Ensham Resources

Residual Void Project - Groundwater Assessment Stage 2

(Confidential)

FOR

Idemitsu Australia Resources Pty Ltd

BY

NPM Technical Pty Ltd trading as HydroSimulations

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<td>Dr Noel Merrick (NPM Technical Pty Ltd)</td>
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# TABLE OF CONTENTS

Table of Contents ........................................................................................................................................... i
List of Figures .................................................................................................................................................. ii
List of Tables .................................................................................................................................................. iii

## EXECUTIVE SUMMARY ............................................................................................................................. iv

1 INTRODUCTION ........................................................................................................................................... 1
   1.1 Objectives ............................................................................................................................................... 1
   1.2 Scope of Work ......................................................................................................................................... 2
   1.3 This Report ............................................................................................................................................ 3

2 EXISTING CONDITIONS ................................................................................................................................. 4
   2.1 Site Overview ......................................................................................................................................... 4
   2.2 Geology Overview .................................................................................................................................. 4
       2.2.1 Quaternary Sediments ................................................................................................................ 4
       2.2.2 Triassic Rewan Group ............................................................................................................... 5
       2.2.3 Permian Rangal Coal Measures ............................................................................................... 5
   2.3 Hydrogeology Overview ......................................................................................................................... 6
       2.3.1 Quaternary Sediments ............................................................................................................... 6
       2.3.2 Rewan Group .................................................................................................................................. 6
       2.3.3 Permian Rangal Coal Measures ............................................................................................... 6
   2.4 Literature Review .................................................................................................................................... 7
   2.5 Conceptual Model .................................................................................................................................... 9

3 GROUNDWATER MODEL .............................................................................................................................. 10
   3.1 Software .................................................................................................................................................. 10
   3.2 Model Setup .......................................................................................................................................... 10
   3.3 Scheduling ............................................................................................................................................. 14
   3.4 Model Refinement .................................................................................................................................. 15
       3.4.1 Open Cut Updates ....................................................................................................................... 15
       3.4.2 Underground Mine Updates .................................................................................................... 15
       3.4.3 Climatic Updates ....................................................................................................................... 16
       3.4.4 Flooded Pit Representation ...................................................................................................... 16
       3.4.5 Other Refinements .................................................................................................................... 16

4 OPTION 1 ASSESSMENT – LANDFORM LEVEE ......................................................................................... 17
   4.1 Void Water Levels and Flows ................................................................................................................ 17
   4.2 Underground Flows ............................................................................................................................... 17
   4.3 Scenario Summary ................................................................................................................................ 18
   4.4 Equilibrium .......................................................................................................................................... 18

5 OPTION 3 ASSESSMENT – BACKFILL TO PMF ......................................................................................... 19
   5.1 Void Water Levels and Flows ................................................................................................................ 19
   5.2 Underground Flows ............................................................................................................................... 19
   5.3 Scenario Summary ................................................................................................................................ 19
   5.4 Sensitivity Analysis ............................................................................................................................... 20

6 OPTION 2 ASSESSMENT – FLOOD MITIGATION AND BENEFICIAL USES .................................................. 21
   6.1 Discharge-Stage Curves ....................................................................................................................... 21

7 FAR-FIELD MODEL OUTPUTS .................................................................................................................... 22
   7.1 Key Hydrographs ................................................................................................................................. 22
   7.2 Water Table Maps ................................................................................................................................ 23
   7.3 Drawdown Maps .................................................................................................................................. 23

8 CONCLUSION ............................................................................................................................................... 24

9 REFERENCES ................................................................................................................................................ 25
LIST OF FIGURES

Figure 1   General location plan
Figure 2   Open-cut pit names
Figure 3   Perspective views of current and future mined volumes, with undisturbed rock hidden
Figure 4   Conceptual cross section through Nogoa River and Quaternary sediments
Figure 5   Conceptual hydrogeological model of Ensham Mine
Figure 6   Former underground mine plan, pits, model mesh and rivers
Figure 7   Transient calibration to groundwater levels
Figure 8   Transient calibration to mine inflow
Figure 9   Groundwater monitoring network
Figure 10  Past open cut mining schedule
Figure 11  Future underground mining schedule
Figure 12  Option 1 predicted water levels and flows – Pit A South
Figure 13  Option 1 predicted water levels and flows – Pit A North
Figure 14  Option 1 predicted water levels and flows – Pit B
Figure 15  Option 1 predicted water levels and flows – Pit C
Figure 16  Option 1 predicted water levels and flows – Pit D
Figure 17  Option 1 predicted water levels and flows – Pit E
Figure 18  Option 1 predicted water levels and flows – Pit F
Figure 19  Option 1 predicted water levels and flows – Pit Y
Figure 20  Option 1 predicted underground mine inflow
Figure 21  Option 1 predicted long-term water levels and flows – Pits B, C, D
Figure 22  Option 3 predicted long-term water levels and flows – Pits A South and A North
Figure 23  Option 3 predicted long-term water levels and flows – Pits B and C
Figure 24  Option 3 predicted long-term water levels and flows – Pits D and E
Figure 25  Option 3 predicted long-term water levels and flows – Pits F and Y
Figure 26  Option 3 predicted underground mine inflow
Figure 27  Option 3 predicted long-term water levels and flows at Pit C  [a] base model;  [b] modified TVM
Figure 28  Option 2 estimated discharge-stage curves for Pits B and C
Figure 29  Predicted water table elevations [mAH] for Option 3 – Pits B to D
Figure 30  Predicted water table drawdowns [m] for Option 3 – Pits B to D

LIST OF TABLES

Table 1  Summary of Site Stratigraphy
Table 2  Summary of Adopted Hydraulic Properties from Other Bowen Basin Studies
Table 3  Stratigraphy – Model Layer Summary
Table 4  Simulated Aquifer Properties
Table 5  Simulated Properties Relative to Field Data Ranges
Table 6  Recharge Values
Table 7  Pit Dewatering Timing
Table 8  Rest Water Levels
EXECUTIVE SUMMARY

Ensham Mine is required to complete a documented "Residual Void Project" (RVP) by 31 March 2019. This is a condition of the Environmental Authority (EA) (issued by the Department of Environment and Heritage Protection (DEHP) (now Department of Environment and Science [DES]) on 26 May 2017.

Groundwater studies are required under Condition G20 of the EA:

"Void hydrology, addressing the long-term water balance in the voids, connections to groundwater resources and water quality parameters in the long term."

The groundwater investigation has been based on groundwater flow modelling using a model developed by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE), most recently updated in 2016. This model is unchanged during the calibration period (to August 2016) but has been modified for predictive purposes. For the current stage (Stage 2) of the RVP, no re-calibration has been undertaken. Nor has any change in spatial discretisation ("meshing") been applied. Both aspects will be reviewed in Stage 3 of the RVP.

The objectives of the groundwater component of the RVP are to predict the following:

A. individual residual void final water recovery levels;
B. individual residual void, backfill zone, spoil tip and underground mining area time/head-variant groundwater fluxes; and
C. time-variant water table drawdown and piezometric decline and recovery across the model domain and at selected locations.

Predictive simulations have been run for three management scenarios:

- Preferred Option 1: Landform Levee.
- Preferred Option 2: Flood Mitigation & Beneficial Use.
- Preferred Option 3: Backfill to PMF.

For Options 1 and 3, the model has been used to predict time-varying groundwater inflows/outflows and water levels in each of eight residual voids, as well as regional groundwater levels.

For Option 2, discharge-stage curves for Pits B and C have been generated for use in surface water specialist modelling of final pit lake levels and salinities.

The main finding of the modelling is that the adjacent underground workings are expected to take many decades to be replenished with water, drawn substantially from the open water in proximal pit lakes. This has the effect of holding nearby pit lake water at low elevations for a long time, before the lakes are able to recover towards (but never reaching) pre-mining water levels.
1 INTRODUCTION

Ensham Mine is a coal mine owned and operated by Ensham Resources Pty Ltd (Ensham), located in Central Queensland between the towns of Emerald and Blackwater. A general location plan is shown at Figure 1. The mine produces high energy, low-ash thermal coal through a combination of open-cut pit and more recently underground mining (since 2010).

Ensham is required to complete a documented “Residual Void Project” (RVP) by 31 March 2019. This is Condition G16 of Environmental Authority (EA) EPML00732813 issued by the Department of Environment and Heritage Protection (DEHP) (now Department of Environment and Science [DES]) on 26 May 2017. Expected groundwater studies are implied in clause (c) of Condition G20 of the EA:

(c) “Void hydrology, addressing the long-term water balance in the voids, connections to groundwater resources and water quality parameters in the long term.”

Previous groundwater investigations have been conducted by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE):

- 2017: Modelling of underground mining (AGE, 2017a)

AGE has also prepared quarterly groundwater monitoring reports (e.g. AGE, 2017b).

The groundwater model developed by AGE has been transferred to HydroSimulations for use and adaptation on the RVP. The current version of the groundwater model was converted by AGE in 2016 from a structured grid using MODFLOW-SURFACT software to a Voronoi unstructured grid using MODFLOW-USG + AlgoMesh software. This allowed finer spatial resolution along the streams, across the open-cut pits, and over the underground mine footprint.

1.1 OBJECTIVES

The objective of the latest AGE model was to predict environmental impacts of open-cut and underground mining, as well as inflows to the underground mine, excluding an assessment of the residual voids. The objective of the earlier 2015 model was to predict pit inflows during operations as well as post-mining inflows to residual voids, out to 250 years into the future, excluding the effects of underground mining.

The objectives of the groundwater component of the RVP are to predict the following:

A. individual residual void final water recovery levels;
B. individual residual void, backfill zone, spoil tip and underground mining area time/head-variant groundwater fluxes; and
C. time-variant water table drawdown and piezometric decline and recovery across the model domain and at selected locations.
1.2 SCOPE OF WORK

The scope of work has three phases:

1. Phase 1: Groundwater model review.
2. Phase 2: Groundwater modelling for Stage 2 of the RVP.
3. Phase 3: Groundwater modelling for Stage 3 of the RVP.

**Phase 1** has the following tasks:

- to assess the objectives of the RVP and the requirements and implications of three options (for minimising final void area and volume) as they relate to groundwater;
- to reconsider the suitability of the conceptual hydrogeological model underlying the numerical model and the merit of alternative conceptualisations;
- to confirm the suitability of interpretation of the conceptual model or models in the numerical model with which further calibration and predictive work will be conducted to explore the merits of each of the three options;
- to examine previously documented recommendations and their implementation; and
- to identify key information and data, the incorporation of which into any model revision within the timescale for the project, is required to achieve the objectives of the study.

The three Preferred Options are:

 Preferred Option 1: Landform Levee
 Preferred Option 2: Flood Mitigation & Beneficial Use
 Preferred Option 3: Backfill to PMF

**Phase 2** has the following tasks:

- to conduct test runs on the existing AGE model;
- to modify the existing model for significant changes to the mine plan since it was modelled in AGE (2017a);
- to modify the existing model for advised changes in final landforms and timing; and
- to conduct production model runs for the three preferred options.

Note that Phase 2 specifically excludes any re-calibration of the AGE model or re-meshing of the adopted AGE Voronoi grid.

**Phase 3** has the following tasks:

- to re-mesh model space if necessary;
- to re-calibrate the model if necessary;
- to conduct production runs of the modified model for the preferred option(s);
- to explore uncertainty in conceptualisation through the consideration of alternative conceptualisations of the hydrogeological characteristics or functions pertinent to model predictions; and
• to explore uncertainty in numerical representation of model variables.

Of particular note is the deferral of model re-calibration and model re-meshing (if necessary) to Phase 3.

1.3 THIS REPORT

The objectives of this report are:

1. To document changes made to the AGE model for Phase 2 assumptions.
2. To define the simulation assumptions for the three preferred rehabilitation options.
3. To present the results of Option 1.
4. To present the results of Option 3.
5. To present the results of Option 2.
6. To comment on the significance of sensitivity experiments.
7. To summarise findings to date.
2 EXISTING CONDITIONS

2.1 SITE OVERVIEW

The terrain is generally low-lying, and the few hills within the area are capped by duricrusts. The main drainage of the area is via the Nogoa River, which flows in an easterly and south-easterly direction through the mine lease before joining the Mackenzie River near the town of Comet. The river is used for irrigation and stock water supply, with flow maintained by releases from Fairbairn Dam south of Emerald (Section 2.3, AGE, 2017a). The low-lying area includes floodplains and riparian zones along the Nogoa River and an anabranch which runs to the north of the Nogoa River (Figure 2).

The Ensham mine site covers an along-strike length of over 20 km, from Pit A in the south to Pit Y (Yongala) in the north (Figure 2). Pits A South, A North and B are located south of the Nogoa River, with Pits C, D, E, F and Y all located north of the Nogoa and its anabranch. Pits A and B have been flooded since 2009.

The mining operation at Ensham comprises both open-cut and underground workings, with open-cut operations ramping down due to increasing strip ratios as the coal seams have been followed down dip to increasing depths. Underground operations commenced in 2011, as a small trial bord and pillar mine, with the main working seam followed through a high-wall portal from Pit C, as shown in Figure 3, progressing in a south-westerly direction underneath the Nogoa flood plain.

2.2 GEOLOGY OVERVIEW

The Ensham Mine is located in the western Bowen Basin, which is one of five major foreland sedimentary basins formed along the eastern side of Australia during the Permian period. The Bowen Basin is the largest productive coal basin in the country.

The stratigraphic sequence across Ensham Mine comprises unconsolidated Quaternary sediments unconformably overlying consolidated Permian and Triassic sequences. The Permian and Triassic strata form regular layered fluvio-deltaic sedimentary sequences, while the Quaternary sediments are more complex and irregular. The coal deposits mined at Ensham are found within the Rangal Coal Measures, which is the uppermost Permian unit. Table 1 provides a summary of the stratigraphy encountered at Ensham (Table 2.1, AGE, 2017a).

2.2.1 QUATERNARY SEDIMENTS

The Quaternary alluvial sediments unconformably overlie the Triassic Rewan Group and Permian coal measures. A weathering surface is evident at the contact. Within the Nogoa floodplain, the alluvial sequence is comprised of silts and clays underlain by a basal unit of sands and gravels. The alluvium is itself overlain by a deep clay-rich black soil, which tends to be highly absorbent during rainfall events. The alluvial sequence varies in thickness, but typically does not exceed more than 25 m below surface (Section 2.1, Table 2.1, AGE, 2017a).
Table 1. Summary of Site Stratigraphy (Table 2.1, AGE 2017a)

<table>
<thead>
<tr>
<th>Age</th>
<th>Unit</th>
<th>Description</th>
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<tr>
<td>Quaternary</td>
<td>-</td>
<td>Alluvium – comprising soil, silt, clay, sand and gravel</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Emerald Formation</td>
<td>Mudstone, sandstone, conglomerate, siltstone sediments, weekly consolidated in parts. Tertiary volcanics (basalt) are also mapped as being present over 10km west of the site.</td>
</tr>
<tr>
<td>Triassic</td>
<td>Rewan Group</td>
<td>Mudstone with lithic sandstone interbeds</td>
</tr>
<tr>
<td>Permian</td>
<td>Rangal Coal</td>
<td>Feldspathic and lithic sandstone, carbonaceous mudstone, siltstone, tuff and coal seams. Coal seams include the Aries, Castor, Pollux and Orion seams. The main economic seams at Ensham are the Aries 2 and Castor seams.</td>
</tr>
<tr>
<td></td>
<td>Measures</td>
<td></td>
</tr>
<tr>
<td>Permian</td>
<td>Burngrove Formation</td>
<td>Sandstones, siltstones and mudstones, and banded coal seams frequently interbedded with tuff and tuffaceous mudstones - coal seams include the Virgo and Leo seams.</td>
</tr>
<tr>
<td>Permian</td>
<td>Fair Hill Formation</td>
<td>Lithic and feldspathic labile sandstone, siltstone, mudstone and conglomerate.</td>
</tr>
<tr>
<td>Permian</td>
<td>Macmillan Formation</td>
<td>Lithic and feldspathic sublabile mudstone, siltstone and sandstone.</td>
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2.2.2 TRIASSIC REWAN GROUP

The Rewan Group has generally been removed by erosion in the subcrop area of the Rangal Coal Measures at Ensham. Where present, the Rewan Group is comprised of siltstone and mudstone, with interbeds of lithic and volcanic sandstones and has a distinct greenish tint in colour.

2.2.3 PERMIAN RANGAL COAL MEASURES

The Rangal Coal Measures consist of sandstone, siltstone, mudstone, coal and tuff (towards the base) and have a thickness of up to 100 m. The seams subcrop over a strike length of about 80 km around the northern and eastern limits of the area. The coal seams that occur at Ensham include the Aries A1 Seam, Aries 2-Castor Seam (A2C) which is about 4.3 m thick, and the Castor Seam Lower Split (C22) which is between 0.2 m to 0.4 m thick. The seams are separated by a mudstone parting that varies between 0.1 m and 0.4 m in thickness. The Pollux Seam is between 6 m to 12 m below the C22 Seam in the central Ensham area. The Pollux Seam is a banded seam and is only mined at Yongala where it is cleaner and close to the C22 Seam (Section 2.1.3, AGE, 2016).

The Permian stratigraphy at Ensham is structurally relatively simple, with minimal folding or faulting. The strata dip at generally less than 5° towards a synclinal axis that is plunging to the southwest, with only minor faulting noted. Where present, faulting is generally normal trending east-west to southeast-northwest, with throws of less than
10 m, although occasional low angle thrust faulting has been noted (Section 2.1.4, AGE, 2016).

2.3 HYDROGEOLOGY OVERVIEW

The principal groundwater bearing strata at Ensham Mine are associated with the Permian coal seams and the Quaternary alluvium, with the siltstones and sandstones that make up the majority of the overburden largely found to have a low permeability.

2.3.1 QUATERNARY SEDIMENTS

An AGE investigation in 2004 (Section 6.2.2, AGE 2006) found that groundwater occurrence in the alluvium was highly variable, with thin saturated zones of poor quality water in deeper sections of an otherwise largely unsaturated formation.

Water level data show the seasonal variability in groundwater to be limited and coincident with the heterogeneous distribution of these sediments (Figure 3). Shallow silts and clays are anticipated to be partially isolating the Nogoa River, limiting leakage from the river into the basal sands and gravels. It is possible that leakage may occur where these clays are absent or where the basal sands are exposed within the river. However, this is conceptually thought to occur only in localized areas. This hydraulic separation of the alluvium from the Nogoa River means that whilst the water in the river is fresh, the underlying alluvium can be brackish to highly saline.

The alluvium can, therefore, be considered as a largely unconfined system which is recharged by rainfall and upward leakage from the underlying Rewan Group or Rangal Coal Measures. The alluvium may also receive localised baseflow recharge from the Nogoa Rover, where clay and silt layers are absent.

2.3.2 REWAN GROUP

There is no hydraulic data for the Rewan Group available at site or from the immediately surrounding regions (Section 2.1.2, AGE, 2017a). However, regional data in the Bowen Basin is presented in Section 2.4.

It is noted by AGE that experience of the Rewan Group in other regions has shown it is likely to have similar hydraulic properties to the Permian overburden units.

2.3.3 PERMIAN RANGAL COAL MEASURES

The most permeable lithological units at Ensham are the coal seams, which form aquifers that generally exhibit low transmissivities, and are confined by overlying and underlying shales and mudstones (AGE, 2017a). Groundwater storage and movement largely occurs within the coal seam, along cleats and fissures and occasionally within minor fault zones that intercept the seams. The other lithologies present in the overburden and interburden sequence are usually considered to be relatively impermeable and form aquitards. The Permian strata can be categorised into the following hydrogeological units:

- very low to low permeability sandstone and siltstone that comprise the majority of the Permian interburden / overburden; and
• low to moderately permeable coal seams, of varying degrees of competency (and therefore fracturing).

There are no site-specific data on the hydraulic conductivity of the interburden material (according to Section 2.1.3, AGE 2017a). However, field data collected at Baralaba North (SKM, 2013) indicates a range in horizontal hydraulic conductivity of between $1.8 \times 10^{-2}$ m/day and 1.15 m/day, with decreasing conductivity with increased depth. Additional regional data are summarised in Section 2.4.

There is insufficient groundwater level data for the Rangal Coal Measures to adequately interpolate the regional groundwater flow direction, particularly south to south-west of the mine. However, based on available data, the Rangal Coal Measures largely flow towards the active underground mine area (Figure 4). Slightly elevated groundwater levels around A Pit and B Pit are likely due to water storage within the pits.

The Rangal Coal Measures outcrop along the eastern edge of Ensham Mine, where recharge will occur from direct rainfall to the ground surface, infiltrating into the formations through the thin soil cover, weathered profile and spoil at site. The coal measures also subcrop in localised zones beneath alluvium associated with the Nogoa River, where the unit may be recharged by downward seepage where there is an absence of clay and silt layers. Recharge may also occur via downward leakage from the Triassic Rewan Group and from areas of site surface water storage (i.e. in pit water storage). It is also possible, and a significant risk to underground operations, that direct recharge to the coal seams may also occur down exploration boreholes that have not been effectively grout-sealed within the Nogoa floodplain.

Site-specific reports reviewed do not provide substantive information to constrain the conceptual flows within the Rangal Group. Radial flow towards the underground workings is implied by sparse data to the west and north-west; weak connection between the AB Pits and underground is implied by the presence of retained surface water in these pits and local elevated groundwater conditions. Fracture flow and flow through seams as depicted in Figure 4 is assumed but unproven. It is anticipated that there is increased risk of connection from historical drilling programmes. The risk may be to future development of the mine into connected areas and from connection of the flood plain to existing areas of the underground mine.

2.4 LITERATURE REVIEW

Reported hydraulic and storage properties of key formations in the broader Bowen Basin have been gathered from many sources into Table 2. Not unexpectedly, there is a very wide range of values in each formation.

Coffey (2014) compiled packer testing data from many mines in the northern Bowen Basin, and found that although there was a degree of variability in the dataset due to irregular fracturing there is a general trend of reducing hydraulic conductivity with depth. This is likely due to increasing overburden pressure resulting in a reduction in fracture aperture. Hydraulic conductivity of the coal seams is typically three times higher than the interburden.
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<td>Rewan Fm Triassic</td>
<td>1.0E-5 to 1.0E-4</td>
<td>1.0E-6 to 1.0E-4</td>
<td>5.0E-3</td>
<td>1.0E-6</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td></td>
<td>5.0E-2</td>
<td>5.0E-6</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>1.0E-4</td>
<td>1.0E-5</td>
<td>1.0E-2</td>
<td>1.0E-5</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>3.6E-4</td>
<td>7.4E-6</td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>1.3E-5 to 2.7E-3</td>
<td>5.8E-9</td>
<td>2.2E-8</td>
<td>3.0E-5</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>5.0E-4 to 5.0E-2</td>
<td>1.0E-7 to 1.0E-4</td>
<td>1.0E-1 to 2.5E-1</td>
<td>5.0E-6 to 5.0E-4</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>2.0E-3</td>
<td>5.0E-4</td>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>1.0E-3</td>
<td>2.0E-4</td>
<td>3.0E-2</td>
<td>8.6E-6</td>
<td></td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>9.0E-4</td>
<td>5.4E-5</td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
<tr>
<td>Rangal Coal Measures</td>
<td>Permian</td>
<td>2.8E-3 to 4.7E-2</td>
<td></td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>1.0E-5 to 5.0E-2</td>
<td>5.0E-4 to 5.0E-3</td>
<td>0.01 to 0.12</td>
<td>5.0E-6 to 5.0E-4</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>0.01</td>
<td>2.5E-3</td>
<td>0.05</td>
<td>8.6E-6</td>
<td></td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>2.0E-5 to 2.3</td>
<td>2.0E-6 to 0.1</td>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>
In comparison with packer test hydraulic conductivities of coal measures in the Sydney Basin, the conductivities in the Bowen Basin are approximately one order of magnitude higher than those of the Sydney Basin at the same given depth. This is associated with a lower horizontal stress field in the Bowen Basin, and is one of the reasons that the Bowen Basin is targeted for gas extraction.

