HORSE PIT EXTENSION EPBC ACT REFERRAL

APPENDIX F – PART 8 OF 9

Groundwater Impact Assessment Report 2021
Figure 4-2  Predicted Final Void Recovery
5 Sensitivity Analysis

5.1 Sensitivity Analysis

5.1.1 Calibration Sensitivity

As an additional step in the calibration process, a parameter sensitivity file containing the “composite sensitivity” of each parameter with respect to all observations was generated. The Relative Composite Sensitivity (RCS) of a parameter is obtained by multiplying its composite sensitivity by the magnitude of the value of the parameter. Therefore, RCS is a measure of the composite changes in model outputs that are incurred by a fractional change in the value of the parameter (PEST Manual, Doherty 2010).

Composite parameter sensitivities are used in identifying those parameters that may be degrading the performance of the parameter estimation process through lack of sensitivity to model outcomes. Relative Composite Sensitivity is a measure of the composite changes in the model outputs that have resulted by a change in the value of the parameter. RCS also show how much the model calibration is sensitive to an input parameter. The groundwater model is more sensitive to the parameters that have high RCS value. Where parameters have low RCS (<1), the model calibration is less sensitive to those which indicates a greater uncertainty associated with them.

The composite sensitivity values were calculated during the PEST calibration and are presented in Figure 5-1 and Figure 5-2. Figure 5-1 shows the RCS for the horizontal conductivity, anisotropy (KZ/Kx) and the slope used in the depth dependence equations used in the model (Section 2.7). Figure 5-2 shows the RCS for the specific yield, specific storage, and recharge.

Most parameters shown in Figure 5-1 have RCS of less than 1. The only exception is the slope in depth dependence equation for Q Seam that shows the calibration is highly sensitive to this parameter. In Figure 5-2, all the storage and recharge parameters have an RCS of less than 1 indicating the model has a relatively low sensitivity to these parameters.

As discussed in Section 6, the uncertainty analysis is guided by the results of this sensitivity analysis to explore more extreme values within the constraints of the model calibration statistics.
Figure 5-1 Composite Sensitivity – Kx, Kz/Kx and Slope
Figure 5-2 Composite Sensitivity – Sy, SS and Recharge
5.1.2 Calibration Identifiability

Identifiability describes a parameters capability to be constrained by the model calibration. Identifiability values range from zero to one. As identifiability approaches one, the parameter is increasingly able to be constrained. Likewise, as values approach zero the parameter is increasingly unable to be constrained by the calibration and uncertainty of model results is not reduced through calibration.

The PEST utility GENLINPRED was used to provide an estimate of parameter identifiability for each of the model parameters. Estimated identifiability values for the calibrated parameters horizontal hydraulic conductivity, Anisotropy, Specific yield and recharge are summarised in Figure 5-3 through Figure 5-7.

Figure 5-3 indicates that in general the calibration process was successful in constraining the horizontal conductivity. Notably, the conductivity of alluvium, Rewan Group, Leichhardt Seam, Vermont Seam, D Seam and Q Seam units are well constrained by calibration (high identifiability values above 0.80). The horizontal hydraulic conductivity of most of the faults generally has not been able to be constrained well during calibration, relative to their surrounding unit. The exception to this is the Isaac fault zone, which has been constrained during the calibration.

Identifiability of hydraulic conductivity anisotropy for model zones is presented in Figure 5-4. Anisotropy in the weathered Permian, Moranbah Coal Measures interburden, Fort Cooper Coal Measures overburden and Moranbah Coal Measures overburden have high identifiability values indicating these can be constrained and contribute to reducing model uncertainty. All other zones feature low values (equal to and below 0.40) and are less constrained by calibration.

In general, specific yield and specific storage of other zones in the model domain has low identifiability (Figure 5-5 and Figure 5-6). Figure 5-6 shows except in the D Seam and the interburden unit above the D seam, the calibration was not able to constrain this variable in the other layers.

