NSW DEPARTMENT OF PLANNING & ENVIRONMENT

GEOTECHNICAL AND HYDROGEOLOGICAL REVIEW

ERARING ASH DAM EXPANSION

DECEMBER 2018

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Geotechnical and hydrogeological review
Eraring Ash Dam Expansion

NSW Department of Planning & Environment

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EXECUTIVE SUMMARY

Origin Energy (Origin) owns and operates the Eraring Power Station and associated Eraring Ash Dam, where coal combustion products generated during the production of electricity are reclaimed or deposited via pipelines as a slurry to the dam. Origin is proposing to augment the ash dam using an alternative placement strategy for fly ash and landform design to increase the ash storage capacity and accordingly an environment assessment has been prepared (AECOM, 2018a).

The NSW Department of Planning and Environment (DPE) engaged the services of a specialist geotechnical engineer and hydrogeologist (WSP Australia Pty Ltd) to provide:

- Advice on the measures proposed by Origin to address the geotechnical and hydrogeological risks.
- Recommendations for any additional mitigation measures, including monitoring or requirements for the detailed design stage to inform the DPE's assessment.

Portions of the proposed augmented ash dam (site) are underlain by flooded, abandoned mine workings which can impact the ash dam through mine subsidence in the form of sinkholes and/or troughs. Sinkholes occur due to the failure of the mine roof into the mine workings and may be 5 m in diameter at the surface. Trough subsidence occurs due to failure of the coal pillars and results in the fracturing of the roof and a depression at the surface that can occur over a large area. A sinkhole has been observed on site and other subsidence features may exist, but further assessment is needed to determine whether other subsidence features are present. Subsidence could increase the permeability of the materials underlying the site due to fracturing of the rock, possibly allowing water leakage from the site and/or release of ash, potentially impacting the groundwater. On a non-undermined site, the potential release of these materials can be reduced by using a liner system. However, constructing a liner over an unstabilised mined area requires that the liner be able to accommodate the potential subsidence deformations.

Potential subsidence impacts can be mitigated by grouting, over-excavation, and/or spanning the mine workings. Grouting involves the injection of a cementitious fly ash grout into the workings through boreholes drilled from the surface. Over-excavation involves digging out the workings to remove the potential for mine subsidence and backfilling the area with compacted fill. Spanning involves placing a material, such as geogrid or reinforced concrete, over the mined area to support the overlying material so that deflections of the over-lying material are to an acceptable level. Due to the shallow depth of the workings in the site area, flooded conditions, and unlikely ability to span potential subsidence features without excessive deflection, grouting is likely to be required.

Grouting has been used in the Newcastle Region to mitigate mine subsidence impacts since late 1987 and has been used in the United States to mitigate potential impacts to disposal facilities.

The environmental assessment for the proposed modification has been based on a mine subsidence impact assessment undertaken by SCT Operations Pty Ltd (SCT) (2018), undertaken to review and assess potential geotechnical risks due to the proximity of the underground mine workings. SCT (2018) assessed two main risks:

- Potential for subsidence impacting the proposed south western embankment.
- Connectivity from the ash dam to underground workings (and hence potential to flow into streams).

Origin Energy propose several options to mitigate potential adverse impacts, with one or a combination of the following to be used as their preferred strategy to be called a Mine Void Rehabilitation Plan:

- Stabilise the underground workings below the proposed extension area by injecting a fly ash/cement mix into the mine workings from boreholes drilled from the surface.
- Construct a mine level barrier up to 100 m beyond from the proposed edge of the extension area by injecting a fly ash/cement mix into the mine workings through boreholes drilled from the surface.

— Excavating and collapsing the mine workings and installing an impervious barrier (collapsing the mine workings is not recommended by WSP).

A number of factors need consideration for the design of mine mitigation work for adequate grouting and reducing the risks to the groundwater system, including the creation of a barrier to groundwater flow and changing the groundwater quality. Thus, the groundwater system needs to be better conceptualised, the risks identified, investigations conducted and monitoring undertaken. The use of cement stabilised fly ash in an underground environment will require evaluation, testing and monitoring to ensure contamination of groundwater and surface water does not occur. The chemistry and leaching potential will need to be determined; there is the immediate or short-term potential release of metals and alkalinity, as well as the longer term consideration due to dissolution or weathering.

The following recommendations are provided for the detailed design phase of the of the ash dam augmentation to be incorporated into the Mine Void Remediation Plan (MVRP):

1. A mine subsidence expert be retained by Origin, who is approved by DPE, to assess subsidence impacts to the site and mitigation, particularly as only conceptual information has been provided on mine subsidence impacts and mitigation.
2. A qualified and experienced hydrogeologist be engaged by Origin, who is approved by DPE, to:
   - Better conceptualise the groundwater system.
   - Assess and refine the potential risks to groundwater.
   - Inform the detailed design.
   - Design and implement a water monitoring program.
3. Investigation of the mine workings and subsurface conditions in the site area be undertaken, including:
   - Desktop study of mining and geology.
   - Site reconnaissance to look for and locate mining and subsidence features, springs, and other items of interest.
   - Subsurface investigation with boreholes, downhole investigation techniques and test pits.
4. Mitigation of existing and potential mine subsidence impacts at the site be undertaken. Several options have been proposed, which need further assessment including:
   - Type, extent, analyses, and effectiveness of proposed mitigation option.
   - Stabilisation material assessment including trial mixes to assess strength, conductivity, flowability, and leachability.
   - Impacts to groundwater flow from the stabilisation/barrier material at the mine level and in the overburden.
5. The recommendations provided within this document be included in the MVRP, to be submitted to DPE for review and approval prior to implementation.
6. Regularly consult DPE during the development of the MVRP, detailed design and implementation stages to allow opportunities for DPE review and advice during the process, including the establishment of performance measures for subsidence and hydraulic leakage into the underground workings.

In summary, it appears that expanding the Eraring Ash Dam over abandoned mine workings is feasible if appropriate subsidence mitigation and groundwater controls are implemented.

1 INTRODUCTION

1.1 INTRODUCTION

The NSW Department of Planning and Environment (DPE) required the services of a specialist geotechnical engineer and hydrogeologist to provide peer review and independent advice on the proposed stabilisation and barrier creation of the underground workings associated with the Eraring Ash Dam Augmentation Project, proposed by Origin Energy (Origin) (AECOM, 2018a).

The proposed expansion of the ash dam, including a new western embankment, extends over historic bord and pillar underground coal mine workings of the Awaba Mine which are at a depth of 20-50 m. This shallow depth of cover has consequential implications for possible connectivity between the ash dam extension and nearby surface waters via the underground workings and subsided overburden.

Origin Energy propose to stabilise the underground workings below the proposed extension area by injecting a fly ash/cement mix into the workings via boreholes and/or direct excavation, and construct a mine level barrier up to 100 m beyond from the edge of the extension area. Other mitigation measures such as lining systems may be considered.

The environmental assessment for the proposed modification has been informed by a *mine subsidence impact assessment* undertaken by SCT Operations Pty Ltd (SCT) (2018), undertaken to review and assess potential geotechnical risks due to the proximity of the underground mine workings. SCT (2018) assessed two main risks:

- Potential for subsidence impacting the proposed south western embankment.
- Connectivity from the ash dam to underground workings (and hence potential to flow into tributaries of Dora Creek).

Submissions received during the exhibition period also raised concerns regarding the stability of the mine workings and potential for groundwater contamination to occur through the stabilisation works into the Awaba Mine.

1.2 SCOPE

The WSP Australia Pty Ltd (WSP) scope of work was as follows:

- Undertake a site visit to Eraring Power Station's disposal site to obtain further background and information for the review.
- Undertake a desktop review of relevant information, including the following:
  - The environmental assessment for the Ash Dam Augmentation Project, including the mine subsidence impact assessment (AECOM, 2018a; SCT, 2018).
  - Any other geotechnical and hydrogeological reports and data available.
- Prepare a report on the findings and conclusions of the peer review, including the following:
  - Background to the review.
  - Summary of the findings of the desktop review, including geotechnical (mine subsidence) and hydrogeological context/setting of the ash dam relative to the underground workings.
  - Summary of the field visit.
  - Advice/conclusions on the measures proposed by Origin to address the geotechnical and hydrogeological risks.
  - Recommendations for any additional mitigation measures, including monitoring or requirements for the detailed design stage to inform the DPE's assessment.

1.3 REVIEW TEAM

The review team are well qualified for these roles and experienced with projects involving the assessment of mine subsidence and hydrogeological impacts to developments. David L. Knott (mine subsidence) and Andrea Madden (hydrogeology) are the primary reviewers. They are supported by Robert Kingsland (mine subsidence internal review) and Ray Hatley (hydrogeology internal review). A summary of the experience of the review team is provided below, with curricula vitae provided in Appendix A.

- David L. Knott is a senior geotechnical engineer with over 35 years of broad ranging experience with particular expertise in mine subsidence investigation, assessment, and mitigation. He has worked on disposal facilities, including those for coal combustion by-products, with some underlain by mine workings. He has significant understanding of the potential subsidence impacts to disposal facilities including liner systems, mitigation approaches and associated environmental issues. In addition, he has worked on a dam underlain by mine workings and a dam with abutments in abandoned mine workings.

  David has significant experience dealing with mining conditions in Newcastle Region and has recently completed a large-scale study of mine subsidence impacts to the Newcastle CBD area on behalf of Subsidence Advisory NSW. He has also performed peer reviews for other mine subsidence related projects, including portions of the Hunter Expressway Alliance.

- Andrea Madden is a Principal Hydrogeologist and an accredited Registered Professional Geoscientist in the field of Hydrogeology with 17 years' experience in groundwater investigations across several industry sectors. Andrea has extensive experience with the coal mining industry, particularly in the Hunter Valley and Southern Coalfield, NSW. The experience extends from greenfield sites to existing coal mines, open cut and underground. Andrea has experience with storage facilities (particularly tailings storage facilities) and recently undertook a groundwater assessment associated with a proposed long-term waste landfill at the Bayswater Power Station.

  Andrea was approved by the NSW government as the groundwater specialist on the Independent Risk Assessment Panel for Russell Vale Colliery Underground Expansion Project and as the groundwater specialist on independent environmental audit teams. Andrea has provided technical advice to industry and government, particularly relating to coal mining and its influence on groundwater and groundwater dependent ecosystems. Andrea has authored papers and presented at industry conferences.

- Robert Kingsland is a Technical Executive – Geotechnics and has over 30 years' experience of geotechnical engineering practice in both government and private consulting primarily in the transport, mining and power infrastructure sectors. Robert has particular expertise in dam engineering and mine subsidence, road and rail geotechnics, earthworks and reactive soils, slope stability and landslide risk management, pavement analysis and design.

  Robert has managed and provided technical leadership for teams; small and large, working independently or as part of major multi-disciplinary infrastructure projects in a range of settings; remote regional, urban design office and project based, and has operated under design only, D&C and alliance contract environments.

- Ray Hatley is the Capability Executive for Hydrogeology and has 37 years' experience providing geological, hydrogeological and environmental services to mining, energy, industrial, land development, construction, state and federal government clients and community groups. He has worked on projects for these clients in various countries in project director, project management, coordinator, technical advisor or review roles.

  Ray has completed work pertinent to the Queensland and NSW coal mining industry covering groundwater impact assessment to State and Federal authorities (including EIS, EA Modifications, trigger level setting, closure); water resource management; conceptual geological and hydrogeological models for surface and underground mining operations; groundwater modelling and water balance modelling; hydrogeochemical assessment (source, pathway, receptor assessments), dewatering, seepage and inflow assessments, rock bolt assessments; floor heave mitigation studies; mine salinity impact assessment; waste rock dump assessment; and groundwater exploration and resource testing, water supply wellfield design and development, groundwater well installation and testing.

2 CURRENT UNDERSTANDING

2.1 BACKGROUND

Origin owns and operates the Eraring Power Station and associated Eraring Ash Dam as shown on Drawing 1 in Appendix B. Coal combustion products generated during the production of electricity are reclaimed or deposited via pipelines as a slurry into the Eraring Ash Dam. Origin is proposing to augment the ash dam using an alternative placement strategy for fly ash and landform design to increase the ash storage capacity and accordingly an environment assessment has been prepared (AECOM, 2018a).

2.2 INFORMATION REVIEW

The following information was provided by the proponent (Origin) or DPE and reviewed:

- Environmental assessment for the Ash Dam Augmentation Project (AECOM, 2018a).
- Mine subsidence impact assessment (SCT, 2018), Appendix D of the Ash Dam Augmentation Project environmental assessment.
- Response to submissions report (AECOM, 2018b).
- Environmental Assessment Upgrade and Expansion of the Coal Combustion Product Management System, Eraring Power Station (HLA, 2007).
- Groundwater Management Plan - Coal Combustion Product Management Facility Eraring Power Station (AECOM, 2009).

In addition to the information provided above, additional sources were obtained and reviewed, such as the mine maps (RT606). Where relevant, this information is summarised and presented in this report, with references also provided.

2.3 THE PROJECT – ASH DAM AUGMENTATION

The proposed ash dam augmentation (the project) broadly involves the following components:

- Amendment of the ash deposition strategy, including a combination of beaching and ash terrace deposition methods, and the construction of new decant infrastructure associated with ash terraces.
- Establishment of the Western Emplacement Area to enable ash deposition to relative level (RL) 140 (using the Eraring Datum and 40 m Australia Height Datum (AHD)) within existing operational areas, requiring the construction of a western saddle embankment, reconfiguration of an access road, and filling of mine voids (workings) underlying the Eraring Ash Dam.
- Upgrades to ancillary infrastructure, including stormwater diversion systems and ash delivery line re-configuration.
- Decommissioning and relocation of bottom ash recycling infrastructure (AECOM, 2018a).

The following subsections include descriptions of the project that are relevant to this review.

2.3.1 AMENDED ASH DEPOSITION STRATEGY

The proposed ash dam augmentation will involve the placement of ash using a combination of techniques depending on the fly ash characteristics and ash dam surveillance, and final design landform. The site is shown on Figure 2.1. The placement techniques are as follows:

- *Hydraulic ash placement* – the hydraulic pumping of dense phase ash slurry (up to 70% ash and 30% water) via pipeline and subaerial deposition onto the surface of the ash dam. Typically, ash is deposited from the perimeter of the ash dam, beaching towards the main embankment at a grade of 1 to 2.5%.
- *Cell deposition* – involves the establishment of self-contained cells on the ash dam surface with interior containment bunds. Ash would be progressively deposited so that each cell would slope downwards to the north and upwards towards the new ash terrace to the south. The ash would be deposited such that decant water is allowed to escape the cell and reach the decant pond via low spots within the cells. These low spots would be raised progressively as the level of the ash rises within each cell.
- *Progressive ash terrace deposition strategy* – the ash terrace would 'step' up from the south before reaching its high point and sloping down towards the RL140 roadway (AECOM, 2018).

Note some changes to the deposition strategy were discussed during the site walkover and meeting (refer to Section 3).

2.3.2 WESTERN EMPLACEMENT AREA

A western saddle embankment is required along the perimeter of the Western Emplacement Area to enable safe placement of ash to RL 140 m. The concept design for the western saddle embankment incorporates an earthfill embankment approximately 600 m in length and constructed to a maximum height of 10 m (AECOM, 2018a).

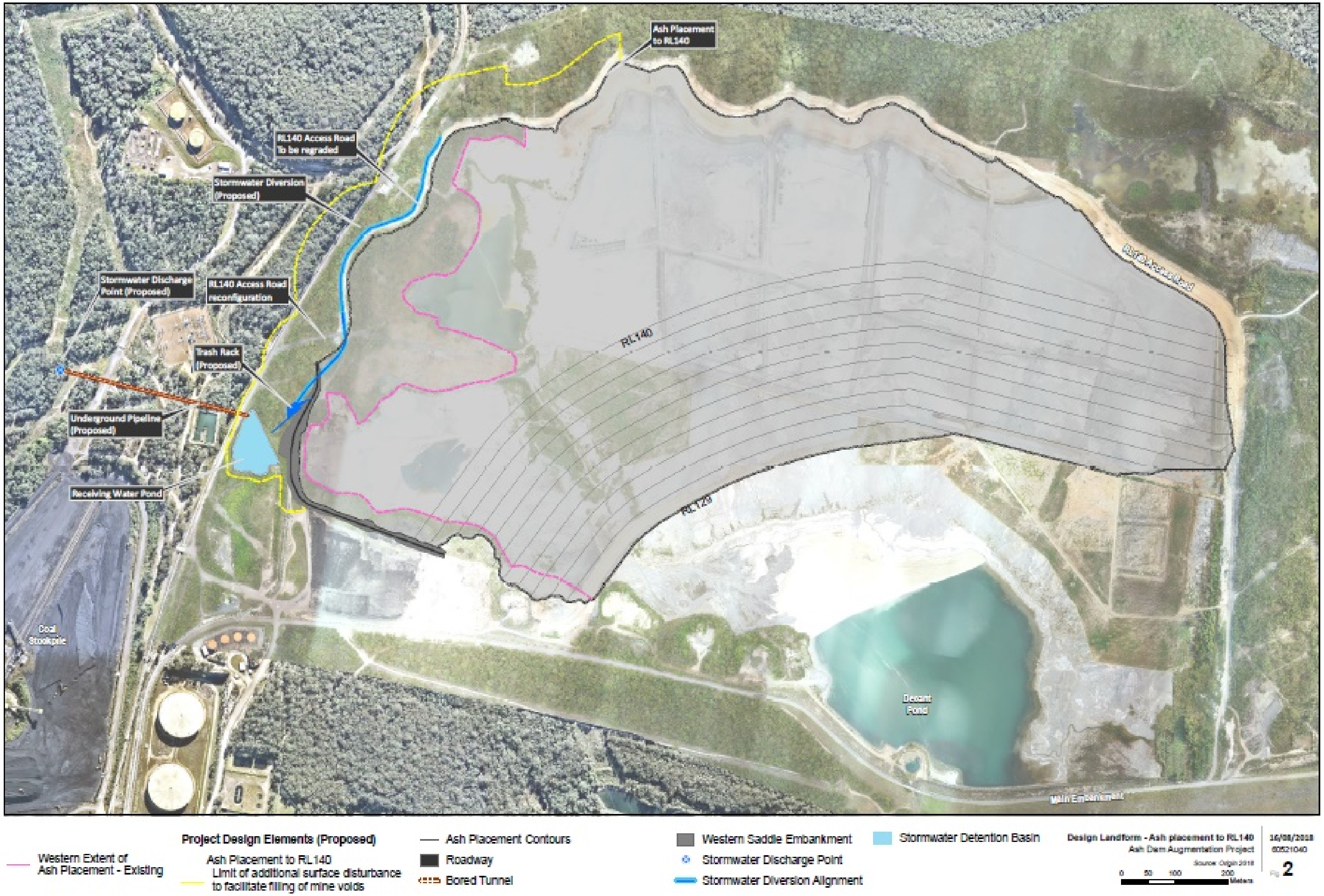

Figure 2.1 Design landform (figure 2 from AECOM, 2018a)

2.4 GEOLOGY

The regional geology of the Lake Macquarie area comprises of Quaternary alluvium, including gravel, sand, silt and clay, overlying claystones, sandstones and shale of the Triassic Narrabeen Group (HLA, 2007). The Newcastle Coal Measures, in turn, underlie the Narrabeen Group (AECOM, 2018a).