### 2.5 CONCEPTUAL MODEL

The hydrogeological regime of the Ensham area comprises two main groundwater systems:

- Alluvial groundwater system.
- Porous rock groundwater system.

Section 2.6 of AGE (2017a) summarises the conceptual model for the Ensham area, as illustrated in Figure 3 and Figure 4.

HydroSimulations concurs with AGE’s conceptualisation.
3 GROUNDWATER MODEL

3.1 SOFTWARE

The groundwater model was built in 2016 by AGE (2017a) using MODFLOW-USG (Panday et al., 2013) coupled with mesh generation AlgoMesh software developed by HydroAlgorithmics Pty Ltd (Merrick and Merrick, 2015), plus bespoke toolsets. Functionality of the MODFLOW-USG package has been employed to represent discontinuous lithology, time-variant hydraulic properties and improved model stability under desaturated conditions.

The spatial discretisation is an unstructured grid of Voronoi cells. Enhanced spoil and underground void properties are represented by the Time Variant Materials (TVM) process developed by HydroAlgorithmics Pty Ltd (Merrick and Merrick, 2017), as implemented in MODFLOW-USG beta.

An earlier model (AGE, 2015) used MODFLOW-SURFACT with a structured grid. This is believed to have been built in 2012, with changes only to the mine plan and final landform between 2012 and 2015.

Figure 6 shows the model scale, pit areas (purple) and the underground mined area (pink) at the time of model development by AGE (2017a). The mine plan has since changed. The Voronoi polygon mesh is shown in grey.

The model utilised in this study retains the Voronoi polygon mesh as developed in the 2017 model without change.

3.2 MODEL SETUP

Model Grid

There are 12 layers in the model. However, as a fully unstructured model, the layers are not required to be present in all areas as was the case in former versions of MODFLOW. The Ensham model utilises the pinching capability of MODFLOW-USG so that the maximum number of cells is 770,190 in the overall model compared to 952,236 cells in an equivalent layered model. This represents a saving of about 20%, given that the maximum number of cells in any layer is 79,353.

The Stratigraphic units which are represented by each model layer are summarised in Table 3.

Boundary Conditions

The mine and associated spoils are implemented through the use of MODFLOW drain cells and the TVM process. The underground mine simulates the gradually developing underground workings. The Open Cut region of the model is also simulated though drain cells but is more rapidly emplaced than occurs in reality. This aspect of the model has been improved in the current study with a more gradual development. Waste Rock from the operation is backfilled and the TVM package is used to ensure appropriate hydraulic conductivity and storage properties are applied as the voids and backfills evolve. Spoil is given an hydraulic conductivity of 1 m/d and a specific yield of 4%.
Groundwater interaction with surface drainage was modelled using the stream package for major rivers and creeks, and using the river package for minor drainage lines.

From review of AGE model input files, Stream cells are set with identical stage, top and bottom. This results in a boundary which acts as a drain cell which can receive water but not leak. Conductances are fairly high, in the 200-300 m²/day range.

River cells have more moderate conductances ranging from 5 to 20 m²/day and again set up such that they act as drain cells (gaining but never losing) (AGE 2017a; Table 3.5).

Temporal Discretisation

Two models are used in sequence: a calibration period model and a predictive period model. The calibration model runs for 22 years from 1 September 1994 to 31 August 2016, the end of the calibration period. The first eight years are split into two 4-year stress periods. The remainder of the model has a quarterly time increment. The predictive model runs from 1 September 2016 to 1 December 2056 and has a quarterly time interval. Long-term recovery was not investigated with this model, but was simulated with the previous SURFACT model (AGE, 2015) for 250 years post-mining.

Calibration

AGE (2017a) conducted manual and automated steady-state and transient calibration to 72 groundwater level monitoring sites, and achieved calibration performance statistics of 7.6 mRMS and 4.9 %RMS. The scattergram, reproduced as Figure 7, indicates bias towards overestimation of heads by the model, especially at large distances from the open cut pits.

Although not part of the RMS statistics, calibration also considered observed mine inflows. The result, reproduced as Figure 8, indicates general agreement with the magnitude of inflow (about 2-6 ML/day) but with opposite trend over time. The incorrect trend is to be resolved in Phase 3 re-calibration. It could be due to mining

Table 3. Stratigraphy – Model Layer Summary (Table 3.1, AGE, 2017a)

<table>
<thead>
<tr>
<th>Model layer</th>
<th>Geological age</th>
<th>Stratigraphic unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Quaternary</td>
<td>Regolith (CSIRO, 2015) and less productive alluvium (Qa)</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Highly productive alluvium (basal gravels)</td>
</tr>
<tr>
<td>3 - 4</td>
<td>Triassic</td>
<td>Rwan Group – fine grained sandstone and siltstone</td>
</tr>
<tr>
<td>5</td>
<td>Permin</td>
<td>Rangal Coal Measures</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>Sandstone / siltstone / shale</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>Aries 1 Seam</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>Sandstone / siltstone / shale</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>Aries 2 Seam and Castor Seam</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>Sandstone / siltstone / shale</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Pollux Seam</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>Burngrove Formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sandstone / siltstone / shale / coal</td>
</tr>
</tbody>
</table>
towards areas with lower overburden storage properties, which would require spatially distributed storage properties in the re-calibrated model.

Although calibration could be improved, the agreement in the scope of work was for no recalibration to be done in Stage 2 of the RVP, as the predictions based on the unmodified base model should be sufficient to inform the relative behaviours of the alternative residual void options. Recalibration will be conducted in Stage 3 (commencing March-April 2018) and will include recently available data on historical pit water levels.

The groundwater monitoring network is shown in Figure 9. Simulated hydrographs at key sites (marked as purple squares) during the calibration period are presented in the Appendix as Figures D1 - D4. The residuals map, as prepared by AGE (2017a; Figure 3.4), is reproduced at Figure D5. The agreement between simulated and measured groundwater levels is best close to the pits.

For the few selected bores with a lengthy historical record, good water level trends are reproduced by simulation at sites WSMB2D and WSMB3D. However, the hydrographs at EC01 and EC14 (in alluvium) show contrary trends. As re-calibration was specifically excluded from Phase 2, these matters will be investigated in Phase 3. At the other sites, the data record is too short to confirm or deny the simulated trends; at most sites there is a substantial offset in absolute elevations.

Most of the key sites were selected to examine far-field behavior. AGE (2017a) notes that the largest residuals occur distant from the pits (Figure D5), and that is borne out by this analysis, as most bores have more than the “average” 7.7 mRMS residual.

Bore EC14, in alluvium on the northern side of Pit B, performs extremely well. EC01, also in alluvium but to the west of Pit C, does not replicate the observed rising trend; its residual varies from 4 m to zero.

The WSMB series are installed in “Coal Measures Overburden” [S] or “Coal Measures” [D]. As WSMB2S and WSMB2D are within the outline of Pit A North, a mining effect should be noticeable. However, only a mild decline is evident in the observed data. The model performs very well at the deeper WSMB2D. WSMB3S and WSMB3D are close to the western edge of Pit A South. The observed trend at WSMB3D is replicated very well by the model, with a low point around 2010, although the residual is about 8 m. The residual at WSMB3S is only 1-2 m.

The RB series of bores is installed in coal seams at depths of about 100-240 m. RB5 is 2 km from Pit A South but the others are generally 4-5 km from any mining stress. There is no definitive mining effect at any bore in the observed dataset, but the model indicates quite plausibly that RB5 would have been affected if measurements had commenced earlier. The model is consistently overestimating the heads at these bores by 6-17m.

The Yongala bore in the Burngrove Formation, at 74 m depth, performs poorly (residual 14 m). The reason is to be investigated in Phase 3.

The cumulative discrepancy is -0.13% at the end of the run; the discrepancy in any one stress period ranges between -0.8% and 0.26%.
Model Properties

Summaries of the model layer properties in general, and the hydraulic conductivities relative to field data, are presented in Table 4 and Table 5 respectively. Recharge rates are summarised in Table 6.

Table 4. Simulated Aquifer Properties (Table 3.2, AGE 2017a)

<table>
<thead>
<tr>
<th>Model layer</th>
<th>Lithology</th>
<th>Horizontal hydraulic conductivity (K_h) (m/day)</th>
<th>Vertical hydraulic conductivity (K_v) multiplier</th>
<th>Specific yield (S_y)</th>
<th>Specific storage (S_s) (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surficial alluvium (clay / silt)</td>
<td>1.0 x 10⁻¹</td>
<td>K_h/10</td>
<td>0.01</td>
<td>1.0 x 10⁻⁵</td>
</tr>
<tr>
<td>1, 2</td>
<td>Regolith</td>
<td>1.4 x 10⁻¹</td>
<td>K_h/10</td>
<td>0.01</td>
<td>1.0 x 10⁻⁵</td>
</tr>
<tr>
<td>1, 2</td>
<td>Permian subcrop</td>
<td>2.4 x 10⁻²</td>
<td>K_h/100</td>
<td>0.02</td>
<td>1.0 x 10⁻⁵</td>
</tr>
<tr>
<td>2</td>
<td>Basal alluvium (sand / gravel)</td>
<td>10.0</td>
<td>K_h/10</td>
<td>0.20</td>
<td>5.0 x 10⁻⁵</td>
</tr>
<tr>
<td>3</td>
<td>Rewan Group</td>
<td>4.2 x 10⁻²</td>
<td>K_h/100</td>
<td>0.01</td>
<td>1.7 x 10⁻⁵</td>
</tr>
<tr>
<td>4</td>
<td>Rewan Group</td>
<td>1.2 x 10⁻⁴</td>
<td>K_h/100</td>
<td>0.01</td>
<td>1.5 x 10⁻⁵</td>
</tr>
<tr>
<td>5</td>
<td>Sandstone / siltstone / shale</td>
<td>1 x 10⁻⁴ to 1 x 10⁻¹</td>
<td>K_h/11</td>
<td>0.00</td>
<td>1.0 x 10⁻⁴</td>
</tr>
<tr>
<td>6</td>
<td>Aries 1 Seam</td>
<td>5.0 x 10⁻⁴ to 5.0</td>
<td>K_h/9</td>
<td>0.01</td>
<td>1.0 x 10⁻⁴</td>
</tr>
<tr>
<td>7</td>
<td>Sandstone / siltstone / shale</td>
<td>1 x 10⁻⁴ to 1 x 10⁻¹</td>
<td>K_h/14</td>
<td>0.00</td>
<td>5.0 x 10⁻⁴</td>
</tr>
<tr>
<td>8</td>
<td>Aries 2 and Castor Seam</td>
<td>5.0 x 10⁻⁴ to 5.0</td>
<td>K_h/10</td>
<td>0.01</td>
<td>5.0 x 10⁻⁴</td>
</tr>
<tr>
<td>9</td>
<td>Sandstone / siltstone / shale</td>
<td>1 x 10⁻¹ to 1 x 10⁻¹</td>
<td>K_h/10</td>
<td>0.00</td>
<td>5.0 x 10⁻⁴</td>
</tr>
<tr>
<td>10</td>
<td>Pollux Seam</td>
<td>5.0 x 10⁻⁴ to 5.0</td>
<td>K_h/9</td>
<td>0.01</td>
<td>5.0 x 10⁻⁴</td>
</tr>
<tr>
<td>11</td>
<td>Sandstone / siltstone / shale</td>
<td>1 x 10⁻⁴ to 1 x 10⁻¹</td>
<td>K_h/12</td>
<td>0.00</td>
<td>5.0 x 10⁻⁴</td>
</tr>
<tr>
<td>12</td>
<td>Burngrove Formation</td>
<td>1.0 x 10⁻⁴</td>
<td>K_h/9</td>
<td>0.00</td>
<td>5.0 x 10⁻⁵</td>
</tr>
<tr>
<td>-</td>
<td>Spoil</td>
<td>1.0</td>
<td>1.00x10⁻¹</td>
<td>0.64</td>
<td>1.0 x 10⁻³</td>
</tr>
<tr>
<td>-</td>
<td>Void</td>
<td>1000.0</td>
<td>1000.0</td>
<td>1.00</td>
<td>1.0 x 10⁻⁴</td>
</tr>
<tr>
<td>-</td>
<td>Bord and Pillar zone</td>
<td>100.0</td>
<td>100.0</td>
<td>1.00</td>
<td>1.0 x 10⁻⁴</td>
</tr>
<tr>
<td>-</td>
<td>Faults</td>
<td>1.0 x 10⁻³ to 1.0 x 10⁻⁴</td>
<td>K_h/10</td>
<td>0.01</td>
<td>1.0 x 10⁻³</td>
</tr>
</tbody>
</table>

Note: Corrected Sy values:
- Layer 5: 0.05
- Layer 7: 1.84E-3
- Layer 9: 1.04E-3
- Layer 11: 1.03E-3
- Layer 12: 1.0E-3
### Table 5. Simulated properties relative to field data ranges (Table 3.3, AGE 2017a)

<table>
<thead>
<tr>
<th>Model layer</th>
<th>Lithology</th>
<th>Horizontal hydraulic conductivity (m/day)</th>
<th>Field data range</th>
<th>Previously modelled and other models</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surficial alluvium (clay / silt)</td>
<td>$1.0 \times 10^{-3}$</td>
<td>$9.0 \times 10^{-4} - 1.0 \times 10^{-3}$</td>
<td>$8.6 \times 10^{-5} - 1.0 \times 10^{-2}$</td>
</tr>
<tr>
<td>1, 2</td>
<td>Colliuvium / regolith</td>
<td>$1.4 \times 10^{-1}$</td>
<td>$4.3 \times 10^{-1}$</td>
<td>$1.0 \times 10^{-2} - 4.0 \times 10^{-1}$</td>
</tr>
<tr>
<td>1, 2</td>
<td>Permian subcrop</td>
<td>$2.4 \times 10^{-2}$</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Basal alluvium (sand / gravel)</td>
<td>$1.0$</td>
<td>$9.0 \times 10^{-2} - 1.3 \times 10^{2}$</td>
<td>$7.7$</td>
</tr>
<tr>
<td>3</td>
<td>Rewan Group</td>
<td>$4.2 \times 10^{-2}$</td>
<td>-</td>
<td>$5.0 \times 10^{-5} - 1.0 \times 10^{-1}$</td>
</tr>
<tr>
<td>4</td>
<td>Rewan Group</td>
<td>$1.2 \times 10^{-4}$</td>
<td>-</td>
<td>$5.0 \times 10^{-5} - 1.0 \times 10^{-1}$</td>
</tr>
<tr>
<td>5</td>
<td>Sandstone / siltstone / shale</td>
<td>$1 \times 10^{-4}$ to $1 \times 10^{-3}$</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$1.9 \times 10^{-4} - 2$</td>
</tr>
<tr>
<td>6</td>
<td>Aries 1 Seam</td>
<td>$5.0 \times 10^{-3}$ to $5.0$</td>
<td>$9.0 \times 10^{-3} - 5.9$</td>
<td>$4.0 \times 10^{-3} - 2.4 \times 10^{-1}$</td>
</tr>
<tr>
<td>7</td>
<td>Sandstone / siltstone / shale</td>
<td>$1 \times 10^{-4}$ to $1 \times 10^{-3}$</td>
<td>$1.8 \times 10^{-2} - 1.19$</td>
<td>$1.0 \times 10^{-5}$</td>
</tr>
<tr>
<td>8</td>
<td>Aries 2 and Castor Seam</td>
<td>$5.0 \times 10^{-2}$ to $5.0$</td>
<td>$9.0 \times 10^{-3} - 5.9$</td>
<td>$4.0 \times 10^{-2} - 2.4 \times 10^{-1}$</td>
</tr>
<tr>
<td>9</td>
<td>Sandstone / siltstone / shale</td>
<td>$1 \times 10^{-4}$ to $1 \times 10^{-3}$</td>
<td>$1.8 \times 10^{-2} - 1.19$</td>
<td>$1.0 \times 10^{-5}$</td>
</tr>
<tr>
<td>10</td>
<td>Polux Seam</td>
<td>$5.0 \times 10^{-3}$ to $5.0$</td>
<td>$9.0 \times 10^{-3} - 5.9$</td>
<td>$4.0 \times 10^{-3} - 2.4 \times 10^{-1}$</td>
</tr>
<tr>
<td>11</td>
<td>Sandstone / siltstone / shale</td>
<td>$1 \times 10^{-4}$ to $1 \times 10^{-3}$</td>
<td>$1.8 \times 10^{-2} - 1.19$</td>
<td>$1.0 \times 10^{-5}$</td>
</tr>
<tr>
<td>12</td>
<td>Burpengrove Formation</td>
<td>$1.0 \times 10^{-4}$</td>
<td>-</td>
<td>$1.0 \times 10^{-4} - 1.0 \times 10^{-2}$</td>
</tr>
<tr>
<td>-</td>
<td>Spoil</td>
<td>$1.0$</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 6. Recharge Values (Table 3.4, AGE 2017a)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Diffuse recharge rate</th>
<th>% of annual rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surficial alluvium</td>
<td>5.18</td>
<td>0.8</td>
</tr>
<tr>
<td>Regolith</td>
<td>0.64</td>
<td>0.01</td>
</tr>
<tr>
<td>Permian subcrop</td>
<td>0.64</td>
<td>0.01</td>
</tr>
<tr>
<td>Spoil</td>
<td>53.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Open cut void</td>
<td>647.5</td>
<td>100</td>
</tr>
</tbody>
</table>

### 3.3 SCHEDULING

The AGE (2017a) model has been interrogated to reveal the open cut pit schedule displayed in **Figure 10**. At each pit, mining has progressed from east to west. The outline of future underground mining is also shown on **Figure 10**.

There have been many revisions of the underground mine plan. That modelled by AGE (2017a), indicated in **Figure 1**, extended beyond the mine lease and has been reduced in
extent and changed in design for ongoing modelling. The current underground mining schedule is presented in Figure 11.

3.4 MODEL REFINEMENT

As no re-calibration was undertaken for Stage 2 of the project, the calibration model of AGE (2017a) has been left unmodified. However, changes have been made to the model used for prediction, so as to be suitable for void closure option assessment which was not undertaken with the AGE (2017a) model. Model enhancements are listed below.

3.4.1 OPEN CUT UPDATES

1. Pit and spoil areas were updated to be consistent with current mine plans. With the exception of storage, the hydraulic properties for void and spoil have been replicated from the former model’s setup and applied to these new volumes.
2. Pit and spoil confined storage has been substantially reduced, and all other properties retained. The former model configuration resulted in double counting of storage as model layers saturate during rebound.
3. Pit and spoil hydraulic properties that do not change in the rebound simulation have been ported from the time-variant materials (TVM) package to the static Layer Property Flow (LPF) package. This simplifies model setup.
4. Active dewatering of the open pits is simulated with MODFLOW ‘Drain’ cells. The distribution, elevation and timing of mine advance and pump shut-off has been updated as the mine plan has evolved. The current timings for each pit are summarised in Table 7.

Table 7. Pit Dewatering Timing

<table>
<thead>
<tr>
<th>Pit</th>
<th>Water Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (south)</td>
<td>Flooded, no active level control or top-up</td>
</tr>
<tr>
<td>A (north)</td>
<td>Flooded, no active level control or top-up</td>
</tr>
<tr>
<td>B</td>
<td>Flooded, no active level control or top-up</td>
</tr>
<tr>
<td>C</td>
<td>Actively dewatered to end 2028. Following this time natural rebound permitted</td>
</tr>
<tr>
<td>D</td>
<td>Actively dewatered to end 2028. Following this time natural rebound permitted</td>
</tr>
<tr>
<td>E</td>
<td>Actively dewatered to end 2028. Following this time natural rebound permitted</td>
</tr>
<tr>
<td>F</td>
<td>Actively dewatered to end 2022. Following this time natural rebound permitted</td>
</tr>
<tr>
<td>Y</td>
<td>Actively dewatered to end 2017. Following this time natural rebound permitted</td>
</tr>
</tbody>
</table>

3.4.2 UNDERGROUND MINE UPDATES

1. The underground mine development is represented though the use of MODFLOW drain cells. These are spatially isolated from the equivalent cells used to represent the open pit drainage (as illustrated in Figure 3). The underground mine plan has been updated to the current plan and terminates in 2028 (Figure 11).
2. The original MODFLOW-USG model represented active drainage for 2 years from the commencement of mining within an area. The underground mine plan for this

---

1 The AGE (2015) modelling of residual voids used an erroneous specific storage value of 1 m$^{-1}$ instead of the more appropriate 4.6E-6 m$^{-1}$
tranche of work initially did not include the 2-year limit on drainage per worked area and remained actively drained for the life of underground mining. This setup was subsequently changed, and the 2-year limit has been implemented into the current mine plan. This is what has been presented herein. It is however useful to note that this change does affect the predicted inflows to the underground mine, and these assumptions may need to be revisited.

3. TVM properties have been updated to be consistent with the new underground mine progression.

3.4.3 CLIMATIC UPDATES

1. Pit and spoil recharge zones have been updated to be consistent with the new void and spoil surface areas.
2. Pit and spoil evaporation/evapotranspiration zones have been updated to be consistent with the new void and spoil surface areas.
3. The method of evapotranspiration representation in the model has been adjusted. The former model implemented this only in upper layers, which prevented the process from occurring under depressed water level conditions within the void areas. The updated method permits evapotranspiration also to occur within the pit.

3.4.4 FLOODED PIT REPRESENTATION

1. Currently, flooded pits are represented with a constant head in calibration models, and with an initial fixed head at the start (only) of the prediction models. In the prediction models the pit lake stage is not forced. The constant heads applied are included in all void cells which imparts a small improvement at the start of the model run relative to the original model.
2. Within the original model flooded pits were held at constant water levels. This is not the case in the revised predictive models. There is freedom for the pit water levels to adjust to dynamic inflows and outflows.

3.4.5 OTHER REFINEMENTS

1. Model time discretisation has been improved to be consistent with mine plan dates and more closely follow calendar quarters. The model runs at an equivalent temporal resolution to the previous work.
2. The backfill scenario (Option 3) includes refinement to the model geometry (backfill) and its hydraulic properties.
3. An error in the MODFLOW-USG and MODFLOW-USG Beta code was identified. This bug affects the study as it is related to constant heads. We have corrected the error and tested to confirm appropriate simulation.

In all predictive simulations, the cumulative discrepancy is <0.01% at the end of a run; the discrepancy in any one stress period is <0.05%.
4 OPTION 1 ASSESSMENT – LANDFORM LEVEE

The Landform Levee scenario applies the final landform data for void elevation and dewatering level control where and when active open pit operations are in progress. In this option, the voids are allowed to fill or adjust existing water levels naturally. Pits A South, A North and B start at the existing water levels as applied in the AGE (2017a) model.

