condition 15 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 field trial (for a 5 year duration or longer) for rehabilitation techniques at a swamp or swamps that have been impacted by subsidence;
- 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 OEH, WaterNSW and DRE (T&I). The SRRP is to be implemented to the satisfaction of the Director General (now Secretary) DP&E. A draft SRRP was provided to key Government Agencies (including OEH, WaterNSW and T&I) 3rd October 2013 for comment. Submissions on the draft SRRP have been provided by DP&E, T&I, OEH and WaterNSW. The Wollongong Office of T&I hosted a joint Agency workshop with Illawarra Coal to discuss the SRRP. The workshop was held 16th December 2013 with the following agencies attending DP&E, OEH, Water NSW and T&I.
Dendrobium Mine
SWAMP REHABILITATION RESEARCH PROGRAM

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 1.

**Table 1: Consultation for Dendrobium Area 3B Swamp Rehabilitation Research Program**

<table>
<thead>
<tr>
<th>Agency</th>
<th>Issue</th>
<th>Response</th>
<th>Where</th>
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<tbody>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- No evidence of consultation</td>
<td>- A draft SRRP was provided to Government Agencies (including OEH, WaterNSW and T&amp;I) 3rd October 2013 for comment</td>
<td>- SRRP Section 3</td>
</tr>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- A very basic overview of sealing rock fractures, injection grouting, knick point control and water spreading is provided</td>
<td>- Detailed descriptions of the installed monitoring and proposed rehabilitation methods are provided in the SIMMCP</td>
<td>- SIMMCP Section 2 Plan Requirements</td>
</tr>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- The program states that monitoring will be installed to assess rehabilitation results against pre-mining levels – monitoring should already be installed</td>
<td>- Additional detail has been included in the SRRP</td>
<td>- SIMMCP Section 5.4 Mitigation and Rehabilitation</td>
</tr>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- The research program should outline a field trial and schedule where the methods are scientifically tested</td>
<td>- Field trials are proposed for Swamps 1A, 1B, 5 and 15B</td>
<td>- SRRP Sections 5.3 to 5.12 and Appendix 1</td>
</tr>
<tr>
<td>DP&amp;E Water NSW T&amp;I</td>
<td>- Further detail needs to be provided with regard to either investigation of new techniques or the development of current techniques for swamp rehabilitation</td>
<td>- Field trials will investigate sealing of rock fractures, injection grouting, knick point control, water spreading and restoring groundwater levels in swamps</td>
<td></td>
</tr>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- The research program should lead to a peer-reviewed journal paper</td>
<td>- The research conducted by IC can be published subject to South32 publishing rules</td>
<td>- SRRP Section 10</td>
</tr>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- The program should include an itemised budget of costs</td>
<td>- Indicative costs of the research program are provided</td>
<td>- SRRP Section 6</td>
</tr>
<tr>
<td>DP&amp;E Water NSW</td>
<td>- Data collection to meet approval conditions should not be included unless such monitoring is directly informing a project under the SRRP</td>
<td>- Data collection costs will only be included where such monitoring is directly informing a project under the SRRP</td>
<td></td>
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<tr>
<td>DP&amp;E Water NSW</td>
<td>- DP&amp;E will advise the company of research expenditure protocols</td>
<td>-</td>
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<tr>
<td>DP&amp;E OEH Water NSW</td>
<td>- Appendix 1 does not include a specific swamp rehab project</td>
<td>- Specific projects have been included for Swamps 1A, 1B, 5 and 15B</td>
<td>- SRRP Sections 5.8 to 5.11 and Appendix 1</td>
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<tr>
<td>DP&amp;E OEH Water NSW</td>
<td>- Suitable sites include: Swamps 12, 15B, 1A, 1B, and 5</td>
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<th>Agency</th>
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<th>Response</th>
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<tr>
<td>OEH</td>
<td>- OEH does not believe the research on Isotopic Assessment of Swamp</td>
<td>- The assessment of swamp ecohydrology has been removed from the SRRP&lt;br&gt;- 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&lt;br&gt;- 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 for these assessments will be researched&lt;br&gt;- The assessment of pre-mining hydrology has been removed from the SRRP&lt;br&gt;- The swamp geomorphology research has been removed from the SRRP</td>
<td>- SRRP Section 5</td>
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<td>Ecohydrology is relevant to swamp rehabilitation&lt;br&gt;- Research on Height of Connective Fracturing has little ability to rehabilitate or restore impacted swamps&lt;br&gt;- Pre-mining hydrology research to develop a water balance for a swamp has occurred&lt;br&gt;- Much of the work on swamp geomorphology has already been done&lt;br&gt;- 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</td>
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<td>- The SRRP should identify who is to undertake the trial</td>
<td>- The responsibilities under the SRRP are outlined in Section 8&lt;br&gt;- The SRRP is subject to Independent Audit every 3 years, in accordance with Condition 6, Schedule 8, of the Consent&lt;br&gt;- Reporting of SRRP results will be undertaken in accordance with Condition 5, Schedule 8 of the Consent</td>
<td>- SRRP Section 9</td>
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<td>- Auditing and review of the SRRP should go through an external peer</td>
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<td>review process to ensure scientific rigour&lt;br&gt;- Public access should be provided to ensure findings are available to inform and guide future mining</td>
<td>- The SRRP will be implemented as required by Condition 15 of the Area 3B SMP Approval&lt;br&gt;- IC will work cooperatively with research and industry partners, including Government Agencies</td>
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<td>- Recommend establishment of a Research Program Steering</td>
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<td>Committee from the company, experts, government agencies and researchers</td>
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<td>- Consider other research and/or literature reviews e.g. Department of Environment</td>
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<td>- SRPP to state that a minimum of $3.5 million dollars will be expended</td>
<td>- Commitment to $3.5 million expenditure over the period of the SRRP&lt;br&gt;- SRRP Sections 2 and 6</td>
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4 STATUTORY REQUIREMENTS