The recharge zones for all the zone except the Isaac River Channel Alluvium, are highly constrained by the calibration. The other zones have low identifiability (Figure 5-7). Note that the stream channel alluvium represents a narrow zone along the Isaac River, with a small area relative to the other recharge zones. It is, therefore, considered less impactful to model predictions.
Figure 5-3 Identifiability – Horizontal Hydraulic Conductivity (Kx)
Figure 5-4 Identifiability – Anisotropy ($K_z/K_x$)
Figure 5-5 Identifiability – Specific Yield (Sy)
Figure 5-6 Identifiability – Specific Storage (SS)
Figure 5-7 Identifiability – Recharge (RCH)
5.1.3 Prediction Identifiability

Prediction identifiability describes parameters capability on impacting the model predictions. To calculate the prediction identifiability the groundwater model is run once per each parameter. The predictions included in the analysis were the project only inflows and maximum cumulative drawdown. The analysis then utilised the GENLINPRED utility to provide an estimate of parameter identifiability for each of the model parameters.

As identifiability approaches one, the parameter is increasingly able to change model predictions. On the contrary, as values approach zero the parameter is increasingly unable to change model predictions.

The Murray Darling Basin Modelling Guidelines (MDBC, 2000) recommends classifying sensitivity by the resultant changes (or contribution) to the model calibration and predictions. According to this process models can be classified as one of the four main types:

- Type I: Insignificant changes to calibration (low identifiability) and prediction (low uncertainty contribution);
- Type II: Significant changes to calibration (high identifiability) – insignificant changes to predictions (low uncertainty contribution);
- Type III: Significant changes to calibration (high identifiability) – significant changes to predictions (high uncertainty contribution); and
- Type IV: Insignificant changes to calibration (low identifiability) – significant changes to predictions (high uncertainty contribution).

Types I-III are of less concern, as these Types have an insignificant impact on model predictions or constrained by calibration. Type IV is classed as ‘a cause for concern’ as non-uniqueness in a model input might allow a range of valid calibrations but the choice of value impacts significantly on a prediction (MDBC, 2000).

To classify the sensitivity contribution to the model calibration and predictions for each model parameter, the calibration and prediction identifiability were compared against each other for each parameter.

**Figure 5-8** presents the relationship between the identifiability of the predicted Project only inflow and the identifiability of the calibration. Sensitivity classifications for the sensitivity types have been assigned using judgement based on the range of the identifiability. The results show that the key parameters that require further work to reduce their influence on predictive uncertainty in relation to Permian groundwater inflows include the specific yield of the Moranbah Coal Measures interburden (Layer 15).

As shown in **Figure 5-8**, for the inflow predictions most parameters are classified as Type I or Type II which indicates they have low uncertainty contribution in inflow predictions.

**Figure 5-9** presents the relationship between identifiability of the maximum predicted drawdown within the alluvium and the identifiability of the calibration. Sensitivity classifications for the sensitivity types have been assigned using judgement based on the range of the posterior predictions. The results show that the key parameter that require further work to reduce its influence on predictive uncertainty in relation to the maximum drawdown extent is specific storage of the Moranbah Coal Measures interburden (Layer 11).

**Figure 5-9** shows horizontal conductivity parameters in the model are mostly classified as Type II indicating they significantly impact the model calibration but have insignificant contribution in reducing uncertainty of the maximum drawdown.
Figure 5-8 Uncertainty contribution (predicted mine inflow) versus identifiability
Figure 5-9 Uncertainty contribution (maximum cumulative drawdown) versus identifiability
6 Uncertainty Analysis

A Type 3 Monte Carlo uncertainty analysis (IESC, 2018) was undertaken to estimate the uncertainty in the future impacts predicted by the model. This method operates by generating numerous alternative sets of input parameters to the deterministic groundwater flow model (realisations), executing the model independently for each realisation, and then aggregating the results for statistical analysis.

The first step in Monte Carlo analysis is to define the parameter distribution and range. For this project, the parameters are assumed to be log-normally distributed around the optimum value derived from the calibration and the standard deviation attributed to the log (base 10) of parameter is 0.5. The distribution for each parameter were checked and constrained such that upper or lower ranges do not go beyond ranges in literature for physical constraints. 1100 model realisations were generated, each having differing values of key parameters. The realisations were run, and calibration quality was assessed. In this case, models were considered to have an acceptable calibration if they achieved an SRMS less or equal to calibration SRMS of 5.4%. Of the 1100 model runs, 250 model runs were found to be meet the above criteria. These were used in all model scenarios (calibration, Cumulative Mining, Approved Mining, and No Mining) and statistically analysed for uncertainty analysis.