The relevant prediction models are:

- Run 017 [G1812_pred_GS115_017] – 45 year simulation.

4.1 VOID WATER LEVELS AND FLOWS

Figure 12 to Figure 19 present the results for each pit in turn, for 45 years from time zero at 1 September 2016 to 31 August 2061. Both open cut and underground mining are planned to finish in 2028 (mining year 12).

The simulated pit lake stage is shown in red, active dewatering in blue and general net flow to or from the void in green. The blue quantity is the water that reports to the MODFLOW drain cells and is assumed to be pumped out of the pit. The green quantity is the net flow of water into or out of the pit from all sources and discharge mechanisms (e.g. groundwater seepage, rainfall, evaporation). These rates are a net for the whole void. The magnitude and direction of flow through the void face can vary spatially within the model.

Flow polarity is defined as:

- Negative for losing conditions, with the void acting as a source of water.
- Positive for gaining conditions, with the void acting as a sink for water.

Conceptual icons are added to each figure to reinforce whether inflow or outflow is predicted.

4.2 UNDERGROUND FLOWS

Figure 20 presents the results for the entire underground mine until closure in 2028, for 45 years from time zero at 1 September 2016.

The flow represented by the dark blue line is raw model output and includes artificial high instantaneous inflows. This is an artefact of quarterly advances in mine plans and the associated storage release. A more useful measure is the smoothed inflow per quarter (light blue). The grey line is the flow entering the cells hosting underground workings. This shows inflow to the underground void after active dewatering ceases (that is, after the drain cells are deactivated). This does not represent the full inflow into the dewatered, or at least depressurised, surrounding aquifer material - only the flow to the cells directly hosting mined voids.
4.3 SCENARIO SUMMARY

Pits A and B (Figures 12, 13, 14) start from a flooded condition at 139-141 mAH. As there is no active dewatering (no drain cells), the blue line is constant at zero. The outflows from the pit (green line) are simulated to increase in the first year of underground mining and subsequently reduce. The outflows from the pit are stage driven and reduce as the stage of the pit drops. Steady pit levels of about 120, 105 and 80 mAH are simulated in pits A South, A North and B respectively at about 30 years after the end of mining (that is, mining year 42). These steady conditions do not represent cessation of outflow but rather a balance between groundwater outflow, evaporation and rainfall surcharge. The seasonality is evident in the groundwater outflows and becomes a more prominent feature as the stage and outflow approach a dynamic equilibrium.

Pits C and D (Figures 15, 16) do not rebound within the examined 45-year time period. Water entering the pits would seep to groundwater or would evaporate within the hydrological year. The elevation presented here is for the deeper areas of these pits.

Pits E, F and Y (Figures 17, 18, 19) maintain water within the pits. Pit E is simulated to maintain a stage of 105 mAH. Pits F and Y maintain a steady stage of 140 and 145 mAH, respectively. Both pits F and Y simulate a net gain from groundwater (and loss to evaporation), with spasmodic gains at Pit E in the early years until mining ceases. The predicted flow to the underground workings (Figure 20) is significant for this scenario. Mine inflows of approximately 10-20 ML/d are predicted during the life of the underground mine (to 2028). This water is primarily simulated to be released from local storage, but a portion is also derived from pit voids or the surrounding near-surface areas. As the underground mine develops, the dewatered, or at least depressurised, volume surrounding the mine expands and a greater proportion of pit water, or water which otherwise would have gone to the pits, is simulated to flow into that depleted volume. With the simulated high storages and moderate hydraulic conductivities, this process takes some time. The grey line (Figure 20) does not represent the full volume of flow into the depleted zone, only the underground void areas, but does show an inflow from 15 to 20 ML/d sustained for the duration of the simulation.

4.4 EQUILIBRIUM

As Pits B, C and D (Figures 14, 15, 16) showed no rebound, a longer simulation was run for an additional 200 years with annual time stepping (no seasonality). The results are shown in Figure 21 starting at year 45 from time zero.

All pit lake levels settle eventually at about 96 mAH. The rise in level towards equilibrium commences at different times for each pit, from years 45 to 55. This indicates the time required to satisfy the demand of the underground voids and overlying desaturated rocks.
5 OPTION 3 ASSESSMENT – BACKFILL TO PMF

The Backfill to PMF scenario applies the final landform data for void elevation and dewatering level control where and when active open pit operations are in progress, and a backfill elevation of 164 mAHDI or the pre-mining topographic surface (whichever is lower) for Pits A South, A North, B, C and D.

Option 3 precedes Option 2 because the equilibrium levels identified with this scenario are used to inform the target pit water levels for Option 2.

The relevant prediction models are:


5.1 VOID WATER LEVELS AND FLOWS

Figure 22 to Figure 25 present the results for each pair of pits, for 245 years from time zero at 1 September 2016. Both open cut and underground mining are planned to finish in 2028 (mining year 12).

The simulated pit lake stage is shown in red, active dewatering in blue and general net flow to or from the void in grey.

Flow polarity is defined as:

- Negative for losing conditions, with the void acting as a source of water.
- Positive for gaining conditions, with the void acting as a sink for water.

5.2 UNDERGROUND FLOWS

Figure 26 presents the results for the entire underground mine for 245 years from time zero at 1 September 2016.

The flow represented by the light blue line is the smoothed inflow. The grey line is the flow entering the cells hosting underground workings. This shows inflow to the underground void after active dewatering ceases (that is, after the drain cells are deactivated). This does not represent the full inflow into the dewatered, or at least depressurised, surrounding aquifer material - only the flow to the cells directly hosting mined voids.

5.3 SCENARIO SUMMARY

As the backfilled Pits A, B and C (Figures 22, 23) have no active drains, there can be no active dewatering (the blue line is constant at zero). The early parts of each red line (void water level) and each grey line (losses of water to rock) are equilibrations from initial conditions that are not readily definable. As observed with Option 1, the void water level does not approach its ultimate rest level until about 100 years after commencement of the simulation (that is, about 2116).
The partially backfilled Pit D (Figure 24) has a much reduced requirement for pumping from the sump.

Pits C and D (Figures 23, 25) both commence rebounding a decade earlier.

As Pits E, F and Y (Figures 24, 25) do not require any backfill, their responses are expected to be similar to those of Option 1. This is indeed the case for the more distant Pits E and Y, but Pit E requires slightly higher volumes of water to be pumped out in the early years. All rest levels are similar to those of Option 1.

Ultimate equilibrium water levels are listed in Table 8.

<table>
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<th>Pit</th>
<th>Rest Level</th>
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<tbody>
<tr>
<td>A (south)</td>
<td>125.5 mAHD</td>
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<tr>
<td>A (north)</td>
<td>99.5 mAHD</td>
</tr>
<tr>
<td>B</td>
<td>92.9 mAHD</td>
</tr>
<tr>
<td>C</td>
<td>111.5 mAHD</td>
</tr>
<tr>
<td>D</td>
<td>108.8 mAHD</td>
</tr>
<tr>
<td>E</td>
<td>105.5 mAHD</td>
</tr>
<tr>
<td>F</td>
<td>139.7 mAHD</td>
</tr>
<tr>
<td>Y</td>
<td>138.9 mAHD</td>
</tr>
</tbody>
</table>

The predicted flow to the underground workings (Figure 26) is not significantly different from that predicted for Option 1. Mine inflows of approximately 10-20 ML/d are predicted during the life of the underground mine (to 2028). The grey line (Figure 26) does not represent the full volume of flow into the depleted zone, only the underground void areas, but does show an inflow from 15 ML/d at the end of mining down to zero about 65 years after commencement of the simulation (that is, about 2081).

### 5.4 SENSITIVITY ANALYSIS

The properties of the underground mine have a significant effect on the pit lake water levels, the time to reach equilibrium, and whether a pit lake operates as a gaining or losing system.

Run 023 was designed to test the sensitivity of model predictions to underground void properties adopted in the model. The enhanced properties from underground mining were delayed by one quarter (without changing underground dewatering drainage) and the specific yield of the worked areas was reduced from 100% to 75% as an approximation of pillar volumes. A lower storage value should result in more rapid recovery of the water level in the void and in the groundwater system.

The effect of this change is a small reduction in estimated underground pumping requirements and a more rapid replenishment of the underground storage/earlier pit lake stage rebound. An example is presented in Figure 27 for Pit C.
6 OPTION 2 ASSESSMENT – FLOOD MITIGATION AND BENEFICIAL USES

The Flood Mitigation and Beneficial Uses scenario investigates the forcing of water levels in Pits B and C, proximal to Nogoa River, to take advantage of potential flood waters that could be captured in these pits.

Levees would be equipped with engineered breach structures to regulate ingress of water from the Nogoa River at or above specified flood frequencies. Other regulating structures would permit controlled transfer of water between adjoining pit lakes and pumping equipment would regulate discharges of stored pit lake waters to the receiving environment. The catchments of pits A & B and C & D would be redesigned to capture surface water flows in the pits where feasible and to balance regulated inflows, store until required and discharge to downstream end users; e.g. irrigators. Minimum pit lake water levels would be managed to minimise saline groundwater ingress whilst providing adequate freeboard to provide storage for economic quantities of irrigation water and contribute to reducing the consequences of downstream flooding.

6.1 DISCHARGE-STAGE CURVES

HEC Consulting, the surface water consultant, requires from the groundwater model a discharge-stage curve for each pit. The specifications were to find steady-state (equilibrium) inflow/outflow at each pit across a range of nominated void water levels:

- Pit B void RL 70, 90, 110, 130 and 150 m AHD
- Pit C void RL 60, 80, 100m, (120) and 135 m AHD

Five steady-state simulations were conducted, with progressively increasing paired water levels in Pits B and C.

The results are shown in Figure 28. In each case, the pits are expected to gain water until their natural rest levels are achieved, found from Option 3 modelling as 92.9 m AHD for Pit B and 111.5 m AHD for Pit C (Table 5). For higher forced water levels, the pits would lose water, at significant rates, to the underground groundwater system which would not have fully recovered within the investigated long-term period of 245 years.

Sequential steady-state simulation using progressively increasing constant heads is a common procedure requested by surface water specialists to enable generation of a stage-discharge curve which they use in combination with rain, runoff and evaporation to better simulate final void water level and salinity. While this approach is an approximation, the error in this case is not large because the natural rest levels on Figure 28 (obtained by long transient simulation) are in good agreement with the zero crossings of the blue and purple lines interpolated between pairs of steady-state simulations.
7 FAR-FIELD MODEL OUTPUTS

The following additional information has been extracted from the groundwater model:

- Simulated (versus observed) groundwater hydrographs during the 1994-2016 calibration period, combined with predictions to 2060, for 12 key bores nominated at Figure 9 – Options 1 and 3.

- Simulated water table contours for Option 1 at January 2017, December 2028, December 2061, and December 2260.

- Simulated water table contours for Option 3 at January 2017, December 2028, December 2061, and December 2260.

- Simulated water table drawdown contours for Option 3 at January 2017, December 2028, December 2061, and December 2260.

Drawdown has been determined as the difference between scenario heads and those produced by a null simulation [Run 024] which has no open cut or underground mining, no enhanced material properties, and base recharge and evapotranspiration not modified for spoil or void infill.

7.1 KEY HYDROGRAPHS

The 12 key sites are:

- EC01, EC14 [Figure D1]
- WSMB2S, WSMB2DS, WSMB3S, WSMB3D [Figure D2]
- Yongala, RB1, RB2, RB3, RB4, RB5 [Figures D3, D4]

Their hydrographs are presented as Figures D1-D4 in the Appendix. The charts include simulated hydraulic heads from the historical ‘calibration’ model (blue), observed data (circles), void base case scenario [Run 020] (orange) and backfilled PMF scenario [Run 021] (grey).

Two models were used to produce these plots:

2. The modified model for the prediction period.

As no re-calibration has been done on the original model, the comparison of observed and simulated data to 2016 is identical to what was achieved by AGE (2017a). Where differences occur, they are already represented in the calibration statistics (7.6 mRMS and 4.9 %RMS) and the scattergram reproduced as Figure 7.

A poor match is observed at bore EC01 (Figure D1). The observed rises in water level are due to flood events in 2008 and 2011, which are not in the AGE calibration model. This suggests the need to incorporate a flood mechanism in the Stage 3 model re-calibration, as well as resetting of initial head conditions.
Apart from the most distant Yongala bore, all bores are expected to experience a reduction in water level during the post-mining period. The strongest response, as expected, would occur at alluvial bore EC14 near the northern edge of Pit B.

There is no significant difference in final water levels between Option 1 [Landform Levee] and Option 3 [Backfill to PMF].

7.2 WATER TABLE MAPS

The water table maps for Option 1 and Option 3 are gathered in the Appendix for January 2017, December 2028, December 2061, and December 2260.

Figures A1-A4 and Figures B1-B4 show very similar patterns regardless of year. Groundwater flow is directed to the pits from the west and from the east, with significantly stronger hydraulic gradient from the east. Differences are evident only in close proximity to the residual voids.

An example of the water table pattern for Option 3, focused on Pits B-D is shown in Figure 29. The far-right panel (year 2260) shows the ultimate rest water levels in the residual voids.

7.3 DRAWDOWN MAPS

The water table drawdown maps for Option 3 are gathered in the Appendix for January 2017, December 2028, December 2061, and December 2260.

Figures C1-C4 show post-mining patterns that differ substantially from those at January 2017 due to infilling of historical pits and recovery of groundwater levels in the spoil.

An example of the water table drawdown pattern for Option 3, focused on Pits B-D is shown in Figure 30. The far-right panel (year 2260) shows smaller drawdowns at the residual voids due to rest water levels having been achieved. The drawdown in the adjacent groundwater system appears to have expanded with time to the west of Pit D.
8 CONCLUSION

The stated objectives of the groundwater component of the RVP are to predict the following:

A. individual residual void final water recovery levels;
B. individual residual void, backfill zone, spoil tip and underground mining area time/head-variant groundwater fluxes; and
C. time-variant water table drawdown and piezometric decline and recovery across the model domain and at selected locations.

This has been done for Preferred Options 1 and 3. For Preferred Option 2, discharge-stage curves for Pits B and C have been generated for use in surface water specialist modelling of final pit lake levels and salinities.

The main finding of the modelling is that the adjacent underground workings are expected to take many decades to be replenished with water, drawn substantially from the open water in proximal pit lakes. This has the effect of holding nearby pit lake water at low elevations for a long time, before the lakes are able to recover towards (but never reaching) pre-mining water levels.

There is not much difference between Option 1 and Option 3 in terms of underground mine inflows or ultimate equilibrium water levels in the pit lakes. Mine inflows of approximately 10-20 ML/day are predicted during the life of the underground mine (to 2028). Ultimate pit lake water levels are predicted to be:

<table>
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</tr>
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</table>

There is a clear pattern of high final water levels at the southern and northern pits, and lower levels proximal to the underground workings and the Nogoa River.

There are admitted weaknesses in the calibration performance of the model, although it satisfies national guideline performance statistics. For this reason, predicted rates and magnitudes should be viewed as indicative, subject to refinement. The primary finding of substantial consumption by the underground mine is very unlikely to change. The latest calibration was performed in 2016 without the benefit of information on pit lake water levels or dewatering rates. The model is to be re-calibrated early in the Phase 3 investigations.

For Option 2, where Pits B and C are forced to hold progressively higher water levels, the pits are expected to gain water until their natural rest levels are achieved (92.9 mAHD for Pit B; 111.5 mAHD for Pit C). For higher forced water levels, the pits would lose water, at significant rates, to the underground groundwater system which would not have fully recovered within the investigated long-term period of 245 years.
9 REFERENCES


Figure 1. General location plan [from AGE, 2017a]
Figure 2. Open-cut pit names
Figure 3. Perspective views of current and future mined volumes, with undisturbed rock hidden
Figure 4. Conceptual cross section through Nogoa River and Quaternary sediments (Figure 8, AGE, 2006)

Figure 5. Conceptual hydrogeological model of Ensham Mine (Figure 2.13, AGE, 2017a)
Figure 6. Former underground mine plan (pink), pits (brown), model mesh and rivers (Figure 3.1, AGE, 2017a)
Figure 7. Transient calibration to groundwater levels [AGE, 2017a]

Figure 8. Transient calibration to mine inflow [AGE, 2017a]
Figure 9. Groundwater monitoring network
Figure 10. Past open cut mining schedule
Figure 11. Future underground mining schedule [black areas already mined]
Figure 12. Option 1 predicted water levels and flows – Pit A South

Figure 13. Option 1 predicted water levels and flows – Pit A North
Figure 14. Option 1 predicted water levels and flows – Pit B

Figure 15. Option 1 predicted water levels and flows – Pit C
Figure 16. Option 1 predicted water levels and flows – Pit D

Figure 17. Option 1 predicted water levels and flows – Pit E
Figure 18. Option 1 predicted water levels and flows – Pit F

Figure 18. Option 1 predicted water levels and flows – Pit Y
Figure 20. Option 1 predicted underground mine inflow
Figure 21. Option 1 predicted long-term water levels and flows – Pits B, C, D
Figure 22. Option 3 predicted long-term water levels and flows – Pits A South and A North
Figure 23. Option 3 predicted long-term water levels and flows – Pits B and C
Figure 24. Option 3 predicted long-term water levels and flows – Pits D and E
Figure 25. Option 3 predicted long-term water levels and flows – Pits F and Y
Figure 26. Option 3 predicted underground mine inflow
Figure 27. Option 3 predicted long-term water levels and flows at Pit C: [a] base model; [b] modified TVM
Figure 28. Option 2 estimated discharge-stage curves for Pits B and C
Figure 29. Predicted water table elevations [mAHD] for Option 3 – Pits B to D
Figure 30. Predicted water table drawdowns [m] for Option 3 – Pits B to D
APPENDIX
Figure A1. Option 1 simulated water table 1/1/2017
Figure A2. Option 1 simulated water table 31/12/2028
Figure A3. Option 1 simulated water table 31/12/2061
Figure B2. Option 3 simulated water table 31/12/2028
Figure B3. Option 3 simulated water table 31/12/2061
Figure B4. Option 3 simulated water table 31/12/2260
Figure C1. Option 3 simulated drawdown of water table relative to no mining scenario 1/1/2017
Figure C2. Option 3 simulated drawdown of water table relative to no mining scenario 31/12/2028
Figure C3. Option 3 simulated drawdown of water table relative to no mining scenario 31/12/2061
Figure C4. Option 3 simulated drawdown of water table relative to no mining scenario 31/12/2260
Figure D1. Groundwater hydrographs at EC01 and EC14
Figure D2. Groundwater hydrographs at WSMB2S, WSMB2D, WSMB3S and WSMB3D
Figure D3. Groundwater hydrographs at Yongala, RB1 and RB2
Figure D4. Groundwater hydrographs at RB3, RB4 and RB5
Figure D5. Calibration residuals [AGE, 2017a]
Ensham Coal Mine
Residual Void Project
Stage 2 Void Water and Salt Balance Modelling

Prepared for: Ensham Resources Pty Limited

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</tbody>
</table>
# TABLE OF CONTENTS

**EXECUTIVE SUMMARY** 4

1.0 **INTRODUCTION** 5

2.0 **SUMMARY OF PREVIOUS FINAL VOID STUDIES** 7

3.0 **SCOPE OF CURRENT STUDY** 8

4.0 **CONCEPTUAL MODEL OF FLOODPLAIN VOIDS** 9

5.0 **FLOW REGIME OF NOGOA RIVER AT ENSHAM** 11

6.0 **WATER AND SALT BALANCE MODELLING** 13

6.1 **MODEL DESCRIPTION**

6.1.1 **MODELLED RAINFALL – RUNOFF AND CATCHMENTS** 13

6.1.2 **GROUNDWATER** 15

6.1.3 **EVAPORATION** 16

6.1.4 **SPILLS** 17

6.2 **SALT SOURCES** 17

6.3 **ASSUMPTIONS AND MODEL LIMITATIONS** 18

6.3 **MODELLED SCENARIOS** 19

6.4 **WATER AND SALT BALANCE MODEL SIMULATION RESULTS** 20

6.4.1 **SCENARIO 1 RESULTS** 20

6.4.2 **SCENARIO 2 RESULTS** 22

6.4.3 **SCENARIO 3 RESULTS** 24

6.4.4 **SCENARIO 4 RESULTS** 26

6.4.5 **SCENARIO 5 RESULTS** 28

6.4.6 **SCENARIO 6 RESULTS** 30

6.4.7 **SCENARIO 7 RESULTS** 31

7.0 **RECOMMENDATIONS FOR STAGE 3 STUDIES** 34

8.0 **REFERENCES** 35
<table>
<thead>
<tr>
<th>LIST OF FIGURES</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIGURE 1 ENSHAM COAL MINE – OPEN CUT PIT LAYOUT AND CATCHMENTS</td>
<td>6</td>
</tr>
<tr>
<td>FIGURE 2 CONCEPTUAL MODEL OF FLOODPLAIN VOID DURING FILLING PHASE</td>
<td>9</td>
</tr>
<tr>
<td>FIGURE 3 CONCEPTUAL MODEL OF FLOODPLAIN VOID DURING POST FILLING PHASE</td>
<td>10</td>
</tr>
<tr>
<td>FIGURE 4 RECORDED STREAMFLOW AT DUCK PONDS GAUGING STATION (ML/DAY)</td>
<td>11</td>
</tr>
<tr>
<td>FIGURE 5 FLOW DURATION CURVE OF DAILY FLOW RECORDED AT THE DUCK PONDS GAUGING STATION</td>
<td>12</td>
</tr>
<tr>
<td>FIGURE 6 FLOW DURATION CURVES FOR MODELLLED AND RECORDED FLOWS AT DUCK PONDS GAUGING STATION</td>
<td>15</td>
</tr>
<tr>
<td>FIGURE 7 PREDICTED GROUNDWATER FLOWS PIT B VOID (HYDRO-SIMULATIONS, MARCH 2018)</td>
<td>16</td>
</tr>
<tr>
<td>FIGURE 8 PREDICTED GROUNDWATER FLOWS PIT C VOID (HYDRO-SIMULATIONS, MARCH 2018)</td>
<td>20</td>
</tr>
<tr>
<td>FIGURE 9 SIMULATED TOTAL WATER VOLUME PIT A-B VOID – SCENARIO 1</td>
<td>21</td>
</tr>
<tr>
<td>FIGURE 10 SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 1</td>
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<tr>
<td>FIGURE 11 SIMULATED SALT MASS INVENTORY PIT A-B - SCENARIO 1</td>
<td>23</td>
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<td>FIGURE 12 SIMULATED TOTAL WATER VOLUME PIT A-B VOID – SCENARIO 2</td>
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<td>FIGURE 13 SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 2</td>
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<tr>
<td>FIGURE 14 COMPARATIVE SALT MASS INVENTORY PIT A-B VOID SCENARIOS 1 AND 2</td>
<td>26</td>
</tr>
<tr>
<td>FIGURE 15 SIMULATED TOTAL WATER VOLUME PIT A-B VOID – SCENARIO 3</td>
<td>27</td>
</tr>
<tr>
<td>FIGURE 16 SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 3</td>
<td>28</td>
</tr>
<tr>
<td>FIGURE 17 COMPARATIVE SPILLWAY INFLOWS – NOGOA RIVER TO PIT A-B VOID</td>
<td>29</td>
</tr>
<tr>
<td>FIGURE 18 SIMULATED TOTAL WATER VOLUME PIT A-B VOID – SCENARIO 4</td>
<td>30</td>
</tr>
<tr>
<td>FIGURE 19 SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 4</td>
<td>31</td>
</tr>
<tr>
<td>FIGURE 20 SIMULATED TOTAL WATER VOLUME PIT A-B VOID – SCENARIO 5</td>
<td>32</td>
</tr>
<tr>
<td>FIGURE 21 SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 5</td>
<td>33</td>
</tr>
<tr>
<td>FIGURE 22 SIMULATED CUMULATIVE WATER RELEASE FROM PIT A-B VOID TO NOGOA RIVER - SCENARIO 5</td>
<td>34</td>
</tr>
<tr>
<td>FIGURE 23 COMPARATIVE CONTROLLED RELEASES – LOW AND HIGH SPILLWAYS</td>
<td>35</td>
</tr>
<tr>
<td>FIGURE 24 SIMULATED TOTAL WATER VOLUME PIT A-B VOID – SCENARIO 7</td>
<td>36</td>
</tr>
<tr>
<td>FIGURE 25 SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 7</td>
<td>37</td>
</tr>
<tr>
<td>FIGURE 26 COMPARISON SIMULATED AVERAGE SALINITY PIT A-B VOID – SCENARIO 1 AND SCENARIO 7</td>
<td>38</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

A void water and salt balance model has been applied to the proposed floodplain voids at Ensham Mine under the proposed Flood Mitigation and Beneficial Use option being investigated by Ensham Resources Pty Ltd. The model has been used to investigate the likely water balance and salinity levels during initial filling and post-filling. The Flood Mitigation and Beneficial Use preferred option involves rapid filling of the floodplain voids using divertible flows in the Nogoa River and the subsequent management of void water quality via controlled diversions during periods of high flow in the Nogoa catchment.