IC 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 12 of the DP&E SMP Approval. Rehabilitation and research activities described in the SRRP will be undertaken in accordance with the DP&E Area 3B SMP Approval.

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

- Dendrobium Mining Lease CCL 768;
- Environmental Protection Licence (EPL) 3241;
- Dendrobium Mining Operations Plan (MOP) 2011 to June 2015;
- Relevant OH&S and HSEC approvals; and
- Any additional leases, licences or approvals resulting from the Dendrobium Approval.

In addition, supplementary approvals may be required from the 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 IC will develop further understanding of the factors which influence swamp health and function, if and how swamps have been changed due to mining and what rehabilitation methods may be required for swamp restoration.
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 and trial rehabilitation techniques which mitigate the above two mechanisms. Targeted rehabilitation programs will initially be trialled as these will inform and refine the implementation of any large scale rehabilitation i.e. looking at whole of swamp bedrock/landscape rehabilitation.

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. IC 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.

5.3 Height and Depth of Connective Fracturing

IC is currently undertaking research to investigate the connective fracturing above longwall panels and the potential impacts on connected water systems, such as upland swamps.

A project includes a study above Longwall 9 in Area 3B on an access road between Swamp 5 and Swamp 8. This research site includes diamond core holes drilled at key locations to provide information on the following:

- Pre-mining hydraulic characteristics of the overburden from the base of the Bulgo Sandstone to the surface;
- Post-mining hydraulic characteristics of the overburden from the base of the Bulgo Sandstone to the surface; and
- Hydraulic conductivity of the fractured rock mass and connectivity of fractures.

The research uses 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 longwall mining operations, and specifically to identify inherent horizontal and vertical flow paths related to connected fractures and other flow paths. The study commenced prior to mining impacting the site and has been repeated after Longwall 9 passed through the area. Monitoring at the site is ongoing.

Through the investigation of pre and post mining groundwater conditions and assessment of connected fracturing, IC is able to better understand how mining influences groundwater. Where groundwater levels have an ecological consequence, this study can assist with identifying fracture networks which need to be targeted to restore groundwater levels.

Understanding subsurface hydraulic behaviour is a key outcome of the connective fracturing research. This research has provided additional evidence that the fracture network is not connected from the surface. Ongoing research will be implemented to further define the fracture network from the surface to the constrained zone. This research will focus on swamps and associated streams and will directly contribute to the design of rehabilitation research identified within the SRRP. Additional sites will be installed near and under swamps to assess surface fracture network development and groundwater response during mining. A variety of techniques and technologies will be trialled to define fracture networks, in consultation with research providers and other stakeholders. The types of technologies available for this research include: packer testing, down hole flow testing, cross-hole tracer tests, extensometers, peizometers, geophysics, seismic reflection and refraction and other tools and techniques identified during the research program.

Modelling is undertaken using monitoring and research data to build a conceptual understanding of mining impacts to swamps. This conceptual understanding is important for developing rehabilitation
plans (e.g. layout and depth etc.) as well as rehabilitation targets and success criteria. The fluxes within the model are informed by the height and depth of fracturing research.

Further understanding of the surface fracture network (i.e. change in effective permeability, and cracking depth) is fundamental to understanding impacts to swamps and will significantly contribute to rehabilitation design and the likelihood of success. In previous assessments (prior to the Longwall 9 research) it has been accepted that these cracks extend to depths of more than 5 m, are likely to be connected to 15-20 m depth, and could extend to 30 m.

Earlier literature (e.g. Guo et al, 2007) suggested that the surface zone may extend 20-30 m below ground, and result in hydraulic conductivity changes of:

- Vertical: 5-40 x the host vertical permeability
- Horizontal: approximately 100 x the host horizontal permeability.

Changes to specific yield have been estimated deeper in the profile in earlier literature, but not implemented in modelling of the surface cracking zone.

Based on the work by PB (2015) a refined conceptual model has been developed where the depth of the surface cracking zone is approximately 20 m and the enhancement to permeability is:

- Vertical: 1-10 x the host vertical permeability
- Horizontal: 50-100 x the host horizontal permeability

PB (2015) suggested that changes in specific yield (Sy) within the Hawkesbury Sandstone, where the swamps are located, would be:

- Surface cracking zone: an increase of 0.025-0.05, e.g. from a host value of 0.025 to 0.05 or 0.075;
- Constrained zone: an increase of 0.025, e.g. from 0.01 to 0.035.