The Awaba Colliery mined within the Great Northern Seam, which typically comprises a conglomerate roof and a claystone floor. Some weathering of the conglomerate roof strata is likely to have occurred over time and the claystone floor has the potential to deteriorate over time, particularly when the mine becomes flooded. Overburden depth near the edge of the proposed ash dam ranged from 20 m near the edge of the Awaba workings to over 50 m at a distance of 300 m from the edge of the ash dam (AECOM, 2018a).

2.5 HYDROGEOLOGY

Groundwater beneath the site is expected to be present within the shallow soils and former ash placement areas of the former Wangi Power Station. The nearest groundwater receptors surrounding the Ash Dam are Crooked Creek and Lake Macquarie, which are both located approximately 400 m from the main embankment (AECOM, 2018a).

A search of the nearby registered bores undertaken in 2005 indicate groundwater levels ranging from 16 to 21 m below ground level (HLA, 2006; AECOM, 2018a). According to HLA (2007), it is generally believed that groundwater migrates from north of the ash dam, down gradient, towards Myuna Bay. Historical groundwater monitoring results obtained on site indicate that there are trace metals in groundwater beneath the ash dam which have occasionally been recorded in concentrations in excess of the ANZECC/ARMCANZ (2000) guidelines. It is unclear whether the concentrations can be attributed to background or naturally elevated conditions (HLA, 2007).

There are four groundwater monitoring locations, with monitoring undertaken in accordance with EPL 1429. The locations are shown in Figure 2.2. MW01 (EPL point 21) is located directly adjacent to the proposed western emplacement area and will be maintained and monitored in accordance with EPL 1429 (AECOM, 2018a).

The Awaba Colliery is flooded and fully connected across the footprint of the mine. Only small areas of the mine in the north and east are dry; the seam floor rises above the water level in the mine in these areas. SCT (2018) notes (based on discussions with Centennial Coal Pty Ltd (Centennial Coal)) that:

- The water level within the mine is artificially maintained at 16.5 mAHD to 17 mAHD from pumping at one or two locations and by natural overflow at low points within the surface topography in the south western parts of the mine.
- One of the reasons for this pumping is to control the potential for artesian outflows at Eraring Power Station during periods of extended rainfall.
- The water level increases with increasing rainfall consistent with the inflow of water through fractured and naturally jointed overburden strata (AECOM, 2018a).

Figure 2.2 Groundwater monitoring locations (Figure 5 from AECOM, 2018a)

2.6 WATER MANAGEMENT

Improved controls and structures will be required to effectively manage stormwater and process flows in and around the ash dam. This will include new stormwater works intercepting potential surface flows to the Western Emplacement Area, diverting these clean water flows to water storages within the broader Eraring catchment. During operation, additional runoff from the catchment area will be diverted to a receiving pond, with overtopping storages to be utilised during high rain events (AECOM, 2018a). The volume of surface flows currently entering the ash dam would therefore be reduced, minimising the potential for surface water to enter the ash dam and infiltrate groundwater (AECOM, 2018b).

Water within the deposited ash slurry will drain towards the water collection point at the lowest part of the ash dam (AECOM, 2018a).

A depression approximately 3 ha in extent, located within the current western extent of the ash dam, currently collects some stormwater drainage from the immediate catchment area. This water storage will be made redundant by the proposed stormwater diversion works. Ash placed within this area during the Project would displace water, reducing the volume of standing water available to infiltrate as groundwater in this area (AECOM, 2018a).

2.7 MINE SUBSIDENCE RISKS

The Western Emplacement Area is located above abandoned mine workings of Centennial Coal's Awaba Mine. An assessment of potential mine subsidence impacts associated with the proximity of the underground mine workings was undertaken, with two potential risks identified:

– Subsidence in the form of either pillar collapse or roof failures leading to fracturing, ground movements and sinkhole formation, and impacting on the ash dam and the western saddle embankment.

- Mining induced fractures resulting in direct water connectivity between the ash dam and the mine workings (AECOM, 2018a).

A Mine Void Rehabilitation Plan (MVRP) will be prepared in consultation with Subsidence Advisory NSW and Centennial Coal prior to the commencement of remediation activities. The MVRP will identify the void treatment methods, excavations, a material placement strategy and design criteria. The MVRP will also identify bulk material handling practices, water management procedures and safeguards to minimise risks to the environment. The MVRP will be informed by and contain the following:

- Geotechnical investigations, including drilling, geotechnical core logging and/or borehole camera inspection.
- Geotechnical and hydrologic models to assist in identifying groundwater flow paths, discharge locations and water quality parameters.
- Assessment of subsidence and resulting hydraulic connectivity for preferred design scenarios.
- Construction quality control measures to be implemented describing monitoring and verification works and quality control of grouting materials.
- Performance measures, and if required, long-term monitoring (AECOM, 2018b).

A mine void rehabilitation verification report will be prepared to determine the effectiveness of the rehabilitation works. This report will be informed by, and contain, the following:

- A summary of geotechnical and/or groundwater investigations undertaken to verify performance measures identified in the MVRP are met.
- If necessary, any further monitoring or geotechnical work required to manage residual risk associated with subsidence and surface water connectivity risks (AECOM, 2018b).

2.8 SUBSIDENCE MITIGATION

A preferred strategy involving a combination of techniques is proposed to mitigate both subsidence and surface water connectivity hazards. The area to be remediated would depend on a range of factors including the hydraulic conductivity of the stabilisation material and the effectiveness of the filling strategy used. The strategies mentioned include the following:

- Filling of mine voids with stabilised fill material.
- Excavating and collapsing of shallow mine workings.
- Installing an impervious barrier using clays or suitable stabilised fill materials (AECOM, 2018a).

Mechanically stable fill material would be used to fill voids and fractures that exist within the overburden strata. Boreholes would be drilled from the ground surface to the mine voids to enable deposition of a cement stabilised fly ash fill material (AECOM, 2018a).

The cement ratio required to stabilise the fill would be confirmed based on detailed design and site parameters but is expected to be 2 to 4% cement content for fly ash fill. The fill material would be designed to be viscous enough to displace in situ groundwater present within the voids being filled and to avoid dilution of the grout material (AECOM, 2018a).

To achieve effective treatment, an estimated 100-130 boreholes would be drilled from the ground surface to depths between 15 and 40 m. Boreholes would be spaced according to the Awaba mine plan and located in areas of overlap with the Eraring Ash Dam and key project elements. Additional boreholes would be drilled as required to minimise the potential for direct water connectivity between the Eraring Ash Dam and mine workings. The volume of mine voids to be filled is estimated to be approximately 200,000 m^3 (AECOM, 2018a).

Excavations may be undertaken to collapse shallow workings and improve stability. Remedial works will extend up to around 100 m from the proposed limit of ash placement. The limit of additional disturbance associated with these works is shown in Figure 2.1 (AECOM, 2018a).

The design would be further developed relying on further testing and the available engineering approaches (AECOM, 2018a).

2.9 SUBSIDENCE AND WATER CONNECTIVITY RISKS AND CONTROLS

2.9.1 *WATER FLOW*

2.9.1.1 HAZARD

Mining induced fractures caused by mining at shallow depths are expected to provide a flow pathway between the ash dam and the underground workings of Awaba Colliery. This flow pathway is expected to extend from these underground workings to locations where the ground surface above the Awaba Colliery workings is less than the water level within the flooded workings. An observed sinkhole is consistent with the presence of a flow pathway near the existing ash dam. There are likely to be similar features along the edge of areas where coal has been extracted, including directly below the existing ash dam, along the edge of 102 Panel (SCT, 2018).

Under these conditions, a flow pathway may establish between surface water in the ash dam and the nearby tributaries of Dora Creek (SCT, 2018) (Figure 2.3). The water level in Awaba Colliery is currently managed by pumping and maintaining a water level of 16-17 mAHD. At this water level, artesian flow could be expected to reach tributaries of Dora Creek. Figure 2.4 shows where artesian flows are likely to emerge and flow into the tributaries of Dora Creek when the water level in the mine is greater than about 16 mAHD (AECOM, 2018a).

Without intervention, the cessation of pumping at the closure of Awaba Colliery and Eraring Power Station would potentially lead to the creation of an ongoing flow pathway whereby processed water from the Eraring ash dam flows into the Awaba Colliery workings and would potentially flow into the nearby tributaries of Dora Creek. Water falling as rainfall onto the surface of the ash dam will always be at a higher elevation (40 mAHD) than the water level in the colliery (17-20 mAHD depending on rainfall). Water would potentially continue to flow as artesian flow into waterways around the edge of Awaba Colliery at multiple low points within the topography as it currently does (AECOM, 2018a; SCT, 2018).

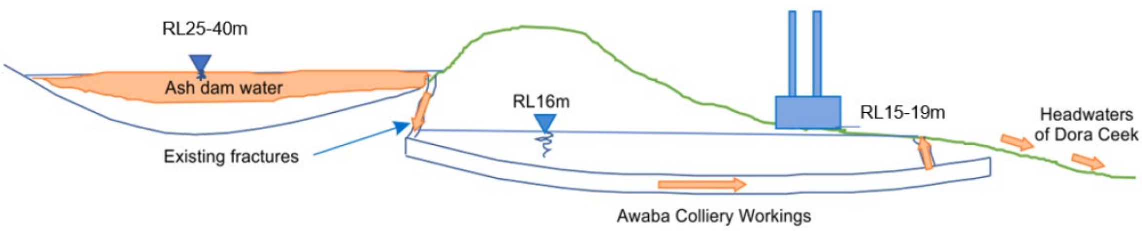

Figure 2.3 Potential flow pathways (Figure 3 from SCT, 2018)

Figure 2.4 Potential water outflow points from Awaba colliery (Figure 4 from SCT, 2018)

2.9.1.2 CONTROL

SCT (2018) state that the potential for water connectivity between the ground surface and the underground workings will be controlled if the voids are filled with stabilised material of low hydraulic conductivity for a sufficient distance to limit flow rates to low levels, and that cement stabilised fly ash has a sufficiently low hydraulic conductivity to provide an effective barrier. Suitable design and testing of the fill material will be required to confirm the hydraulic conductivity and determine how far the barrier would need to extend laterally to control flows to low enough levels to be acceptable.

The sections of the mine where the pillars are still standing will need to be completely filled at seam level and ideally pressure grouted. Those sections of the mine where coal has been extracted and the overburden has subsided would need to be filled from seam level through the goaf zone to the surface. Pressure grouting would be helpful to ensure voids are filled but would need to be limited controlled so as not to induce hydraulic fractures of the overburden strata (SCT, 2018).

SCT (2018) envisage that to control the water flow risk, the footprint of void filling activities is likely to extend up to 100 m from the edge of the proposed ash dam. However, the actual area required to be filled will depend on a range of factors including the hydraulic conductivity of the fill material, void density and extent, grout characteristics and the effectiveness of the filling strategy used. The detail of this design would rely on further testing and the engineering approach used.

2.9.2 OTHER CONSIDERATIONS

SCT (2018) understands that the flow of water into the Awaba Colliery underground workings is currently being managed by extracting water from one or two locations. Once pumping ceases at the closure of Awaba Colliery and Eraring Power Station, mine water is expected to continue to flow out of the mine workings as artesian flow to streams (refer to Section 5.2.2.1).

2.9.3 OPERATIONAL MITIGATION MEASURES

During the operation of the Project, the following mitigation measures were proposed:

- The Water Management Plan (Umwelt, 2013) would be reviewed and updated if necessary to incorporate the Project.
- The existing surface water and groundwater monitoring program will continue to be implemented in accordance with Project Approval and environment protection licence (EPL) conditions (AECOM, 2018a).

Note the water management plan has not been sighted by WSP.

3 SITE WALKOVER AND MEETING

A site walkover and meeting was held on 14 November 2018 and the following comments are provided:

- General:
  - Stantec is now the Engineer of Record.
  - It is not clear if SCT are involved with the work going forward.
  - Stantec and Origin do not appear to have a strong background in subsidence/mitigation.
  - Much of the meeting focused on planning requirements and beneficial use of ash.
  - A liner was not used at the existing disposal site.
  - The permeability of the site would need to be the same as a non-mine impacted site.
  - The area of interest is the proposed extension area, not the whole disposal area.
- Groundwater:
  - Groundwater monitoring is undertaken in accordance with their EPL.
  - Apparently, no groundwater monitoring wells are in the mine workings, with only one monitoring well in the vicinity of the proposed extension area.
  - It appears that a Centennial Coal dewatering borehole exists (Well 10S).
  - Origin measure groundwater levels in monitoring wells twice a year.
  - Groundwater flows to the east/southeast.
  - The mine is a 'sink'.
- Facility design:
  - Origin are still reviewing overall storage options.
  - The cell deposition technique is unlikely to be used in the future, with beaching currently the preferred method.
  - A conceptual closure plan is to be developed.
- Mine subsidence/mitigation:
  - Origin does not have mine maps (Record Tracings).
- Mitigation options include:
  - Grout barrier in mine workings to block the flow of ash/leachate from the site into extended mine workings.
  - Lined facility and grouting the mine workings under facility.
- Apparently, grouting will be performed under the dam embankment.
- Centennial Coal is amenable to grouting, but are concerned about "spon com" (spontaneous combustion of coal due to the reaction of minerals, such as pyrite with air and generating heat) if over-excavate coal seam.
- The area where SCT reported a sinkhole has been disturbed by clearing. The sinkhole may have been located during the site walkover (difficult to state with certainty due to the disturbed ground) and a request made to have the location surveyed.
- Subsidence Advisory NSW (SANSW) approval is still needed.
- NSW Dam Safety Committee (DSC) approval is needed.

The following photos were taken during the site walkover.

Figure 3.1 View from existing facility looking towards proposed site

Figure 3.2 View of downstream side of cell at existing facility

Figure 3.3 View of existing facility looking towards station

Figure 3.4 “Piping” in ash cell wall

Figure 3.5 View showing extent of existing facility looking towards station

Figure 3.6 View of possible sinkhole location

Figure 3.7 Closer view of possible sinkhole

Figure 3.8 View looking towards sinkhole area

4 ADDITIONAL INFORMATION

This section includes additional relevant information based on research undertaken by the reviewers.

4.1 GEOLOGY

Information on the geology was developed from mine maps (RT606) and other sources. The site is in the Newcastle Coalfield based on information in Hawley and Brunton (1995). It is underlain by rock belonging to the Narrabeen Group and Moon Island Beach Subgroup of the Newcastle Coal Measures as shown on Drawing 2 in Appendix B. The approximate stratigraphy of the site area from boreholes shown on the mine maps is reproduced as Figure 4.1. The Great Northern Seam belongs to the Moon Island subgroup and was mined in the past as discussed in later section. It was about 2.5 m to 3 m thick as shown on seam sections reproduced as Figure 4.2. The mine maps (RT606) indicate the overall dip of the Great Northern Seam is to the west at 1V:116H, with structural contours within the mine workings showing variations in dip. Northwest to southeast trending normal faults are shown on the mine map to the northwest of the area of interest and stop about 250 m beyond the proposed extent of the facility.