Model simulations have been undertaken using current estimates and predictions of salinity in water inflows to the voids and groundwater flow rates at different stages and water levels. Results of seven different scenarios have been presented. Whilst both the Pit A-B Void and the Pit C-D voids were simulated, the results for the Pit A-B void only have been presented for simplicity. Results of modelling demonstrate that the overall behaviour of both sets of floodplain voids would be similar under similar assumptions and inputs.

Modelling confirms the advantages to void water quality of rapid filling through diversion of flow from the Nogoa River during periods of elevated flow. Modelling also demonstrates the significance of the currently predicated groundwater outflows from the void at elevated void water levels on salt concentration. The simulations indicate that with management of inflow and outflow, salt concentrations in the void should be able to be maintained at levels consistent with water quality guidelines for irrigation.

There would be advantages if structures were constructed which enabled more regular diversion of flows during moderate and higher flows in the Nogoa compared to limiting inflows to less frequent periods of higher flows only. Modelling has also demonstrated that the void storage could be used to enhance flow regulation in the Nogoa River.
1.0 INTRODUCTION

The Ensham Coal Mine is a combined open cut and underground coal mine complex located some 40 km east of Emerald in central Queensland. ECM is a joint venture comprising Bligh Coal Limited, Idemitsu Australia Resources Pty Ltd and LG International (Australia) Pty Ltd and is operated by Ensham Resources Pty Ltd (ERPL) a wholly owned subsidiary of Idemitsu Australia Resources Pty Limited.

ERPL has undertaken mining in seven open cut pits known as Pits A, B, C, D, E, F and Y which will remain as final voids at the completion of mining. Pits A and B form a semi-continuous mine area on the southern side of the Nogoa River. Pits C, D and E are located on the northern side of the Nogoa River and form another semi-continuous mine area. Pit F and Pits Y North, Y Central and Y South are located further north – refer Figure 1 The open cut mines are aligned roughly north-south with mining progressing in a down-dip (westerly) direction. Levees have been constructed to protect Pits A and B and Pits C and D from flooding in the Nogoa River.

As a condition of its Environmental Authority, ERPL is required to submit a “Residual Void Project” to the administering authority by 31 March 2019. Following on from earlier studies ERPL is proposing to rehabilitate the non-floodplain open pit voids so they become long term stable contained water bodies (i.e. void lakes). There are currently three options being evaluated for the floodplain voids (i.e. open pit voids A, B, C and D)

1. Landform Levee – with existing flood levees maintained and modified with waste rock backfill to be placed as a buttress between the levees and the final voids.
2. Flood Mitigation and Beneficial Use– with existing flood levees modified to incorporate engineered spillways allowing flow into and out of the voids.
3. Backfill to PMF – with voids on the Nogoa River floodplain backfilled up to predicted probable maximum flood (PMF) level.

As part of the supporting studies Hydro Engineering & Consulting Pty Ltd (HEC) was commissioned to update the void water and water quality modelling with an initial focus on Option 2 which would potentially have a significant interaction and performance dependency on flows in the Nogoa River.

The updated void water balance modelling was used to inform component studies of the Residual Void Project (RVP) is being undertaken in stages. The current stage 2 study aims to define the comparative environmental and cost implications of the three main final void options identified in the first stage of the study. A third stage of the study would further develop the preferred option or options to a detailed design level sufficient for final decision making.

This report summarises the water and salt balance modelling conducted to support the revised final void management plan. It builds on the modelling conducted by Gilbert & Associates Pty Ltd in 2012 which was updated in 2015, and includes changes made to the void final landforms and updated and refined flood modelling. The water and salt balance model relies on results of groundwater modelling conducted by Hydro-Simulations.

The objective of the final void hydrological study is to quantify the long-term water and salt balance of the final voids including likely filling rates, average salinity, likelihood, frequency and magnitude of spills to the surrounding environment, and likely nature and significance of interactions with the
surrounding groundwater system. The modelling has also investigated potential opportunities for using the floodplain voids as supplementary regulating storages for downstream water use.

Figure 1  Ensham Coal Mine – Open Cut Pit Layout and Catchments
2.0 SUMMARY OF PREVIOUS FINAL VOID STUDIES

The likely performance of the floodplain voids was previously investigated by Gilbert & Associates Pty Ltd (G&A). In 2012 G&A investigated the likely difference between retaining the flood levees compared to removing them. Results of that modelling indicated that, relative to the no levee case, the pits took much longer to reach an equilibrium level with the flood levees in place. Without flood levees, the floodplain void water levels were estimated to stabilise within 15 years. Conversely it was estimated that the void water levels would take some 50 years to stabilise with the levees retained. In the “no levees” case, void inflows were dominated by river inflows. This resulted in a two-fold effect. Firstly, the rate of void filling was faster (being dependent of the timing of the first few significant flood inflow events) and the equilibrium water levels were higher than without the levees. This in turn caused a number of spills from the voids to the river. Secondly, it caused the salt concentrations in voids to be much lower relative to the “with levees” scenario.

The modelling results demonstrated that without a levee, the water balance would be dominated by river inflows. River flows would maintain water surface elevations which were higher than those simulated in the with levee scenario and would result in lower void salinity. With a levee in place, the floodplain voids were predicted to take significantly longer to reach their equilibrium water surface elevation and the equilibrium level would be lower than that predicted without the levee.

An update to the 2012 study was undertaken by HEC in 2016 using results of revised and updated floodplain modelling conducted by KBR in 2013. Water balance modelling of the final voids confirmed that the water balance and the likely salt concentrations that would be experienced in the final voids with the levees removed, and with the consequent direct connection to floodplain flows in the Nogoa River, would be dominated by the large exchanges of water which would occur during significant flood events. Based on the available flow record at the Duck Ponds gauging station (GS 130219A) there were three flood events which would have resulted in significant inflows to the Pit B and Pit C voids in the period of recorded flows (May 1993 and September 2015). Assuming a similar frequency and magnitude of flooding occurs post-closure, it was predicted that the salt concentration in the floodplain voids (once they had reached a pseudo steady state) would be below 1,000 mg/L during spill events. Spills from these voids to the Nogoa River were expected to occur during and significant flood events and have relatively little effect on downstream salinity in the Nogoa River. Pit void water levels would tend to decline slowly between flood events.
3.0 SCOPE OF CURRENT STUDY

The previous studies had assessed the treatment of floodplain voids with the mine levees retained at their current height or with them removed entirely. The current study focuses on the potential to develop a residual void configuration which would leave the floodplain voids for longer term beneficial use. This would involve enabling inflows and outflows from the voids to occur in a controlled manner to maintain water quality in the voids consistent with downstream environmental values and such that water could be released consistent with downstream beneficial uses.

The hydrological and water quality behaviour of voids is a complex matter particularly in circumstances where there are significant interactions with surrounding surface and groundwater resources. Mixing processes in void lakes also complicate water quality processes.

The current study aims at providing an understanding of the likely overall performance of the voids and the effect key assumptions would have on void dynamics. The objective is to assess whether the proposed Flood Mitigation and Beneficial Use option is viable as a concept and whether it warrants further assessment in Stage 3 when additional information on void water quality from the Stage 3 geochemical investigations and groundwater model calibration have been completed.
4.0 CONCEPTUAL MODEL OF FLOODPLAIN VOIDS

Schematic representations of the conceptual model and the hydrological processes that were simulated in the model are shown during the initial void filling and longer term situations are depicted in Figure 2 and Figure 3 below.

![Conceptual Model of Floodplain Void during Filling Phase](image)

**Figure 2 Conceptual Model of Floodplain Void during Filling Phase**

During the filling phase water would accumulate in the pit void as a result of rainfall runoff processes over the void catchment. The void catchments comprise mostly rehabilitated overburden areas within and adjacent to the open pit and other rehabilitated areas adjacent to the pit void. The void high wall and pit floor area comprise exposed rock with relatively high runoff potential. Groundwater would flow into the voids as it recovered to its long term level. Evaporation would occur from the void lake surface. Evaporation rates would however be lower than occurs in “normal” shallow exposed surface lakes due to the shading effects of deep narrow voids. It is expected that potential evaporation rates would increase as the void water level rise and become increasingly exposed to surface climatic conditions.

The water quality characteristics of the void lake will depend on a number of inputs and processes that occur within void lakes. Salt is typically associated with most coal mining operations in the Bowen Basin. Elevated salt concentrations are often found in groundwater associated with Permian coal measures. Mining and placement of saline overburden within mined out pit areas provides another source of salt which is leached out of the overburden and is transported to the void. Naturally high infiltration rates associated with un-rehabilitated overburden stockpiles can be reduced...
by effective rehabilitation practices which promote evapotranspiration through surface covering and revegetation and decreasing the infiltration capacity of the rehabilitated surface.

Groundwater recovery is normally a slow process and filling of the void is normally controlled by surface water inflows. Rapid filling of the voids is typically a desirable outcome as it reduces the build-up of salt mass inventory in the void during the filling phase.

In arid areas mine voids can become permanent groundwater sinks where the evaporative potential of void lake results in the void lake surface being depressed below the surrounding groundwater system. If the void water is contained (i.e. there are no outflows to the surface environment) and with on-going net input of salt there will be an ongoing increase in salt concentrations in the void.

![Figure 3 Conceptual Model of Floodplain Void during Post Filling Phase](image)

If the void water level is maintained above the recovered surrounding groundwater level a hydraulic gradient will be established which results in an outflow to groundwater. In situations where the outflows are significant relative to other components in the water balance the outflows will form a control on the build-up of salt in the void.
5.0 FLOW REGIME OF NOGOA RIVER AT ENSHAM

Flows in the Nogoa River at Ensham are regulated by the Fairbairn Dam which is located some 45 km upstream of the Ensham Mine. The Fairbairn Dam was constructed to support irrigation for agriculture downstream of Emerald. The Dam has a capacity of some 1,300 gigalitres (1,300 GL). In addition to regulating flows the Dam would potentially reduce peak flood flows downstream.

The closest gauging station to the mine site is the Duck Ponds gauging station (GS 130219A). The Duck Ponds gauging station is operated by the Department of Natural Resources, Mines and Energy (DNRM) and was established in 1993. The streamflow record for the Duck Ponds gauging station was obtained from DNRM. The recorded daily flows at the Duck Ponds gauging station are shown on Figure 4.

![Figure 4 Recorded Streamflow at Duck Ponds Gauging Station (ML/day)](image)

The flow duration curve of recorded daily flows generated from the DNRM record is shown in Figure 5.
The median flow is about 100 ML/day. The Nogoa River has a catchment area of some 27,800 km² upstream of the Ensham Mine. The mean daily flow calculated from the available flow record at the Duck Ponds is some 1,820 ML/day which equates to an average yield of some 4% of average daily rainfall.
6.0 WATER AND SALT BALANCE MODELLING

The water and salt balance model used in the current study has been developed from the model used in the HEC (2016) study.

6.1 Model Description

The model has been developed using the GoldSim\(^1\) simulation package. GoldSim is a graphically based model simulation system which enables probabilistic simulation of hydrological systems. The model was set-up to simulate a 129 year period using the full period of available climatic data for the region. The model simulated the water and salt balance of each void on a daily basis using the following inflows and outflows on a daily time step. – refer Table 1 below.

**Table 1**  
Void Water Balance Components

<table>
<thead>
<tr>
<th>Void Inflows</th>
<th>Void Outflows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident rainfall on void</td>
<td>Evaporation from void water surface</td>
</tr>
<tr>
<td>Groundwater inflows from surrounding groundwater system</td>
<td>Seepage from void</td>
</tr>
<tr>
<td>Runoff from void catchment</td>
<td>Spill from the void. (Internal and spills to environment).</td>
</tr>
<tr>
<td>Infiltration and seepage flows through spoil overburden</td>
<td></td>
</tr>
<tr>
<td>Inflows during floods in the Nogoa River via spillway channels</td>
<td>Extraction for downstream beneficial use</td>
</tr>
<tr>
<td>Inflows from overflow from an adjacent void, (Internal spill)</td>
<td></td>
</tr>
</tbody>
</table>

The difference between inflows and outflows represents the change (increase or decrease) in water contained within the void.

The void water balance modelling has been undertaken assuming saturation of the backfilled material up to the void water surface with water being progressively taken up saturating the backfilled (overburden) portions of the void as it fills with water.

6.1.1 Modelled Rainfall – Runoff and Catchments

A 129-year rainfall and pan evaporation sequence for use in the model for the ECM area was obtained using the SILO Data Drill\(^2\). Rainfall was included in the model as direct rainfall into the void and as an input to the catchment runoff model.

Catchment runoff was simulated using the Australian Water Balance Model (AWBM) (Boughton, 2004). The AWBM is a nationally-recognised catchment-scale water balance model that estimates streamflow from rainfall and evaporation.

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\(^1\) https://www.goldsim.com/Web/Products/GoldSim/Overview/

\(^2\) The SILO Data Drill provides synthetic data sets for a specified point by interpolation between surrounding rainfall recording site data maintained by the Bureau of Meteorology.
Estimates of surface runoff and infiltration/percolation were generated for each catchment area configuration reporting to the void. The AWBM parameters used in the AWBM are summarised in Table 2 below. The model is uncalibrated and AWBM parameters were derived from reported values and experience.

### Table 2

**AWBM Parameters for Simulating Void Catchment Area Runoff**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overburden Dump catchment Areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>75 mm</td>
<td>C2</td>
<td>75 mm</td>
<td>C3</td>
<td>200 mm</td>
</tr>
<tr>
<td>A1</td>
<td>0.2</td>
<td>A2</td>
<td>0.4</td>
<td>A3</td>
<td>0.4</td>
</tr>
<tr>
<td>BFI</td>
<td>0.85</td>
<td>K_b</td>
<td>0.85</td>
<td>K_s</td>
<td>0.3</td>
</tr>
<tr>
<td>Natural Catchment Areas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>15 mm</td>
<td>C2</td>
<td>100 mm</td>
<td>C3</td>
<td>400 mm</td>
</tr>
<tr>
<td>A1</td>
<td>0.013</td>
<td>A2</td>
<td>0.444</td>
<td>A3</td>
<td>0.543</td>
</tr>
<tr>
<td>BFI</td>
<td>0.21</td>
<td>K_b</td>
<td>0.85</td>
<td>K_s</td>
<td>0</td>
</tr>
</tbody>
</table>

The layout and extent of modelled catchments are shown on Figure 1. The simulated areas of these catchments are summarised in Table 3 below.

### Table 3

**Void Catchment Areas**

<table>
<thead>
<tr>
<th>Pit Void</th>
<th>Catchment Type</th>
<th>Rehabilitated (ha)</th>
<th>Natural (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit A</td>
<td>Surface</td>
<td>103</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Sub-surface</td>
<td>164</td>
<td>32</td>
</tr>
<tr>
<td>Pit B</td>
<td>Surface</td>
<td>394</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sub-surface</td>
<td>795</td>
<td>0</td>
</tr>
<tr>
<td>Pit C</td>
<td>Surface</td>
<td>294</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sub-surface</td>
<td>449</td>
<td>0</td>
</tr>
<tr>
<td>Pit D</td>
<td>Surface</td>
<td>379</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sub-surface</td>
<td>520</td>
<td>0</td>
</tr>
</tbody>
</table>

A catchment model was also developed to simulate flows in the Nogoa River catchment upstream of the mine. This enabled the relatively short recorded flow record at the Duck Ponds gauging station to be expanded to cover the full 129 years of available climatic record. The catchment model was developed using the AWBM. The AWBM was not developed to simulate regulated flows or other effects of a large dam in a catchment. The model used a single climatic sequence and does not allow spatial variability in rainfall. It is recognised that the use of a more comprehensive model such as the IQQM model or e-Water Source model developed for the Nogoa catchment would provide more reliable estimates of likely flow at Ensham Mine site area. However the use of the lumped AWBM model in the current study provides a reasonable basis for evaluating the likely water and salinity balances to controlled inflows from the Nogoa River. Because inflow to the voids from the Nogoa River were limited to periods of relative high flow when flow is dominated by rainfall runoff processes downstream of the Dam rather than Dam releases the model was calibrated to reproduce the higher flow portion of the flow duration curve over the period of recorded flows. The AWBM parameters derived from the calibration process are summarised in Table 4.
Table 4
AWBM Parameters used in Simulating Nogoa River Catchment at Ensham

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nogoa River Catchment at Ensham Mine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C1</td>
<td>25 (mm)</td>
<td>C2</td>
<td>225 (mm)</td>
<td>C3</td>
<td>400 (mm)</td>
</tr>
<tr>
<td>A1</td>
<td>0.05</td>
<td>A2</td>
<td>0.53</td>
<td>A3</td>
<td>0.6</td>
</tr>
<tr>
<td>BFI</td>
<td>0.05</td>
<td>K₀</td>
<td>0.98</td>
<td>Kₛ</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The fit between modelled and monitored flow duration curve is shown in Figure 6 below. The fit is considered acceptable for the current purpose.

![Flow Duration Curves for modelled and Recorded Flows at Duck Ponds Gauging Station](image)

Figure 6 Flow Duration Curves for modelled and Recorded Flows at Duck Ponds Gauging Station

A pan factor of 0.83 was used to simulate evapotranspiration from the catchment surface.

6.1.2 Groundwater

Groundwater flow rates into the pits were provided by Hydro-Simulations. The groundwater model provided estimated water flow rates into each of the pit voids during the post-closure groundwater recovery phase. The groundwater model simulated both groundwater inflows and outflows from the voids. The simulated groundwater fluxes as a function of void water level for the Pit B and Pit C voids are shown on Figure 7 and Figure 8 below.
6.1.3 Evaporation

The void water balance model accounted for open water evaporation from the void water surface using historical pan evaporation data obtained from the Data Drill service for the site. A Pan Factor of 0.7 was used to convert pan evaporation rates to open water evaporation rates in the voids. The effect of evapotranspiration from the catchment surface is simulated in the AWBM rainfall runoff model.
6.1.4 Spills
The relationships between:

1. free water storage and water depth,
2. surface area and depth and
3. depth and pore volume in the overburden;

were derived from data provided by ERPL.

External spill was simulated when water volumes in the voids exceeded the capacity at which void water could be contained. The spill level was set to the low point on the perimeter of the void.

6.1.5 Controlled Inflows from Nogoa River
Two alternative concepts for managing inflows from the Nogoa River into the voids were investigated. The first involved simulating spillway channels excavated through the existing flood levee at levels which would enable inflows to the voids to occur during higher floods from the floodplain. The alternative concept involved constructing spillway channels at lower levels consistent with enabling flows into the voids when there were smaller flow events from the Nogoa River and its northern anabranch. These alternative concepts are referred to as the high level and low level spillway channels respectively.

Inflows from the Nogoa River were simulated using relationships linking flow in the Nogoa River and flows through the spillway channel which were developed using a hydraulic model of the Nogoa system. Details of the hydraulic modelling and the derived rating relationships are outlined in HEC, 2018.

6.2 Salt Sources
The salt sources were assumed to supply salt to the void at a constant concentration representative of each source. The concentrations adopted in the modelling are presented in Table 5. Surface runoff concentrations were based on geochemical testing of the overburden3. Seepage salinity was based on the geochemical testing and sampling from shallow bores in the overburden dump. Regional groundwater concentrations were based on observed concentrations in bores intercepting deep groundwater. River salinity was based on recorded concentrations at the Duck Ponds Gauging Station.

Final void salinity has been simulated under simplifying assumptions of conservation of mass and fully-mixed behaviour. Losses of salt from the voids were simulated in seepage outflow and spills. The concentration of salt in these void outflows was assumed to be equal to the fully mixed salinity of the void at the time the outflows were simulated.

---

3 URS Australia Pty Ltd, 2006. *Geochemical Characterisation and Assessment of Overburden and Potential Coal Reject Material at the Ensham Central Project.* Prepared on behalf of Enham Resources Pty Ltd.
Table 5
Simulated Salt Sources and Concentrations

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Salinity – Total Dissolved Solids, (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface runoff from rehabilitated overburden areas</td>
<td>268</td>
</tr>
<tr>
<td>Seepage flows percolating through backfilled spoil</td>
<td>3,250</td>
</tr>
<tr>
<td>Regional groundwater</td>
<td>1,300</td>
</tr>
<tr>
<td>Alluvium in Proximity of Pit B</td>
<td>9,750</td>
</tr>
<tr>
<td>Flood inflows from Nogoa River</td>
<td>230</td>
</tr>
</tbody>
</table>

Compared to the assumptions made during the 2016 study (HEC 2016) the assumed salinity of seepage flows percolating through the backfilled spoil has been increased from 650 mg/L to 3,250 mg/L to reflect verbal advice from the geochemistry consultants that the 2016 value may be significantly underestimated. The salinity value used to simulate the salt imported with river inflow has also been changed consistent with the average electrical conductivity at the Duck Ponds gauging station. Electrical conductivity has been converted to Total Dissolved Solids using a factor of 0.65.

6.3 Assumptions and Model Limitations

Key assumptions:

1. Climate – future climate will be similar to the past climate – over the last 129 years.

2. Evaporation from void surface will be equivalent to pan evaporation multiplied by a pan factor of 0.7.

3. Salt fluxes to and from the void would occur at the constant salt concentrations as outline in Table 4 above and that these concentrations would not change into the future.

4. Salt concentrations are calculated assuming the void waters are completely mixed.

5. The flow regime of the Nogoa River and the operating procedures of the Fairbairn Dam would not change in the future.

6. There would be no significant additional flow regulating storages constructed in the Nogoa catchment upstream of the mine.