Ditton Geotechnical Services has suggested for other mines that the depth to which surface cracking occurs is governed in part by the topographic landform, with the extent of cracking on different terrain/landforms:

- Flat terrain (slope <18º) – cracking to 7.5-12 m below ground (mBG);
- Bases of valleys – cracking to 12-15 mBG;
- Ridgelines or high side of panel beneath steep slopes (slope >18º) – cracking to 15-20 mBG.
- Low side of panel along steep slopes (>18º) – cracking to 3.5-5 mBG. Ditton also suggests that cracking frequency is reduced on the low side of the panel.

As a result of this enhanced permeability, the ability of the shallow subsurface strata to transmit water is increased. This means that the shallow system can become more dynamic, with the result that in an area where surface cracking occurs (more) water can be transferred between surface waterbodies and groundwater in shallow strata. Additionally, it may be that more water is gained by...
surface water features or swamps and/or the timing of gains and losses changes due to the presence of enhanced permeability. The exact nature of gains and losses and the timing of these will be dependent in part on the type of swamp (e.g. headwater or valley fill swamp) and on the relative position in the landscape of the swamp and nearby surface cracking zone.

The groundwater model for Dendrobium Mine is progressively being updated, and aims to better address issues associated with the swamps at Dendrobium. The revised model has been enhanced and calibrated with the findings of PB (2015).

An understanding of the relationship of swamp vegetation to pre and post mining hydraulic and hydrogeologic conditions is important in assessing the implications of changes to shallow and deep aquifers and surface water systems due to longwall mining. This study will prove beneficial to determine any consequences to upland swamps that result from mining and if rehabilitation of a swamp is to be considered due to mining impacts.

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 cementitious (or alternative) grout. Grouting will be focused where fractures result in diversion of flow from pools or through the controlling rockbar. Trials into grouting the bedrock below swamps will also be undertaken. Significant success has been achieved in the remediation of the Georges River where four West Cliff longwalls directly mined under the river and pool water level loss was observed.

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

Such operations do have the potential to result in additional environmental impacts and are carefully planned to avoid contamination. Mixing areas will be restricted to cleared 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 will be undertaken in consultation with WaterNSW and be based on demonstrated effectiveness and ensuring that there is no significant impact to water quality or ecology.

Research into the sealing of fractures with grout will target the following technical aspects:

- Grout design, including; the constituent materials, mixing methods, setting time and effectiveness.
- Application of the grout to fractures.
Effectiveness of the technique in achieving the aim of restoring groundwater levels and groundwater recharge response behaviour to pre-mining levels.

Controls required to reduce any impacts to the environment, including; the potential for leaching from the grout, access to the site, containing the grout to the targeted fracture, prevention of spillage, site clean-up and site restoration.

5.5 Injection Grouting

The sealing of fractured bedrock 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 cementitious (or alternative) grout.

Injection grouting involves the delivery of grout through holes drilled into the bedrock targeted for rehabilitation. The intention of this grouting is to achieve a low permeability ‘layer’ below any affected pool as well as the full depth of fracturing in any controlling rockbar.

Where alluvial materials overlie sandstone, grouts may be injected through grout rods to seal voids in or under the soil or peat material. 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 drilled through in order to grout the underlying strata using purpose built grouting pipes.

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

Where grouting is required to the full fracture depth a small vehicle mounted or demountable drill would be used. These drills are required to produce the power needed to drill up to 20m depth. It is impractical for hand held equipment to drill to these depths.

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.

Where access to an area of swamp is impractical for hand held equipment or for a vehicle mounted drill, directionally drilled holes using a larger drilling rig can be used where there is suitable access for this equipment. This technique was used to grout fractures beneath Marhneys Hole on the Georges River where the pool retained water and hence made access to the pool difficult.
Research into injection grouting will target the following technical aspects:

- Grout design, including; the constituent materials, mixing methods, setting time and effectiveness.
- Identification of the extent of the fracture network and the efficient application of the grout to these zones.
- Grout delivery techniques, including; maximum flow distances, optimum pumping pressures and varying types of packers to seal grout delivery to the hole.
- The practicality and effectiveness of surface grouting and grouting to the full depth of the fracture network.
- Effectiveness of the technique in achieving the aim of restoring groundwater levels and groundwater recharge response behaviour to pre-mining levels.
- Controls required to reduce any impacts to the environment, including; the potential for leaching from the grout, access to the site, containing the grout to the targeted fracture network, prevention of spillage, site clean-up and site restoration.

5.6 Erosion and Knickpoint Control

Control of any sheet, rill, gully, tunnel and stream channel erosion resulting from mine subsidence is addressed in the SIMMCP and the Area 3B SMP Approval Conditions. Where any mining induced erosion develops within swamps and there is limited ability for the erosion to stabilise naturally there is a requirement to rehabilitate the erosion with appropriate and approved stabilisation techniques. Knickpoint control will be used where head-ward progression of gully erosion is or is likely to occur.

Erosion channels can create preferred flow paths and dewater swamp sediments. To arrest this type of erosion, ‘coir log dams’ are installed at knickpoints in the channelised flow paths or at the inception of tunnel/void spaces. The square coir logs used for the construction of these small dams were developed specifically for swamp rehabilitation and have been successfully used during a number of swamp rehabilitation programs of recent years in the Blue Mountains and Snowy Mountains.

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, or the surface of the swamp. The coir logs are held in place by wooden stakes and bound together with wire.