6.1 Parameter Distribution

Table 6-1 to Table 6-5 show the parameter ranges explored during the sensitivity and uncertainty analysis simulation.

Parameters were assumed to possess a log-Normal distribution. Instead of simple random sampling, the Latin Hypercube Sampling (LHS) method was used to create random realisations from parameter distribution. LHS aims to spread the sample points evenly across all possible values. In doing so, it divides parameter space into N intervals of equal probability and chooses one sample from each interval. The generated random numbers derived from LHS approach is distributed sufficiently across the parameter space even at the small sample size. The main advantage of LHS over simple random sampling is that a lower number of realisations are needed to obtain a reasonable convergence of the uncertainty results. The parameter distribution for the converged and calibrated model runs are provided as Appendix E.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Layer - Unit</th>
<th>Horizontal Hydraulic Conductivity (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (Log10)</td>
</tr>
<tr>
<td>1</td>
<td>Layer 1 - Alluvium</td>
<td>1.08</td>
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<tr>
<td>2</td>
<td>Layer 1 - Regolith</td>
<td>0.00</td>
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<tr>
<td>3</td>
<td>Layer 1 - Weathered Permian</td>
<td>-0.19</td>
</tr>
<tr>
<td>4</td>
<td>Layer 1 - Duaringa Formation</td>
<td>-0.30</td>
</tr>
<tr>
<td>5</td>
<td>Layer 1/2 - Tertiary Basalt</td>
<td>0.51</td>
</tr>
<tr>
<td>6</td>
<td>Layer 2 - Regolith</td>
<td>0.00</td>
</tr>
<tr>
<td>7</td>
<td>Layer 3-19- Faults_zone1</td>
<td>-0.91</td>
</tr>
<tr>
<td>8</td>
<td>Layer 3-Rewan</td>
<td>-2.63</td>
</tr>
<tr>
<td>Zone</td>
<td>Layer - Unit</td>
<td>Mean (Log10)</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>9</td>
<td>Layer 4 - RCM O/B</td>
<td>-2.16</td>
</tr>
<tr>
<td>10</td>
<td>Layer 5 - Leichhardt Seam</td>
<td>-1.02</td>
</tr>
<tr>
<td>11</td>
<td>Layer 6 - RCM I/B</td>
<td>-2.93</td>
</tr>
<tr>
<td>12</td>
<td>Layer 7 - Vermont Seam</td>
<td>-1.96</td>
</tr>
<tr>
<td>13</td>
<td>Layer 8 - RCM U/B</td>
<td>-3.00</td>
</tr>
<tr>
<td>14</td>
<td>Layer 9 - FCCM O/B</td>
<td>-3.00</td>
</tr>
<tr>
<td>15</td>
<td>Layer 10 - FCCM Seam</td>
<td>-2.94</td>
</tr>
<tr>
<td>16</td>
<td>Layer 11 - FCCM U/B</td>
<td>-0.39</td>
</tr>
<tr>
<td>17</td>
<td>Layer 12 - Q Seam</td>
<td>-1.00</td>
</tr>
<tr>
<td>18</td>
<td>Layer 13 - MCM U/B</td>
<td>0.69</td>
</tr>
<tr>
<td>19</td>
<td>Layer 14 - P Seam</td>
<td>0.69</td>
</tr>
<tr>
<td>20</td>
<td>Layer 15 - MCM I/B</td>
<td>-0.52</td>
</tr>
<tr>
<td>21</td>
<td>Layer 16 - H Seam</td>
<td>-0.98</td>
</tr>
<tr>
<td>22</td>
<td>Layer 17 - MCM I/B</td>
<td>-0.65</td>
</tr>
<tr>
<td>23</td>
<td>Layer 18 - D Seam</td>
<td>-1.00</td>
</tr>
<tr>
<td>24</td>
<td>Layer 19 - MCM U/B</td>
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</tr>
<tr>
<td>25</td>
<td>Layer 3-19 - Faults zone 2</td>
<td>-0.46</td>
</tr>
<tr>
<td>26</td>
<td>Layer 7 - Faults zone 3</td>
<td>-0.32</td>
</tr>
<tr>
<td>27</td>
<td>Layer 8 - Faults zone 4</td>
<td>-0.40</td>
</tr>
<tr>
<td>28</td>
<td>Layer 2 - Regolith under alluvium</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Standard deviation = 0.5 order of magnitude for all units.
O/B = Overburden.
I/B = Interburden.