7. The current predicted groundwater inflows and outflows from the floodplain voids are reliable estimates and they would be invariant over time.

8. There would be no significant catchment land use changes into the future (that could affect rainfall runoff).

---

4 Total dissolved solids is a measure of the concentration of dissolved ionic species or salinity of water.
6.3 Modelled Scenarios

Model simulated scenarios simulated for floodplain voids are summarised in Table 6.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hydraulic Connection to Nogoa River</th>
<th>Groundwater – Void Fluxes</th>
<th>Salinity</th>
<th>Beneficial Releases</th>
<th>Purpose of Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Voids connected to Nogoa River channel via low invert level spillway channels</td>
<td>Stage 2 Hydro-Simulations base-case</td>
<td>Current base-case</td>
<td>No</td>
<td>Base-case</td>
</tr>
<tr>
<td>2</td>
<td>Voids connected to Nogoa River channel via low invert level spillway channels</td>
<td>10% of Stage 2 Hydro-Simulations base-case</td>
<td>Current base-case</td>
<td>No</td>
<td>To demonstrate importance of current groundwater flow predictions on void water and salt dynamics</td>
</tr>
<tr>
<td>3</td>
<td>Voids connected to Nogoa River channel via high invert level spillway channels</td>
<td>Stage 2 Hydro-Simulations base-case</td>
<td>Current base-case</td>
<td>No</td>
<td>To demonstrate the implications of limiting flow diversions from Nogoa River to relatively high “flood” during flow conditions</td>
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<tr>
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<td>Current base-case</td>
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<td>To demonstrate the effect of lower than predicted groundwater flows on the high level (limited access) spillway case</td>
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<tr>
<td>5</td>
<td>Voids connected to Nogoa River channel via low invert level spillway channels</td>
<td>Stage 2 Hydro-Simulations base-case</td>
<td>Current base-case</td>
<td>5 ML/day from Pit A-B Void when greater than 75% of capacity</td>
<td>To demonstrate potential and consequences of controlled releases for beneficial use on base-case</td>
</tr>
<tr>
<td>6</td>
<td>Voids connected to Nogoa River channel via high invert level spillway channels</td>
<td>10% of Stage 2 Hydro-Simulations base-case</td>
<td>Current base-case</td>
<td>5 ML/day from Pit A-B Void when greater than 75% of capacity</td>
<td>To demonstrate implications of the high level Nogoa River connection on potential for beneficial release</td>
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<tr>
<td>7</td>
<td>No Spillways</td>
<td>Stage 2 Hydro-Simulations base-case</td>
<td>Current base-case</td>
<td>No</td>
<td>To demonstrate implications of permanent isolation from the Nogoa River</td>
</tr>
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</table>
6.4 Water and Salt Balance Model Simulation Results

Model simulations were conducted for all voids. It was found that Pit A-B and CD voids behaved similarly under equivalent situations and for the purposes of demonstrating the overall performance of the floodplain voids it is sufficient to present results for the Pit A-B void only.

6.4.1 Scenario 1 Results

Scenario 1 Pit A-B Void represents the current base-case assuming potential connection to the Nogoa River at times when flows exceed 1,000 m³/s (86,400 ML/day). The simulated total water volume and average salinity levels during the filling and post filling phases are shown in Figure 9 and Figure 10 respectively.

![Figure 9 Simulated Total Water Volume Pit A-B Void– Scenario 1](image-url)
With relatively regular inflows from the Nogoa River the void simulation resulted in the void filling within the first 20 years - following commissioning of the spillway channels. The actual time it would take to fill the voids will obviously depend on climate and flow conditions experienced during the void filling period. The void then remained at near capacity over the remaining 110 years of the simulation due to the regular ‘top-ups’ provided by Nogoa River inflow.

The simulated average salinity (TDS) in the void fluctuated during the early stages of void filling when simulated water volumes were small and evapo-concentration effects resulted in relatively elevated salinity. After filling the simulated salinity concentrations were relatively steady at between 500 and 600 mg/L, which is about twice the assumed salinity of the influent Nogoa River water. The simulated mass of salt in the void reached a relatively steady level in about 50 years confirming the simulated mass flux of salt mobilised in runoff inflows, water infiltrating through the overburden transporting salt to the void and salt in inflows from the Nogoa River were being balanced by simulated salt outflows via seepage to the groundwater and void spills – refer Figure 11.

Figure 10 Simulated Average Salinity Pit A-B Void – Scenario 1
6.4.2 Scenario 2 Results

Scenario 2 shows, by comparison with Scenario 1, the relative effect of the high predicted groundwater outflows from the void once void water level rises above the expected equilibrium groundwater level. The groundwater fluxes both into the void during low void water levels and out of the void at high void water levels have been reduced to 10% of their currently predicted rates. The resulting simulated void water levels and salinity levels are shown on Figure 12 and Figure 13 respectively.
Figure 12 Simulated Total Water Volume Pit A-B Void – Scenario 2

Figure 13 Simulated Average Salinity Pit A-B Void – Scenario 2
Relative to the base-case the simulated lower groundwater outflows in Scenario 2 result in the void being full more often and experiencing smaller drawdown during dry periods. Simulated salt concentrations were however significantly higher and increased over the simulation period. This reflects the effect of less salt being removed from the void in the reduced groundwater outflows. This can also be seen in the simulated total salt mass inventory over time which was correspondingly higher and are increased throughout the 130-year simulation – refer Figure 14 below.

![Figure 14 Comparative Salt Mass Inventory Pit A-B Void Scenarios 1 and 2](image)

6.4.3 Scenario 3 Results

Scenario 3 enables the relative effects of high level connection channels/spillways linking the Nogoa River floodplain to the floodplain voids. This is a contrasting approach which would limit inflows to periods of significant flood events in the Nogoa River. Potential inflows have been simulated to occur when flow in the Nogoa River exceeds 100 m³/s (8,640 ML/day). The simulated total water volume and average salinity levels during the filling and post filling phases are shown in Figure 15 and Figure 16 respectively.
Relative to the simulated base-case, the effects of the reduced frequency of River inflows via the higher level spillway channel connection can be seen as greater fluctuation in void water volumes/water level and extended periods of relatively low void water volume. Void salinity was also affected however the high predicted groundwater outflows resulted in void salinity being maintained.
at relatively similar levels to the base-case when void levels were high. The relative performance of the “high” and “low” spillways is shown in Figure 17. The low-level spillway resulted in higher inflow spikes and longer periods of no inflows. In comparison the low spillways enabled the void to be topped up more regularly.

![Figure 17 Comparative Spillway Inflows – Nogoa River to Pit A-B Void](image)

**Figure 17 Comparative Spillway Inflows – Nogoa River to Pit A-B Void**

### 6.4.4 Scenario 4 Results

Scenario 4 enables the relative effects of groundwater inflow and groundwater outflow fluxes on the void performance assuming high level channels/spillways linking the Nogoa River floodplain to the floodplain voids. The simulated total water volume and average salinity levels during the filling and post filling phases are shown in Figure 18 and Figure 19 respectively.
As expected the effect of lower groundwater outflow flux was higher simulated total void volumes (i.e. the void volumes did not fall to as lower levels as they did when simulated under Scenario 3 assumptions) – compare Figure 18 and Figure 15. The reduced groundwater outflow fluxes resulted in lower salt removal rates and higher salt concentrations in the void - compare Figure 19 and Figure 16.
6.4.5 Scenario 5 Results

Scenario 5 simulates the effects of controlled releases to the Nogoa River on void behaviour. Releases have been simulated at a constant rate of 5 ML/day. For the purposes of the current study they have been simulated on days when the water volume stored in Pit A-B void was greater than 80% of its capacity. The low-level spillway configuration and base-case groundwater fluxes have been adopted for this scenario i.e. it is the same as Scenario 1 except that controlled releases have also been simulated.

The simulated total water volume and average salinity levels during the filling and post filling phases are shown in Figure 20 and Figure 21 respectively.

Figure 20 Simulated Total Water Volume Pit A-B Void– Scenario 5
The effect of the simulated releases can be seen as a minor increase in frequency of simulated drawdown of void volume – compare Figure 9 and Figure 20. Void salinity was largely unaffected by releases. The predicted void salinity levels are consistent with guideline (ANZECC, 2000) recommendations for crop irrigation which range from 0.95 to 1.9 dS/cm (equivalent to 600 mg/L to 1,200 mg/L) for moderately sensitive crops.

The simulated releases occurred regularly after the void has reached its pseudo steady state. The simulated void water levels were maintained by regular diversions from the Nogoa River during periods of moderate and higher flow – refer Figure 22.
6.4.6 Scenario 6 Results

Scenario 6 simulates the limitations on controlled release associated with high level spillways (i.e. less frequent inflows from the Nogoa River). Releases have been simulated at the same constant rate of 5 ML/day and when void volumes are greater than 80% void capacity (as adopted in Scenario 5).

The simulated cumulative releases are shown in Figure 23 below. The reduced frequency of river derived inflows resulted in sustained periods when releases were not made because the void volumes were ‘low’.

Figure 22 Simulated Cumulative Water Release from Pit A-B Void to Nogoa River - Scenario 5
6.4.7 Scenario 7 Results

Scenario 7 simulates the case where the Pit A-B was isolated from inflows from the Nogoa. In effect this simulates the void behaviour if the mine pit levees were retained at a high level, i.e. such that inflows from the Nogoa River did not occur. The simulation was undertaken assuming current predicted groundwater fluxes between the surrounding groundwater and the void occurred.

The simulated total water volume and average salinity levels during the simulation are shown in Figure 24 and Figure 25 respectively.
As expected the void water level/volume remained below spill level at about 15% of void capacity. Simulated average void salinity increased rapidly during the filling phase and continued to slowly increased during the remainder of the simulation reaching some 3,000 mg/L at the end of the simulation. This is in stark contrast to the behaviour of the void with managed inflows from the Nogra River –refer Figure 26.
Figure 26 Comparison Simulated Average Salinity Pit A-B Void – Scenario 1 and Scenario 7
7.0 RECOMMENDATIONS FOR STAGE 3 STUDIES

The current study has assessed the likely performance characteristics (water and salt balance) of the floodplain voids if controlled flow from the Nogoa River was allowed to flow into the floodplain void(s) via constructed spillway channels.

The following recommendations are made for the Stage 3 studies:

- Refinement of the spillway design and simulation of spillway hydraulics using the Nogoa River flood model over a wider range of operating conditions to support Stage 3 water balance modelling and the civil design of these structures.

- Generation of a long flow sequence for the Nogoa River at Ensham using a comprehensive and well calibrated model of the Nogoa River system (e.g. IQQM or e-Water Source model developed for the Fitzroy Basin catchment). Ideally this would be undertaken in collaboration with DNRME with the Ensham floodplain voids integrated into the model to provide an integrated assessed of the potential for their longer term beneficial use as flow regulating storages.

- Simulation of the salt/water quality sources affecting void performance utilising results from geochemistry testing currently in progress. This would necessitate development of the water balance models into a form which enabled more realistic simulation of solute transport processes within the overburden and flow and mixing processes within the void lakes.

- Simulation of the non-floodplain void dynamics using the updated groundwater modelling and geochemistry results produced during the Stage 3 studies.
8.0 REFERENCES


Hydro Engineering & Consulting Pty Ltd, “Ensham Coal Mine Residual Void Project Stage 2 Catchment Hydrology and Flood Study”, April 2018


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Stage 2 Technical Report
Geotechnical Design
Ensham Resources Pty Ltd

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<td>M. Black</td>
<td>24/04/2018</td>
</tr>
<tr>
<td>Reviewed by:</td>
<td>D.L. Knott</td>
<td>24/04/2018</td>
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<td>24/04/2018</td>
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## TABLE OF CONTENTS

1 INTRODUCTION .................................................................................1
1.1 BACKGROUND ...........................................................................1
1.2 PURPOSE ..................................................................................1

2 PREFERRED REHABILITATION OPTIONS .......................3
2.1 OPTION 1 – LANDFORM LEVEE ..............................................3
2.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE .................................................4
2.3 OPTION 3 – BACKFILL TO PROBABLE MAXIMUM FLOOD LEVEL (PMF) ...................................5

3 GEOTECHNICAL DATA REVIEW SUMMARY ...............6
3.1 REVIEW OF INFORMATION PROVIDED ..................................6
3.2 PRELIMINARY SITE MATERIALS ASSESSMENT ................11

4 LIMITATIONS ............................................................................13
1 INTRODUCTION

1.1 BACKGROUND

Ensham Mine, an open cut and underground bord and pillar coal mine located approximately 35km east of Emerald, is operated by Ensham Resources Pty Ltd (Ensham), a wholly owned subsidiary of Idemitsu Australia Resources Pty Ltd (Idemitsu), on behalf of the Ensham Mine joint venture (JV) partners. The JV partners and holders of the Environmental Authority are Bligh Coal Limited, Idemitsu and Bowen Investment (Australia) Pty Ltd. EA EPML00732813, dated 26 May 2017, is the relevant environmental authority under which Ensham operates the mine.

Condition G16 of the EA states that a Residual Void Project (RVP) must be completed and submitted to the administering authority for review and comment by 31 March 2019. The minimum content of the RVP is specified within Condition G16 of the EA as:

- Terms of Reference;
- Residual Void Study;
- Progress Reports; and
- Rehabilitation success criteria for voids.

In compliance with Condition G19 of the EA, “the Residual Void Project must be carried out in accordance with the approved Terms of Reference”. A Terms of Reference (ToR) (Ensham Resources, 2017a) was approved by Queensland’s Department of Environment and Science (DES, formerly Department of Environment and Heritage Protection, DEHP) on 21 July 2017.

Condition G20 of the EA identifies the minimum content of the RVP identified in Condition G16.

In accordance with the ToR, the project has been divided into five stages:

- Stage 1 - Project Definition and Options Identification;
- Stage 2 - Preferred Options Technical Studies;
- Stage 3 - Preferred Options Detailed Design;
- Stage 4 - Most Preferred Option Identification; and
- Stage 5 - Regulatory Documentation.

Stage 1 - Project Definition and Options Identification for the RVP has been completed. The Stage 1 Options Assessment report has been prepared in draft and issued to DES, Department of Natural Resources, Mines and Energy (DNRME, formerly DNRM) and the Community Reference Group (CRG) for comment. Following receipt of comments, the report has been independently peer reviewed and revised to address peer review comments. The final report has been submitted to DES for review and comment as per the requirements of the ToR.

1.2 PURPOSE

The Options Analysis workshop of Stage 1 of the RVP identified two options:

- Option 1: Landform Levee;
- Option 2: Flood Mitigation and Beneficial Use.

DES required a third option to be included in the study, being:

- Option 3: Backfill to PMF.
All three options have been advanced to Stage 2 of the RVP and are referred to as the ‘Preferred Options’.

Stage 2 is now underway. The purpose of Stage 2 is to identify the Environmental Values (EVs) in the immediate and surrounding area of Ensham Mine and determine through appropriate environmental assessment which EVs are likely to be affected by each Preferred Option. The level of detail in each environmental assessment must be consistent with Appendix B of the Terms of Reference (where appropriate) and:

— provide a description of the EV that is likely to be affected by a Preferred Option;
— detail any emissions or releases likely to be generated by a Preferred Option relative to the EV;
— describe the risk and likely magnitude of impacts of a Preferred Option on the EV; and
— describe the management practices to be implemented to prevent or minimise the potential impacts for a Preferred Option, which will be detailed in Stage 3: Preferred Options Detail Design;

The ToR specifies that Stage 2 of the RVP (Preferred Options Technical Studies) “must commence with an environmental values (EVs) workshop” and that “where it is determined that an EV is not likely to be affected by a Preferred Option, the reasons for this must be discussed and explained in the EVs workshop report”. Ensham has prepared and submitted the Stage 2 Environmental Values Workshop Report to DES, DNRME and the CRG for review and comment.
Three rehabilitation options have been identified for assessment as part of the Stage 1 rehabilitation strategy for the Ensham Mine, which are described below.

### 2.1 OPTION 1 – LANDFORM LEVEE

The existing northern and southern levees are currently engineered structures and require annual inspection and maintenance. This option aims to convert these maintained structures effectively into permanent landforms by augmenting the levees and the pits they protect. In limited circumstances, the levee is too close to the pit for adequate backfill to be placed and in those circumstances, partial backfilling of the pit would be required to support the levee backfill. The conceptual arrangement of the Landform Levee option is depicted in Figure 2.1 below.
Outside of the areas protected by the levees, the voids would be rehabilitated to various slopes to achieve stable landforms.

### 2.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE

The existing northern and southern levees would be retained in their current configuration, but would incorporate engineered structures to permit off-take of flood waters to specified ARI flood events feeding water from identified watercourses to residual voids within the floodplain. Whilst pits would be rehabilitated to achieve stable landforms, the shape of the residual voids would be optimised to store water, minimise evaporative losses and maximise re-usable water storage capacity. A minimum water level would be maintained to offset groundwater head and minimise saline groundwater inflow. Figure 2.2 indicates a conceptual arrangement of this option.
It is probable that the system will be operated as two separate storage units, with A-pit and B-pit being the southern storage unit, and C-pit and D-pit the northern storage unit. Pits within a storage unit will be hydraulically linked in some way. E-pit is partially backfilled already and would not be included in the scheme, whilst F-pit and the Yongala pits are shallow and not considered likely to be able to contribute significantly to beneficial water qualities in C/D-pits. However, they will be required to be rehabilitated to stable landforms.

Water stored in pits A, B, C and D may be used for beneficial purposes such as to supply downstream irrigation demands or in-pit uses such as ecosystem functions and recreation. Discharge would be managed to ensure that the water level in each pit does not fall below the critical level required to offset groundwater inflow, spoil seepage and evaporative losses expected until the next design re-inundation event.

2.3 OPTION 3 – BACKFILL TO PROBABLE MAXIMUM FLOOD LEVEL (PMF)

Those pits occupying the pre-mining flood plain of the Nogoa River would be backfilled to original (pre-mining) ground levels. Parts of those pits straddling the boundary of the floodplain, as defined by the PMF event extent, would also be backfilled, whilst parts lying outside of that boundary would remain unfilled. The existing levees and spoil dumps within the PMF footprint will be removed as well, to restore the pre-mining landscape.

Outside of the flood plain, the residual voids would be rehabilitated to various slopes to achieve stable landforms.

![Option 3 - Conceptual Cross-Section](image)
3 GEOTECHNICAL DATA REVIEW SUMMARY

3.1 REVIEW OF INFORMATION PROVIDED

The results of the geotechnical review of information made available at the time of compiling this report are summarised below in the following tables.

Table 3.1 Review Data Summary - Levees

<table>
<thead>
<tr>
<th>Flood Levee Reports</th>
<th>Consultant</th>
<th>Date</th>
<th>Comments</th>
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<tr>
<td>Ensham Mine Flood Levee Upgrade - 47793</td>
<td>Douglas Partners</td>
<td>2009</td>
<td>Upgrading of the existing levees following flooding in 2008. Report provides information on:</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>— General inspection information on the location, levee dimensions, appearance and condition</td>
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<td></td>
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<td>— Information regarding backfilling of the levees following flood breaches</td>
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<td>— Preliminary comments regarding seepage through the B-Pit levee</td>
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<td></td>
<td></td>
<td>— Information regarding structures and bedding orientations in B Pit and C Pit</td>
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<td></td>
<td></td>
<td>— Stability analysis of B Pit levee</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>— Recommendations for design and construction of B and C pit levee upgrades</td>
</tr>
<tr>
<td>Proposed C Pit Levee and Upgrade of B Pit Levee Design</td>
<td>Kellogg Brown and Root Pty Ltd</td>
<td>2009</td>
<td>Preliminary design report for the levee approvals process. Levees to be upgraded to provide flood immunity from 100yr ARI to 1000yr ARI</td>
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<tr>
<td>Report BEE603.009-C-REP-004 Rev A</td>
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<td>— Provides background on relevant flood studies and the design and construction of the existing flood levees</td>
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<td>— New levee design details and design details for B Pit and D Pit levee upgrades</td>
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<td></td>
<td>— Material specifications for levee materials</td>
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<td>— No design drawings included in file</td>
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<td>Summary Report on Geotechnical Assessment Reports for</td>
<td>Douglas Partners</td>
<td>2013</td>
<td>Revision and summary of previous reports carried for the Ensham Mine levees</td>
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<td>Levees</td>
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<td>— Provides general information regard location, purpose and dimensions of the levees</td>
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<td>— Review of reports, construction and upgrade works which have been undertaken for the levees since 2008</td>
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<td>— Some of these reports are not currently available for review</td>
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<td>MINE PIT REPORTS</td>
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<td>DATE</td>
<td>COMMENTS</td>
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<td>Engineering Geology of Ensham Central Area</td>
<td>Seedsman Geotechnics</td>
<td>2003</td>
<td>Provides a discussion of the engineering geology of the Ensham Central area coal resource based on borehole data from the 2002/2003 exploration program. No borehole logs included</td>
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<tr>
<td>Engineering Geology of Ensham Central Area - Subsidence</td>
<td>Seedsman Geotechnics</td>
<td>2003</td>
<td>Detailed assessment subsidence issues and recommendations for pillar and panel design for underground mining</td>
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<td>— Rock strength data, RMR, Q, CMRR</td>
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<td>— Joint and structure orientations</td>
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<td>— Some borehole logs</td>
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<td>— UCS lab test reports</td>
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<td>Site Visit</td>
<td>PSM</td>
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<td>Assessment of several geotechnical issues at the mine</td>
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<td>— Recommendations for excavation of overburden material for Yongala 9S Bridge</td>
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<td>— Recommendations to address mud in old pit north of Ramp 9 in Yongala pit</td>
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<td>— Assessment of rockfall risks from highwalls</td>
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<td>— Photos and site plan of assessed areas</td>
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| Dragline Mining - Yongala                            | PSM        | 2004 | Recommendations for design guidelines and design parameters for recommencement of dragline mining in the Yongala Pit and F Pit  
|                                                      |            |      | — Discussion of soil and rock conditions expected – refinement of the geotechnical model for the Yongala Pit  
|                                                      |            |      | — Discussion of dragline mining methods  
|                                                      |            |      | — Summary of geotechnical conditions in each of the mining areas  
|                                                      |            |      | — Recommended design parameters for highwalls, spoil dumps and spoil bridges  
|                                                      |            |      | — Mine strip plans, weathering profile plans, Seam floor contours, topographic contours, lox line, model of rock conditions, Yongala pit design area plan  
| Geotechnical Review – Central Project Part 1 and 2   | PSM        | 2005 | Geotechnical review of planned mining operations under the Nogoa River floodplain for preparation of final endwall and highwall design for the section adjacent to the Nogoa River  
|                                                      |            |      | — Discussion of site description, exiting mining and proposed mine extension  
|                                                      |            |      | — Geotechnical model developed for analysis of highwall stability, discussion of each geotechnical unit including strength characteristics  
|                                                      |            |      | — Discussion of groundwater conditions  
|                                                      |            |      | — Stability analysis  
|                                                      |            |      | — Recommendations for long and short term highwall design stability and endwall design  
|                                                      |            |      | — Site photos, site and mine plans, stability calcs  
| Ensham Central Project – EIS - Rehabilitation        | Hansen     | 2006 | Discussion of the land disturbance types associated with the Ensham Central Project and proposed rehabilitation and decommissioning strategies  
|                                                      |            |      | — Concept mine decommissioning plan  
|                                                      |            |      | — Floodplain rehab schematic  
|                                                      |            |      | — Concept subsided area drainage plan  
|                                                      |            |      | — Photo of flood plain mining at HVO  
| Geotechnical Review of the Ramp 3 Trial Mine Layout  | Seedsman Geotechnics | 2007 | Geotechnical review of the underground trial mine access from the Ramp 3 highwall  
|                                                      |            |      | — Geology of the underground mining area  
|                                                      |            |      | — Rock strength and structure orientations  
|                                                      |            |      | — Pillar and panel design review  
|                                                      |            |      | — Subsidence constraints  
|                                                      |            |      | — No borehole logs included  