The coir log dam slows the flows in the eroding drainage line such that the drainage line will silt up and water in the swamp will flow through the swamp rather than being concentrated in the eroding channel.

The most important aspect of these coir dams is the positioning of the first layer of coir logs. A trench is cut into the swamp soil so the first layer sits on the underlying substrate or so the top of the first coir log is at ground level.
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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. At this point the stream becomes, once again, a net water contributor to the swamp and not a net drainer of water from the swamp. Where increased filtering of flows is required the coir logs are wrapped in fibre matting.

Research into erosion and knickpoint control will target the following technical aspects:

- Sediment dam design, including; the constituent materials, construction methods, resistance to scouring during significant run-off periods and effectiveness.
- Ability of the sediment dams to prevent head-ward erosion, including; techniques to measure progression of erosion within the swamp, placement and spacing of the dam(s) and effectiveness of capturing and retaining sediment.
- Re-establishment of vegetation into retained sediment.
- Effectiveness of the technique in achieving the aim of restoring groundwater levels and groundwater recharge response behaviour to pre-mining levels.
- Controls required to reduce any impacts to the environment, including; the potential for contamination from the materials used, access to the site, disturbance of the site, site clean-up and site restoration.

5.7 Water Spreading

Maintenance of swamp moisture can be enhanced by water spreading techniques, involving long lengths of coir logs and hessian ‘sausages’ linked together across the contour such that water flow builds up and slowly seeps through the water spreaders. Where required the water spreaders would be installed in shallow trenches within the swamp and along the higher margins.

Water spreading involves soft-engineering materials that will contribute to and function as part of the swamp system but will eventually degrade (totally biodegradable) and become integrated into the soil of the swamps. This also removes the requirement for any post-rehabilitation removal of structures or materials.

Research into water spreading will target the following technical aspects:

- Water spreading design, including; the constituent materials of any sausage(s), construction methods, resistance to being dislodged from the target area during significant run-off periods and effectiveness.
- Ability of the water spreading to contribute to swamp moisture, including; preventing or controlling the progression of erosion within the swamp, placement and spacing of the sausage(s) and effectiveness of capturing and retaining water and sediment.
- Re-establishment of vegetation into areas of increased moisture.
- Effectiveness of the technique in achieving the aim of restoring groundwater levels and groundwater recharge response behaviour to pre-mining levels.
Dendrobium Mine
SWAMP REHABILITATION RESEARCH PROGRAM

- Controls required to reduce any impacts to the environment, including; the potential for contamination from the materials used, access to the site, disturbance of the site, site clean-up and site restoration.

5.8 Field Trials

IC will establish field trials (for >5 years) whenever the above rehabilitation techniques are required by any of the triggers in the SIMMCP. Where these specific rehabilitation actions require new technology or further development, subsequent research will be scheduled and provided to relevant Government Agencies for review and assessment. A schedule for subsequent trials, development of work plans and ongoing reporting will be undertaken as required by the SMP Approval.

Initially trials will be established in areas of subsidence impact in Areas 3A and 3B as well as an erosion site that was identified in 2003 prior to any mining impacting the area. Although these sites did not trigger the need for rehabilitation as required by the SMP Approval or Development Consent they are useful sites to research the proposed rehabilitation methodologies described above. The sites proposed for the initial round of research include:

- Swamp 15B (Figures 2 and 3)
- Swamps 1A and 1B (Figures 4, 5 and 6)
- Swamp 5 (Figures 6 and 7)

5.9 Swamp 15B

Swamp 15B was mined under by Longwall 8 in Area 3A. Impacts were observed at the basal step of the swamp which is also within the first order stream SC10C. Impacts were reported as required by the Watercourse and Swamp TARPs (September 2012) and were designated as impact DA3LW8_144. No impacts related to the swamp landscape monitoring triggers were observed in the swamp. Groundwater triggers have been met for the swamp and these and the fractures are described in the Longwall 8 End of Panel (EoP) Report.

On the 4th of September a zone of rock fracturing was observed just upstream of SC10C Pool 10 which covered an approximate area of 7 metres x 5 metres. By the 22rd of October the rock fracturing covered a length of 8 m along the rock-shelf and the width of the exposed bedrock. There are numerous areas of hairline fracturing and associated uplift creating fractured plates of sandstone.

The following rehabilitation techniques will be trialled at Swamp 15B:

- Sealing of rock fractures
- Injection grouting
5.10  **Swamps 1A and 1B**

Swamps 1A and 1B were mined under by Longwalls 9 and 10 in Area 3B. Impacts were observed on a rock platform between the two swamps which is also within the second order stream DC13. Impacts were reported as required by the Watercourse and Swamp TARPs (May 2013) and were designated as impact DA3LW9_003. No impacts related to the swamp landscape monitoring triggers were observed in the swamps. Groundwater triggers have been met for the swamp and these and the fractures are described in assessment reports and the Longwall 9 EoP Report provided to Government Agencies.

The fracturing is on DC13_RB21 and resulted in a loss of pool water levels near the fracturing. This fracturing is a Level 2 Trigger according to the Dendrobium Area 3B Swamp TARP.

Studies undertaken by Earth Tech (2003 and 2005) and Tomkins and Humphrey (2006) identified pre-mining erosion within Swamp 1A.