U/B = Underburden.
RCM = Rangal Coal Measures.
FCCM = Fort Cooper Coal Measures.
MCM = Moranbah Coal Measures.
Table 6-2 Uncertainty Parameter Range for Vertical to Horizontal Conductivity (Kz/Kx)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Layer - Unit</th>
<th>Anisotropy (Kz/Kx)</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (Log10)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Layer 1 - Alluvium</td>
<td>-0.70</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>2</td>
<td>Layer 1 - Regolith</td>
<td>-1.00</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>3</td>
<td>Layer 1 - Weathered Permian</td>
<td>-1.18</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>4</td>
<td>Layer 1 - Duaringa Formation</td>
<td>-1.25</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>5</td>
<td>Layer 1/2 - Tertiary Basalt</td>
<td>-1.00</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>6</td>
<td>Layer 2 - Regolith</td>
<td>-1.52</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>7</td>
<td>Layer 3-19 - Faults zone 1</td>
<td>-1.02</td>
<td>No constraint</td>
</tr>
<tr>
<td>8</td>
<td>Layer 3 - Rewan</td>
<td>-1.11</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>9</td>
<td>Layer 4 - RCM O/B</td>
<td>-1.01</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>10</td>
<td>Layer 5 - Leichhardt Seam</td>
<td>-2.66</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>11</td>
<td>Layer 6 - RCM I/B</td>
<td>-0.97</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>12</td>
<td>Layer 7 - Vermont Seam</td>
<td>-1.43</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>13</td>
<td>Layer 8 - RCM U/B</td>
<td>-2.65</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>14</td>
<td>Layer 9 - FCCM O/B</td>
<td>-1.00</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>15</td>
<td>Layer 10 - FCCM Seam</td>
<td>-0.79</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>16</td>
<td>Layer 11 - FCCM U/B</td>
<td>-2.33</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>17</td>
<td>Layer 12 - Q Seam</td>
<td>-0.70</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>18</td>
<td>Layer 13 - MCM U/B</td>
<td>-0.70</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>19</td>
<td>Layer 14 - P Seam</td>
<td>-1.29</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>20</td>
<td>Layer 15 - MCM I/B</td>
<td>-1.33</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>21</td>
<td>Layer 16 - H Seam</td>
<td>-2.14</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>22</td>
<td>Layer 17 - MCM I/B</td>
<td>-1.21</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>23</td>
<td>Layer 18 - D Seam</td>
<td>-1.42</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>24</td>
<td>Layer 19 - MCM U/B</td>
<td>-2.23</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>25</td>
<td>Layer 3-19 - Faults zone 2</td>
<td>-1.02</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>26</td>
<td>Layer 7 - Faults zone 3</td>
<td>-2.99</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>27</td>
<td>Layer 8 - Faults zone 4</td>
<td>-2.21</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>28</td>
<td>Layer 2 - Regolith under alluvium</td>
<td>-2.11</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>

Standard deviation = 0.5 order of magnitude for all units.
### Table 6-3 Uncertainty Parameter Range for Specific Yield