<table>
<thead>
<tr>
<th>MINE PIT REPORTS</th>
<th>CONSULTANT</th>
<th>DATE</th>
<th>COMMENTS</th>
</tr>
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</table>
| Instability in F Pit and Highwall Design | PSM | 2007 | Advice for mitigation low wall failures in F pit and ongoing high wall design for F Pit  
- Background information on low wall failures in F Pit  
- Structure orientation information, seam floor dips  
- Test pit excavation results for low wall failures  
- Discussion on causes of failure and recommended remedial measures  
- High wall design advice for F Pit |
| Highwall Risk Assessment | PSM | 2007 | Risk assessment of highwalls in A, B, C, D Pits and Yongala Pit  
- Review of fault data  
- Identification of low to high risk areas in each of the pits |
| Highwall Mining in the Nogoa Floodplain | PSM | 2007 | Geotechnical recommendations for highwall mining in the Nogoa Floodplain between Ramp 26 (B Pit) and Ramp 3 (C Pit)  
- Information regarding trench to be mined  
- Discussion of geotechnical units in the area to be mined  
- Recommendations for design of highwalls within the geotechnical units to be exposed  
- Figures showing location of the trench and recommended trench design drawings  
- Site photographs |
| Highwall Risk Assessment - October | PSM | 2007 | Further risk assessment of highwalls in A, B, C, and F Pits  
- Review of fault data  
- Identification of low to high risk areas in each of the pits  
- Figures showing location of inspected highwalls  
- Photographs of inspected highwalls |
| Assessment of Stability of Final Void and Landform Shaping Options, Ensham Coal Mine | Landloch | 2015 | Assessment of final void landforms developed by Xenith Consulting using soil erosion and landform evolution modelling to assess soil erosion risk of the proposed options  
- Discussion of soil material properties and geochemistry |
Table 3.3  Review Data Summary - Dumps

<table>
<thead>
<tr>
<th>SPOIL DUMP REPORTS</th>
<th>CONSULTANT</th>
<th>DATE</th>
<th>COMMENTS</th>
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<tr>
<td>Geochemical</td>
<td>URS</td>
<td>2007</td>
<td>Geochemical characterisation of overburden and coal reject to assist management strategies for overburden dump construction and rehabilitation.</td>
</tr>
<tr>
<td>Characterisation</td>
<td></td>
<td></td>
<td>— Drill hole location plan</td>
</tr>
<tr>
<td>and Assessment of</td>
<td></td>
<td></td>
<td>— Sampling and testing methodologies</td>
</tr>
<tr>
<td>Overburden</td>
<td></td>
<td></td>
<td>— Test results</td>
</tr>
<tr>
<td>and Potential Coal</td>
<td></td>
<td></td>
<td>— Discussion of test result implications and suitability for re-use</td>
</tr>
<tr>
<td>Reject Material</td>
<td></td>
<td></td>
<td>— Borehole logs</td>
</tr>
<tr>
<td>at the Ensham</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Project</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proposed C Pit</td>
<td>Kellogg Brown and Root Pty Ltd</td>
<td>2009</td>
<td>Preliminary design report for the levee approvals process. Levees to be upgraded to provide flood immunity from 100yr ARI to 1000yr ARI.</td>
</tr>
<tr>
<td>Levee and</td>
<td></td>
<td></td>
<td>— Provides background on relevant flood studies and the design and construction of the existing flood levees</td>
</tr>
<tr>
<td>Upgrade of B Pit</td>
<td></td>
<td></td>
<td>— New levee design details and design details for B Pit and C Pit levee upgrades</td>
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<tr>
<td>Levee Design Report</td>
<td></td>
<td></td>
<td>— Material specifications for levee materials</td>
</tr>
<tr>
<td>BEE603.009-C-REP-004</td>
<td></td>
<td></td>
<td>— No design drawings included in file</td>
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3.2 PRELIMINARY SITE MATERIALS ASSESSMENT

Based on a review of the information provided we anticipate to encountered the following materials exposed in the pit walls:

- Higher strength fresh Permian, less prone to slaking, extends through Pit B to the south end of Ramp 83 pit.
- Lower strength fresh Permian, slaking more evident, occurs in Pit A in the south to the north, includes half of Ramp 83 and into Yongala.
- Weathered Permian, limited to less than 10m in thickness in the pre-strip horizon.
- Tertiary clays in the Yongala area and dominate the pre-strip horizon.

The parameters adopted by PSM in their 2015 report (PSM687-222L Geotechnical Review of Final Landform) and shown below, generally appear reasonable for the materials expected at the site (see references cited). These parameters will be further verified early in Stage 3 work by way of a site visit, more thorough review of existing geotechnical information provided by Ensham, acquisition of laboratory test results referenced in the PSM report referenced above, and general literature review, culminating in production of selected design criteria for stability assessment modelling purposes, which will be forwarded to the third-party reviewer for early comment. Stability analysis modelling will include an assessment of the sensitivity of results to upward and downward variation around the selected parameter value.

Table 3.4 Material Parameters (PSM, 2015)

<table>
<thead>
<tr>
<th>UNIT</th>
<th>γ KN/M³</th>
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<tr>
<td></td>
<td>C’ KPA</td>
<td>Ø’ DEG</td>
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<tr>
<td>Coal</td>
<td>15</td>
<td>-</td>
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</table>

1 - Report reference: PSM687-222L Geotechnical Review of Final Landform

4 LIMITATIONS

This report should be read in conjunction with the appended “Limitations of Geotechnical Investigation”, in Appendix A which provides important information regarding geotechnical assessments.

Any changes to the scope of development of this site, or significant variation in subsurface conditions from those anticipated should be reported to this firm for reassessment.
APPENDIX A
LIMITATIONS
Limitations of Geotechnical Site Investigation

Scope of services

This geotechnical site assessment report (the 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 (the data). 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.

Geotechnical investigation

Geotechnical engineering is based extensively on judgment and opinion. It is far less exact than other engineering disciplines. Geotechnical engineering reports are prepared to meet the specific needs of individuals. A report prepared for a consulting civil engineer may not be adequate for a construction contractor or even some other consulting civil engineer. This report was prepared expressly for the client and expressly for purposes indicated by the client or his representative. Use by any other persons for any purpose, or by the client for a different purpose, might result in problems. The client should not use this report for other than its intended purpose without seeking additional geotechnical advice.

This geotechnical report is based on project-specific factors

This geotechnical engineering report is based on a subsurface investigation which was designed for project-specification factors, including the nature of any development, its size and configuration, the location of any development on the site and its orientation, and the location of access roads and parking areas. Unless further geotechnical advice is obtained this geotechnical engineering report cannot be used:

- when the nature of any proposed development is changed
- when the size, configuration location or orientation of any proposed development is modified.

This geotechnical engineering report cannot be applied to an adjacent site.
Limitations of Geotechnical Site Investigation

The limitations of site investigation

In making an assessment of a site from a limited number of boreholes or test pits there is the possibility that variations may occur between test locations. Site exploration identifies specific subsurface conditions only at those points from which samples have been taken. The risk that variations will not be detected can be reduced by increasing the frequency of test locations; however, this often does not result in any overall cost savings for the project. The investigation program undertaken is a professional estimate of the scope of investigation required to provide a general profile of the subsurface conditions. The data derived from the site investigation program and subsequent laboratory testing are extrapolated across the site to form an inferred geological model and an engineering opinion is rendered about overall subsurface conditions and their likely behaviour with regard to the proposed development. Despite investigation the actual conditions at the site might differ from those inferred to exist, since no subsurface exploration program, no matter how comprehensive, can reveal all subsurface details and anomalies.

The borehole logs are the subjective interpretation of subsurface conditions at a particular location, made by trained personnel. The interpretation may be limited by the method of investigation, and can not always be definitive. For example, inspection of an excavation or test pit allows a greater area of the subsurface profile to be inspected than borehole investigation, however, such methods are limited by depth and site disturbance restrictions. In borehole investigation, the actual interface between materials may be more gradual or abrupt than a report indicates.

Subsurface conditions are time dependent

Subsurface conditions may be modified by changing natural forces or man-made influences. A geotechnical engineering report is based on conditions which existed at the time of subsurface exploration.

Construction operations at or adjacent to the site, and natural events such as floods, or groundwater fluctuations, may also affect subsurface conditions, and thus the continuing adequacy of a geotechnical report. The geotechnical engineer should be kept appraised of any such events, and should be consulted to determine if additional tests are necessary.

Avoid misinterpretation

A geotechnical engineer should be retained to work with other appropriate design professionals explaining relevant geotechnical findings and in reviewing the adequacy of their plans and specifications relative to geotechnical issues.

Bore/profile logs should not be separated from the engineering report

Final bore/profile logs are developed by geotechnical engineers based upon their interpretation of field logs and laboratory evaluation of field samples. Customarily, only the final bore/profile logs are included in geotechnical engineering reports. These logs should not under any circumstances be redrawn for inclusion in architectural or other design drawings. To minimise the likelihood of bore/profile log misinterpretation, contractors should be given access to the complete geotechnical engineering report prepared or authorised for their use. Providing the best available information to contractors helps prevent costly construction problems. For further information on this matter reference should be made to ‘Guidelines for the Provision of Geotechnical Information In Construction Contracts’ published by the Institution of Engineers Australia, National Headquarters, Canberra 1987.

Geotechnical involvement during construction

During construction, excavation is frequently undertaken which exposes the actual subsurface conditions. For this reason geotechnical consultants should be retained through the construction stage, to identify variations if they are exposed and to conduct additional tests which may be required and to deal quickly with geotechnical problems if they arise.
Limitations of Geotechnical Site Investigation

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). Other parties 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.
Stage 2 Technical Report
Landform Design
Ensham Resources Pty Ltd

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Brisbane QLD 4000
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Brisbane QLD 4001

Tel: +61 7 3854 6200
Fax: +61 7 3854 6500
wsp.com

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<td>G.Wray</td>
<td>26/04/2018</td>
</tr>
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<td>Reviewed by</td>
<td>C.Deaconos</td>
<td>26/04/2018</td>
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PS107225-RES-REP-002 Rev 3_Landform
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26 April 2018
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th></th>
<th>INTRODUCTION</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>BACKGROUND</td>
<td>1</td>
</tr>
<tr>
<td>1.2</td>
<td>PURPOSE</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>PREFERRED REHABILITATION OPTIONS</td>
<td>3</td>
</tr>
<tr>
<td>2.1</td>
<td>OPTION 1 – LANDFORM LEVEE</td>
<td>3</td>
</tr>
<tr>
<td>2.2</td>
<td>OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE</td>
<td>4</td>
</tr>
<tr>
<td>2.3</td>
<td>OPTION 3 – BACKFILL TO PROBABLE MAXIMUM FLOOD LEVEL (PMF)</td>
<td>5</td>
</tr>
<tr>
<td>2.4</td>
<td>REGULATORY FRAMEWORK</td>
<td>5</td>
</tr>
<tr>
<td>2.5</td>
<td>LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td>2.6</td>
<td>CURRENT REHABILITATION PRACTICES ON SITE</td>
<td>7</td>
</tr>
<tr>
<td>2.7</td>
<td>LANDFORM DESIGN</td>
<td>11</td>
</tr>
<tr>
<td>2.7.1</td>
<td>SAFE TO HUMANS AND WILDLIFE</td>
<td>11</td>
</tr>
<tr>
<td>2.7.2</td>
<td>NON-POLLUTING</td>
<td>12</td>
</tr>
<tr>
<td>2.7.3</td>
<td>STABILITY</td>
<td>12</td>
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<td>2.7.4</td>
<td>ABLE TO SUSTAIN AGREED POST-MINING LAND USE</td>
<td>13</td>
</tr>
<tr>
<td>2.7.5</td>
<td>CRITERIA PROPOSED</td>
<td>13</td>
</tr>
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<td>2.8</td>
<td>SPECIFIC LANDFORM ISSUES RELEVANT TO PREFERRED OPTIONS</td>
<td>16</td>
</tr>
<tr>
<td>2.8.1</td>
<td>OPTION 1 - LANDFORM LEVEE</td>
<td>16</td>
</tr>
<tr>
<td>2.8.2</td>
<td>OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE</td>
<td>17</td>
</tr>
<tr>
<td>2.8.3</td>
<td>OPTION 3 - BACKFILL TO PMF</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>CONCLUSIONS</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>LIMITATIONS</td>
<td>20</td>
</tr>
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<td></td>
<td>BIBLIOGRAPHY</td>
<td>21</td>
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1 INTRODUCTION

1.1 BACKGROUND

Ensham Mine, an open cut and underground bord and pillar coal mine located approximately 35km east of Emerald, is operated by Ensham Resources Pty Ltd (Ensham), a wholly owned subsidiary of Idemitsu Australia Resources Pty Ltd (Idemitsu), on behalf of the Ensham Mine joint venture (JV) partners. The JV partners and holders of the Environmental Authority are Bligh Coal Limited, Idemitsu and Bowen Investment (Australia) Pty Ltd. EA EPML00732813, dated 26 May 2017, is the relevant environmental authority under which Ensham operates the mine.

Condition G16 of the EA states that a Residual Void Project (RVP) must be completed and submitted to the administering authority for review and comment by 31 March 2019. The minimum content of the RVP is specified within Condition G16 of the EA as:

- Terms of Reference;
- Residual Void Study;
- Progress Reports; and
- Rehabilitation success criteria for voids.

In compliance with Condition G19 of the EA, “the Residual Void Project must be carried out in accordance with the approved Terms of Reference”. A Terms of Reference (ToR) (Ensham Resources, 2017a) was approved by Queensland’s Department of Environment and Science (DES, formerly Department of Environment and Heritage Protection, DEHP) on 21 July 2017.

Condition G20 of the EA identifies the minimum content of the RVP identified in Condition G16.

In accordance with the ToR, the project has been divided into five stages:

- Stage 1 - Project Definition and Options Identification;
- Stage 2 - Preferred Options Technical Studies;
- Stage 3 - Preferred Options Detailed Design;
- Stage 4 - Most Preferred Option Identification; and
- Stage 5 - Regulatory Documentation.

Stage 1 - Project Definition and Options Identification for the RVP has been completed. The Stage 1 Options Assessment report has been prepared in draft and issued to DES, Department of Natural Resources, Mines and Energy (DNRME, formerly DNRM) and the Community Reference Group (CRG) for comment. Following receipt of comments, the report has been independently peer reviewed and revised to address peer review comments. The final report was submitted to DES on Sunday the 18th of March 2018.

1.2 PURPOSE

The Options Analysis workshop of Stage 1 of the RVP identified two options:

- Option 1: Landform Levee;
- Option 2: Flood Mitigation and Beneficial Use.

DES required a third option to be included in the study, being:

- Option 3: Backfill to PMF.
All three options have been advanced to Stage 2 of the RVP and are referred to as the ‘Preferred Options’.

Stage 2 is now underway. The purpose of Stage 2 is to identify the Environmental Values (EVs) in the immediate and surrounding area of Ensham Mine and determine through appropriate environmental assessment which EVs are likely to be affected by each Preferred Option. The level of detail in each environmental assessment must be consistent with Appendix B of the Terms of Reference (where appropriate) and:

- provide a description of the EV that is likely to be affected by a Preferred Option;
- detail any emissions or releases likely to be generated by a Preferred Option relative to the EV;
- describe the risk and likely magnitude of impacts of a Preferred Option on the EV; and
- describe the management practices to be implemented to prevent or minimise the potential impacts for a Preferred Option, which will be detailed in Stage 3: Preferred Options Detail Design;

The ToR specifies that Stage 2 of the RVP (Preferred Options Technical Studies) “must commence with an environmental values (EVs) workshop” and that “where it is determined that an EV is not likely to be affected by a Preferred Option, the reasons for this must be discussed and explained in the EVs workshop report”. Ensham has prepared and submitted the Stage 2 Environmental Values Workshop Report to DES, DNRME and the CRG for review and comment. The revised report has been independently peer reviewed, revised and finalised.
Three rehabilitation options have been identified for assessment as part of the Stage 1 rehabilitation strategy for the Ensham Mine, which are described below.

### 2.1 OPTION 1 – LANDFORM LEVEE

The existing northern and southern levees are currently engineered structures and require annual inspection and maintenance. This option aims to convert these maintained structures effectively into permanent landforms by augmenting the levees and the pits they protect. In limited circumstances, the levee is too close to the pit for adequate backfill to be placed and in those circumstances, partial backfilling of the pit would be required to support the levee backfill. The conceptual arrangement of the Landform Levee option is depicted in Figure 2.1 below.
Outside of the areas protected by the levees, the voids would be rehabilitated to various slopes to achieve stable landforms.

### 2.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE

The existing northern and southern levees would be retained in their current configuration, but would incorporate engineered structures to permit off-take of flood waters to specified ARI flood events feeding water from identified watercourses to residual voids within the floodplain. Whilst pits would be rehabilitated to achieve stable landforms, the shape of the residual voids would be optimised to store water, minimise evaporative losses and maximise re-usable water storage capacity. A minimum water level would be maintained to offset groundwater head and minimise saline groundwater inflow. Figure 2.2 indicates a conceptual arrangement of this option.

---

**Figure 2.1**  Option 1 - Conceptual arrangement

**Figure 2.2**  Option 2 – Conceptual arrangement
It is probable that the system will be operated as two separate storage units, with A-pit and B-pit being the southern storage unit, and C-pit and D-pit the northern storage unit. Pits within a storage unit will be hydraulically linked in some way. E-pit is partially backfilled already and would not be included in the scheme, whilst F-pit and the Yongala pits are shallow and not considered likely to be able to contribute significantly to beneficial water qualities in C/D-pits. However, they will be required to be rehabilitated to stable landforms.

Water stored in pits A, B, C and D may be used for beneficial purposes such as to supply downstream irrigation demands or in-pit uses such as ecosystem functions and recreation. Discharge would be managed to ensure that the water level in each pit does not fall below the critical level required to offset groundwater inflow, spoil seepage and evaporative losses expected until the next design re-inundation event.

2.3 OPTION 3 – BACKFILL TO PROBABLE MAXIMUM FLOOD LEVEL (PMF)

Those pits occupying the pre-mining flood plain of the Nogoa River would be backfilled to original (pre-mining) ground levels. Parts of those pits straddling the boundary of the floodplain, as defined by the PMF event extent, would also be backfilled, whilst parts lying outside of that boundary would remain unfilled.

Outside of the flood plain, the residual voids would be rehabilitated to various slopes to achieve stable landforms.

2.4 REGULATORY FRAMEWORK

The Department of Environment and Sustainability (DES) have published guidelines for rehabilitation requirements for mining resource activities (EM1122), which provides information on both progressive and final rehabilitation requirements for resource projects operating in Queensland under the Environmental Protection Act 1994. This guideline recognises that mining activities, unlike other industrial activities, have a finite life, which is reached when the resource is depleted or it is no longer economically viable to extract. Rehabilitation is required under the Environmental Protection Act 1994, which has its object the attainment of ecologically sustainable development (ESD). The guideline sets out overarching rehabilitation goals for land disturbed by mining activities, required to return the site to a condition that is:

- safe to humans and wildlife;
In the Australian Government, Leading Practice Sustainable Development Program for the Mining Industry guideline on mine rehabilitation the following definition for rehabilitation is adopted:

“Rehabilitation comprises the design and construction of landforms as well as the establishment of sustainable ecosystems or alternative vegetation, depending on the desired post-operational land-use.”

Overarching rehabilitation obligations required to be met by Ensham Mine are documented in the Environmental Authority EPML00732813, dated 26 May 2017.

The Ensham EA (G4) requires all surface areas significantly disturbed by mining activities to be rehabilitated to a safe, stable and non-polluting landform, with self-sustaining vegetation cover in accordance with the approved Completion Criteria. Condition G15 requires that Residual Voids must not cause any serious environmental harm to land, surface waters or any recognised groundwater aquifer, other than the harm constituted by the existence of the residual void itself.

2.5 LITERATURE REVIEW

There is a significant body of literature, guidelines and research material available for reference in the field of rehabilitation and landform design, a summary of some of the relevant references are described below.

The Australian Coal Association Research Program (ACARP) has published several guidelines relating to rehabilitation of mine sites, including C14048 Rehabilitation of High Walls and C12031 Rehabilitation of Dispersive Tertiary Spoil in the Bowen Basin. Findings and suggested rehabilitation considerations (which are applicable to the Ensham voids) in the C14048 Report include:

- In the Bowen Basin highwalls generally comprise the following sedimentary overburden material: Tertiary soil overlying weathered Permian (Weathered Coal Measures), which in turn overlies unweathered Permian (Fresh Coal Measures).
- Most Tertiary and weathered Permian high wall materials would not exhibit long-term geomechanical stability.
- Coal measures characteristically contain less clay, have the same alkalinity, and are less sodic than Tertiary materials.
- Given the higher strength of unweathered Permian materials, highwall failures rarely occur through intact rock, but rather at specific joints, bedding planes and faults, and are thus very specific to location.
- The study went on to detail 11 highwall stability-treatment strategies categorised by cost, including bund and fencing, regrading the high wall, regrading both high and lowwalls, and backfilling the pit. Some guidance was provided regarding suitable regrade slopes and surface treatments to prevent erosion.

In BMA’s Caval Ridge Final Landform Management Plan (2009) the following conclusions or recommendations were drawn regarding rehabilitation:

- From a geotechnical perspective, batters which include slopes ranging from 10% (1:10) to 25% (1:4) are inherently stable, and are not likely to be affected by varying water levels in the final void.
- Endwalls usually exhibit greater instability than highwalls due to the exposed alignment of bedding and faulting planes.
- Erosion mitigation on long slopes caused by regrading of highwalls, lowwall, and endwalls require erosion mitigation in the form of rock mulch.
— Deterioration in groundwater quality due to poor residual void water quality is unlikely as they tend to operate locally as a groundwater sink with groundwater flow toward the void. In this Plan several sources are listed to support this assertion, including the ACARP Project C7007 Water Quality and Discharge Prediction for Final Void and Spoil Catchments Report.

— The Plan goes on to detail 3 residual void rehabilitation design strategies; fence and bund, 25% regrade (both low and highwalls), and 10% regrade (both low and highwalls).

An assessment of stability of final landform shaping options for Ensham Coal Mine was undertaken by Landloch Pty Ltd in 2015, and salient findings were published in their report dated 07 September 2015, including the following:

— The Ensham rehabilitation strategy utilises relatively flat slopes compared with most central Queensland coal mines (10% as opposed to 17%).