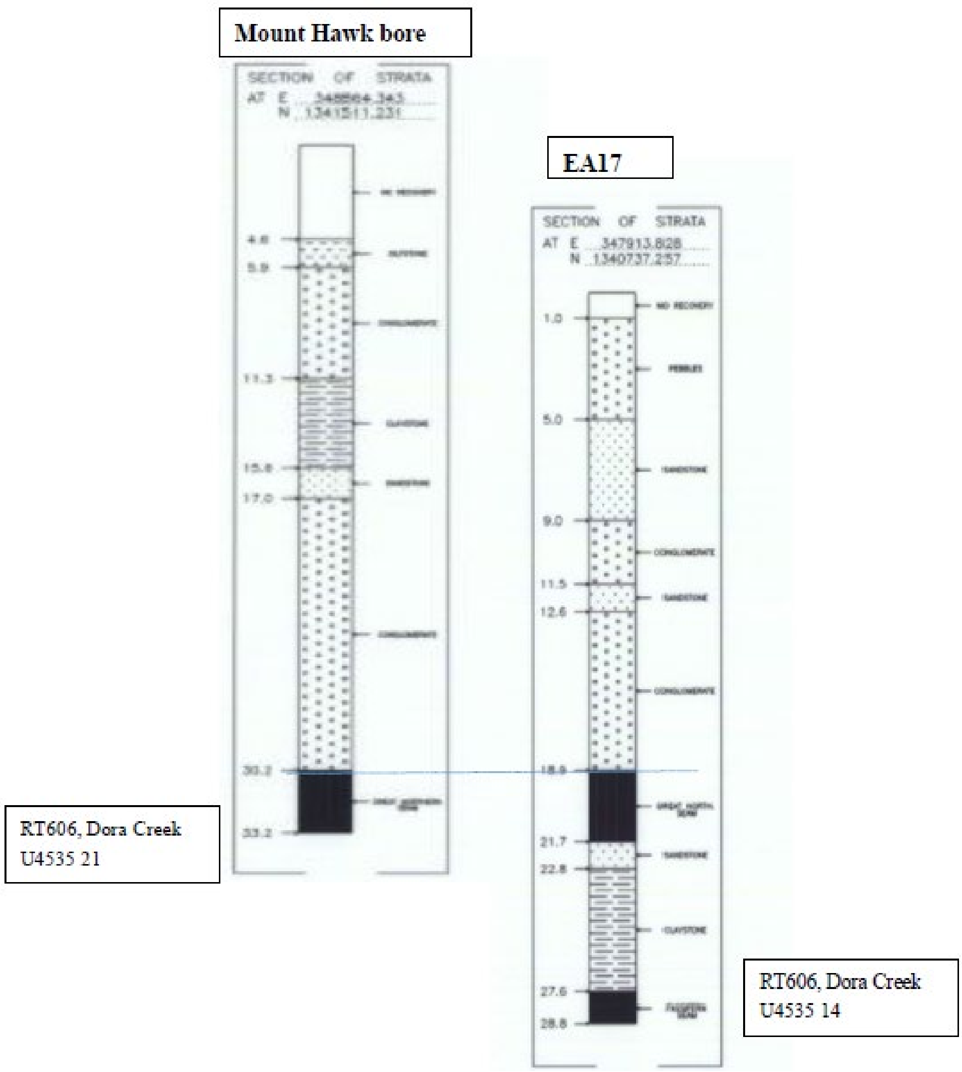

Figure 4.1 Representative stratigraphy in site area

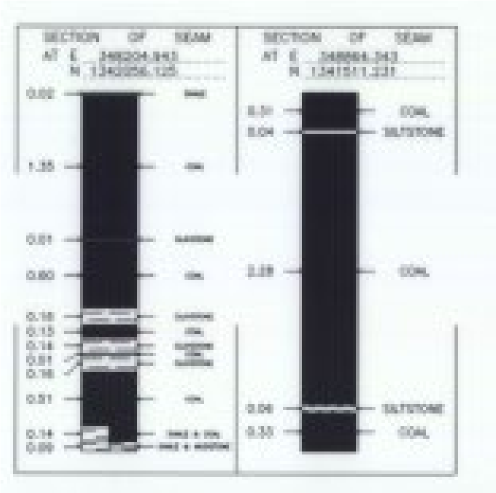

Figure 4.2 Great Northern Seam sections (RT699 – Sheet Dora Creek U4535 21)

4.2 SUBSIDENCE

4.2.1 MINING

The Great Northern Seam was mined beneath portions of the site as shown on Drawing 3 in Appendix B. The mining was initially performed using the bord (room) and pillar method, where blocks of coal approximately 30 m square (pillars) were left unmined between about 6 m wide roadways. This initial mining is known as “development”. After development, retreat mining, where all or the majority of the coal was mined from the pillars was typically performed in the northeast portion of the site and secondary mining, where the pillars were split (quartered), was typically performed in the southwest portion of the site. Barrier pillars were left in some areas to separate the mining areas (panels).

4.2.2 MINE SUBSIDENCE BACKGROUND

Mine subsidence refers to the downward movement of the ground surface due to failure of support at mine level. Subsidence can take the form of sinkholes and/or troughs as shown on Figure 4.3.

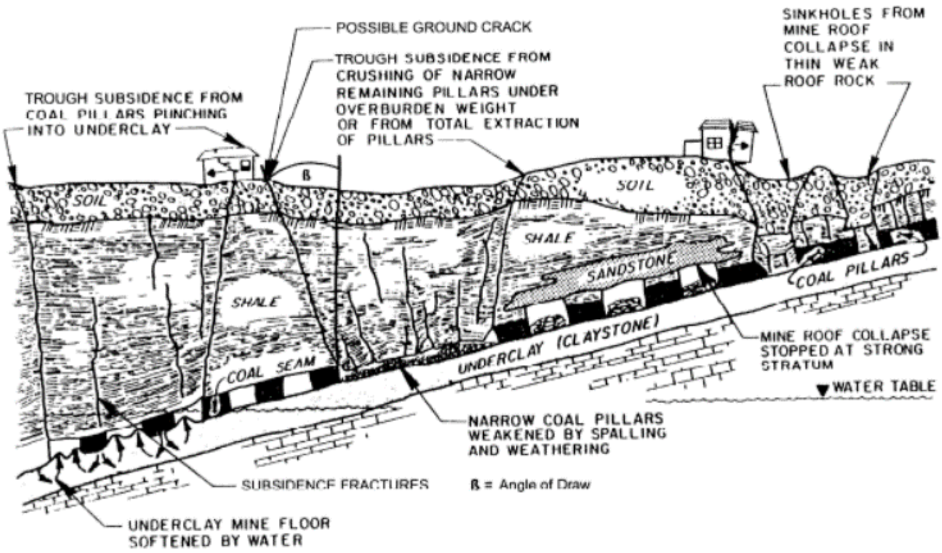

Figure 4.3 Types of mine subsidence (Knott, 2006; modified from Bruhn et, al., 1978)

Sinkholes (potholes) are usually circular collapse depressions with sides that can be steep and abrupt or gently sloping towards the centre. Sinkhole formation is controlled by the thickness of the soil and rock overburden, jointing of the rock, mining conditions and bulking of roof fall material. Sinkholes are generally limited to mining where the rock overburden thickness is within ten times the mined thickness of the coal seam. The surface diameter is usually less than 5 m in the Newcastle Region. A sinkhole was reported at the site in the SCT report and its approximate location is shown on Drawings 3 and 4 in Appendix B.

Troughs are broad, shallow depressions that result from the failure of one or more pillars. Pillars can fail by crushing or punching into the roof or floor. The trough size and deformations depend on the mined width, mined height, thickness and strength of the overburden rocks and pillar stability. Deformations from trough subsidence can extend beyond the limits of mining. The zone beyond the limit of mining that is impacted by trough subsidence is delineated by the angle of draw (Angle β in Figure 4.3). The angle β typically used in the Newcastle Coal Measures is 26.5° (0.5H:1V). It can vary. Therefore, should workings at a depth of 30 m and within 15 m from the edge of the site fail, some surface subsidence of the site would be expected.

Associated with the vertical component of subsidence are additional movements as shown on Figure 4.4 and Figure 4.5. These movements include:

- Horizontal displacements, which are typically towards the centre of the subsidence feature.
- Strain, due to elongation or shortening of the surface.
- Slope, due to the subsidence feature being deeper in some areas.
- Curvature, due to the shape of the subsidence curve.

Ground cracks can occur at the perimeter of the subsidence trough due to the ground moving towards the centre of the trough.

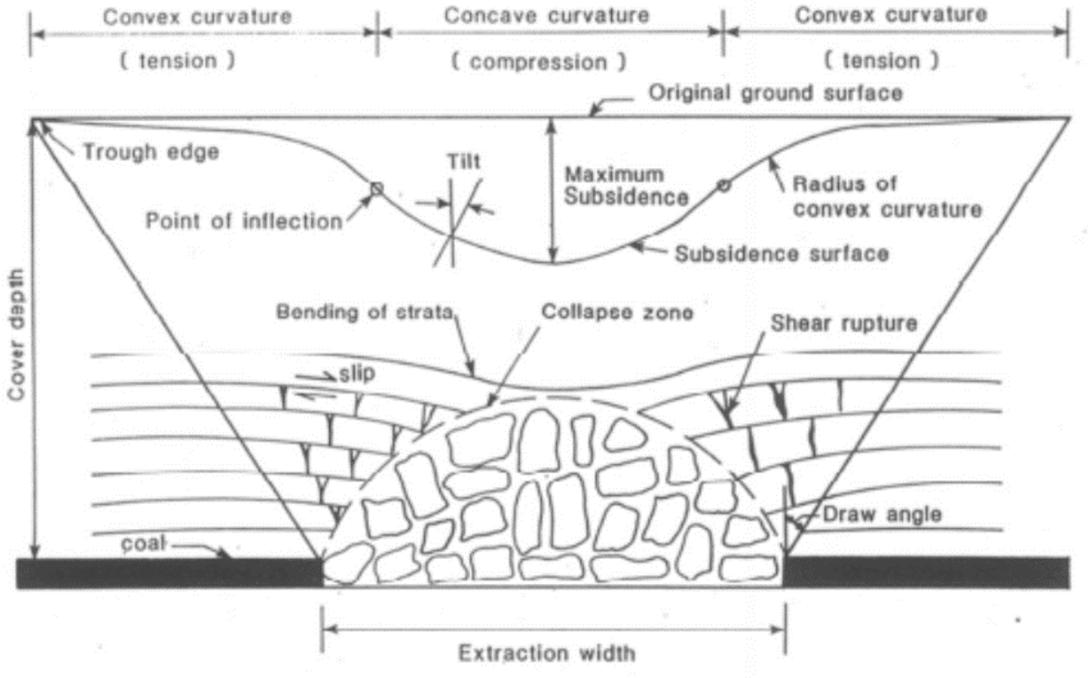

Figure 4.4 Subsidence parameters (Holla, 1987)

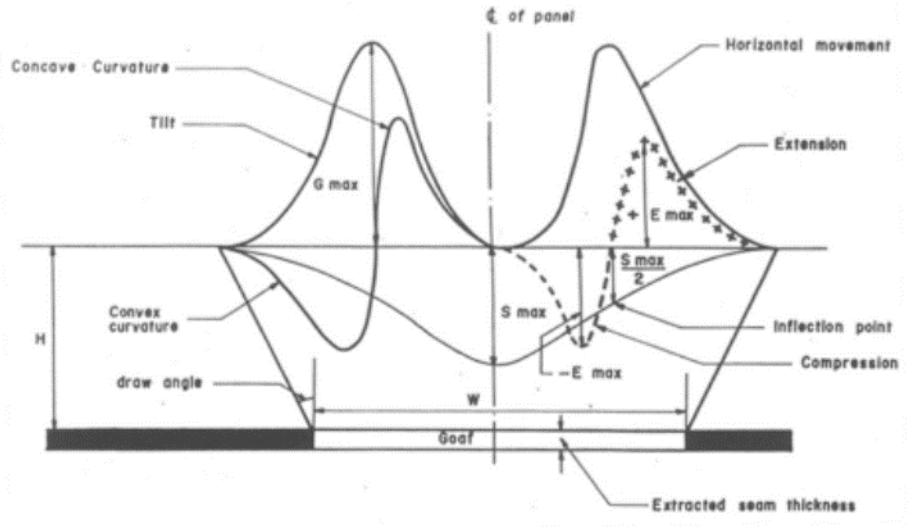

Figure 4.5 Subsidence parameter curves (Holla, 1987)

4.3 FAILURES OF COAL TAILINGS FACILITIES FROM SUBSIDENCE

Subsidence has resulted in the failure of coal slurry (tailings) ponds in the US, where significant amounts of slurry have been discharged. These types of failures are known as “breakthroughs” and are summarised in Michael et al. (2013). Generally, these slurry ponds are constructed in valleys above stream level, with the underlying workings above stream level. A breakthrough in 1990 at the Big Branch impoundment in Martin County, Kentucky resulted in the drainage of an estimated 1,158,336 m^3 of water and slurry from the impoundment. Michael et al. (2013) highlight some key issues as follows:

- Slurry flowability.
- Assessing flow characteristics of impounded slurry.
- What precautions and restrictions can be used to prevent breakthroughs.
- Breakthrough potential for an impoundment underlain by underground mining that is below drainage.

4.4 MINE SUBSIDENCE MITIGATION – BACKGROUND

Several methods can be used to mitigate potential mine subsidence impacts as indicated in the remainder of this section.

4.4.1 GROUTING

4.4.1.1 BACKGROUND

The term grouting can apply to several injection processes and injection materials. In this report, the terms “grouting” and “pressure grouting” will be used as follows:

- “Grouting” generally refers to the injection of a cement fly ash grout sometimes with sand instead of fly ash, and sometimes with aggregate into the mine workings and overlying caved materials at atmospheric or limited pump pressure. The purpose of the injected grout is to fill voids and densify materials, thus helping to stabilise the mine workings by providing support to the overlying materials and providing confinement to pillars and reducing permeability. Generally, mined areas between pillars would be targeted by the boreholes to improve the potential for encountering workings.

- "Pressure grouting" refers to the injection of materials such as neat cement and / or chemical grouts into fractures or natural discontinuities (defects) in the rock and / or soil above the mine workings under pressure to achieve greater penetration into fractures or discontinuities and reduce permeability. Pressure grouting is typically performed under dams to reduce seepage.
- General

  Boreholes are normally drilled vertically for ease of drilling however; angled holes may be needed in some areas due to surface constraints as shown on Figure 4.6.

Grout can be mixed on site or offsite and delivered to the site by truck or pumped via pipeline. It can be injected into a grout hole until the grout hole is filled, thereby allowing the grout to flow longer distances and reducing the number of grout holes. The grout typically needs a flow cone value in the range of 25 sec to 35 sec to flow longer distances. Thicker grouts may be applicable in open mine level workings and even thicker grout could be used to create barriers to contain grout flow. The travel of the grout needs to be monitored in other grout holes using dipping with a weighted tape, borehole camera and borehole sonar.

The grouting would need to be performed in a manner so as to reduce and/or control the amount of water from the mine workings expelled from the grout holes and possibly old boreholes that may not have been sealed properly, shafts, and subsidence features. Expelled water may need to be treated. Extraction pumping during grouting may be needed in some areas where the flow of water displaced by the grout at mine level is blocked and/or restricted so that water is not expelled or displaced. Also, high groundwater levels may be present. The grouted area may impact groundwater flow, resulting in potential changes to the groundwater regime should be assessed prior to grouting. (refer to Section 5.2 for more information regarding potential groundwater impacts).

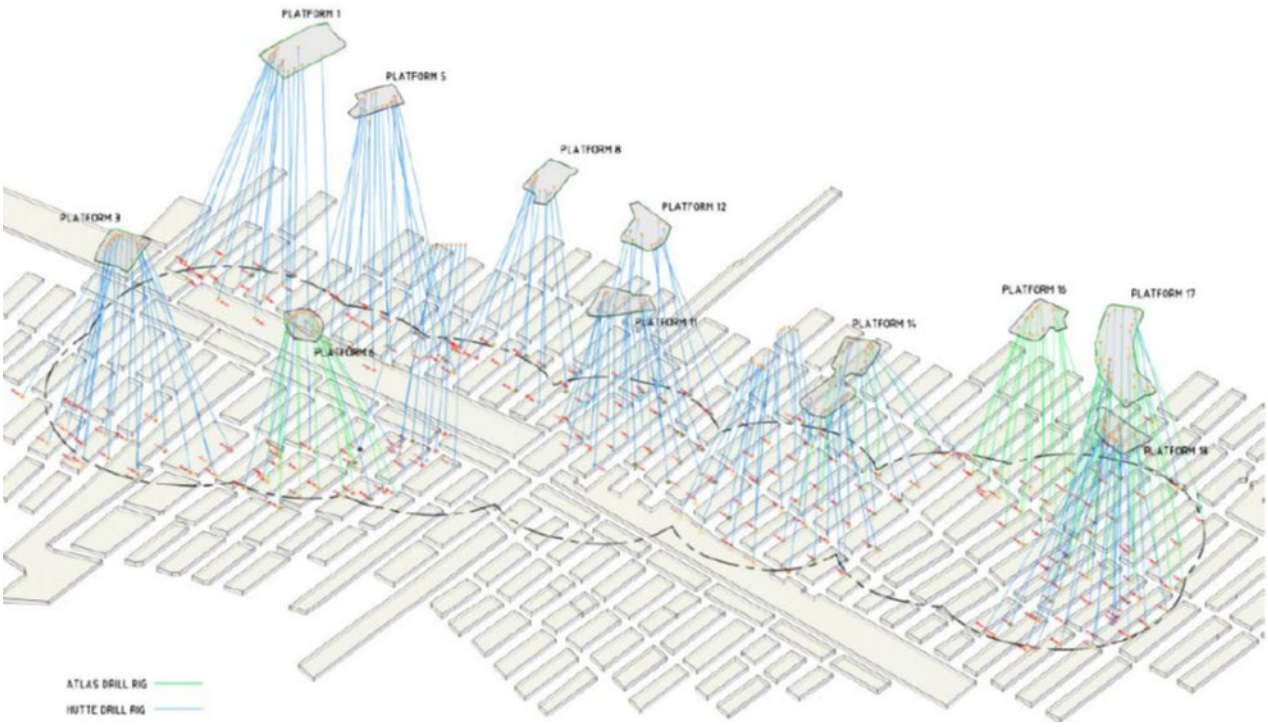

Figure 4.6 Grouting in environmentally sensitive area (Kingsland et al., 2011)

4.4.1.2 LOCAL EXPERIENCE WITH GROUTING

The use of cement fly ash grout to stabilise abandoned mine workings is commonly done in the Newcastle Region and other mined areas in Australia to mitigate subsidence impacts to structures. Potentially, the first use of a cement fly ash grout injected into abandoned mine workings in Australia was in Newcastle in 1987 to 1988 (Pells et al., 1988). The workings were flooded. Other examples include:

- Swansea Bends Deviation Project – This project involved the use of over-excavation to the floor of the workings for a roadway with grouting of the workings beneath the cut side slopes with a cement fly ash grout. The project was located south of Newcastle and the workings were "dry" (Kopandy and Francis, 1991).
- Telstra Building, Newcastle – Grouting of flooded workings in the Yard Seam in Newcastle (Fennell, 1997).
- Ipswich Motorway upgrade, Ipswich, QLD – This project involved the injection of a cement fly ash grout into dry and flooded mine workings for the upgrade of a motorway (Millar and Holz, 2010).
- Hunter Expressway, North of Newcastle – Grouting of portions of a 13 km alignment (Kingsland et al., 2011).
- Various other projects in the Newcastle Region – The projects included grouting of flooded mine working in Newcastle and over-excavation, grouting, and shaft capping by Maitland. (Knott, 2013).