Due to terrain, vegetation and access restrictions, the primary method of identifying and measuring gully erosion over Area 3B is with Airborne Laser Scanning (ALS). 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. This landscape model identifies active pre-mining erosion of 179m in DC13, adjacent to Swamp 1A, and 8m within the swamp (Figure 4).

The following rehabilitation techniques will be trialled at Swamps 1A and 1B:

- Sealing of rock fractures
- Injection grouting
- Knickpoint control

5.11  **Swamp 5**

Swamp 5 has been mined under by Longwalls 9 10 and 11 in Area 3B. Impacts were observed on the basal step of the swamp which is also within the first order section of Donalds Castle Creek. Impacts were reported as required by the Watercourse and Swamp TARPs (September 2013) and were designated as impact DA3LW9_006. No impacts related to the swamp landscape monitoring triggers were observed in the swamps. Groundwater triggers have been met for the swamp and these and the fractures are described in assessment reports and the Longwalls 9 – 11 EoP Reports provided to Government Agencies.

The fracturing is on DC_RB33 and resulted in diversion of surface flow. This fracturing is a Level 2 Trigger according to the Dendrobium Area 3B Swamp TARP.
The following rehabilitation techniques will be trialled at Swamp 5:

- Sealing of rock fractures
- Injection grouting

5.12 Restoring Groundwater Levels

Monitoring has been installed to investigate whether the methods trialled to rehabilitate swamps contribute to the restoration of groundwater levels and groundwater recharge behaviour. Additional monitoring will be installed as required and the monitoring data will be assessed against pre-mining levels and reference sites.

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. Within Area 3B long-term piezometer records are available for Swamp 11 as well as additional sites installed since 2011. Swamps 2, 7, 15a, 22, 24, 25, 33, 84, 85, 86, 87 and 88 (SIMMCP) have or will be instrumented as reference sites for shallow groundwater. This data is used to compare differences in shallow groundwater levels within swamps and hill-slope aquifers before and after mining and following any rehabilitation. 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 which are installed on a permanent basis to a depth of 1.5m with loggers are being trialled and with the agreement of the WaterNSW will be considered for further roll-out within Area 3B. 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_01, 01a_02, 01a_03, 01a_04, 01a_04i, 01a_04ii, 01a_04iii, 01a_04iv, 01a_04v

- **Swamp 1B**
  - Piezometers 01b_01, 01b_02, 01b_02i, 01b_02ii, 01b_02iii, 01b_02iv, 01b_03
  - Flow monitoring site DC13S1

- **Swamp 5**
  - Piezometers 05_01, 05_02, 05_03, 05_03i, 05_03ii, 05_04, 05_05, 05_06
  - Soil moisture meter S05_S01, S05_S02, S05_S05, S05_S08
  - Flow monitoring site DCS2

- **Swamp 15B**
  - Piezometers S15b-H1, S15b-H2, S15b-H3, GW_15b_20, GW_15b_21, GW_15b_22, GW_15b_23, GW_15b_24, GW_15b_25, GW_15b_26, GW_15b_27, GW_15b_28, GW_15b_29, GW_15b_30, GW_15b_31, GW_15b_32, GW_15b_33, GW_15b_34, GW_15b_35, GW_15b_36, GW_15b_37, GW_15b_38, GW_15b_39
  - Flow monitoring site SC10CS1

- **Reference sites**
  - Piezometers 02_01, 07_05, 07_06, 15a_02, 15a_03, 15a_04, 15a_06, 15a_07, 15a_08, 15a_09, 15a_11, 15a_12, 15a_15, 22_01, 22_02, 24_01, 25_01, 33_01, 33_02, 84_02, 85_01, 85_02, 22_01, 22_02, S24_S01, S25_S01, S33_01, S33_03, S84_S02, S85_S01, S85_S02, S86_S01, S86_S02, S87_S01, S87_S02, S88_S01, S88_S02
  - Soil moisture meter S02_S01, S07_S05, S07_S06, S15a_S01, S15a_S04, S15a_S06, 22_01, 22_02, S24_S01, S25_S01, S33_01, S33_03, S84_S02, S85_S01, S85_S02, S86_S01, S86_S02, S87_S01, S87_S02, S88_S01, S88_S02
  - Flow monitoring sites C1, SCU

Additional monitoring (including groundwater level monitoring) will be established in Swamps 1A, 1B, 5, 15B and reference sites as required by the research program.

### 5.13 Investigations to Support Swamp Rehabilitation

Investigations and studies would be undertaken to understand subsidence impacts to swamps. The objectives of proposed investigations are to:

- Characterise the near-surface fracture zone in terms of fracture distribution and spatial extent beneath swamps and controlling rockbars.
- Characterise the post-mining hydrogeological regime (perched and regional groundwater) within swamps.
- Identify areas of flow diversions and quantify or estimate the proportion of the diverted flow.
- Inform the design of grout-injection and other remediation options.
Based on field observations and local experience, swamps are naturally fed by a combination of surface flow and groundwater from hillside aquifers perched on sub-horizontal claystone bedding planes or ironstone bands. It is likely that at least the valley infill swamps also gain seepage from the regional aquifer, but the complexity of the steeply stepped terrain makes it difficult to estimate where the pre-mining gaining and losing portions of the swamps would have been. Both types of aquifer are likely to have been affected by subsidence effects.