— A consistently high level of vegetative cover of pasture grasses and legumes, and absence of areas of concentrated runoff on rehabilitated areas and formal drainage structures, were observed during a site visit on 14 January 2015.

— The Ensham rehabilitation works have been highly successful relative to “most, if not all” mines in the region.

— A broad transition of topsoil type used for rehabilitation from the north to the south of the site was observed, with black cracking clays to the south, red/brown loam in the central area, and sandy soils to the north. When modelled with vegetation consistent with grazed grassland all three topsoil types yielded similar erosion characteristics, indicating erosion response is controlled more by vegetation than by soil properties.

— SIBERIA landform evolution modelling was undertaken for several landform options per residual void over a 500-year period, which predicted high rates of erosion (higher than sustainable for grazing land use) for steep areas surrounding the pit and in areas where saddles had been created due to partial backfilling of ramps; however, regraded outward sloping spoil indicated low rates of erosion irrespective of whether a “grazed” or “ungrazed” surface cover modelling parameter was used, concluding that the landform could be grazed sustainably. High rates of erosion on steeper slopes reporting to the void were not considered to be of concern as they have no impact on the wider environment, unless gullies and associated headcuts extend from the pits, although it was noted that actual erosion on steeper slopes is likely to be significantly higher as high rates of erosion will detrimentally affect vegetation growth and cover. A reduction in erosion over time was predicted due to a reduction in batter slope after successive erosion events. No specific mention was made of how settlement of spoil rehabilitation is handled by the model.

— Modelling showed that the evolution of landform will tend to create concave slopes, which is consistent with common geomorphological observation that as catchment increases, gradient decreases. Hence designed landforms that exhibit concave slopes will tend to be more stable than convex or rectilinear slopes. Ideally constructed landform should hence be concave, although this may be difficult to achieve practically.

— Landloch developed incipient erosion curves for each topsoil type observed on site, that indicate a point at which erosion will commence for a given contributing catchment and slope. The curves become nearly asymptotic for all topsoil types at approximately 10% slope gradient, meaning they would exhibit high stability for almost any size contributing catchment at this slope, which is consistent with the high levels of stability of the existing rehabilitated landform.

2.6 CURRENT REHABILITATION PRACTICES ON SITE

Progressive rehabilitation has been undertaken on site during mining operations, which has been predominantly limited to the outward slopes of spoil dumps. Current rehabilitation practices are undertaken in accordance with the site Rehabilitation Management Plan V2.0 dated 20 June 2017. The rehabilitation strategy set out in this plan may be summarised as follows:
Coal resources at Ensham have been mined by way of both underground and open-cut strip mining. The RVP relates to only open cut mining areas, where the resource has been accessed by removal of overburden by way of blasting and placement in spoil dumps by dragline. The initial boxcut spoil is placed external to the pit, with subsequent placement of spoil within the pit as the mining front progresses. Spoil dumps comprise either Tertiary or Permian materials, or in some cases a mixture. No selective placement of spoil has been undertaken. Spoil dumps tend to stand at an angle of natural repose; however, significant rilling and gullies develop on these slopes over time (Photo 2.1). Based on site observations, spoil dumps containing Tertiary spoil are more susceptible to erosion than the rockier, less weathered Permian spoil, and hence for these materials flatter rehabilitation slopes are preferred (Photo 2.2). In the Rehabilitation Management Plan, Tertiary overburden material is identified as occurring in every pit at Ensham with the most saline and sodic material characteristics on site, making them prone to excessive dispersion and erosion, requiring conservative slope gradients to control erosion.

Rehabilitation commences with reshaping of spoil dumps by way of dozer pushing, with maximum slopes of 10% (1:10 or 5.7°) for Tertiary spoil material and 15% (1:6.7 or 8.5°) for Permian spoil.

Rehabilitated slopes are terraced with maximum slope lengths of 100 m for Permian overburden and 200 m for Tertiary overburden, with a 10 m wide contour bench separating each slope. The contour benches are graded to shed water down-slope rather than transport it off the slope, so are not typical drainage benches incorporated in many spoil rehabilitation operations. Free drainage of these benches prevents ponding of water on the benches, and tunnel or overtopping failures which concentrate stormwater runoff resulting in rapid gully formation.

No formal drainage structures are incorporated in the rehabilitated landforms.

On completion of land shaping, a topsoil layer of 200 mm is spread over the spoil material, followed by dozer ripping of the topsoil and underlying spoil material to a depth of 600 mm along the contour, to ensure water can penetrate the ground and be stored, and to create a root penetration zone. During this process, some rocks in the underlying spoil material are brought to the surface; however, these are relatively small and fragmented and will not impact on the proposed grazing post-mining land use.

After ripping the slopes are seeded with grass, and benches are planted with tree tube-stock, followed by application of hay mulch on the surface for erosion protection while vegetation is establishing. Where necessary gypsum is applied as a soil ameliorant.

The Management Plan is silent on rehabilitation requirements for the residual voids in terms of geotechnical and erosional stability, or revegetation strategy, deferring specifically to the outcomes of the RVP study.

The revegetation strategy adopted to date on site is in line with best practices identified during the literature study, and areas which have attained maturity in terms of revegetation appear to be in very good condition, with no visible signs of erosion, rilling, or gully formation. In some areas grazing has been introduced on a trial basis. The progressive stages of the current strategy are shown in Photo 2.3, Photo 2.4 and Photo 2.5 taken during a site visit.
Photo 2.1  Typical dragline-placed spoil dump at angle of repose prior to rehabilitation (Permian material)

Photo 2.2  Erodible Tertiary material in oversteep embankment (at the base of a rehabilitated area)
Photo 2.3  Recently rehabilitated landform (E-Pit)

Photo 2.4  Vegetation establishing on rehabilitation site (E-Pit)
2.7 LANDFORM DESIGN

The Ensham EA (G4) requires all surface areas significantly disturbed by mining activities to be rehabilitated to a safe, stable and non-polluting landform, with self-sustaining vegetation cover in accordance with the approved Completion Criteria. Condition G15 requires that Residual Voids must not cause any serious environmental harm to land, surface waters or any recognised groundwater aquifer, other than the harm constituted by the existence of the residual void itself.

The Ensham Rehabilitation Management Plan sets out several rehabilitation goals, which are common to those contained in the DES rehabilitation guideline EM1122, to achieve the requirements of conditions G4 and G15, which are:

- safe to humans and wildlife
- non-polluting
- stable
- able to sustain an agreed post-mining land use.

The implications of these requirements, as far as they can be managed or influenced by landform design, are described in the sections below.

2.7.1 SAFE TO HUMANS AND WILDLIFE

On completion of rehabilitation to the final landform, safety conditions are similar to surrounding unmined landscapes. The Management Plan is again silent on safety issues related to the final void domain, with potentially steep, geotechnically competent rock faces remaining as part of the residual landscape. Adequate controls can be put in place to manage the presence of these features, such as using bunds, fences, dense vegetation barriers and signage.

For the purposes of the landform design, the rehabilitation outcomes should be:

- stabilisation of incompetent geotechnical strata by regrading to avoid catastrophic slope failures
— creating localised barriers to restrict access to steep slopes, such as localised earth embankment bunding or dense vegetation screens adjacent to highwalls
— minimising rehabilitation areas with steep slopes.

2.7.2 NON-POLLUTING

For the final landform to achieve an outcome of being non-polluting, there must be no degradation of downstream surface water or groundwater quality, other than would have occurred naturally in a pre-mining landscape. Typical sources of pollutants after mine closure are: elevated levels of sediment from erosion of outward facing rehabilitated spoil dumps, overflow of residual void water with high levels of salinity into watercourses during periods of high rainfall, and leachate from spoil dumps that potentially contain acid forming (PAF) minerals. Material characterisation of spoils at Ensham have indicated that these are benign, and do not contain PAF materials, hence they can be considered non-polluting, and no special treatment of any materials will be required.

The potential for the overflow of poor quality waters from the residual voids during periods of high rainfall is dependent on the residual void hydrology, which may be influenced by final landform in terms of reporting catchments. The landform should therefore result in residual void catchments that are sufficiently small to result in a low risk of spills to the surrounding watercourses for both Options 1 and 3, while for Option 2 water quality in the residual voids will require interaction with the floodplain, and hence the design landform must support this. Rehabilitation and revegetation of outward facing spoil dumps should be undertaken to minimise erosion potential to prevent an increase in sediment load on receiving waters, which may be carried downstream and off-site.

For the purposes of the landform design, the rehabilitation outcomes should be:
— Minimising erosion potential by adopting conservative slope gradients stipulated in the site Rehabilitation Management Plan (10% for Tertiary and 15% for Permian overburden materials).
— For Options 1 and 3, residual void shaping must result in a reporting catchment, and storage capacity, that complies with void hydrology or water balance modelling outcomes in terms of creating a low risk of spillage during wet weather events. Water and salinity balance modelling will be undertaken by others during Stage 2 and 3 to determine if dilution of residual void water during a wet weather event of sufficient magnitude to cause a spill event would improve water quality sufficiently for it to be considered non-polluting in character.
— For Option 2, ensuring that the landform design supports the requirement for residual void / flood plain interaction.

2.7.3 STABILITY

Altering natural ground shape invariably introduces a degree of instability, with a tendency for readjustment by way of mass soil movement, either by rapid catastrophic failure such as slumping, sliding, or gradual erosion and deposition through surface processes. Catastrophic failures can represent a safety issue depending on land use of the area surrounding the failure, while erosion takes place over a significant period. Both readjustment mechanisms can hamper or cause the failure of rehabilitation efforts.

Catastrophic failure can occur in two ways: rotational failure due to oversteep slopes or soft foundation materials, or sliding wedge failure due to, for example, undercutting of softer material below more competent layers, or intersecting joints and faults. It is relatively easy to remedy the causes of catastrophic failure by way of reducing slopes or loading the toe of cuttings. Erosional stability is dependent on several factors, including land slope, surface preparation and vegetation cover, which can be managed by landform design.

For the purposes of the landform design, the rehabilitation outcomes should be:
— Batter slopes on all landform that exhibit a low risk of failure, considering long term weathering properties of exposed materials, and all possible scenarios with respect to water levels in the residual void and adjacent ground water, and fluctuations of these levels in time.
— Erosionally sustainable slopes on all outward facing rehabilitated slopes that report to downstream watercourses. Slightly higher levels of erosion may be tolerated on inward facing spoil rehabilitation slopes, provided long term erosion modelling does not predict significant gully erosion through the ridge line of the rehabilitated landform.

### 2.7.4 ABLE TO SUSTAIN AGREED POST-MINING LAND USE

The final topography or landform of the site is going to be a function of the pre-mining topography, mining method, and reshaping strategy. Given the nature of strip mining which results in spoil piles and a final void a realistic key driver is to achieve a sustainable end land use that has been identified in consultation with the wider community and the Administering Authority. Ensham has identified a reshaping strategy that returns the landform to one which will support a post-mining land use.

In terms of this reshaping strategy, commitments should relate to broad concepts that promote land capability. Slope characteristics need to be sufficiently gentle to prevent erosion of replaced soils at greater than sustainable rates. Erodibility rates depend on several factors including regional rainfall intensity and soil type. Excessively steep slopes do not promote seed retention, topsoil retention or water infiltration and hence have reduced land capability. This will result in unsustainable pastures and increased erosion due to lack of vegetation cover. It may be acceptable to incorporate areas of the final landform that are incompatible with the proposed post-mining use, such as slopes that report back into the final void, which are likely to be too steep to support grazing use, and therefore higher levels of erosion may be tolerated. Slopes should also be greater than a certain minimum as deep spoil mounds will incur settlement over a long period time, which will result in localised hollows forming on flat surfaces with ponding of runoff rain water. It has been found that ponded rehabilitation landforms on dispersive spoil perform particularly poorly (ACARP, C12031 July 2004). Surfaces with some minimum grade will tolerate settlement without the formation of hollows, maintaining free draining conditions.

To permit the revegetation of rehabilitated areas and undertake maintenance operations of grazing pastures, slopes should be kept below a maximum slope to permit the operation of agricultural equipment, which can generally operate up to a gradient of 1:5 or 20%. Ensham have adopted rehabilitation slopes of 10% for Tertiary material and 15% for Permian materials, so these slopes are well within those required for agricultural purposes.

For the purposes of the landform design, the success criteria in terms of achieving a landform that is sustainable for the identified post-mining land use will be:

— Maximising potential land capability and minimising erosion potential by adopting flatter than maximum batter grades wherever practically possible.

— Adoption of the existing site proven rehabilitation strategy where practicable.

### 2.7.5 CRITERIA PROPOSED

Criteria suggested in some of the literature described earlier are summarised in Table 2.1 for reference and comparison, and the criteria proposed for Stage 2 landform design are included in Table 2.2. These criteria will be further refined as the study proceeds into Stage 3, when geotechnical stability analysis results are available for consideration.

<table>
<thead>
<tr>
<th>TABLE 2.1 Criteria identified in literature search</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SOURCE</strong></td>
</tr>
<tr>
<td>Caval Ridge Final Void &amp; Landform Management</td>
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</tbody>
</table>
### Highwall

- Competent rock – geotechnically and erosionally stable – regrade to < 65° and fence and bund; or
- Incompetent rock highwall – regrade to < 17° (1:3.3 or 30%) and clad with durable rock mulch.
- Regrade to 5° (1:11.4 or 9%), topsoiled and pastured if stability not practical with steeper treatment.

### ACARP (C14048)

- **Tertiary spoil:** 30% batter with 2m Permian cover, topsoil, and seed.

<table>
<thead>
<tr>
<th>Source</th>
<th>Material</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highwall</td>
<td>Various strategies propose depending on long term stable slope of highwall, including:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Throwblast Tertiary and weathered Permian for 10% regrade; or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blast Tertiary material into pit to act as softwall and leave Permian as is; or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Throwblast Tertiary and Permian highwall into pit to create 30% regraded highwall (approx.)</td>
<td></td>
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<tr>
<td></td>
<td>Balanced cut and fill 10% regrade of high and lowwalls; or</td>
<td></td>
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<tr>
<td></td>
<td>Lay back Permian to a slope with very low possibility of failure (1:1 or 1:2).</td>
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</tr>
</tbody>
</table>

### Guidelines for the Rehabilitation of Mined Land (Chamber of Mines South Africa)

- **Outward facing slope of spoil:** Maximum slope between 1:5 (20%) to 1:7 (14.3%) for post-mining grazing land use.
- **Boxcuts, voids and dumps:** Preferred strategy is to minimise slopes to maximise potential land capability and minimise erosion risk.

<table>
<thead>
<tr>
<th>Source</th>
<th>Material</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highwall</td>
<td>Blast or regrade to a maximum slope of 1:3 (33%) to the top of the final void water level after permanent ground water table recovery.</td>
<td></td>
</tr>
<tr>
<td>Lowwall and spoil dumps</td>
<td>Regrade to a maximum slope of 1:3 (33%) – with proviso that it is preferable to regrade at a lesser slope to reduce erosion and maximise land capability for agriculture, for which a maximum slope of 1:5 is recommended (20%).</td>
<td></td>
</tr>
<tr>
<td>SOURCE</td>
<td>DOMAIN</td>
<td>TREATMENT</td>
</tr>
<tr>
<td>--------</td>
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</tr>
<tr>
<td>Proposed</td>
<td>General criteria</td>
<td>Final landform to be water-shedding with no ponding shapes – minimum slopes of 1% to be adopted draining to voids or to watercourses. Final landforms to be generally free-draining other than into residual voids.</td>
</tr>
<tr>
<td></td>
<td>Outward slope of spoil</td>
<td>Regrade to a slope of 10% for Tertiary spoil rehabilitation in line with current successful site practices. Regrade to a slope of 15% for Permian spoil rehabilitation in line with current successful site practices. No permanent drainage structures. Limit banks to 100 m length, with 10 m wide non-drainage bench to break runoff velocity in line with current successful site practices.</td>
</tr>
<tr>
<td></td>
<td>Inward slope of spoil to void</td>
<td>Inward slopes of the void are not likely to be suitable for grazing and therefore stability is main criteria. Stage 2 designs based on regrade to 25% - flatter slopes will be considered in areas of Tertiary spoil dumps, and for materials balance reasons.</td>
</tr>
<tr>
<td></td>
<td>Highwalls</td>
<td>Incompetent rock – 25% batter into the residual void. Fresh Permian – to be determined with geotechnical modelling. To be confirmed after geotechnical stability analysis completed.</td>
</tr>
<tr>
<td></td>
<td>Levee landform</td>
<td>Free draining landform with no water damming behind the levee. Water-facing slopes where flood plain is constricted – 25% batter with rock mulching. Water-facing slopes where flood plain is not constricted – 15% with topsoil and pasture vegetation. Inward void facing slopes – 25% batter with rock mulching or Permian cover, topsoiling and grassing. Level to provide PMF protection + 0.5m freeboard.</td>
</tr>
<tr>
<td></td>
<td>Backfill to PMF</td>
<td>Truck and fill backfill to pre-mining ground levels – poorly compacted backfill. Surcharge backfill to allow for settlement – 2 m proud of pre-mining ground for footprint of backfill. Footprint of backfill – to end 50 m past PMF footprint. Backfill slope into pit where partially filled – 25% batter with rock mulching or Permian cover, topsoiling and grassing.</td>
</tr>
</tbody>
</table>
2.8 SPECIFIC LANDFORM ISSUES RELEVANT TO PREFERRED OPTIONS

Landform design on the RVP entails creation of stable residual voids for all the pits on site, which is a desired outcome that is common to all the preferred options. There are however specific requirements in terms of landform that apply to individual options. These specific requirements are described in this section along with outcomes of Stage 2 landform modelling that has been undertaken to further understand the implications of these landform requirements, identify possible alternatives arrangements, and develop preliminary bulk earthworks quantities, in so far as they differentiate the options.

2.8.1 OPTION 1 - LANDFORM LEVEE

In addition to stabilising residual voids for all the pits comprising the Ensham RVP, Option 1 requires that the residual voids are isolated from flood events up to a PMF. To achieve this outcome a landform will be created around the residual voids that are within the PMF extent, effectively permanently isolating the residual voids from the floodplain. These landforms will nominally be located proximate to the existing northern and southern levees where possible; however, they will be significantly higher than these as they were designed for a lower 1 in 1000-year flood event. Sketch plans of several preliminary landform levees considered during Stage 2 are included in Appendix A.

The following philosophy has been adopted in developing these preliminary landform levees:

— Landform levees will result in a free draining landform, with runoff captured behind the structures directed to residual voids.

— Wherever possible residual voids will remain part of the post-mining landscape, although in some locations where the landform levee alignment constrains the existing Nogoa River, it may be necessary to extend the landform levee into the residual void to accommodate the foundation for the higher landform, resulting in partial backfilling of the void.

— Inward and outward batter slopes on the landforms will be steeper than that which would support the propose post-mining land-use, due to spatial constraint issues, as well as the fact that these will function as bunds surrounding the residual voids to prevent cattle straying onto the inward slopes of the residual voids. To ensure long terms stability, the outward facing embankments may require partial rock mulch or rip rap protection.

— The water-facing embankment may need to be sheeted with a compacted layer of non-dispersive clay material to prevent unwanted seepage during significant wet weather rainfall events.

Two preliminary southern landform levee options were considered during Stage 2 (as shown on drawing PS107225-SK-1000 in Appendix A), one on the alignment of the existing levee structure (landform levee B2), and one that is less intrusive on the flood plain and will provide a free-draining landform (landform levee B1). For both options the following general design constraints and assumptions have been made:

— All areas behind the landform levee are to be free draining back to the residual voids.

— The landform levee to the west of Pit B will be constructed from highwall spoil and excess material generated from regrading the Tertiary and weathered Permian strata in the highwall. For the purposes of Stage 2 work, an assumption has been made regarding the regrade profile out of Pit B, with a slope of 25% assumed, based on the criteria developed earlier (Table 2.2), which will be confirmed once the geotechnical stability assessment has been undertaken.

— The proximity of the Nogoa River flood plain to the northern extent of Pit B will result in the need to infill the ramp into Pit B in this area and northern extent of Pit B to create a stable landform levee capable of providing PMF immunity. The proposed landform levee to the north of Pit B does not encroach any further than the current
levee structure in the Nogoa River flood plain, as this area represents a hydraulic “pinch-point” in the flood plain that constricts flow causing affluxes upstream.

— For landform levee B1, the levee to the west of Pit B has been aligned to minimise the amount of fill material required to create a free draining profile, remove levee constrictions from the Nogoa flood plain in this area, and utilise existing rehabilitated landform as part of the final landform as much as possible.

The northern levee is currently wedged between the Nogoa River Anabranch and the highwall of Pit C and D, which means there is very limited space to create a landform of the height required to provide PMF immunity to the residual void. The constraints and assumptions identified for the southern levee apply to this levee as well, with the following additional consideration:

— The proximity of the Nogoa River anabranch flood plain to the western extent of Pit C and D, will result in the need to partially backfill Pit C and D to create a stable landform levee, capable of providing PMF immunity. The proposed landform levee cannot be significantly shifted to the west without its footprint encroaching on the anabranch. This option poses some stability concerns, in that some of the void backfill would be founded on loose lowwall material, and would be of varying height, which might result in differential collapse and long term settlement. (As shown on drawing PS107225-SK-1001 in Appendix A – landform levee C2).

Further iterations of the northern and southern landform levees will be undertaken in Stage 3, that incorporate broader landform considerations, such as residual void stabilisation requirements, materials balance, and flood plain enhancement.

2.8.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE

Option 2 does not include any specific landform requirements in addition to stabilising residual voids. The existing northern and southern levees will be retained as they are, with intake structures created to encourage flood plain interaction with the Pit A, B, C and D residual voids. Localised watercourse training works will be required to achieve this interaction; however, the scale of these works do not render them landform in nature, but are more engineering features, and hence are not addressed here.

2.8.3 OPTION 3 - BACKFILL TO PMF

In addition to stabilising residual voids for all the pits comprising the Ensham RVP, Option 3 requires that residual voids within the extent of the PMF be backfilled to approximately the pre-mining landform.

To simulate the bulk earthworks requirements for backfilling of the residual voids within the extent of the PMF, Ensham have provided two sets of ground data, one representing the final void footprints of Pits A, B, C and D, and one representing the pre-mining landform. These two sets of data have been superimposed utilising 12D ground modelling software, and an earthworks balance obtained, by way of calculating level differences between the two ground models for a defined calculation area.

It is likely that backfilling will be undertaken with no systematic compactive effort, resulting in fill material settling over time. A preliminary assessment of settlement has been undertaken based on studies undertaken by Charles and Burford (1987) and Hills and Denby (2002), regarding settlement in open cut mine backfills in the UK, which were placed without systematic compaction. The studies identified the mechanisms of short-term collapse and long-term creep settlement occurring in these fills, and identified several treatments, including tolerating settlement without treatment. The reported settlement measurements indicated that most of collapse settlement would be completed within 3 or 4 years following the commencement of inundation of the fill, while creep settlement generally followed a log-time relationship. In the case of landform in remote, agricultural settings, large ground movements can be accommodated; however, it is recommended that deep fills be overfilled to compensate for settlement over time and by so doing prevent large depressed hollows forming.

The above references are believed to be relevant to this project, as coal measures and overburden materials both in the UK and on this project area consist of similar materials including mudstone, sandstone and coal. However, it is noted that
the settlements also depend on other factors such as mining methods, compaction conditions, and groundwater conditions.