4.4.1.3 SUBSIDENCE MITIGATION EXAMPLES AT DISPOSAL SITES

The following is a partial list of projects where disposal facilities have been constructed over abandoned mines after mitigation of mine subsidence impacts:

- Stark Construction and Demolition Landfill, East Canton, Ohio, USA (Bowser and Morner, 2018).

The site was underlain by abandoned mine workings in the Middle Kittanning Coal Seam (No 6 coal) and the deeper Kittanning Fire Clay. The workings were stabilised by drilling boreholes into the mine workings and injection of grout. The site has obtained approval from the regulator, the Ohio Environmental Protection Agency.

- Flue Gas Desulfurization Disposal Facility, northern Appalachia, USA (Bruhn et al, 1995).

The site was underlain by abandoned mine workings in the Pittsburgh Coal Seam, with different portions of the site subject to sinkhole and trough subsidence. A clay liner was required by the regulator. The portion of the site subject to sinkhole subsidence, 4.9 ha, was stabilised by grouting of the mine workings with a cement fly ash grout. Due to variation in strain from trough subsidence varying over the site, and its associated impacts to the liner, several approaches were used as follows:

- Where the liner could accommodate the strain, no mitigation was performed (14.6 ha).
- Where the liner could not accommodate the strains and potential ground cracks, a high strength geogrid was placed beneath the liner (7.3 ha).

The site was approved by the regulator.

- Three Municipal Waste Sites in South Western and Central Pennsylvania were discussed in Wood (1994). They were approved by the regulator. The sites are as follows:
  - Site 1 – A 3.2 Ha lined site underlain by abandoned mine workings in the Upper and Lower Kittanning Coal Seams. Grouting using a cement fly ash grout was performed in the Upper Kittanning Coal Seam.
  - Site 2 – A 0.6 Ha lined site underlain by abandoned mine workings in the Pittsburgh Coal Seam. A sand cement grout injected into the mine workings through boreholes was used to stabilise the site.
  - Site 3 – The site was underlain by abandoned mine workings in the Pittsburgh Coal Seam. Potential subsidence impacts were mitigated by over-excavation of much of the 0.44 Ha site area with grouting performed to stabilise the workings beneath the highwall at the edge of the over-excavation. Two grout mixes were used – a sand and cement mix and a fly ash, sand, and cement mix.

4.4.2 OVER-EXCAVATION

Over-excavation involves excavation of the mine workings and backfilling the excavation with compacted fill. It can be complicated by the presence of water in the workings, gases, and the potential for spontaneous combustion.

4.4.3 STRUCTURAL/SPANNING

Structural/spanning involves using a structural member such as a reinforced concrete slab or a geogrid. The deflection of the spanning material is a key issue, since geogrids achieve their strength by stretching and the overlying load can also cause deflection. Therefore, the material overlying the geogrid also deflects. The approach is generally used for individual sinkholes where the deflection is acceptable.

4.5 ERARING FLY ASH

The Eraring fly ash has a pH of 10.5 and is slightly soluble (Flyash Australia, 2016). According to Aiken and Heidrich (2013), the Eraring fly ash is characterised as having a pH (1:5) of 12, total % calcium of 0.89 and total % magnesium of 0.06.

4.6 HYDROGEOLOGY

4.6.1 GROUNDWATER DEPENDENT ECOSYSTEMS

Based on the *Groundwater Dependent Ecosystems Atlas* by the Bureau of Meteorology (BOM), there are high, moderate and low potential terrestrial groundwater dependent ecosystems (GDE) in the project area, with high potential terrestrial GDE's appearing to coincide with the coastal wetlands identified in AECOM (2018a) and shown in Figure 4.7.

Figure 4.7 Coastal wetlands (Figure 9 from AECOM, 2018a)

The potential outflow from the Awaba Colliery (SCT, 208) to creeks, appears to flow to the coastal wetland and Muddy Lake.

4.6.2 GROUNDWATER QUALITY

In 2009, it was assumed that there was some seepage and downward vertical migration of saline water (recirculated Lake Macquarie water) used in the conditioning and mixing of fly ash from the Coal Combustion Product (CCP) Management Facility (Eraring Ash Dam) after placement. Water seepage through the base of the CCP Facility and seepage water at the toe of the dam that was not collected at the toe drain had the potential to impact local groundwater quality as well as the water quality of groundwater receptors surrounding the site via leaching of contaminants from the lean phase emplacement, as well as, seawater trace element components (such as boron and major ions including magnesium, calcium, potassium and bicarbonate) from the water used for mixing the CCP (AECOM, 2009).

The expansion of the CCP Facility and dense phase placement of fly ash (Project Approval 07_0084 (29 April 2008)) was not anticipated to meaningfully impact the groundwater quality beneath or down-gradient of the CCP Facility (Eraring Ash Dam) (AECOM, 2009). The dense phase placement technique requires less water during the conditioning and mixing process to form the dense phase slurry, thus reducing the quantity of water within the CCP storage facility and the likelihood of seepage to groundwater compared to the previous lean phase placement. In addition, AECOM (2009) stated that the cementitious nature of the dense phase emplacement would likely form a low permeability layer across the surface of the existing lean phase emplacement, as well as across the surface of the proposed expansion area of the CCP Facility, minimising the potential for seepage to groundwater.

Groundwater quality from monitoring well MW01 (EPA identification number 21, according to EPL 1429), MW02 (EPA identification number 22) and MW06 (EPA identification number 23), all sampled on 8 June 2018, are provided in Table 4.1. MW01 is located to on the north-eastern edge of the ash dam and appears to be directly over the edge of the mine workings. This monitoring well was installed in 2008, has a total depth of 11.9 m, and its purpose is for monitoring the background quality of the groundwater entering the site (AECOM, 2009). MW02 and MW06 are located downgradient of the ash dam and decant pond, near Myuna Bay (Figure 2.2). Elevated species concentrations at the downgradient monitoring wells are evident, such as calcium, iron, magnesium, potassium and electrical conductivity.

Table 4.1 Groundwater quality (from Origin, 2018)

ANALYTE	UNIT	MW01	MW02	MW06
Arsenic	µg/L	0.3	7.2	6.4
Cadmium	µg/L	<0.05	<0.05	<0.05
Calcium	µg/L	2000	327000	451000
Chromium	µg/L	<0.2	0.8	0.7
Copper	µg/L	1.6	<0.5	<0.5
Electrical conductivity	mS/cm	0.379	15.8	21.3
Iron	µg/L	270	5140	11900
Lead	µg/L	0.2	<0.1	<0.1
Magnesium	µg/L	4000	216000	270000
Manganese	µg/L	102	1090	390
Nickel	µg/L	4.3	1.9	0.8
pH	pH units	5.67	6.46	6.58
Potassium	µg/L	4000	109000	124000
Selenium	µg/L	<0.2	0.2	0.4

ANALYTE	UNIT	MW01	MW02	MW06
Zinc	µg/L	35	13	2

According to the BOM's Australia Groundwater explorer, there are fourteen registered groundwater bores in close proximity of each other at the Eraring Power Station. Some salinity information was available, with total dissolved solids of up to 1,705 (assumed to be mg/L (no units provided)). An electrical conductivity value is available for a bore to the south, near Muddy Lake, of 2,190 µS/cm.

4.6.3 GROUNDWATER LEVELS

Groundwater levels measured on 8 June 2018 at the monitoring network associated with EPL 1429 (Section 4.6.3), were 1.65 m at MW06, 4.24 m for MW02, and 10.17 m for MW01. From the information provided, it is not clear whether this is metres below ground level or metres below top of casing. Monitoring well D26 (EPA identification number 24, according to EPL 1429) was dry.

There was no groundwater level data available for the registered groundwater bores in close proximity to the Eraring Power Station.

4.6.4 GROUNDWATER FLOW

In the vicinity of the ash dam, groundwater is anticipated to flow to the south-southeast towards Lake Macquarie (AECOM, 2009).

Based on the topography, to the west of the ash dam and in the area where the mine workings are to be grouted, local groundwater is anticipated to mostly flow to the south.

5 REVIEW

5.1 MINE SUBSIDENCE

5.1.1 MINE SUBSIDENCE RISKS

5.1.1.1 INTRODUCTION

Potential mine subsidence risks were assessed based on the facility being safe, serviceable, and repairable if a subsidence event occurred and practice. For the proposed disposal site this includes no loss of support to the facility and no erosion of ash into the mine workings. The items in Section 4.3 should be considered in the assessment.

5.1.1.2 SINKHOLES

As indicated in the SCT report, and based on the approach in Piggot and Enyon (1997) utilising the ratio of rock overburden thickness to mined height, sinkholes could occur at the site. One has been found at the site as indicated in the SCT report, which is shown on Drawings 3 and 4 in Appendix B. Sinkholes could create a void under a liner, thus potentially damaging the liner and allowing leakage and potentially fly ash from the disposal facility into the mine workings depending on the liner systems ability to accommodate deformation or if not lined, allow fly ash to enter the mine workings. Sinkholes would be difficult to repair once the area is covered in ash.

Sinkholes could also impact the dam by creating a zone where the material in the dam could fall into the workings and/or material from the dam could 'pipe' into the workings, resulting in distress to the dam and possibly fly ash being released from the site.

5.1.1.3 TROUGH SUBSIDENCE

Trough subsidence was indicated as being a potentially possible in the SCT report and we concur. It could or may have occurred due to pillar extraction, pillar failure, and pillar punching. Trough subsidence deformations could cause distress to a liner system if they could not be accommodated and allow leakage from the site and they could result in leakage from an unlined site due to fractures in the ground. They could also change the direction of flow in leachate collection systems.

Trough subsidence could also impact the dam and result in the overall lowering of the dam and/or cracking of the dam, which could allow water and ash to be released.

It would likely be very difficult to repair the site if it were subject to trough subsidence once in operation.

5.1.2 MINE SUBSIDENCE INVESTIGATION

An investigation of the mining and subsurface conditions has not been performed. The tasks and techniques in the remainder of this section have been used on other projects and are listed to help guide future work by Origin. They are as follows:

- Desktop study of mining and geology.
- Site reconnaissance to look for and locate mining and subsidence features and springs, etc.
- Subsurface investigation:
  - Boreholes (cored and non-cored) can be used to provide information on the subsurface conditions at the site.
  - Downhole techniques, such as the following, can supplement the information obtained from boreholes:
    - Downhole geophysical logging

  - Borehole camera.
  - Borehole sonar (3D preferred).
  - Borehole deviation.
  - Borehole mapping - assess orientation of fractures, bedding, and discontinuities.
  - Sonic velocity.
- Test pits – assess soil conditions, depth to rock, and subsidence features.

5.1.3 SUBSIDENCE MITIGATION

The options proposed for subsidence mitigation and comments on their use are as follows:

- Grouting of the workings – stabilisation of the mine workings beneath the site by grouting is considered feasible as it provides support and has been previously used for this purpose.
- Collapsing the workings – this approach is not considered an effective method to mitigate potential subsidence impacts for the following reasons:
  - It creates a “rubblised” zone of broken rock pieces which would be difficult to grout due to the irregular nature of the rubblised material and size of opening between the rock pieces.
  - The rubblised material could settle.
  - The workings are flooded.
  - Vibrations caused by the collapsing treatment (e.g. Deep Dynamic Compaction -a technique that involves dropping heavy weights) could cause vibrations which could impact the existing facility.
- Grout barrier – this approach is proposed as an option to mitigate the flow of water from the site into the workings. Its position with respect to the dam is not known, but the grouting would need to protect the dam. This approach will need further assessment to protect the dam from subsidence impacts such as the extent of grouting to support the dam, including angle of draw impacts and abutment loading/pillar run. Pressure grouting of the overburden above mine level is expected to be needed for groundwater control.
- Over-excavation – this approach is expected to be difficult due to the flooded condition of the mine workings.

5.1.4 MINE GROUTING CONSIDERATIONS

As mine grouting is likely to be needed, the following comments are provided to help assess the effectiveness of the mine grouting:

- Develop a grouting program considering items such as project objectives; mine level, open/caved and flooded mine workings. and environmental considerations; ; and grout requirements.
- Trial mix design to demonstrate the grout has the desired flowability, conductivity, and strength.
- Modify the program as needed to fit the conditions encountered, such as adjusting the grout hole pattern and grout flow characteristics.
- Monitoring during grouting consisting of strength and flowability testing and assessing grouting effectiveness, such as tracking grout flow in boreholes.
- Verification after grouting involves drilling boreholes into the grouted area to obtain samples of the grout and assess the effectiveness of the grout. Inplace conductivity testing of the grouted mine workings and overburden may also be needed.

5.1.5 SUMMARY

In summary, the site is susceptible to sinkhole and/or trough subsidence. Subsidence may have already occurred. Subsidence can be mitigated by over-excavation and controlled backfilling and/or grouting. Subsidence should be mitigated prior to site development, as is expected to difficult to mitigate for a disposal facility once it is in operation. Investigation of mining and subsurface conditions is needed. We note that successful treatment requires careful planning, design, mix trials and monitoring and verification. The proponent should engage a specialist consultant and contractor for this work. Pressure grouting may be needed to control groundwater seepage.

5.2 HYDROGEOLOGY

5.2.1 CONCLUSIONS ON THE PROPOSED MEASURES

From a hydrogeological and groundwater perspective, a preferred strategy (or a combination of techniques) should be employed to mitigate both subsidence and surface water connectivity hazards, and include the following:

- Grouting of mine workings.
- Excavating of shallow mine workings.
- Installing an impervious barrier using clays or suitable stabilised fill materials (AECOM, 2018a).

Very little information is provided in AECOM (2018a) on the strategies associated with collapsing the mine workings and installing an impervious barrier, thus little can be stated in response:

- With the excavation and collapse of mine workings, there are likely to be difficulties with grouting due to the irregular nature of the broken rock resulting from collapsing the workings, as identified in Section 5.1.3. From a groundwater perspective, an effective low permeability barrier is required to reduce any water from the ash dam infiltrating the groundwater system, which may be difficult with this approach.
- The installation of an impervious barrier using clays or suitable stabilised fill materials is assumed to relate to a clay liner beneath the extended area of the ash dam. If used in isolation, this method is unlikely to adequately restrict the inflow of water from the ash dam infiltrating the mine workings and groundwater system. There may be benefits, if it is used in combination with the grouting of the mine workings and pressure grouting the overburden fractures/ discontinuities, in further impeding inflow.

The majority of the information provided in AECOM (2018) and SCT (2018) relates to the grouting of the mine workings (and overburden fractures), although still relatively conceptual in nature. From a hydrogeology perspective, grouting of the mine workings and pressure grouting overburden fractures/discontinuities with cement stabilised fly ash is deemed to be a feasible strategy to reduce the risk associated with direct water connectivity between the site and the underlying mine workings. A consideration is the lateral extent of grouting, including beyond the extent of the mine workings to the east, given mining-induced fracturing will extend beyond the extent of mining. A nominal barrier width of up to 100 m is suggested by SCT (2018), however a minimum distance is not specified. The scientific basis for the distance of 'up to 100 m' has not been presented.

A number of factors need consideration for the design of the mine stabilisation/barrier for adequate grouting and reducing the risk to the environment. The risk to groundwater is discussed below.

5.2.2 RECOMMENDATIONS

Limited groundwater information was provided within the environmental assessment (AECOM, 2018a), with much of the information based on what was presented in the 2007 environmental assessment for the upgrade and expansion of the coal combustion production management system at Eraring Power Station (HLA, 2007). There is no discussion of GDE's or potential impacts to the groundwater system associated with the mine grouting strategy. The groundwater monitoring outlined focusses on the monitoring associated with EPL 1429, with no discussion of any monitoring associated with the mine grouting strategy.

It is recommended that a qualified and experienced hydrogeologist be engaged by Origin to:

- Better conceptualise the groundwater system, particularly in the vicinity of the mine grouting.
- Assess and refine the potential risks to groundwater, including those identified in Section 5.2.2.2.
- Work closely with Stantec and Origin to inform and refine the detailed design, including the mine grouting/barrier design and program, to reduce any potential groundwater impacts, as well as any studies/investigations that will be required.
- design and implement a water monitoring program that allows for the capture of required groundwater information, including water quality, levels and flow during baseline, construction and operational regimes.

5.2.2.1 GROUNDWATER CONCEPTUALISATION

Conceptualisation of the groundwater system would include an assessment of the following:

- GDE's.
- Geology, including the dip of the mined coal seam.
- Recharge and discharge processes and locations, including to the tributaries of Dora Creek (note, it appears the potential outflow points identified by SCT (2018) are not tributaries of Dora Creek, but of another creek system).
- Artesian versus non-artesian conditions (information to support artesian flow is not provided in SCT (2018)).
- Groundwater levels, including the expected groundwater level should Centennial Coal cease to extract groundwater and artificially maintaining a level of 16.5-17.0 mAHD.
- Local groundwater flow paths.
- Groundwater quality, including within the mine workings.
- Hydraulic properties.