<table>
<thead>
<tr>
<th>Zone</th>
<th>Layer - Unit</th>
<th>Specific Yield (Sy)</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (Log10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Layer 1 - Alluvium</td>
<td>-1.60</td>
<td>No constraint</td>
</tr>
<tr>
<td>2</td>
<td>Layer 1 - Regolith</td>
<td>-1.67</td>
<td>&lt; Sy_Alluvium; &lt; 0.15</td>
</tr>
<tr>
<td>3</td>
<td>Layer 1 - Weathered Permian</td>
<td>-2.73</td>
<td>&lt; Sy_Alluvium; &lt; 0.15</td>
</tr>
<tr>
<td>4</td>
<td>Layer 1 - Duaringa Formation</td>
<td>-1.71</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>5</td>
<td>Layer 1/2 - Tertiary Basalt</td>
<td>-1.74</td>
<td>&lt; Sy_Alluvium; &lt; 0.1</td>
</tr>
<tr>
<td>6</td>
<td>Layer 2 - Regolith</td>
<td>-1.30</td>
<td>&lt; Sy_Alluvium; &lt; 0.15</td>
</tr>
<tr>
<td>7</td>
<td>Layer 3-19 - Faults_zone 1</td>
<td>-2.09</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>8</td>
<td>Layer 3 - Rewan</td>
<td>-2.02</td>
<td>&lt; Sy_Alluvium; &lt; 0.1</td>
</tr>
<tr>
<td>9</td>
<td>Layer 4 - RCM O/B</td>
<td>-2.00</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>10</td>
<td>Layer 5 - Leichhardt Seam</td>
<td>-3.00</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>11</td>
<td>Layer 6 - RCM I/B</td>
<td>-2.00</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
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<td>12</td>
<td>Layer 7 - Vermont Seam</td>
<td>-2.68</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>13</td>
<td>Layer 8 - RCM U/B</td>
<td>-2.40</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>14</td>
<td>Layer 9 - FCCM O/B</td>
<td>-2.98</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>15</td>
<td>Layer 10 - FCCM Seam</td>
<td>-2.46</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>16</td>
<td>Layer 11 - FCCM U/B</td>
<td>-2.34</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>17</td>
<td>Layer 12 - Q Seam</td>
<td>-3.00</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>18</td>
<td>Layer 13 - MCM U/B</td>
<td>-2.76</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>19</td>
<td>Layer 14 - P Seam</td>
<td>-2.80</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>20</td>
<td>Layer 15 - MCM I/B</td>
<td>-2.57</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>21</td>
<td>Layer 16 - H Seam</td>
<td>-2.74</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>22</td>
<td>Layer 17 - MCM I/B</td>
<td>-2.99</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>23</td>
<td>Layer 18 - D Seam</td>
<td>-3.00</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>24</td>
<td>Layer 19 - MCM U/B</td>
<td>-2.42</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>25</td>
<td>Layer 3-19 - Faults zone 2</td>
<td>-2.59</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>26</td>
<td>Layer 7 - Faults zone 3</td>
<td>-2.22</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>27</td>
<td>Layer 8 - Faults zone 4</td>
<td>-2.67</td>
<td>&lt; Sy_Alluvium; &lt; 0.05</td>
</tr>
<tr>
<td>28</td>
<td>Layer 2 - Regolith under alluvium</td>
<td>-2.77</td>
<td>&lt; Sy_Alluvium; &lt; 0.15</td>
</tr>
</tbody>
</table>