Water tables which support swamps are likely to have fallen below the base of the swamps except for relatively wet periods and therefore rehabilitation which re-seals the surface rocks will only restore run-off water. It is therefore important to have an understanding of the post-mining hydrogeological regime in order to understand the extent to which grout-injection or other types of rehabilitation will restore water levels and flows within swamps.

To investigate the post-mining hydrogeological regime IC proposes to install piezometers within and adjacent impacted swamps, targeting the behaviour of significant perched and regional aquifers and their interaction with surface waters over time, e.g. behaviour after rainfall events and during drier periods.

Characterising the nature and distribution of the fracturing network will be undertaken via core-drilling and testing of open holes at the proposed remediation trial sites. Tracer studies will be implemented by specialist hydrogeologists, including release-and-capture scenarios.

The key design elements for the proposed investigation components are provided in Table 2.

Table 2: Dendrobium Area 3B Swamp Rehabilitation Research Program Investigations

<table>
<thead>
<tr>
<th>Investigation Type</th>
<th>Recommended Investigation</th>
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<tbody>
<tr>
<td>Fracture characterisation</td>
<td>• Drill holes at trial grout-injection sites.</td>
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<tr>
<td></td>
<td>• Appropriate number of holes to be drilled at an angle to identify sub-vertical fracturing.</td>
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<tr>
<td></td>
<td>• Holes logged (using core, acoustic scanners and/or down-hole cameras as appropriate), and</td>
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<tr>
<td></td>
<td>suitable geophysical tools and packer tests may be used to further characterise the fracture</td>
</tr>
<tr>
<td></td>
<td>networks.</td>
</tr>
<tr>
<td></td>
<td>• Drilling to be continued until the depth and interconnectivity of the surface fracture zone</td>
</tr>
<tr>
<td></td>
<td>are adequately characterised.</td>
</tr>
<tr>
<td>Hydrogeological regime characterisation</td>
<td>• Nested piezometers installed at suitable locations within the trial areas.</td>
</tr>
<tr>
<td></td>
<td>• Drilling to identify the water table (5m saturated zone to confirm continuity saturation).</td>
</tr>
<tr>
<td></td>
<td>• Down-hole camera and geophysical tools to identify zones of major cracking and/or inflow.</td>
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</tbody>
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<td>Last Review Date</td>
<td>03/08/2016</td>
<td>Next Review Date</td>
<td>03/08/2017</td>
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The nominal locations for the investigations are shown in Figures 2 - 7. The number and location of the investigations will be subject to ongoing expert review during the studies, in consultation with WaterNSW. The investigations will commence prior to rehabilitation activities so that the data from the studies are available to refine the proposed rehabilitation approach. Four to six weeks is likely required for the installation of equipment for the investigation studies.

The investigations described in Table 2 are to answer the following questions:

- What are the most appropriate strategies for remediating upland swamps, in terms of restoring ecological functions and values?
- To what extent does connective fracturing extend below the base of the swamps?
- What are the most appropriate measures of success to guide remedial efforts and ongoing assessment of the hydrological and ecological functionality of the swamps?

### 5.14 Alternative Remediation Approaches

IC has successfully implemented a subsidence rehabilitation program in the Georges River. This rehabilitation focused on grouting of mining induced fractures and strata dilation to reinstate the structural integrity and water holding capacity of the bedrock. Metropolitan Colliery is currently undertaking work aimed at rehabilitating areas impacted by subsidence using Poly-urethane Resin (PUR) and other grouting materials. IC is consulting with Metropolitan Colliery in relation to these new and emerging technologies. The best grout option available for the rehabilitation work will be identified and agreed with WaterNSW.

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.

### 5.15 Remediation Success

Baseline studies have been completed to record the biophysical characteristics of the upland swamps. Monitoring of the swamps has been conducted before, during and after mining. The monitoring is based on the BACI design.

The monitoring program will remain in place during and after the implementation of the rehabilitation measures. Analyses of monitoring data from pre-mining, control, impact and
mitigation sites will be used to determine the success of the rehabilitation trials. Observations will be made as part of the monitoring program and be used to provide contextual information to the above assessment approach. Monitoring data and observations will be documented and reported.

5.16  Remediation Trial Timing

Implementation and timing of the rehabilitation trials is contingent on:

- Receiving approval of the Plan from DP&E and T&I (2 months).
- Receiving approval from the landholder (WaterNSW) to enter the land to undertake the activity (1 month).
- Tendering and procurement of the investigation equipment and team (1 month).
- Establishment of access to the investigation sites (1 month).
- Implementation and analysis of site investigations (2 months).
- Revision of the Rehabilitation Trial Plan and/or approach, if required, in consultation with key stakeholders (1 month).
- Tendering and procurement of the rehabilitation equipment and team (2 months).
- Establishment of access to the rehabilitation sites (1 month).
- Rehabilitation timing per site (1 – 2 weeks).
- Analysis and reporting (2 months).

Access to the Catchment Area is restricted during wet weather and total fire bans and these can cause significant delays to activities in the area. Grouting activities are an iterative process with periods of grouting followed by periods of testing. Significant dry periods will reduce the potential to test the integrity of the grouting.