5.2.2.2 POTENTIAL RISKS TO GROUNDWATER

Given the conceptual nature of the mine grouting strategy and the limited groundwater information available, the effectiveness of the grouting strategy cannot be determined, nor can it be determined whether the strategy itself will impact upon the groundwater system. The risks to groundwater include the following:

- The potential to change the groundwater quality due to mixing/interaction of the cement stabilised fly ash with groundwater prior to the cement stabilised fly ash setting, such as through an increase in pH. As identified in Section 4.5, the Eraring ash has an elevated pH, as does cement.
- The potential to change the groundwater quality due to the leaching and interaction of the cement stabilised fly ash with groundwater, such as through increasing the pH and metal content. This is not expected to be a notable risk given the use of cement stabilised fly ash in the past (refer to Section 4.4.1.2) and the coal ash exemption 2014. The coal ash exemption was issued by the Environment Protection Authority under clauses 91 and 92 of the Protection of the Environment Operations (Waste) Regulation 2014 (Waste Regulation) and exempts a consumer from certain requirements under the *Protection of the Environment Operations Act 1997* and Waste Regulation in relation to the application of that waste to land, provided the consumer complies with the conditions of the exemption.
- Increasing groundwater levels during grouting and possibly long-term due to the presence of grout.
- Increasing groundwater levels can result in increased outflow to streams (even if only temporarily), which flow to coastal wetlands.

- The release of potentially contaminated groundwater from the mine workings.
- A change to the quantity and quality of flows to the coastal wetland and high potential GDE’s.
- Altered groundwater flow directions given the introduction of the low permeability cement stabilised fly ash creating a barrier to groundwater flow.
- Reduction in groundwater recharge due to rainfall and runoff given the introduction of the low permeability cement stabilised fly ash.

A numerical flow model may be useful to predict the change in levels and flow from the introduction of the low permeability cement stabilised fly ash.

5.2.2.3 ENVIRONMENTAL CONSIDERATIONS FOR MINE GROUTING DESIGN AND INVESTIGATIONS

A number of design considerations and investigations would be required in order for a design that addresses the purpose of the works and does not impact upon the groundwater system, including the following:

- Investigate the leaching potential of the cement stabilised fly ash. Laboratory testing, including leachability testing, of the cement stabilised fly ash under a range of pH conditions, including slightly acidic and neutral, given the expected pH of the local groundwater. Mine water should also be used for the leaching test.
- The hydraulic properties of the aquifer and aquitards will need to be known.
- The rate of introduction of the cement stabilised fly ash will need to be considered to reduce the increase in groundwater levels and allow head change to be more gradual.
- Consideration of a low flowability grout barrier to contain grout to the area of interest.
- Whether some of the groundwater within the flooded mine workings in the stabilisation area will need to be removed by pumping to reduce increasing groundwater levels and discharge of potentially contaminated groundwater.
- Assess if the faults to northwest propagate into site area as they could provide a pathway for groundwater.

5.2.2.4 WATER MONITORING PROGRAM

A water monitoring program needs to be designed and implemented, beyond that specified in EPL 1429, to capture the following:

- Groundwater conditions up-gradient, within and downgradient of the mine grouting area.
- Surface water conditions at the outflow points.
- Water conditions during baseline, construction and operational regimes.
- Water quality, levels and flow directions.

6 RECOMMENDATIONS

The following recommendations are provided for the detailed design phase of the of the ash dam augmentation to be incorporated into the MVRP:

1. A mine subsidence expert be retained by Origin, who is approved by DPE, to assess subsidence impacts to the site and mitigation, particularly as only conceptual information has been provided on mine subsidence impacts and mitigation.
2. A qualified and experienced hydrogeologist be engaged by Origin, who is approved by DPE, to:
   - Better conceptualise the groundwater system.
   - Assess and refine the potential risks to groundwater.
   - Inform the detailed design.
   - Design and implement a water monitoring program.
3. Investigation of the mine workings and subsurface conditions in the site area be undertaken, including:
   - Desktop study of mining and geology.
   - Site reconnaissance to look for and locate mining and subsidence features, springs, and other items of interest.
   - Subsurface investigation with boreholes, downhole investigation techniques and test pits.
4. Mitigation of existing and potential mine subsidence impacts at the site be undertaken. Several options have been proposed, which need further assessment:
   - Type, extent, analyses, and effectiveness of proposed mitigation option.
   - Stabilisation material assessment including trial mixes to assess strength, conductivity, flowability, and leachability.
   - Impacts to groundwater flow from the stabilisation/barrier material at the mine level and in the overburden.
5. The recommendations provided within this document be included in the MVRP, to be submitted to DPE for review and approval prior to implementation.
6. Regularly consult DPE during the development of the MVRP, detailed design and implementation stages to allow opportunities to review and advise during the process, including the establishment of performance measures for subsidence and hydraulic leakage into the underground workings.

7 LIMITATIONS

SCOPE OF SERVICES

This report has been prepared in accordance with the scope of services set out in the contract, or as otherwise agreed, between the client and WSP (scope of services). In some circumstances the scope of services may have been limited by a range of factors such as time, budget, access and/or site disturbance constraints.

RELIANCE ON DATA

In preparing the report, WSP has relied upon data, surveys, analyses, designs, plans and other information provided by the client and other individuals and organisations, most of which are referred to in the report. Except as otherwise stated in the report, WSP has not verified the accuracy or completeness of the data. To the extent that the statements, opinions, facts, information, conclusions and/or recommendations in the report (conclusions) are based in whole or part on the data, those conclusions are contingent upon the accuracy and completeness of the data. WSP will not be liable in relation to incorrect conclusions should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to WSP.

REPORT FOR BENEFIT OF CLIENT

The report has been prepared for the benefit of the client (and no other party). WSP assumes no responsibility and will not be liable to any other person or organisation for or in relation to any matter dealt with or conclusions expressed in the report, or for any loss or damage suffered by any other person or organisation arising from matters dealt with or conclusions expressed in the report (including without limitation matters arising from any negligent act or omission of WSP or for any loss or damage suffered by any other party relying upon the matters dealt with or conclusions expressed in the report). Except as provided below parties other than the client should not rely upon the report or the accuracy or completeness of any conclusions and should make their own enquiries and obtain independent advice in relation to such matters.

OTHER LIMITATIONS

WSP will not be liable to update or revise the report to take into account any events or emergent circumstances or facts occurring or becoming apparent after the date of the report.

The scope of services did not include any assessment of the title to or ownership of the properties, buildings and structures referred to in the report nor the application or interpretation of laws in the jurisdiction in which those properties, buildings and structures are located.

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— RT606, Awaba Colliery mine maps, obtained from NSW Department of Planning and Environment, Maitland, NSW

APPENDIX A

CURRICULA VITAE

ROBERT KINGSLAND

Technical Executive - Geotechnical

25 years with WSP

32 years of experience

AREAS OF EXPERTISE

Dams, hydraulic, structures and tailings storage facilities

Mine infrastructure

Mine subsidence

Roads

Rail

Energy and industry

Landfill

LANGUAGES

English

PROFILE

Robert has over 30 years' experience of geotechnical engineering practice in both government and private consulting primarily in the transport, mining and power infrastructure sectors. Robert has particular expertise in road and rail geotechnics, dam engineering and mine subsidence, earthworks and reactive soils, slope stability and landslide risk management, pavement analysis and design.

Robert has managed and provided technical leadership for teams; small and large, working independently or as part of major multi-disciplinary infrastructure projects in a range of settings; remote regional, urban design office and project based, and has operated under design only, D&C and alliance contract environments.

EDUCATION

Master of Engineering Science (Geotechnical), University of New South Wales; Bachelor of Engineering (Honours) (Civil), University of New South Wales

PROFESSIONAL ASSOCIATIONS

Engineers Australia: Fellow; Australian Geomechanics Society: Member

ANCOLD: Associate Member

Mine Subsidence Technological Society: Member

Chartered Professional Engineer

PROFESSIONAL EXPERIENCE

— **Newcastle CBD Mine Subsidence Risk Model – Stage 1, Newcastle, NSW, Australia (2017–2018): Subsidence Advisory, NSW, Technical reviewer.**

Technical review of deliverables and project management advice. Portions of the Newcastle CBD are underlain by abandoned mine workings. SA NSW commissioned WSP to prepare a Mine Subsidence Deformation Model in order to get a better understanding of the stability of the abandoned mine workings, to consider pre-emptive grouting at selected areas to either eliminate or mitigate the risk of mine subsidence and to create greater certainty and understanding of the mine subsidence requirements for developments within the CBD. The work involved preliminary desktop studies to assess geological and geotechnical data to develop a model of the subsurface conditions; preliminary assessment of the mine subsidence risk profile across the CBD; preliminary grouting strategies; preliminary estimation of the cost and grout volumes required for each grouting option; preliminary plans identifying mine subsidence prediction parameters prior to and following grouting; and a preliminary plan for further geotechnical investigation to confirm assumptions outlined in the model.

— **Mine Subsidence Risk Mitigation Works, Lee 5 and Lot 22 Sites, Honeysuckle Drive, Newcastle, Australia (2017): Hunter Development Corporation, Technical reviewer.**

Technical reviewer for mine stabilisation support services for the Lee 5 and Lot 22 sites on Honeysuckle Drive in Newcastle. Involved the preparation of design and technical specifications for the proposed work; this included downhole camera, sonar and downhole geophysics requirements, specifications for both infill and void filling grout mixtures, grout sampling and testing requirements, comprehensive specifications for verification holes, contractor evaluation assistance, an Office of Water Application for a Groundwater License and Environmental Technical Specification.

- **Mine subsidence investigation for proposed residential subdivision, Bellbird Heights, NSW, Australia (2007): Hardie Holdings, Project manager and technical reviewer.**

  Desktop geotechnical assessment, detailed mapping of surface features, drilling investigation, sampling and testing of the open cut fill to assess the risk of spontaneous combustion and acid rock drainage, CERBERUS down-hole probe gas sampling of the underground workings, video footage and temperature measurement to determine risk of spontaneous combustion and assess the condition of the underground workings. Calculated pillar stability and assessed impacts on the proposed development of the previous open cut and underground mining, including subsidence, heatings, settlement, spontaneous combustion, and acid mine drainage.

- **Investigation and remediation advice for mine subsidence damage, Cessnock Civic site, Vincent Street, Cessnock, NSW, Australia (2007): Hardie Holdings and Mine Subsidence Board, Technical lead and reporting.**

  Subsidence damage included a large (50 m wide and 25 m deep) sinkhole, ground cracking and house damage. Storms in June 2007 and creek flooding triggered the subsidence. Reviewed record tracings, mapping and monitoring of surface features, drilling to establish the extent of competent sandstone roof, test pitting to find out the extent of the open cut workings. Remediation advice included sinkhole backfill recommendations, safe construction access, design of creek remediation incorporating GCL liner and consultation with regulators.

- **Mine Subsidence investigation for the proposed Hunter Economic Zone (HEZ), Kurri Kurri, NSW, Australia (2003–2004): HEZ, Project manager, reporting and review.**

  The HEZ site has been extensively undermined and falls within the Tomalpin Mine Subsidence District. The depth of cover to the mine workings ranges from less than 10 m to the north to over 200 m to the south of the HEZ site. Up to three coal seams have been mined. Historic data and mine survey records review, drilling investigation, pillar stability computations and compilation; presented data in a map format to assist with master planning for a very large industrial development (900 Ha).

- **Hunter Expressway Alliance, Minmi to Buchanan, NSW, Australia (2009–2017): Roads and Maritime Services (RMS), Geotechnical team manager.**

  Responsible for TOC, detailed design, CPS and post-construction treatments for the eastern portion of the $1.7B 40 km new motorway connecting the M1 to Branxton. Established, managed and demobilised a team of up to 25 persons including site investigation, mine subsidence, earthworks, foundation and soft soil, retaining structure, pavements, heritage tunnel assessment, hydrogeology and CPS groups. Represented the geotechnical design team in the Alliance Management Team and coordinated team interactions with the RMS Peer Review Group (PRG), the construction team, the mine subsidence expert panel and the NSW Mine Subsidence Board (MSB). Provided technical oversight and review for the mine subsidence investigations; mine fill treatment design, implementation and validation; infrastructure design for subsidence including bridges, road pavements and retaining structures; and foundation design for large viaduct bridges for horizontal movements up to 300mm. Technical lead for the pavement remediation for the soft soil settlement at Buchanan.

- **Newcastle Light Rail detailed design and construction phase support, Newcastle, NSW, Australia (2017-present): Downer, Geotechnical lead.**

  Technical direction and review for geotechnical engineering discipline for the detailed design and construction phases for the proposed Newcastle Interchange to Pacific Park light rail project. Included geotechnical investigation scoping and mine subsidence, pavement/trackform, earthworks, foundations and ground water design elements.

Delivered the site investigation program in support of the detailed design comprising test pits, drilling, CPT, pavement coring and pavement condition assessment. Mine subsidence challenges included clarifying the pothole risk on the light rail infrastructure at the eastern end of the project and steering the project through Subsidence Advisory, NSW approval. Mine subsidence investigations provided new insights to the extent and nature of convict era workings in East Newcastle. Design support was maintained though the construction delivery, providing timely responses to the day to day construction challenges.

— **Siti 2 Hydropower Project, Mount Elgon, Eastern Region, Uganda (2015–2018): Elgon Hydro Siti (Pvt), Geotechnical advice for Owner's Engineer, technical advisor role.**

The Siti 2 project is a 16.5 MW hydropower project located in the Mount Elgon area, in Eastern Uganda near the border with Kenya. The weir is positioned immediately downstream of the Siti 1 power house, where it diverts water from the Nyalit River into a headrace channel that follows the Nyalit River valley to the edge of an escarpment where the penstock plunges to the powerhouse on the Siti River. Some of the key geotechnical challenges included weir cut off to suit a plunging rock head in alluvium, securing and protecting the penstock through a very steep rock section and designing the power house for deep colluvial soils. This project has currently passed the design freeze phase.

— **Main Tailings Dam, Newstan Colliery, Fassifern, NSW, Australia (2005–2015): Centennial Coal, Principal geotechnical engineer.**

Technical direction and review for the investigation, design and construction of a 32.5 m high, 5,160 ML homogeneous embankment coal tailings dam with chimney drain and foundation drainage. Included drilling and test pit investigations along the embankment alignment and in the potential borrow areas. Performed Slope/W slope stability, Seep/W FE seepage and seismic stability analyses along with a dam break analysis and a consequence rating. Prepared design documentation, including drawings, specification and a design report, for NSW Dams Safety Committee approval. Construction inspections and documentation and Dam surveillance inspections. Also prepared an operation and maintenance manual and dam safety emergency plan.

— **Ashton Coal proposed SEOC Low Permeability Barrier and Levee, near Singleton, Hunter Valley, NSW, Australia (2012): Ashton Coal Operations, report author and technical reviewer.**

Review the concept design of a low permeability barrier at the proposed Aston Coal South East Open Cut (SEOC). The purpose of the barrier was to intercept groundwater flow from Glennies Creek towards the pit and saline mine water flowing back towards the creek. The barrier has been designed to extend through the full depth of the alluvium and key into the underlying bedrock below. Consideration was given to possible design modifications including the use of a Geosynthetic Clay Liner (GCL), an HDPE liner and drainage blanket.

The associated levee was assessed for stability under a flood event with crest settlement and batter stability failure modes being assessed.

— **Bulga 3000ML CHPP Surge Dam, Bulga near Singleton, NSW, Australia (2008–2012): Bulga Coal Management, Technical direction and review**.

Preliminary geotechnical investigation, detailed geotechnical investigation, geotechnical analysis and design including seismic analysis, consequence category and dam break analyses, hydraulic and civil design; tender documentation, tender assessment, construction phase inspections and advice; filter performance evaluation including no-erosion filter (NEF) testing for a 3000ML, 14m high, High C Consequence Rated zoned earthfill mine water dam.

- **Carrington Barrier Wall options assessment, Carrington Mine, near Singleton, NSW, Australia (2007): Coal & Allied Industries Ltd, Technical reviewer.**

  An options assessment for a proposed groundwater seepage barrier wall ("cut-off" wall) at Hunter Valley Operations (HVO) Carrington Mine. The barrier wall was required as part of the West Pit Development Consent and will serve to provide a physical groundwater barrier in the alluvium between the mine and the Hunter River. The site was characterised with reference to published data, options assessed included the use of a compacted clay barrier, bentonite slurry walls, jet grouting, sheet piling, geomembranes and soil mixing techniques. A preliminary assessment of construction methodology, cost, permeability, integrity, durability and site suitability was also carried out for the barrier wall techniques. A compacted clay barrier wall was the recommended option.

- **Kendell Street Reserve Landfill Capping Strategy, Sans Souci, NSW, Australia (2015): Rockdale City Council, Technical reviewer.**

  Development of a strategy for a proposed new landfill capping layer in response to the recommendations of a site audit report. An inadequate capping of the landfill was leading to excessive rainwater infiltration and a safety risk for residents due to a lack of minimum capping depth. Capping design options were investigated with multicriteria analysis used to balance cost, maintenance, performance, durability and constructability to guide the selection of the preferred option.

- **Mount Piper Power Station Ash Disposal Area, near Portland, NSW, Australia (1997–1999): MPA Energy Services, Project manager, field supervisor, assessment and reporting.**

  Installation of groundwater monitoring wells; collation, interpretation and reporting of dust, groundwater, surface water, leachate and weather monitoring to address requirements of EPA Licence.