Standard deviation = 0.5 order of magnitude for all units.
Table 6-4  Uncertainty Parameter Range for Specific Storage (1/m)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Layer - Unit</th>
<th>Specific Storage (SS) 1/m</th>
<th>Mean (Log10)</th>
<th>Constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Layer 1 - Alluvium</td>
<td>-5.83</td>
<td>No constraint</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Layer 1 - Regolith</td>
<td>-5.55</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Layer 1 - Weathered Permian</td>
<td>-6.99</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Layer 1 - Duaringa Formation</td>
<td>-6.49</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
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</tr>
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<td>6</td>
<td>Layer 2 - Regolith</td>
<td>-6.75</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Layer 3-19- Faults zone1</td>
<td>-5.52</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Layer 3-Rewan</td>
<td>-6.25</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Layer 4 - RCM O/B</td>
<td>-5.48</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Layer 5 - Leichhardt Seam</td>
<td>-6.30</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Layer 6 - RCM I/B</td>
<td>-6.30</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Layer 7 - Vermont Seam</td>
<td>-6.30</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Layer 8 - RCM U/B</td>
<td>-5.89</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Layer 9 - FCCM O/B</td>
<td>-6.28</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Layer 10 - FCCM Seam</td>
<td>-5.64</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Layer 11 - FCCM U/B</td>
<td>-5.66</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Layer 12 - Q Seam</td>
<td>-5.60</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Layer 13 - MCM U/B</td>
<td>-5.43</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Layer 14 - P Seam</td>
<td>-5.64</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Layer 15 - MCM I/B</td>
<td>-5.30</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Layer 16 - H Seam</td>
<td>-6.16</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Layer 17 - MCM I/B</td>
<td>-5.87</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Layer 18 - D Seam</td>
<td>-5.32</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Layer 19 - MCM U/B</td>
<td>-6.15</td>
<td>&lt; SS_Alluvium; &lt; 5 x 10^-5</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Layer 3-19- Faults zone 2</td>
<td>-6.24</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Layer 7 - Faults zone 3</td>
<td>-5.42</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Layer 8 - Faults zone 4</td>
<td>-6.13</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Layer 2 - Regolith under alluvium</td>
<td>-5.03</td>
<td>&lt; SS_Alluvium</td>
<td></td>
</tr>
</tbody>
</table>

Standard deviation = 0.5 order of magnitude for all units.
### Table 6.5  Uncertainty Ranges for Recharge Rates

<table>
<thead>
<tr>
<th>Zone</th>
<th>Unit</th>
<th>Mean % of rainfall</th>
<th>Constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Other Alluvium</td>
<td>0.23</td>
<td>&gt;Regolith</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;Weathered Permian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;Duaringa Formation</td>
</tr>
<tr>
<td>2</td>
<td>Regolith</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Weathered Permian</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Duaringa Formation</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Tertiary Basalt</td>
<td>0.30</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Alluvium Isaac River Channel</td>
<td>0.52</td>
<td>&gt;Regolith</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;Weathered Permian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;Duaringa Formation</td>
</tr>
<tr>
<td>7</td>
<td>Alluvium Isaac River</td>
<td>0.23</td>
<td>&gt;Regolith</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;Weathered Permian</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>&gt;Duaringa Formation</td>
</tr>
</tbody>
</table>

Standard deviation = 0.5 order of magnitude for all units.

### 6.2 Uncertainty Results

#### 6.2.1 Uncertainty of Mine Inflows

**Figure 6-1** presents the uncertainty of groundwater inflow into the mine due to the Project from start of the Project (January 2025) that is, four years after the start of cumulative prediction modelling to the end of the prediction model (January 2056). The figure shows the predicted inflows for the base case model and different percentiles including 5th, 33rd, 50th, 66th and 95th prediction bounds. Based on the IESC (2018) guidelines these represent:

- 5th percentile indicates it is very likely the outcome is larger than this value,
- 5th – 33rd indicates it is likely that the outcome is larger than this value,
- 33rd - 66th indicate it is as likely as not that the outcome is larger or smaller than this value,
- 67th - 95th indicates it is unlikely that the outcome is larger than this value, and
- 95th percentile indicates it is very unlikely the outcome is larger than this value.

The bounds in the figure demonstrate the uncertainty within the predicted inflow rate. The bounds show that the calibrated base case model is below the 50th percentile.
Figure 6-1 shows that, while the realisations created in uncertainty analysis provide a reasonable fit to calibration datasets, they generally predict higher inflows than what is reported for the base case (Section 3.5). This can be seen in the figure by comparing the predicted inflow in the base case and the 50th percentile predicted inflow. The difference between the base case inflow and the 50th percentile is likely due to specific yield values in the base case. The specific yield values in the calibrated model were generally at the lower end of the parameter range (0.1 %). While the value of 0.1 % for specific yield for coal seam and interburden is reasonable and consistent with the literature, there were no measured inflow data available to constrain this parameter during the calibration. Therefore, the uncertainty analysis has tested the model with higher values for specific yield and this resulted in higher 50th percentile inflow comparing to the base case (see Appendix E).