The creep settlement \( S_{cl} \) at any time \( t_2 \) is predicted using equation:

\[
S_{cl} = H \cdot \alpha (\log t_2 - \log t_1) / 100, \text{ and}
\]

\( \alpha = 0.2 \), when the spoil is systematically compacted
\( \alpha = 0.4 \), when the spoil is partly/poorly compacted
\( \alpha = 0.8 \), when the spoil is uncompacted

Where \( H \) is the total original spoil depth, \( \alpha \) is creep settlement rate, \( t_1 \) is the time when creep starts.

The collapse settlement \( S_{co} \) is estimated as:

\[
S_{co} = \beta H', \text{ and}
\]

\( \beta = 0.4\% \), when the spoil is systematically compacted
\( \beta = 1.0\% \), when the spoil is partly/poorly compacted
\( \beta = 2.5\% \), when the spoil is uncompacted

Where \( \beta \) is the ratio of settlement to original spoil thickness, and \( H' \) is the inundated depth of the spoil.

The following assumptions are made for the estimation of the total settlement:

- A depth of void and hence conservative fill height of 100 m (\( H = 100m \)), and it has been assumed that the void will be inundated to approximately 20 m from the top of the fill once the pumps in pits are switched off (\( H' = 80m \)).

- Filling is by way of truck and shovel operation resulting in partly / poorly compacted fill (\( \alpha = 0.4; \, \beta = 1.0\% \)).

- The long-term settlement due to creep is the settlement at 500 years after void filling, and it has been assumed that this settlement commences immediately after completion of void filling, which has been assumed to take 2 years to complete.

- A settlement of approximately 2 m is anticipated based on the calculation methodology described above.
3 CONCLUSIONS

The Stage 2 Landform Design work has included the following:

— Identification of regulatory requirements and development of key success criteria to meet these requirements.

— Review of technical literature concerning landform rehabilitation, local and international guidelines for rehabilitation, and previous studies undertaken for the Ensham Mine, a process which will be ongoing into Stage 3 of the project.

— Visiting the Ensham site to observe the current rehabilitation strategy on site and its effectiveness.

— Extraction of pertinent criteria identified in the literature search and site practices, and identify criteria that will be adopted for the landform design.

— Limited landform modelling of specific requirements for Options 1 and 3 to identify potential issues and aspects for further consideration, order of magnitude bulk earthworks quantities, identify any alternative sub-options that may yield the required outcomes more efficiently, and identify additional activities to undertake during Stage 3, that could not be completed during Stage 2, due to lack of information or time constraints.

Based on the work undertaken, the following general conclusions have been made:

— Option 3 requires a substantial earthmoving effort to backfill residual voids to pre-mining levels within the PMF footprint. For all voids within the PMF footprint, preliminary estimates indicate more than 100,000,000 m$^3$ of backfill will be required to restore pre-mining ground levels. A high-level materials balance undertaken shows that for the PMF footprint south of the Nogoa River, there is a significant amount of spoil material surplus to the amount required for backfilling the residual voids to pre-mining levels within the PMF. This option results in the removal of quite large areas of rehabilitated land within the PMF footprint, with possibly limited benefit, and further iterations of this option will be undertaken in Stage 3 to optimise materials balance, and rationalise the extent of restoration of pre-mining landform.

— Option 2 does not require any meaningful specific landform requirements (stabilisation of all Ensham pits will be required as for the other options).

— Option 1 requires significantly less bulk earthworks than Option 3, although partial backfilling of pits may be required depending on the final alignment of the landform levees, which could be in the order of 25,000,000 m$^3$ based on preliminary quantity assessments. Alignments that cannot accommodate the construction of the entire landform external to the voids due to spatial constraints, raise several concerns in terms of the foundation stability of final landforms.

— Final stabilised residual void landforms will be developed during Stage 3, once geotechnical stability assessments have been undertaken for all the pits.
4 LIMITATIONS

Stage 2 works are based on several LIDAR surveys provided by Ensham that are likely to contain elevation discrepancies of sufficient magnitude to result in over or underestimation of quantities. Ensham should make provision in financial modelling for a range of inaccuracy in these values.

Limited landform ground modelling has been undertaken for Stage 2 due to time constraints; however, ongoing landform modelling will take place to develop these options further, as well as developing stable final void landform for all the pits comprising the ERVP.
BIBLIOGRAPHY


— Ensham Resources. (June 2017). Rehabilitation Management Plan V2.0.


APPENDIX A
SKETCH PLANS
Preferred Option 1: Landform Levee B and C Pits
ENSHAM RESOURCES PTY LTD

STAGE 2 TECHNICAL REPORT
CIVIL DESIGN

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23 MARCH 2018
Stage 2 Technical Report
Civil Design

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<td>23/03/2018</td>
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<tr>
<td>Reviewed by: C.Deaconos</td>
<td>23/03/2018</td>
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<td>23/03/2018</td>
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# TABLE OF CONTENTS

1 INTRODUCTION ............................................................................... 1

2 PREFERRED REHABILITATION OPTIONS ......................... 3

2.1 OPTION 1 – LANDFORM LEVEE ........................................... 3

2.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE ......................................................... 4

2.3 OPTION 3 – BACKFILL TO PROBABLE MAXIMUM FLOOD LEVEL (PMF) ........................................ 5

2.4 CIVIL DESIGN ELEMENTS ....................................................... 5

3 STAGE 3 DESIGN CRITERIA AND CONSIDERATIONS .......................................................... 7

3.1 OPTION 1 – LANDFORM LEVEE ........................................... 7

3.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE ........................................................ 8

3.3 OPTION 3 – BACKFILL TO PMF .......................................... 11

4 LIMITATIONS ........................................................................... 12
1 INTRODUCTION

1.1 BACKGROUND

Ensham Mine, an open cut and underground bord and pillar coal mine located approximately 35km east of Emerald, is operated by Ensham Resources Pty Ltd (Ensham), a wholly owned subsidiary of Idemitsu Australia Resources Pty Ltd (Idemitsu), on behalf of the Ensham Mine joint venture (JV) partners. The JV partners and holders of the Environmental Authority are Bligh Coal Limited, Idemitsu and Bowen Investment (Australia) Pty Ltd. EA EPML00732813, dated 26 May 2017, is the relevant environmental authority under which Ensham operates the mine.

Condition G16 of the EA states that a Residual Void Project (RVP) must be completed and submitted to the administering authority for review and comment by 31 March 2019. The minimum content of the RVP is specified within Condition G16 of the EA as:

- Terms of Reference;
- Residual Void Study;
- Progress Reports; and
- Rehabilitation success criteria for voids.

In compliance with Condition G19 of the EA, “the Residual Void Project must be carried out in accordance with the approved Terms of Reference”. A Terms of Reference (ToR) (Ensham Resources, 2017a) was approved by Queensland’s Department of Environment and Science (DES, formerly Department of Environment and Heritage Protection, DEHP) on 21 July 2017.

Condition G20 of the EA identifies the minimum content of the RVP identified in Condition G16.

In accordance with the ToR, the project has been divided into five stages:

- Stage 1 - Project Definition and Options Identification;
- Stage 2 - Preferred Options Technical Studies;
- Stage 3 - Preferred Options Detailed Design;
- Stage 4 - Most Preferred Option Identification; and
- Stage 5 - Regulatory Documentation.

Stage 1 - Project Definition and Options Identification for the RVP has been completed. The Stage 1 Options Assessment report has been prepared in draft and issued to DES, Department of Natural Resources, Mines and Energy (DNRME, formerly DNRM) and the Community Reference Group (CRG) for comment. Following receipt of comments, the report has been independently peer reviewed and revised to address peer review comments. The final report has been submitted to DES as per the requirements of the ToR.

1.2 PURPOSE

The Options Analysis workshop of Stage 1 of the RVP identified two options:

- Option 1: Landform Levee;
- Option 2: Flood Mitigation and Beneficial Use.

DES required a third option to be included in the study, being:
— Option 3: Backfill to PMF.

All three options have been advanced to Stage 2 of the RVP and are referred to as the ‘Preferred Options’.

Stage 2 is now underway. The purpose of Stage 2 is to identify the Environmental Values (EVs) in the immediate and surrounding area of Ensham Mine and determine through appropriate environmental assessment which EVs are likely to be affected by each Preferred Option. The level of detail in each environmental assessment must be consistent with Appendix B of the Terms of Reference (where appropriate) and:

— provide a description of the EV that is likely to be affected by a Preferred Option;
— detail any emissions or releases likely to be generated by a Preferred Option relative to the EV;
— describe the risk and likely magnitude of impacts of a Preferred Option on the EV; and
— describe the management practices to be implemented to prevent or minimise the potential impacts for a Preferred Option, which will be detailed in Stage 3: Preferred Options Detail Design;

The ToR specifies that Stage 2 of the RVP (Preferred Options Technical Studies) “must commence with an environmental values (EVs) workshop” and that “where it is determined that an EV is not likely to be affected by a Preferred Option, the reasons for this must be discussed and explained in the EVs workshop report”. Ensham has prepared and submitted the Stage 2 Environmental Values Workshop Report to DES, DNRME and the CRG for review and comment. The revised report has been independently peer reviewed, revised and finalised.
# 2 PREFERRED REHABILITATION OPTIONS

Three rehabilitation options have been identified for assessment as part of the Stage 1 rehabilitation strategy for the Ensham Mine, which are described below.

## 2.1 OPTION 1 – LANDFORM LEVEE

The existing northern and southern levees are currently engineered structures and require annual inspection and maintenance. This option aims to convert these maintained structures effectively into permanent landforms by augmenting the levees and the pits they protect. In limited circumstances, the levee is too close to the pit for adequate backfill to be placed and in those circumstances, partial backfilling of the pit would be required to support the levee backfill. The conceptual arrangement of the Landform Levee option is depicted in Figure 2-1 below.

![Figure 2-1: Conceptual Cross-Section 1](image1)

**OPTION 1 - Conceptual Cross-Section 1**

Adequate available space

![Figure 2-2: Conceptual Cross-Section 2](image2)

**OPTION 1 - Conceptual Cross-Section 2**

Restricted space
Outside of the areas protected by the levees, the voids would be rehabilitated to various slopes to achieve stable landforms.

2.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE

The existing northern and southern levees would be retained in their current configuration, but would incorporate engineered structures to permit off-take of flood waters to specified ARI flood events feeding water from identified watercourses to residual voids within the floodplain. Whilst pits would be rehabilitated to achieve stable landforms, the shape of the residual voids would be optimised to store water, minimise evaporative losses and maximise re-usable water storage capacity. A minimum water level would be maintained to offset groundwater head and minimise saline groundwater inflow. While Option 2 is primarily a beneficial use scheme, it may offer associated flood mitigation benefits which will be further investigated through hydraulic modelling.

Figure 2-2 provides a conceptual arrangement of this option.
It is probable that the system will be operated as two separate storage units, with A-pit and B-pit being the southern storage unit, and C-pit and D-pit the northern storage unit. Pits within a storage unit will be hydraulically linked in some way, which will be further investigated in Stage 3 of the RVP. E-pit is partially backfilled already and would not be included in the scheme, whilst F-pit and the Yongala pits are shallow and have limited storage capacity and are therefore not considered likely to be able to contribute significantly to the beneficial reuse scheme. However, they will be required to be rehabilitated in accordance with the site’s EA requirements.

Water stored in pits A, B, C and D may be used for beneficial purposes such as to supply downstream irrigation demands or in-pit uses such as ecosystem functions and recreation. Discharge would be managed to ensure that the water level in each pit does not fall below the critical level required to prevent groundwater inflow, due to losses through evaporation and spoil seepage, until the next flood inflow event.

### 2.3 OPTION 3 – BACKFILL TO PROBABLE MAXIMUM FLOOD LEVEL (PMF)

Those pits occupying the pre-mining flood plain of the Nogoa River would be backfilled to original (pre-mining) ground levels. Parts of those pits straddling the boundary of the floodplain, as defined by the PMF event extent, would also be backfilled, whilst parts lying outside of that boundary would remain unfilled. The existing levees would need to be removed. Outside of the flood plain, the residual voids would be rehabilitated to various slopes to achieve stable landforms.

Figure 2-3 provides a conceptual arrangement of this option.

![Figure 2-3: Option 3 - Conceptual arrangement](image)

### 2.4 CIVIL DESIGN ELEMENTS

Each of the Preferred Options described above will require associated civil engineering works to manage run-off, seepage or stored water in order for it to achieve desired outcomes, which may include the following work:

- design of structures to manage water ingress to, and egress from, residual voids;
- structures to facilitate the exchange of water between voids and surface watercourses in accordance with the requirements of other studies; and
— structures to regulate water ingress from watercourses in flood conditions and water discharge to receiving waters in receding conditions.
3 **STAGE 3 DESIGN CRITERIA AND CONSIDERATIONS**

Limited information is available at this stage to compile detailed design criteria for the civil engineering elements of the project, however this section provides the current understanding of the nature and extent of work to be undertaken, informs other Stage 2 studies, as well as some indication of proposed criteria to be adopted for the Stage 3 design.

### 3.1 OPTION 1 – LANDFORM LEVEE

Option 1 will require limited civil engineering design support, which will include the following:

— design of levee embankment slopes for geotechnical and erosional stability, and material selection to ensure dispersive materials are not used, or are treated, for embankment facing to reduce the likelihood of erosion (this will be undertaken as part of the geotechnical design element of the project);

— consideration of erosion protection measures for the water-facing levee embankment, which may include temporary protection to allow for vegetation establishment, or more permanent protection if velocity profiles exceed the capacity of natural erosion protection measures; and

— design of surface water drains to channel surface run-off water to, or away from final void areas in support of void hydrology requirements, or to prevent unwanted ponding of water behind levee backfill areas. This will be considered during landform design as well, with potential regrading of land to avoid the need for drains which can be susceptible to erosion and require ongoing maintenance.

Typical design criteria that are proposed for this work in Stage 3, as well as for informing other Stage 2 studies are tabulated below.

Table 3-1: Option 1 proposed design criteria

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>CRITERIA</th>
<th>DATA REQUIRED FOR DESIGN / COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levee erosion design event</td>
<td>PMF flood.</td>
<td>PMF flood model for the levee-modified flood plain to ascertain flood height / and extent of required levee.</td>
</tr>
<tr>
<td>Levee alignment</td>
<td>Upstream afflux</td>
<td>Alternative alignments for the landform levees to be considered to minimise upstream afflux resulting from the constriction of the flood plain</td>
</tr>
<tr>
<td>Freeboard on levee for PMF event</td>
<td>Minimum of 0.5 m</td>
<td>PMF flood line.</td>
</tr>
<tr>
<td>Water facing levee slope</td>
<td>To be reviewed and flattened to an erosionally stable slope that is in line with proposed post-mining land-use. Maximum 1:6 (15%, 9.5 degrees) – but 1:10 (10%, 5.7 degrees) preferred.</td>
<td>To be confirmed by stability / erosional analysis in geotechnical design stage. Spatial constraints and encroachment on the flood plain may require steeper slopes in areas, with erosion protection by way of rip rap sheeting.</td>
</tr>
<tr>
<td>Levee erosion protection options depending on PMF velocity profile</td>
<td>Vegetated levee face (with or without erosion control blanket protection to assist with vegetation development / protection) or rip rap rock protection depending on velocity / shear profile.</td>
<td>PMF flood velocity profile on levee face.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Levee erosion rip rap design</td>
<td>RIPRAP software will be used to determine suitable permanent rock sheeting should it be considered necessary.</td>
<td></td>
</tr>
<tr>
<td>Water management drain configuration</td>
<td>Trapezoidal or rounded earth drains with suitable erosion protection. Regrading of areas to achieve sheet flow in the desired drainage direction will be considered as a preferable option.</td>
<td>Void hydrology study to identify location and extent of drains. Drains typically require ongoing maintenance, and concentrate run-off which may produce erosive conditions.</td>
</tr>
<tr>
<td>Drain capacity</td>
<td>Size to be determined by time required to drain area to avoid ponding for an unacceptable period of time.</td>
<td></td>
</tr>
</tbody>
</table>

### 3.2 OPTION 2 – FLOOD MITIGATION AND BENEFICIAL USE

Option 2 proposes utilising the post-mining voids to form water storages to capture a proportion of high flow flood water from the Nogoa River, and storing this water for beneficial use. This option will prevent the development of hyper-saline water conditions in the residual voids over time, rendering it suitable for beneficial reuse such as irrigation, or for environmental or recreational use. Only Pits A and B to the south, and Pits C and D to the north of the Nogoa River are to be used for water storage. The southern pits are to be hydraulically linked in such a way that they form a single storage unit, and likewise for the northern pits, with the two storages operated either as one or independently from each other.

Water levels in the pit storages would need to be maintained at a certain minimum level to maintain water quality, and it may be necessary to encourage mixing of fresh water with stored water to prevent stratification. Based on flood mapping provided by Ensham (KBR Report BEW513-W-Rep-002), it is evident that flow in the Nogoa River does not break out of the low flow channel until somewhere between a 1 in 5 and 1 in 10-year ARI flood event, hence flow would only enter the voids through the levee inlet mechanisms in this order of frequency. Flood modelling is currently being updated by Ensham, and the findings of KBR regarding frequency of engagement of the Nogoa flood plain will be reviewed once new flood mapping is made available. Having consideration for the frequency of filling events, it may be necessary to introduce a more regular inflow of water for quality purposes, possibly by way of a river intake pump station or syphon station.

The following infrastructure may be required to support this option:

- design of inlet infrastructure at several locations to allow flood event flows to enter the pits;
- design of water release infrastructure at several locations to allow for the release of water when the pits exceed full storage level;
- stilling basins at inlet and outlet locations to avoid scour;
— inflow channel to the void impoundment areas to convey flow during high flood water filling events;
— outflow channel from the void to the nearest watercourse to convey flow during a release event;
— possible measures to ensure hydraulic connectivity of pits (between A and B pits, and C and D pits);
— low flow river intake infrastructure and pipeline to the residual voids; and
— discharge pump station and pipeline to supply water from the residual voids to downstream beneficial users when the dam is below full spill level. This discharge system will discharge to a watercourse near the voids, not directly to downstream users.

Typical design criteria, issues for consideration, and comments that apply to the Stage 3 work, and for informing other Stage 2 studies are tabulated below.

Table 3-2: Option 2 proposed design criteria

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>CRITERIA</th>
<th>DATA REQUIRED FOR DESIGN / COMMENTS</th>
</tr>
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<tbody>
<tr>
<td>Levee inlet capacity for high flow flood water</td>
<td>Unknown at this stage.</td>
<td>Void hydrology required with nominated design flows for each flood event. Flood modelling based on landform levee to determine height of flood water for each event.</td>
</tr>
<tr>
<td>Levee configuration</td>
<td>Existing 1 in 1000-year flood event immunity level levees to be retained with no raising.</td>
<td>Low probability risk of overtopping and damage in the event of more extreme flood event.</td>
</tr>
<tr>
<td>Levee inlet mechanism for high flood water inflows</td>
<td>Concrete side-spill weir in levee with rock or concrete protection. May be a stepped weir resulting in stepped increase in staging curve as water levels rise. Weir to be designed to discourage the discharge of sediment to the pit during operation.</td>
<td>Alternative options will be considered – but no mechanically operated gate structure is considered appropriate due to infrequent likelihood of operation and high probability of debris blockage and damage. Flow-through option with no control device will be considered.</td>
</tr>
<tr>
<td>Stilling basin capacity at inlet and outlet locations</td>
<td>Design flow at 1 in 1000-year flood height</td>
<td>Rock-lined vs concrete structure will be considered.</td>
</tr>
<tr>
<td>Inflow channel capacity (from weir to void)</td>
<td>Capacity of weir at 1 in 1000-year flood level + freeboard.</td>
<td>An alternative piped inflow arrangement will be considered to avoid the erosion potential of large volumes of water on steep grades in channels. Large diameter PE gravity pipes with high head differential can convey large volumes of water at high velocities.</td>
</tr>
<tr>
<td>Inflow channel configuration</td>
<td>Trapezoidal profile with rock or concrete lining and energy dissipation measures for steep grades. Channels will be modelled using HEC-RAS to identify energy and freeboard requirements. Practicality of constructing a channel discharging over the pit high wall into</td>
<td></td>
</tr>
</tbody>
</table>

Typical design criteria, issues for consideration, and comments that apply to the Stage 3 work, and for informing other Stage 2 studies are tabulated below.
the void storage needs to be considered carefully.

An alternative will be considered allowing inflows to enter on the lowwall side of the voids, utilising existing ramps as inflow channels.

| Outflow channel configuration | Ramps into the voids to be used for outflow direction. Design to be similar in nature to bywash spillway on dams or concrete weir structures, with rock erosion protection. Channels required to link outflow structure with watercourses to be engineered trapezoidal channels with rock lining. Channels will be modelled in HEC-RAS to identify hydraulic conditions. | Depending on the hydraulic gradeline through the void storage during outflow events, it may be possible to not have any outflow structure such as a weir, but a simple outflow channel to the downstream watercourse. |

| Hydraulic interconnectivity of pits | Southern voids are hydraulically balanced, and northern voids are hydraulically balanced. There will be no interconnectivity between the southern and northern voids. | Multiple land bridges currently prevent hydraulic connectivity between voids. The following will be considered: Removal of land bridges to a suitable level. Blasting to a certain depth but without removal of material to create porous land bridges. Boring or directional drilling of interconnection micro-tunnels. |

| Low flow intake capacity | Void hydrology has not been completed to date hence this has not been formally quantified - Ensham have nominated an interim flow of 1 ML per day pending the outcome of modelling. | Consideration will be given to utilising a single abstraction and pump installation to pump to the southern and northern pits on a rotational basis. |

| Low flow intake configuration | Requirement for a fixed installation for each of north and south storages to be investigated. Presence of existing river intake pump systems in the area to be investigated to gauge viability and a suitable pumping arrangement. Prudent to anchor delivery pipelines into the void to ensure discharge occurs below the minimum depth of the storage to achieve a measure of mixing. | Existing pumped intake location structure will be considered to assess the viability for incorporation in the system. |
Discharge pump station for beneficial downstream use capacity

Unknown at this stage.
Design to take cognisance of widely fluctuating pumping head. Appropriate configurations include floating pontoon pump station, inclined shaft bore pumps, submersible pumps on flotation units.
Pumped outfall will be to the outlet stilling basin or will incorporate an energy dissipation structure ahead of any receiving watercourse.

Void hydrology required with nominated minimum water level.
A significant range of operating water levels in storages create multiple issues for pump installations, including highly variable duty points, difficult in accessing and maintaining pumps, difficulty in tethering pump installations, and pipeline arrangement in the storage.

### 3.3 OPTION 3 – BACKFILL TO PMF

Option 3 proposes backfilling the residual voids within the extent of the PMF flood limit to approximately the pre-mining surface level. As such the civil engineering component, will be limited to very similar activities as those associated with Option 1.
4 LIMITATIONS

This report has been compiled with limited information regarding the nature and extent of engineering structures to be designed, particularly for Option 2, and is based on the current philosophy for the operation of this option described in the report – Stage 2 – Environmental Values Workshop, reference IAE17-REP-2-0001-0. As independent studies progress, the criteria applicable to this civil engineering component of the project will become more clear and additional criteria are likely to be added to those described in this report.