SELECTED PUBLICATIONS

- Kingsland, RI 2004, 'The Development of a Mine Subsidence Constraints Map for the Hunter Economic Zone (HEZ) Industrial Lands Project', Proceedings of the 6th Triennial Conference on Mine Subsidence, Maitland, NSW, pp. 195-207
- Black, M, Cliff, D and Kingsland, R.I. 2007, 'Geotechnical Assessment of Potential Underground Mining Impacts for a Proposed Urban Development Project in Cessnock NSW', Australian Journal of Civil Engineering, Vol.3 No.1, pp. 51-66
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- Knott, D.L., Livesey, A., Kingsland, R., Lefchik, T. & Dwyre, E. 'Geotechnical Risks from Abandoned Coal Mines to Transportation Infrastructure and Mitigation - An Overview', Proceedings of the 69th Highway Geology Symposium, Portland, Maine, United States of America, 10-13 September, 2018

ANDREA MADDEN

Principal Hydrogeologist

18 years with WSP

17 years of experience

AREAS OF EXPERTISE

Hydrogeology

Groundwater impact assessment

Groundwater characterisation and conceptualisation

Planning, design and implementation of monitoring programs

Project management

PROFILE

Andrea is a Principal Hydrogeologist and an accredited Registered Professional Geoscientist in the field of Hydrogeology with 17 years' experience in groundwater investigations across several industry sectors, including the extractive industry (mining and coal seam gas). Andrea has specific capability in groundwater characterisation and conceptualisation; environmental impact assessments; planning, design and implementation of groundwater and surface water monitoring programs; design and supervision of monitoring networks; surface water; contaminant hydrogeology; and hydrogeochemical and salinity investigations.

Andrea has extensive experience with the coal mining industry, particularly in the Hunter Valley and Southern Coalfield, NSW. The experience extends from greenfield sites to existing coal mines, open cut and underground. Andrea has experience with storage facilities (particularly tailings storage facilities) and recently undertook a groundwater assessment and task managed a drilling investigation (groundwater monitoring network) associated with a proposed long-term waste landfill at the Bayswater Power Station.

Andrea was approved by the NSW government as the groundwater specialist on the Independent Risk Assessment Panel for Russell Vale Colliery Underground Expansion Project and as the groundwater specialist on independent environmental audit teams.

Andrea has provided technical advice to industry and government, particularly relating to coal mining and its influence on groundwater and groundwater dependent ecosystems. Andrea has authored papers and presented at industry conferences, including an article published in Water Engineering Australia magazine on the extent of longwall mining influence on deep groundwater overlying a Southern Coalfield mine (2009).

EDUCATION

Master of Engineering in Groundwater Management, University of Technology Sydney	2007
Bachelor of Advanced Science, Earth and Environmental Science (Honours First Class), University of New South Wales	2000

PROFESSIONAL ASSOCIATIONS

Registered Professional Geoscientist in Hydrogeology (10066)	RPGeo
Member, International Association of Hydrogeologists	
Member, Australian Institute of Geoscientists	

PROFESSIONAL EXPERIENCE

— **Bayswater Brine Concentrator Caking Plant Project, Preliminary groundwater desktop constraints assessment and establishment of monitoring network, Hunter Valley, NSW, Australia (2018-current): AGL Macquarie, Task manager and principal hydrogeologist.**

Undertook a preliminary groundwater assessment associated with an application for the construction and operation of a long-term waste landfill. The assessment included a review of desktop information and data, characterising the conceptual groundwater conditions, risk to groundwater, mitigation measures and recommendations. Established a groundwater monitoring network to establish baseline groundwater conditions at and near the proposed landfill.

- **Bulga Extension Project – Hydrogeological assessment for proposed tailings storage facility, Hunter Valley, NSW, Australia (2018-current): Bulga Coal (Glencore), Task manager and principal hydrogeologist.**

  The Bulga Extension Project involves relocating tailings from the former Deep Pit Tailings Dam to the open cut void so that mining of the former Deep Pit void can recommence. The hydrogeological assessment involves determining the potential loss of water through seepage out of the proposed tailings storage facility.

- **Liddell Coal Operations – Stage 2 Greater Ravensworth Tailings Strategy, Hunter Valley, NSW, Australia (2018-current): Liddell Coal Operations (Glencore), Principal hydrogeologist.**

  Liddell Coal Operations is assessing options for developing a new Tailings Storage Facility as part of the Greater Ravensworth Tailings System at the Liddell Coal Mine. Various options were considered, with the groundwater works focussing on in-pit disposal of tailings incorporating the use of a water (or 'wet') cover TFS. A preferred option was selected based on the groundwater assessment, with recommendations for additional quantitative assessment works to further refine the outcome.

- **Russell Vale Colliery Underground Expansion Project: Independent Risk Assessment Panel, Southern Coalfield, NSW, Australia (2015): Wollongong Coal, Project manager and principal hydrogeologist.**

  Approved by the NSW Department of Planning and Environment (DP&E) as the 'groundwater expert' on the Independent Risk Assessment Panel (IRAP). In accordance with the recommendations from the Planning Assessment Commission (PAC), IRAP were established to conduct an ongoing assessment of risks to Cataract Reservoir, groundwater, surface water and upland swamps during the extraction of nine longwalls. The project is currently within the project approval process stage. The risk assessment methodology and risk assessment were considered and approved by IRAP.

- **Narama void – water assessment Ravensworth Open Cut, Upper Hunter, NSW, Australia (2015): Project manager, principal hydrogeologist and technical lead.**

  Undertook an assessment of the potential impacts, and a qualitative risk assessment, from storing water in the Narama void. The potential impacts were associated with the outflow of stored water via coal seams and other permeable strata, interaction of stored water with the Hunter River alluvium and Hunter River, and interaction of stored water with the flyash placement and tailings storage. Also undertook the Narama spoil water storage assessment, to determine the amount of water that can be stored and would be available by pumping. This involved a literature review for values of key hydraulic properties within mine spoil and recommendations on whether literature values should be adopted.

- **Investigations for determining the height of connective fracturing, and assessing the sources of water swamp species uptake under differing conditions, Southern Coalfield, NSW, Australia (2011, 2014–2015): BHP Billiton Illawarra Coal (currently South32), Project manager and/or senior/principal hydrogeologist.**

  Involved in the initial works and scope for the research projects located above longwall coal mines. The connective fracturing research project involved an assessment of the changes in the hydrogeological conditions in the geological strata above a longwall, with a focus on mining induced connective fracturing. Investigations were undertaken pre- and post-mining. Primary author assessing the groundwater response to longwall mining at Dendrobium Area 3B and technical reviewer of the post-longwall investigation report.

- **Groundwater investigations for a proposed underground coal mine, Southern Coalfield, NSW, Australia (2011, 2013–2014): Hume Coal, Project manager and/or senior hydrogeologist.**

Groundwater investigations as part of an extension to the mining lease and for ultimate approval of an environmental assessment for an underground coal mine. Groundwater investigations including the installation of a groundwater monitoring network, aquifer sampling and testing.

— **Gujarat Wongawilli Colliery Independent Environmental Audit, Southern Coalfield, NSW, Australia (2013–2014): Gujarat NRE Coking Coal Limited (currently Wollongong Coal), Senior hydrogeologist/technical groundwater specialist.**

Reviewed the adequacy of strategies, plans and programs required under the approvals and recommended measures/actions to improve the environmental performance of the project.

— **Technical groundwater reviews, Gloucester Basin, NSW, Australia (2013–2014): Gloucester Resources, Senior hydrogeologist.**

Technical review of the Groundwater Monitoring Status Report and Annual Monitoring Report for the proposed Rocky Hill Coal Project, a proposed open cut coal mine.

— **Cobbora Coal Project Groundwater Assessment, Cobbora, NSW, Australia (2011, 2013): Cobbora Holding Company, Project manager and senior hydrogeologist.**

The scope included an extension of the groundwater network (>50 piezometers in total), testing and analysis, pumping tests, hydrocensus of groundwater users, assessment of groundwater-surface water connectivity and groundwater dependent ecosystems for the purpose of preparing the groundwater impact assessment. Project approval was achieved under State and Federal legislation in 2014.

— **Doyles Creek Mine Groundwater Assessment, Hunter Valley, NSW, Australia (2011): Doyles Creek Mining (NuCoal Resources), Technical groundwater lead and task manager.**

Groundwater assessment for a proposed longwall coal mine. The Doyles Creek mine site includes protected surface water and groundwater resources. The Project involved regular advice. The groundwater assessment was to involve an analysis of groundwater monitoring data, groundwater model conceptualisation, development of a groundwater model, groundwater assessment and technical reporting.

— **Applied tracers in mining and non-mining impacted catchments, Southern Coalfield, NSW, Australia (2011): Sydney Catchment Authority (currently WaterNSW), Project manager and senior hydrogeologist.**

Seven applied tracer test using salt and fluorescent dyes were undertaken in a mining-impacted and non-mining impacted catchment to quantify surface water loss due to natural or mining enhanced fracturing. Environmental isotopes (^{18}O, ^{2}H and ^{222}Rn) were also investigated to assess groundwater-surface water linkages in both catchments and their tributaries.

— **Groundwater and surface water assessments, Cobbora Coal Project. Cobbora, NSW, Australia (2010–2011): Cobbora Mining Company, Project manager and senior hydrogeologist.**

The Cobbora Coal Project was a proposed open-cut coal mine. Groundwater and surface water assessments were undertaken for the Part 3A Environmental Assessment. The assessments included the installation of an extensive groundwater monitoring network and stream gauging network; baseline monitoring of groundwater and surface water levels and chemistry isotopic analysis; pumping tests; hydrocensus of groundwater users; groundwater numerical modelling; and hydrologic, hydraulic and water balance modelling. The studies assessed: groundwater and surface water use, its users, flows, quality and interactions; hydrologic and hydrogeologic regimes;

proposed mine water management system and balance; potential impacts of mine site discharges on flow regime and water quality receiving watercourses; flood risk; groundwater dependent ecosystems; and water supply and licensing options for a water buying strategy.

— **Secondment - assessment and advice – longwall mining in water supply catchments, Southern Coalfield, NSW, Australia (2007–2009): Sydney Catchment Authority (SCA) (currently WaterNSW), Senior hydrogeologist.**

Worked on secondment with the SCA, assessing the effects of longwall mining on surface water and groundwater in the water supply catchment areas, including alterations to groundwater and surface flow, swamp hydrology, surface water-groundwater interactions and water quality. Undertook a detailed assessment of the changes with mining progress to the deep aquifers and aquitards overlying a longwall mine, including aquifer/aquitard characteristics (confined to unconfined changes, hydraulic gradient and flow direction) and groundwater levels. Provided advice and review of environmental assessments, subsidence management plans, end of panel reports, and monitoring reports provided by mining companies. Participated in the SCA's submission and presentations to the NSW Planning Assessment Commission for the Metropolitan Coal Project. Was a major contributor to the SCA's guideline for designing hydrological and hydrogeological monitoring programs to assess the impact of longwall mining in the SCA's Special Areas.

Selected Publications

— McLean, W., Madden, A., Jankowski, J., Scarff, S. and Moran, S. 2011. Investigating impacts of longwall mining on water resources: a comparison of mines and non-mined water supply catchments. NSW IAH Symposium, 5-6 September 2011, Sydney, Australia.

— Madden, A. 2010. The Scarborough Sandstone and its Connectivity with Longwall Mining in a Water Supply Catchment. Groundwater 2010, 31 October-4 November 2010, Canberra, ACT. [Winner of the IAH NSW 2010 Student Award (under- and post-graduate)]

— Madden, A., Ross, J. B. and Jankowski, J. 2009. Longwall Mining Effects on Deep Groundwater in a Southern Coalfield Catchment, Australia. 32nd Hydrology and Water Resources Symposium, 1-3 December 2009, Newcastle, NSW.

— Madden, A. 2009. Extent of Longwall Mining Influence on Deep Groundwater Overlying a Southern Coalfield Mine. Water Engineering Australia magazine, Vol 3, No. 10, November 2009.

— Madden, A. and Ross, J. B. 2009. Deep Groundwater Response to Longwall Mining, Southern Coalfield, New South Wales, Australia. Proceedings of IAH Groundwater in the Sydney Basin Symposium, 3-4 August 2009, Sydney, NSW.

— Madden, A. and Merrick, N. P. 2009. Extent of Longwall Mining Influence on Deep Groundwater Overlying a Southern Coalfield Mine. Proceedings of IAH Groundwater in the Sydney Basin Symposium, 3-4 August 2009, Sydney, NSW.

— Jankowski, J. and Madden, A. 2009. The Design of Hydrological and Hydrogeological Monitoring Programs to Assess the Impact of Longwall Mining on Water Resources. Proceedings of IAH Groundwater in the Sydney Basin Symposium, 3-4 August 2009, Sydney, NSW.

— Jankowski, J., Madden, A. and McLean, W. 2008. Surface-water – Groundwater Connectivity in a Longwall Mining Impacted Catchment in the Southern Coalfields, NSW, Australia. Proceedings of Water Down Under 2008, 14-17 April 2008, Adelaide, SA.

DAVID L KNOTT

Senior Geotechnical Engineer

2 years with WSP

35 years of experience

AREAS OF EXPERTISE

Mine subsidence investigation, assessment, and mitigation

Earthwork

Dams and hydraulic structures

Desktop studies

Subsurface investigations

Foundations and retaining structures

Instrumentation

Commercial facilities

Road and rail

Industrial facilities

Disposal facilities

LANGUAGES

English

PROFILE

David is a senior geotechnical engineer with over 35 years of broad ranging experience with particular expertise in mine subsidence investigation, assessment, and mitigation; earthworks; dams; foundations; soil and rock slopes; and geological characterisation of sites. He has also worked on road and rail projects.

David has worked in Australia, New Zealand, USA, India and remotely in Canada.

EDUCATION

Bachelor of Science, Civil Engineering, The Pennsylvania State University	1982
Graduate Studies, Geotechnical Engineering, The University of Pittsburgh	Late 1980s – early 1990s

SELECT PROFESSIONAL ACCREDITATIONS / ASSOCIATIONS

Registered Professional Engineer Queensland	RPEQ
Chartered Professional (Geotechnical) - Australasian Institute of Mining and Metallurgy	MAusIMM (CP)
Processional Engineer – Pennsylvania	PE
Professional Geoscientist – Louisiana	PG
Australian Geomechanics Society - Past Newcastle Chapter Executive Secretary	AGS
Mine Subsidence Technical Society	MSTS
Australasian Mining History Association	AMHA
Society for Mining, Metallurgy and Exploration	SME
American Rock Mechanics Association	ARMA
International Society for Rock Mechanics	ISRM
Association of Environmental and Engineering Geologists	AEG

SELECT PROFESSIONAL EXPERIENCE

Mine subsidence and abandoned mines

— **Newcastle CBD: Mine subsidence risk model project- Stage 1, Newcastle, NSW, Australia (2017–2018): Subsidence Advisory NSW, Project Technical Director.**

Oversight for development of subsidence risk model for the Newcastle CBD using empirical and numerical modelling; review of previous subsidence events, existing borehole data, reports and mining information, including mine maps; coordination of peer review by experts; and development of subsidence mitigation options.

— **Lot 22 and Lee 5, Cottage Creek Mine Subsidence Mitigation, Newcastle, NSW, Australia (2017): HDC, Project Technical Director.**

Developed specifications and provided oversight for mitigation activities including drilling six grout holes; assessment of downhole geophysical logs, borehole camera footage, and sonar data; and injecting ≈4,900 m3 of grout and verification using four cored boreholes, including review strength testing of grout from the cored boreholes, strength and flowability testing of production grout, borehole camera observations.

— **Newcastle Light Rail Project –Newcastle, NSW, Australia (2017): Transport for New South Wales, Geotechnical engineer.**

Desktop and borehole assessment of potential mine subsidence impacts from potential mine workings from prior to 1831 by convicts and pre-1860s by the Australasian Agricultural Company. The assessment included coring seven boreholes and downhole assessment using borehole camera, borehole sonar, and downhole geophysical logging.

Select Previous experience

Mine subsidence and abandoned mines

— **Cottage Creek Mine Subsidence Mitigation, Newcastle, NSW, Australia (2015): HDC, Geotechnical engineer.**

Developed specifications and provided oversight for mitigation activities including drilling nine grout holes; assessment of downhole geophysical logs, borehole camera footage, and sonar data; and injecting ≈3,800 m^3 of grout and verification using four cored boreholes, including strength testing of grout from the cored boreholes, strength and flowability testing of production grout, borehole camera observations and downhole logging of cored grout holes.

— **New Space Development, Newcastle, NSW, Australia (2014): University of Newcastle, Geotechnical engineer.**

Oversight for grouting of mine workings in the Borehole Seam at about 70m depth and verification hole assessment. Approximately 5,000 m^3 of grout was injected.

— **Swanbank Development, Ipswich, Qld, Australia (2012): Investa, Geotechnical engineer.**

Assessment and mitigation oversight for stabilisation of abandoned coal mine entries to allow redevelopment of site. Five cut and cover Armco arch entries, two rock tunnels and an airshaft were mitigated. The entries and rock tunnels were grouted and the airshaft was capped with a geotextile sandwich.

— **Honeysuckle Central Development, Newcastle, NSW, Australia (2011): Bolkm, Geotechnical engineer.**

Oversight for drilling and grouting of mine workings in the Borehole Seam at about 70 m depth. Angled holes were drilled in some areas to avoid drilling in a main road. A geotechnical investigation was also performed using a cone penetrometer (CPT).

Later work for HDC in 2015 involved assessment of the openness of the uncompleted grout holes and borehole camera observations of the borehole and mine level conditions.

— **Housing Development, Ashtonfield, NSW, Australia (2009–2010): HDC, Geotechnical engineer.**

Oversight of mine mitigation involving over excavation and grouting of mine workings and shaft capping for housing development underlain by 1870’s coal mining.