As shown in Figure 6-1, the maximum mine inflow in the uncertainty analysis was 1,800 ML/year (4.92 ML/day) (very unlikely outcome is larger than this value). The 5th to 95th range in mine inflows for the 2025 to 2056 period was 14.7 ML/year (0.04 ML/day) to 589.11 ML/year (1.61 ML/day).

![Figure 6-1 Mine Inflow Uncertainty](image)
6.2.2 Groundwater Drawdowns

To illustrate the level of uncertainty in the extent of predicted drawdown, the base case maximum drawdown and the 50th percentile maximum drawdown extent were compared to the maximum drawdown extent for the 5th and 95th percentiles.

The uncertainty analysis results did not show any incremental drawdown impacts greater than 1 m for the Quaternary alluvium as a result of mining at the Project.

Figure 6-2 shows the uncertainty in the extent of predicted 1 m maximum incremental drawdown in regolith. As shown in this figure, the 5th, 50th and 95th percentile maximum drawdowns in the regolith are localised in the northern boundary of the Project area.

Figure 6-3 and Figure 6-4 show the uncertainty in the extent of predicted 1 m maximum incremental drawdown in the Q Seam and H Seam. The figures show that the 95th percentile drawdown in Q Seam and H Seam extends between 10 and 12 km to the north and east of the Project area (down-dip).

6.2.3 Uncertainty of Drawdown at Water Supply Bores

As discussed in Section 3.4.1, the 2020 bore census identified three active water supply and stock bores near to the Project. These bores are Grosvenor Downs 1, Coolibah Downs 01 and Winchester Downs 01 located less than 7 km to the east of the Project area (SLR, 2021a). Grosvenor Downs 1 is installed in the alluvium while the other two bores access the Fort Cooper Coal Measures. None of these bores are predicted to be impacted as a result of mining activities at the Project.

The 95th percentile (very unlikely) maximum drawdown calculated from the uncertainty analysis did show drawdowns greater than 1 m due to the Project in two of the Fort Cooper Coal Measures bores. Table 6-6 summarises the 95th percentile maximum drawdown at the two water supply bores predicted to be impacted during mining to 2056. Both bores have screen elevations that correspond to the layer representing the underburden of the Fort Cooper Coal Measures in the model (i.e. layer 11). The locations of the two Fort Cooper Coal Measures bores that may be impacted are shown in Figure 6-5 along with the model drawdown predictions for layer 11.

Table 6-6 Predicted Drawdown at Water Supply Bores

<table>
<thead>
<tr>
<th>Bore</th>
<th>Easting</th>
<th>Northing</th>
<th>Model Layer</th>
<th>Geology</th>
<th>Baseline Water Level (mbgl)*</th>
<th>Simulated pre-mining Water Level (mAHD)</th>
<th>95th percentile Maximum Drawdown Due to Project (m)</th>
<th>95th percentile Maximum Cumulative Drawdown (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coolibah Downs 01</td>
<td>617388</td>
<td>617388</td>
<td>11</td>
<td>FCCM</td>
<td>191.5</td>
<td>205.6</td>
<td>1.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Winchester Downs 01</td>
<td>618483</td>
<td>618483</td>
<td>11</td>
<td>FCCM</td>
<td>195.7</td>
<td>202.5</td>
<td>1.3</td>
<td>8.7</td>
</tr>
</tbody>
</table>

Note: Coordinates in GDA94 Z55
Baseline water level from SLR (2021a)

The uncertainty results showed no water supply bores in the alluvium are predicted to experience drawdowns greater than 1 m due to the Project.
LEGEND

- ▲ HPE Bore Census (2021) - Water Supply and Stock
- ○ ODS Bore Census (2017) - Water Supply and Stock
- ■ Base Case
- - - Major Drainage
- --- Model Boundary
- □ Model Grid
- ■ Project Mining Lease Boundary
- ▒ Surrounding Mines
- - Horse Pit Extension Project Area