6  EXPENDITURE

Research expenditure will be tracked and reported throughout the program as directed by DP&E. Detailed costing for the research proposed in Sections 5.8 to 5.13 will be provided to DP&E as part of regular reporting once the SRRP is approved. Cost estimates for the first stage of the SRRP (Swamps 15B, 1A, 1B and 5) are provided in Sections 6.2 to 6.5.

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 the 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.
End point of erosion
Swamp boundary

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

Shaded Relief (derived from ALS imagery)

Dendrobium Area 3B
Mapped Erosion- Swamp 01a

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

Version 1
Horizontal Datum
MGA - Zone 56

Figure 4
A number of novel approaches for assessing potential impacts to groundwater systems and connected ecosystems were researched as part of this program. Illawarra Coal 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 Grouting

Grouting of mining induced fractures within the Dendrobium mining area is a key component of the proposed research. The fracture grouting research expenditure can be categorised into the following work packages:

- Program design, review of environmental factors and approvals - $50,000 per campaign
- Site access (geo-fabric, tipper, excavator, crushed sandstone, float) - $20,000 per site
- Grout design, materials, mixing and monitoring (basic cement grout $400 per meter) - $20,000 per site
- Grout delivery via drill holes and packers (drill and grout team with equipment $3,600 per day) - $36,000 per site
- Delivery of water for operations and monitoring the effectiveness restoring surface and groundwater levels ($1800 per day) - $18,000 per site
- Environmental controls, site clean-up and restoration (2 days per site plus consumables) - $5,000 per site
- Supervision and site vehicle ($700 per day) - $7,000 per site
- Monitoring, data recording, analysis and reporting $40,000 per campaign

Total costs of grouting are estimated to be approximately $106,000 per site plus overheads of approximately $90,000 per campaign. Three grouting trials are proposed for the first stage of the SRRP and these would be completed in one campaign, with an approximate cost estimate of $408,000.
6.3  Erosion Control and Water Spreading

Knick point erosion control and water spreading within the Dendrobium mining area is a key component of the proposed research. The erosion control research expenditure can be categorised into the following work packages:

- Site access (geo-fabric, tipper, excavator, crushed sandstone, float) - $20,000 per site
- Project design and materials (50 coir logs at $100 each plus consumables) - $6,000 per site
- Construction of dam(s) and sediment control devices (construction team with equipment $1,800 per day) - $18,000
- Environmental controls, site clean-up and restoration (2 days per site plus consumables) - $5,000 per site
- Monitoring and maintenance of re-establishment of vegetation into retained sediment (2 days per site plus consumables) - $5,000 per site
- Supervision and site vehicle ($700 per day) - $7,000 per site

Total costs of erosion control and water spreading are estimated to be approximately $61,000 per site.

6.4  Investigations and Impact Characterisation

Investigations will be undertaken at each trial rehabilitation site within the Dendrobium mining area. These investigations are a key component of the proposed research. The impact characterisation expenditure can be categorised into the following work packages:

- Research design, study, data analysis, interpretation and reporting - $10,000 per site
- Site access (if additional to grouting/erosion control sites) - $5,000 per site
- Environmental controls, site clean-up and restoration (if additional to grouting/erosion control sites) - $2,000 per site
- Supervision and site vehicle ($700 per day) - $3,500 per site
- Drilling to characterise the near-surface fracture zones (rig mobilisation $6,000, rate per day $3,000, drilling water and fines recovery $1,800 per day) - $6,000 plus $24,000 per site
- Geophysics, packer testing, core logging, flow and tracer tests - $10,000 per site
- Supply and install piezometers ($2,000 per piezometer) - $10,000

Total costs of investigations and impact characterisation are estimated to be approximately $6,000 rig mobilisation plus $64,500 per site. Three grouting trials are proposed for the first stage of the SRRP and these would be completed in one campaign, with an approximate cost estimate of $199,500.

6.5  Monitoring and Data Collection

Monitoring has been installed to investigate whether the methods trialled to rehabilitate swamps contribute to the restoration of groundwater levels and groundwater recharge behaviour. Additional monitoring will be installed as required and the monitoring data will be assessed against...
pre-mining levels and reference sites. 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:

- 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 (rig mobilisation $6,000 per campaign, rate per day $3,000, drilling water and fines recovery $1,800 per day) - $6,000 plus $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
- 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 and maintenance ($30 per site per visit, 76 existing piezometers, 25 existing soil moisture probes, plus additional installations) - $4,000 per month

Total costs of monitoring and data collection are estimated to be approximately $38,900 per drill site plus $6,000 drill rig mobilisation for each campaign. Assuming three additional Hawksbury Sandstone monitoring and data collection sites are installed as part of the SRRP this would have an approximate cost estimate of $122,700. Swamp sediment piezometers and soil moisture monitoring sites have an approximate cost of $5,000. Assuming thirty additional monitoring sites are installed during the SRRP period this would have an approximate cost estimate of $150,000. Monitoring and maintenance of swamp sediment piezometer and soil moisture sites is approximately $4,000 per month, with an approximate cost estimate of $240,000 over a five year period. Total cost estimate for monitoring and data collection over the period of the SRRP is $512,700.

7 RESEARCH AND INDUSTRY PARTNERS

IC will work cooperatively with research and industry partners, including State and Commonwealth Government Agencies. This SRRP is to be prepared in consultation with OEH, Water NSW and DRE (T&I). 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. IC 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 has received considerable funding through this program. IC’s investment in research will be leveraged with this and other sources of additional funding to optimise the results for IC, 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 IC.