— **Cottage Creek Mine Subsidence Assessment, Newcastle, NSW, Australia (2008–2009): HDC, Geotechnical engineer.**

Consultation and review of mine subsidence investigation data and assessment in an area where 25-hectare pillar crushing event occurred during active mining during 1896. The investigation involved drilling seven borings to below the mine, performing downhole geophysical work, research into the history of the crush, and review of previously drilled borings in the area. A review of pillar stability calculations and numerical analyses was also performed.

- **New Georgia Landfill, Birmingham, AL, USA (1990s): City of Birmingham, Geotechnical engineer.**

  Performed consultation for investigation, analysis, and mitigation of subsidence impacts for a 41 ha (100 acre) expansion underlain by abandoned mine workings. Downhole geophysical logging was used to help correlate coal seams to assess potential mining

- **Mine Subsidence Assessment, Marjol Battery Superfund Site, Scranton, USA (1990s) Advanced Geoservices, Geotechnical engineer.**

  - Consultation on mine subsidence and pillar stability for site underlain by abandoned anthracite mine workings in 10 seams where lead surface contamination from a battery recycling facility was present.
  - The cause of a 183 m (600 ft) long, 1.5 m to 6 m (5 ft to 20 ft) wide ground crack present on the site was also assessed to determine if ground cracks could occur in other areas of the site. The ground crack was found to be located over a barrier pillar between two collieries and was caused by the rock over the barrier pillar being 'pulled apart' in tension from trough subsidence occurring during retreat mining in the past on both sides of the barrier pillar.

- **Parks Low Level Radioactive Waste Disposal Facility, Apollo, PA, USA (1993): Arco, Geotechnical engineer.**

  Consultation for mine subsidence analysis and mitigation for a site where radioactive wastes were buried in shallow trenches underlain by abandoned mine workings.

- **Piggots Run Disposal Site, Harrison Power Station, Shinnston, WVA, USA, (1993): Allegheny Power, Geotechnical engineer.**

  - Disposal Site Liner Area – Performed investigation, analysis and development of mitigation approaches to support a lined disposal facility underlain by abandoned mine workings. The investigation included test borings, air rotary borings, borehole camera work, and piezometers to monitor the mine pool.

    The mine workings were grouted in portions of the site susceptible to sinkhole formation and geogrids were used to support the liner where strains from ground cracks resulting from trough subsidence could damage the liner.

    No mitigation of the subsidence was performed for the remaining higher portions of the site susceptible to trough subsidence since the subsidence strains were small enough to be accommodated by the liner. Oversight of 5.3 ha (13 acre) grouting operation was also performed.
  - Sedimentation Pond Dam – Investigation and design of the sedimentation pond dam with the abutments intersecting abandoned deep coal mine workings and the remainder of the dam in a strip mined area. Developed and provided oversight for a grouting program to stabilise the under mined dam abutments.
  - Mine Water Collection System - Performed an investigation and design for a mine water collection system to pick up discharges from abandoned deep mine workings around the sides of the pond. This collection system included plugging mine entries to mitigate subsidence impacts to the sides of the pond and sizing drainage materials to lessen the potential for clogging due to iron precipitate 'Yellow – Boy' deposits.
  - Disposal Site Liner Alternative – Developed innovative approach to use the mine workings beneath the site to collect potential leachate from the facility in lieu of a construction liner. In this approach, the coal underclay would act as a liner due to its very low permeability and subsidence fractures would allow groundwater from the site to flow into the mine workings.

The work involved collecting all of the mine maps underlying and surrounding the site and developing 0.3 m (1 ft) contours on the bottom of the nearly flat lying coal to determine locations where the mine water could flow based on the dip of the coal and mine level features, monitoring mine pool levels with piezometers and mine discharge quantities, developing methods to create mine level barriers to divert the flow of the mine water or 'fracing' of barrier pillars to allow flow to areas more suitable for collection, and determining methods to collect the mine water for treatment. Drilling borings to mine level was planned as an alternative way for groundwater to reach the mine workings.

Even though this approach was less costly in the long run than construction a lined disposal facility and performing mine stabilisation, the utility ultimately elected to line the site in stages to avoid another rate hike to consumers since the utility was in the process of constructing very expensive new air quality emissions control systems at the power station.

— **Colver Dam, Colver, PA, USA (1992): Interpower, Geotechnical engineer.**

Consultation for surface and deep mine impacts to a new earth fill embankment dam and reservoir underlain by mining in the Lower Kittanning seam. The reservoir area also had strip mining in the Upper Freeport seam and deep mining in the Lower Freeport seam. Pillar capacities, subsidence impacts, and mitigation methods by grouting and alternative methods were assessed for the portion of the dam underlain by mine workings

— **Switchyard and Access Roads Grouting, Harrison Power Station, Shinnston, USA (early 1990s): Allegheny Energy, Geotechnical engineer.**

Monitored the injection of grout into abandoned mine workings in the Pittsburgh Seam beneath an existing switchyard and proposed access roads at a 2000-MW power station. In the switchyard area, the workings were overlain by alluvium and in the access roads by colluvium.

— **1220 mm (48-inch) Diameter Water Transmission Line, Shire Oaks to Finleyville, PA, USA (1987): Western Pennsylvania Water Company, Geotechnical engineer.**

The transmission line passed through areas that were undermined, strip mined, or had been filled with coal refuse. A geotechnical evaluation of conditions along the alignment was performed using mine maps, air rotary borings, and borehole camera work. The evaluation indicated that portions of the alignment were subject to sinkhole subsidence that could result in failure of the water line.

Monitoring of the stabilization of the abandoned deep mine workings by grout where subsidence impacts could damage the transmission line was performed.

Mine fires

— **Jharia Coalfield Mine Fires, Dhanbad, India, (1996): World Bank, Geotechnical engineer.**

Consultation for mitigation of mine fires in multiple seams beneath towns, villages, rivers, roads, and railroads throughout the coalfield. The work was performed in the US and India.

Disposal facilities / environmental projects

— **Piggots Run Disposal Site, Harrison Power Station, Shinnston, West Virginia, USA (1990s): Allegheny Power, Geotechnical engineer.**

Investigation and design for expansion of Coal Combustion By-Product (CCB) disposal facility involving mitigating subsidence impacts to liner by mine stabilization and geogrids, soil liner permeability testing, landslide remediation, slope stability analyses, and report preparation.

Monitored grading of soil and fly ash fills and clay liner installation a for Coal Combustion By-Product (CCB) disposal facility.

Provided oversight for field and laboratory investigation of the geotechnical properties of residual waste [Flue-Gas Desulfurization (FGD) by-product] from a new emissions control system at a power plant.

— **Chesterfield Fly Ash Slurry Pond, Richmond, Virginia, USA (1997): Dominion Resources, Geotechnical engineer.**

Developed preliminary approaches to stabilize the dike where sliding was occurring to allow another filling of the pond with slurried fly ash by using cut-off walls installed through the dike to a low permeability layer to eliminate seepage through the dike and native materials below the pond and anchored walls in the deep seated slide area.

Also, developed preliminary approaches stabilize the site so that the height of the facility could be increased for dry ash disposal.

Forensic study

— **Consultation for forensic study of distressed West Virginia College structure, West Liberty, WVA, USA (1990s): State of West Virginia, Geotechnical engineer**

The work involved examining foundations and underlying materials exposed during the demolition of the facility, performing subsurface investigation and analysis of mining conditions, and expert witness testimony.

Research

— **Flowable Backfill Research Project, Pennsylvania, USA (1990s): Pennsylvania Department of Transportation, Researcher.**

Performed research on the use of cement fly ash mixtures for bridge abutment backfills. It included evaluation of existing projects and two demonstration projects that were instrumented and report preparation.

PROFESSIONAL HISTORY

WSP	2016 – Present
Coffey	2008 – 2016
HDR	1999 – 2008
AWK Consulting Engineers	1997 - 1999
GAI Consultants	1989 - 1997
Murray Associates	1983 - 1989

SELECT PUBLICATIONS AND PRESENTATIONS

— Knott, D.L.; Livesey, A.; and Kingsland, R.; Stabilization of Abandoned Coal Mine Workings by Grouting; 61st AEG Annual Meeting/13th IAEG Congress, September, 2018, San Francisco, California

— Knott, D.L. and Streater, H.; “Downhole Techniques to Assess Mine Subsidence and Mitigation Effectiveness”; Mine Subsidence: Adaptive Innovation for Managing Challenges; 10th Triennial Conference Proceedings, Mine Subsidence Technological Society, Pokolbin, NSW, Aus, 5 – 7 November, 2017

— Knott, D.L. Baker, S and Solomou, N., “The use of downhole geophysical logging in assessing subsidence from abandoned coal mines”, 35th International Geological Congress, Cape Town, South Africa, August 30, 2016

— Knott, D.L.; Grubb, K.; Taylor, H.; Deans, J.; and Sadler, M.; ‘Mitigation of Abandoned Mine Entries at Swanbank Enterprise Development, Ipswich, Australia’; *10th Interstate Technical Group on Abandoned Underground Mines Workshop*, *Harrisonburg, VA* July 31 & August 1, 2013.

— Knott, DL; “Some Interesting Abandoned Mine Stabilization Projects in Australia;” 47th US Rock Mechanics/ Geomechanics Symposium, San Francisco, Calif.; ARMA 2013

— Knott, DL; Baker, S; Ditton, S; and Love, A; “Assessment of Mine Subsidence in an Area with a Major Pillar Crushing Event – Newcastle, Australia;’ 46th US Rock Mechanics/ Geomechanics Symposium, Chicago, Ill; ARMA 2102

— Knott, DL; Presentation – A Practical Guide to Abandoned Mine Subsidence Assessment and Mitigation using Examples from the United States and Australia

- Newcastle Chapter Australian Geomechanics Society 20 May 2009

- Sydney Chapter Australian Geomechanics Society 12 May 2010

— Knott, D.L. ‘Assessment of Potential Subsidence Impacts from Coal Mining using Test Borings, Mine Maps, and Empirical Methods’, Technical Group on Abandoned Underground Mines 6th Biennial Workshop; Rochester, NY 2006

— Knott, DL. ‘My Experience Grouting Abandoned Coal Mines’, Technical Group on Abandoned Underground Mines 5th Biennial Workshop; Tucson, Arizona, 2004

— Gray, RE; Bruhn, RW and Knott, DL. ‘Subsidence Misconceptions and Myths’ 15th International Conference on Ground Control in Mining, Colorado Schools of Mines, Golden, Co, August, 1996

— Bruhn, RW; Knott, DL; Sanger, DB and Kyper; TN. ‘Effectively Designing for Potential Mine subsidence at a Disposal Facility in Northern Appalachia’, Proceedings of Joseph F. Poland Subsidence Symposium, Association of Engineering Geologist – Annual meeting, at Sacramento, California, 1995

— Rojas-Gonzalez, LF; Knott, DL and Newman, FB. 'Demonstration Application in the use of Flowable Backfills for bridge Abutments’, Pennsylvania Department of Transportation research Project 90-12, August 1993

— Rojas-Gonzalez, LF; Knott, DL; Newman, FB and Majoris, P. ‘Use of Flowable Backfill for Bridge Abutments,’ Presented at the Tenth Annual International Bridge Conference, Pittsburgh, Pennsylvania, June 14-16, 1993

RAY HATLEY

Capability Executive - Hydrogeology

1 years with WSP

34 years of experience

AREAS OF EXPERTISE

Project management and project directorship of medium to large energy, coal mining and water resource projects.

Hydrogeological assessments for high level mining and oil and gas project approvals.

Groundwater conceptualisation, impact assessment and monitoring plan development for coal mine and unconventional gas project approvals.

Groundwater, inflow and depressurisation investigations.

Groundwater and surface water impact assessment for major infrastructure projects, road and tunnels, include inflow prediction, risk assessment and mitigation planning and implementation.

Contaminated land site assessments, site remediation and validation, pre-acquisition environmental assessments.

Mine post closure assessment and planning

LANGUAGES

English

PROFILE

Ray has 37 years' experience providing geological, hydrogeological and environmental services to mining, energy, industrial, land development, construction, state and federal government clients and community groups. He has worked on projects for these clients in Australia, Africa, China, South America, the USA, Indonesia and Papua New Guinea in project director, project management, coordinator, advisory or review roles.

He has completed energy, oil&gas and mining-related work covering water-related approvals investigations/assessment, water supply and injection schemes, water conveyance, water resource infrastructure, groundwater monitoring, inflow and dewatering/ depressurisation works, mine audit, underground mine development and open pit assessment, as well as, infrastructure, state/federal, defence, industrial, commercial and petrochemical facilities, and mining and mineral process operations.

EDUCATION

BSc (Geology and Chemistry), University of Natal, Durban, South Africa (1974)	1974
BSc(Hon) (Geology), University of Natal, Durban, South Africa (1975)	1975
Grad. Course in Engineering Geology (Hydrogeology), University of NSW, Sydney, Australia (1985)	1985

PROFESSIONAL ASSOCIATIONS

Australasian Institute of Mining and Metallurgy	AusIMM
International Association of Hydrogeologists	IAH
International Mine Water Association	IMWA

PROFESSIONAL EXPERIENCE

Summary of Experience – Energy and Mining

Underground and open pit coal mining experience. NSW and Queensland:

- Open cut and underground coal mine geological, hydrological and hydrogeological assessment investigations, including development of conceptual geological and hydrogeological models for surface and underground mining operations and, waste rock dumps, tailings facilities performance and subsurface excavations,
- Office based and field investigations for catchment-wide surface water and groundwater impact assessments for mining and energy project planning/consent/approvals (including EIS, EA and GIA projects),
- NSW aquifer interference policy implementation (groundwater dependant ecosystems assessments, groundwater connectivity, water accounting and licencing) and strategic regional land use plans assessment;
- Groundwater inflow/seepage analysis and impact assessment, monitoring and mitigation programs implementation for open pit and underground mining projects; mine and excavation dewatering and depressurisation assessment, system design, implementation and management,
- Conceptual groundwater model development for impact prediction assessments and operational water management for open pit and underground operations,
- Water Balance and water management economic/feasibility assessments;

- Groundwater impact evaluation and mitigation, risk-based groundwater dependent ecosystems (GDE) impact assessments for EIS documentation;
- Salinity and acid rock drainage investigations, impact assessment, monitoring and remediation. Coal mine salinity impact assessment (including AIP accounting) and remediation, acid mine drainage investigations;
- Numerical (computer) groundwater modelling oversight and supervision, for groundwater level and flow impact assessment, water quality impacts and solute transport assessments;
- Waste rock dump and Tailing Dam assessments from groundwater perspectives: Salinity, pH and ARD assessments for waste rock dump design, tailing dam siting, construction, management and closure;
- Mine geological assessment, stope mapping, exploration, mine/stope planning, groundwater inflow assessment and mitigation, drilling program management, geophysical survey supervision and surface geological mapping;
- Geological exploration planning, execution and project management, surface geological mapping, geophysical survey supervision, drilling program supervision, and ore deposit/grade estimation.

Pertinent Project Experience – Energy and Coal Mining

Groundwater Characterisation investigations, Hunter Valley Coalfields, NSW (1998)
Client: Pacific Power Corporation
Role: Project hydrogeologist
Key achievements:

¾ Contaminated groundwater characterisation studies for Pacific Power Corporation for flooded coalmine workings as a prerequisite to permitting for discharge to a major waterway system.

Groundwater Impact Assessments for EIS Approvals Documentation, Springvale Colliery and Angus Place Collieries, Western Coalfields, NSW (2012-2013)

Client: Centennial Coal

Role: Project director
Key achievements:

¾ Project director for groundwater and surface water studies, and impact evaluation for input into two EIS documents for two coal mines in the Western Coalfields of NSW. Particular emphasis being applied to: (1) recently introduced Aquifer Interference Policy, Strategic Regional Land Use Policy; (2) subsidence and subsidence-groundwater modelling; and (3) groundwater dependant ecosystems (hanging swamps) requirements for the studies.

Floor Heave Assessment, Springvale Colliery, Western, Coalfields, NSW (2012-2013)
Client: Centennial Coal
Role: Project director
Key achievements:

¾ Project director for a program of geological and hydrogeological studies focused on evaluating the role of groundwater and geotechnical issues as causes for severe floor heave in areas of the underground workings at the Springvale mine.

Groundwater Inflow and Impact Monitoring Assessment, Yancoal-Ashton Coal Mine, Hunter Valley Coalfields, NSW (2012-2013)
Client: Yancoal
Role: Project director
Key achievements:

¾ Project director for groundwater inflow and mitigation monitoring program focussed on the assessing the effects of subsidence and goafing on overlying sensitive alluvial beds associated with Bowmans Creek, a tributary of the Hunter River. Impacts were assessed and likely inflow sources (quantity and location/s) identified. Mitigation measures were also evaluated.

Groundwater Inflow Assessment, Ravensworth, Hunter Valley, Coalfields, NSW
Client: Xstrata (now Glencore)
Role: Project director
Key achievements:

¾ A groundwater inflow and mitigation assessment on a structural conduit resulting in high volume seepages to underground works in the coal mine from the overlying goaf and surface water storage/s at Ravensworth mine in the Hunter Valley Coalfields. Impacts were assessed and likely sources identified. Mitigation measures were also evaluated.

Groundwater Inflow Assessment, Glendell, Hunter Valley, Coalfields, NSW (2002-2003)
Client: Glencore (Xstrata, Glendell Coal)
Role: Project Technical Manager
Key achievements:

¾ A pre-feasibility groundwater inflow assessment and numerical modelling program was undertaken to assess the likely groundwater inflow rates to a proposed open pit mine from the coal measures and overlying alluvial sediments underlying the Glendell Mine in the Hunter Valley Coalfields. Mitigation measures were also evaluated. Evaluation of salinity and contaminant hydro-geochemistry, and surface discharge feasibility option were undertaken.