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 (TICKIT).

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 1: Roles and Responsibilities for Dendrobium Area 3B Swamp Rehabilitation Research Program |
|---|---|---|
| **Role** | **Responsibilities & Accountabilities** | **Authorities** |
| Vice President Processing | - Ensure that the IC 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 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 | - 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  
- Authorise persons as suitably qualified to undertake work under the SRRP |
### Dendrobium Mine
**SWAMP REHABILITATION RESEARCH PROGRAM**

<table>
<thead>
<tr>
<th>Role</th>
<th>Responsibilities &amp; Accountabilities</th>
<th>Authorities</th>
</tr>
</thead>
</table>
| Superintendent Brownfield 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, IC will have the approved SRRP publicly available on its website: [http://www.south32.net/home](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 IC 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.
## APPENDIX 1 - Research projects previously supported, currently underway and planned by IC
(highlighted projects are a component of the SRRP)

<table>
<thead>
<tr>
<th>Research Project</th>
<th>Overview</th>
<th>Timing</th>
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<tbody>
<tr>
<td><strong>Subsidence Modelling and Predictive Tools</strong></td>
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<td></td>
</tr>
<tr>
<td>Incremental Subsidence Profile Model</td>
<td>The Incremental Subsidence Profile Model was developed by MSEC (formally Waddington Kay and Associates) for the Southern Coalfield. Illawarra Coal contributed significant amounts of the empirical data to calibrate the model</td>
<td>Completed in the 1990’s this model is routinely updated based on subsidence survey data provided by Illawarra Coal</td>
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<td>Upsidence and Closure Model</td>
<td>The ACARP Upsidence and Closure Model was developed by MSEC for the Southern Coalfield. Illawarra Coal contributed significant amounts of the empirical data to calibrate the model</td>
<td>Completed in 2001 this model is routinely updated based on subsidence survey data provided by Illawarra Coal</td>
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<tr>
<td>Effects of Geology on Upsidence and Closure Movements and Impacts in Valleys</td>
<td>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. Illawarra Coal is a significant contributor to this project, supplying the majority of empirical data being analysed</td>
<td>Completed in 2014 this model is routinely updated based on subsidence survey data provided by Illawarra Coal</td>
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<tr>
<td>Anomalous Subsidence Review</td>
<td>A review of known anomalous events over the last 20 years from Illawarra Coal mining areas and research into the mechanisms contributing to these events</td>
<td>Completed in 2014</td>
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<td><strong>Groundwater Response to Mining</strong></td>
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<td>Reducing the Impact of Longwall Extraction on Groundwater Systems</td>
<td>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. Illawarra Coal contributed significantly to this project with Dendrobium Mine being one of the key case studies</td>
<td>Completed in 2012</td>
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| Connective Fracturing Research Project | 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. | 2012 - 2015 |
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<td>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>
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<td>Impact Monitoring and Prediction Tools</td>
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<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 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.</td>
<td>Completed May 2007 with continuing development of the techniques by Illawarra Coal</td>
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<tr>
<td>The Effect of Longwall Mining on Vegetated Environments</td>
<td>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 Illawarra Coal mining areas.</td>
<td>Completed January 2010 with continuing development of the techniques by Illawarra Coal</td>
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<tr>
<td>Monitoring Surface Condition of Landscape Features Subject to Mining Subsidence with Very High Resolution Imagery</td>
<td>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.</td>
<td>2012 - 2014</td>
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<td>Subsidence Impact Mitigation and Rehabilitation</td>
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<td>Damage Criteria and Practical Solutions for Protecting River Channels</td>
<td>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</td>
<td>Completed May 2009</td>
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<td>Effects of Surface Topography on Mining Subsidence Damage to River Channels</td>
<td>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. Illawarra Coal contributed significantly to this research, including provision of subsidence data for assessment of DinSAR monitoring.</td>
<td>Completed April 2011 with Illawarra Coal continuing to research DinSAR monitoring techniques</td>
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<tr>
<td>Swamp 15B</td>
<td>Swamp 15B was impacted by Longwall 8 in Area 3A. The following rehabilitation techniques will be trialled at Swamp 15B: sealing of rock fractures and injection grouting. The trials will commence following appropriate approvals to undertake the work are in place.</td>
<td>2016 - 2024</td>
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<tr>
<td>Swamp 1A and 1B</td>
<td>Swamps 1A and 1B were impacted by Longwall 9 in Area 3B. The following rehabilitation techniques will be trialled at Swamps 1A and 1B: sealing of rock fractures, injection grouting and knick point control. The trials will commence following appropriate approvals to undertake the work are in place.</td>
<td>2016 - 2024</td>
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<tr>
<td>Swamp 5</td>
<td>Swamp 5 was impacted by Longwall 9 in Area 3B. The following rehabilitation techniques will be trialled at Swamp 5: sealing of rock fractures and injection grouting. The trials will commence following appropriate approvals to undertake the work are in place.</td>
<td>2016 - 2024</td>
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<td>Additional Swamp Rehabilitation Research</td>
<td>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 specific rehabilitation research projects.</td>
<td>Determined from specific rehabilitation requirements</td>
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<td>IC 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</td>
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