Goaf Dewatering Investigations, Springvale Colliery, Western, Coalfields, NSW - Goaf Dewatering program (1997)
Client: Centennial Coal
Role: Project director
Key achievements:

¾ Provided peer review input on the design and installation of two 380 m deep large diameter shafts for the installation of pumps to dewater the mine workings. Included input into the permitting process by the regulatory authorities, selection of pumps and pump equipment, pipeline and water treatment plant.

Mine Inflow Assessment, Groundwater Assessment, Wambo Coal Mine, Hunter Valley, Coalfields, NSW (1997)
Client: Excel Coal
Role: Project Director
Key achievements:

¾ Conducted an assessment of potential for hazardous groundwater inflows and resolved drainage management issues for an existing and proposed longwall mining area for Wambo Mining. The assessment involved underground and surface rock permeability testing, inflow modelling and mitigation design.

Mine Inflow Assessment, Myuna Colliery (Lake Macquarie), New South Wales (1996)
Client: State Mines of NSW
Role: Project Field Hydrogeologist
Key achievements:

¾ Review of groundwater inflow issues at the Myuna Coal Mine operations. Developed a water management strategy for the testing, monitoring and mitigation of groundwater 'makes' and roof instability at the mine.

Coal Mine Floor Heave Mitigation, Cooranbong Colliery, (Lower Hunter - Lake Macquarie), NSW
Client: State Mines of NSW
Role: Project Field Hydrogeologist
Key achievements:

¾ Evaluation of groundwater inflow and associated floor heave issues in the Cooranbong colliery (State Mines of NSW). Developed a strategy for the mitigation of these problems. Implementation was subsequently undertaken.

Mine Inflow Assessment, Hunter Valley Coalfields, New South Wales (2004)
Client: Wambo Mining Corporation
Role: Excel Coal
Key achievements:

¾ Conducted an assessment of potential groundwater hazard inflows and drainage for existing and proposed longwall mining area. The assessment involved underground and surface rock permeability testing, inflow modelling and mitigation design.

Mine Inflow Assessment, Hunter Valley, Muswellbrook, New South Wales (1987)
Client: Liddell State Colliery and Yeildex
Role: Project Field Hydrogeologist
Key achievements:

¾ Conducted review of persistent and increasing water inflows (1.4-14mL/d) related to two sources; mainly waters from the flooded Hazeldene workings adjacent to them and from Bowmans Creek via fractures resultant from subsidence as longwall mining workings passed beneath the creek. Implemented a local inflow relief program using targeted stabilised clay grouting methods.

¾ Mine water inflow assessment and mitigation proposed for an open cut and underground coal mine in the Hunter Valley Coalfields. Evaluation of salinity and contaminant hydrogeochemistry and surface discharge feasibility assessment with designs.

Mine Tailings and Waste Rock Assessments, Jinfeng Gold Mine. Jinfeng, China. (2005)
Client: Sino Gold / Eldorado Gold
Role: Project Technical Advisor, Groundwater
Key achievements:

¾ - Provided specialist technical input into for the mine planning, design, and geotechnical studies for a proposed gold mine at Jinfeng, China. These studies included: groundwater resource review, mine tailings dam design, stability and siting assessment, impact of a proposed government water supply dam flooding of the proposed tailings dam toe slope, water supply reticulation and pit inflow studies. Data evaluation included groundwater-surface water interaction on the proposed tailing dam downgradient wall, tailing dam seepage and impact prediction, water supply aquifer evaluation, pit inflow and impact prediction, and resource assessment. The results of the investigations form a significant input into the mining project's Bankable Feasibility Study.

Independent Review process – mine flooding event, Browns Creek Gold Mine. NSW, Australia

Client: Durban Roodeport Deep Limited
Role: Project Technical Advisor, Groundwater
Key achievements:

¾ Participated in the Independent Review process conducted as part of the assessment of a mine flooding event arising from associated groundwater inflow issues.

PROFESSIONAL HISTORY

WSP	2015–Present
Arrow Energy	2015
SKM-Jacobs	2013 - 2015
RPS-Aquaterra	2012 - 2013
Golder Associates	2001 - 2012
URS Corporation/Woodward-Clyde	1989 - 2000
Australian Groundwater Consultants (AGC)	1986 - 1989

Earth Resources Foundation, Sydney University	1985 - 1986
CRA Exploration	1981 - 1983
Tsumeb Corporation	1979 - 1981
Union Corporation	1977 - 1979

AWARD

Best Paper Award 2006
Australian Geomechanics Society biannual conference and the International Association of Hydrogeologists, 2004

PUBLICATIONS AND PRESENTATIONS

Publications

¾ Hatley, Raymond Keith. “Hydrogeology of the Botany Basin.” *Journal of the Australian Geomechanics Society*, Volume 39, No. 3, September 2004.

Presentations

¾ Hatley, Raymond Keith. “Hydrogeology of the Botany Basin - Revisited” *Australian Geomechanics Society*, North Sydney, NSW. October 2004.

APPENDIX B

DRAWINGS

Map: PS112385_GIS_003_A1	Author: suansrir
Date: 12/12/2018	Approved by: -

0 250 500 m

1:30,000

Coordinate system: GCS GDA 1994

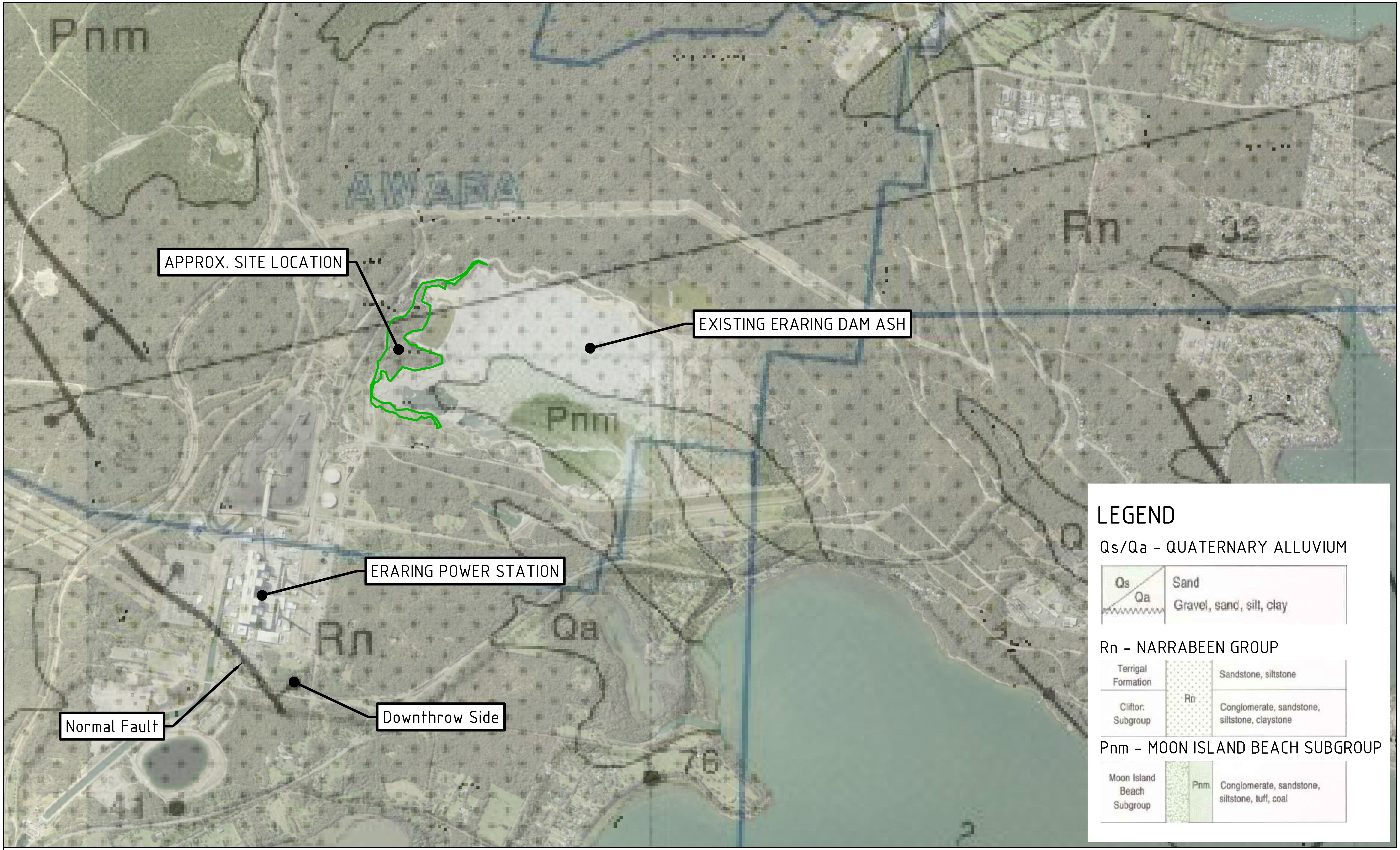
Scale ratio correct when printed at A3

Data source: Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

Eraring Ash Dam Expansion

Drawing 1

Site location plan

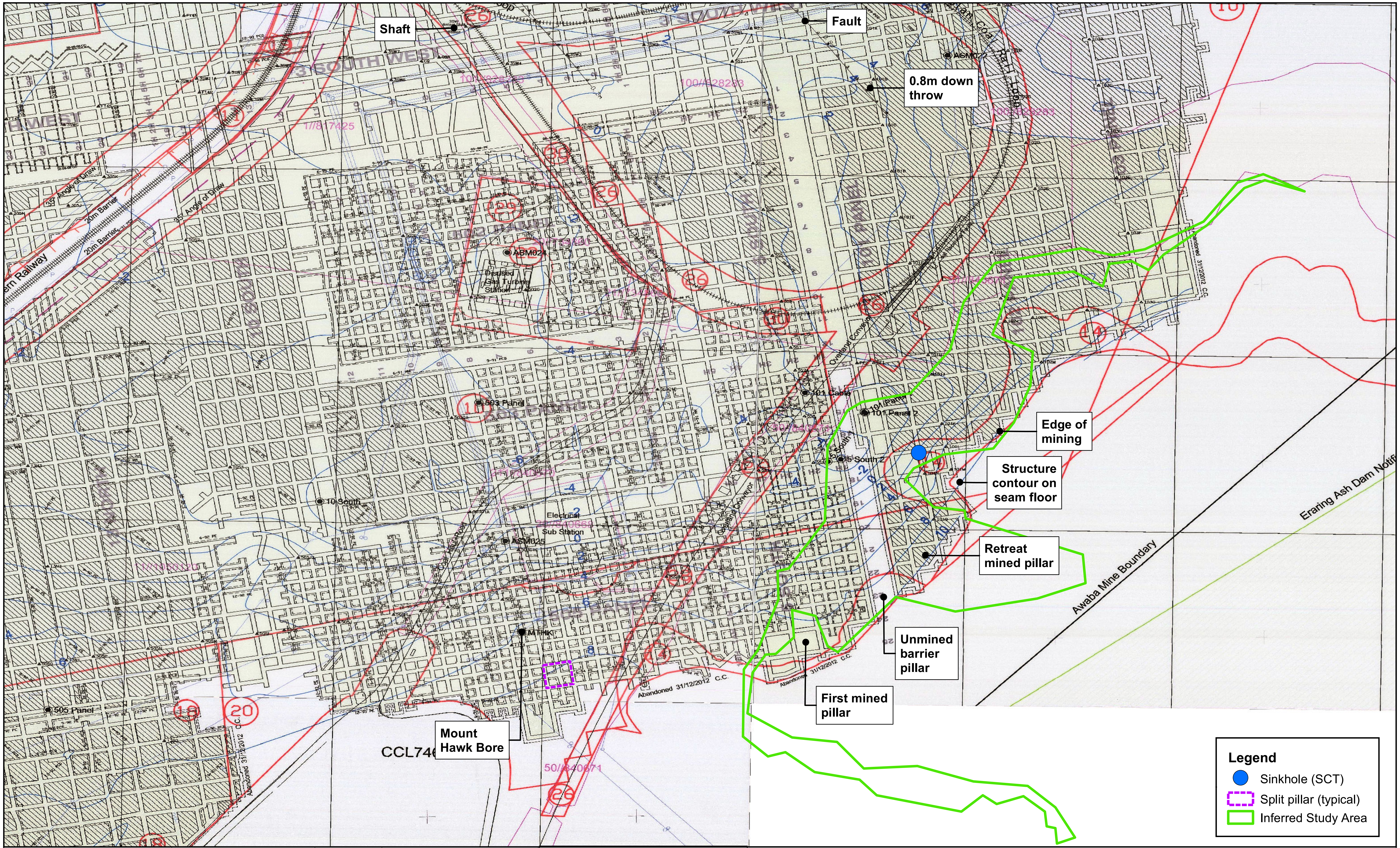


Map: PS112385	Author: TIMOTHY ALLAN	N	0 200 400 600 Full Size 1:20000 A3 SIZE; SCALE (m)
Date: 04/12/18	Approved by: -		1:20,000
Data source:			*Coordinate system: GCS GDA 1994* Scale ratio correct when printed at A3

Newcastle Coal Field Regional Geology
Edition 1, 1995,
Department of Mineral Resources

Proposed Eraring Ash Dam Expansion
Geology Plan

Drawing 2
PS112385



Map: PS112385_GIS_001_A2	Author: suansrir
Date: 12/12/2018	Approved by: -

Data source: Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

0 50 100 m

1:5,000

Coordinate system: GCS GDA 1994

Scale ratio correct when printed at A3

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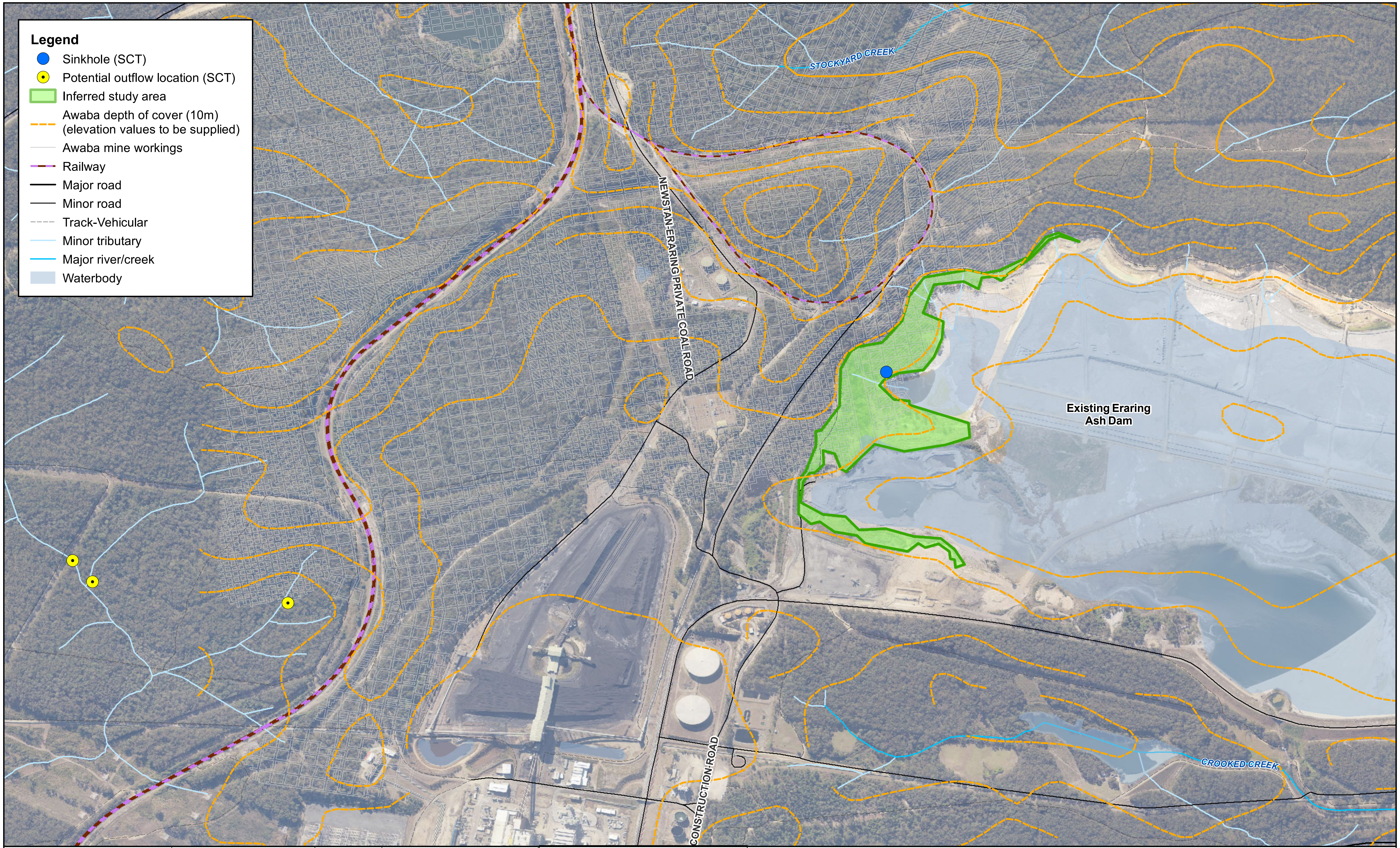
Eraring Ash Dam Expansion

Drawing 3

Mine workings in area of interest

RT606.R10000593 (MGA series)



Map: PS112385_GIS_002_A1	Author: suansrir
Date: 12/12/2018	Approved by: -

0 100 200 m

1:10,000

Coordinate system: GCS GDA 1994

Scale ratio correct when printed at A3

Data source: Sources: Esri, HERE, DeLorme, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), MapmyIndia, NGCC, © OpenStreetMap contributors, and the GIS User Community

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Eraring Ash Dam Expansion

Drawing 4
Depth of cover contours

wsp

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Eraring Power Station

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