Uncertainty in Predicted 1m Maximum Incremental Drawdown in Regolith
Uncertainty in Predicted 1m Maximum Incremental Drawdown in Q Seam (Layer 12)
Uncertainty in Predicted 1m Maximum Incremental Drawdown in H Seam (Layer 16)
Location of Water Supply Bores that may be Impacted and Uncertainty in Predicted 1m Maximum Incremental Drawdown in lower FCCM (Layer 11)
6.2.4 Number of realisations

As discussed above, 250 realisations met the calibration criteria and were selected as calibrated realisations. The predictive model was run using the 250 parameters sets. The results from the predictive model were used to conduct statistical analyses to assess if additional realisations were likely to provide results that would significantly change the reported predictive results. The 95% confidence interval was calculated for the mine inflows and the maximum drawdown.

Figure 6-6 and Figure 6-7 show the 95% confidence intervals of the median and maximum drawdown and predicted inflows, as well as the variance of the median and maximum drawdown and predicted inflows as more realisations are added to the uncertainty analysis. For example, the 95% confidence interval for the maximum drawdown is calculated by first estimating the maximum drawdown for each realisation and then calculating the 95% confidence interval of the maximum drawdowns as each realisation is added to the dataset. As shown in Figure 6-6 and Figure 6-7, additional realisations are unlikely to significantly increase or decrease the confidence intervals of predictions of mine inflows and maximum drawdowns. Therefore, the results from the 250 realisations are considered representative and used for predicted drawdown and indirect water take (alluvium and surface water).

![Figure 6-6 95% Confidence Interval for Pit Inflows](image-url)
Figure 6-7 95% Confidence Interval for Maximum Drawdowns
6.2.5 Uncertainty of Influence on Alluvium and Surface Water Flow

The uncertainty analysis results showed that even for the 95th percentile prediction, which is a very unlikely outcome, the indirect take from the alluvium and the change in Isaac River flow loss due to the Project were insignificant.
7 Model Confidence Level Classification

The groundwater modelling was conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al. 2012), the MDBC Groundwater Flow Modelling Guideline (MDBC 2001) and the released IESC Explanatory Note for Uncertainty Analysis (IESC 2018). These are mostly generic guides and do not include specific guidelines on special applications, such as underground coal mine modelling.

The Australian Groundwater Modelling Guidelines has replaced the model complexity classification of the previous MDBC Groundwater Flow Modelling Guideline by a “model confidence level” (Class 1, Class 2 or Class 3 in order of increasing confidence) typically depending on:

- Available data (and the accuracy of that data) for the conceptualisation, design and construction.
- Calibration procedures that are undertaken during model development.
- Consistency between the calibration and predictive analysis.
- Level of stresses applied in predictive models.

It is generally expected that a model confidence level of Class 2 is required for mining environmental impact assessment. Table 7-1 (based on Table 2.1, Barnett et al. 2012) summarises the classification criteria and shows a scoring system allowing model classification. The groundwater model developed for this Groundwater Assessment may be classified as primarily Class 2 (effectively “medium confidence”) with some items meeting the higher Class 3 criteria, and therefore the model is considered fit for purpose for this Project context.
## Table 7-1  Groundwater Model Classification Table

<table>
<thead>
<tr>
<th>Class</th>
<th>Data</th>
<th>Calibration</th>
<th>Prediction</th>
<th>Indicators</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not much.</td>
<td>Not Possible.</td>
<td>Timeframe&gt;&gt;calibration. Long stress periods. Transient prediction but steady state calibration. Bad verification.</td>
<td>Timeframe&gt;10x. Stresses&gt;5x. Mass balance&gt;1% (or single 5%). Properties&lt;&gt;Field. Bad discretisation. No review.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Spares.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not metered usage.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remote climate data.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not Possible. Large error statistics. Inadequate data spread. Targets incompatible with model purpose.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeframe&gt;&gt;calibration. Long stress periods. Transient prediction but steady state calibration. Bad verification.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeframe&gt;10x. Stresses&gt;5x. Mass balance&gt;1% (or single 5%). Properties&lt;&gt;Field. Bad discretisation. No review.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeframe=3-10x. Stresses=2-5x. Mass balance&lt;1%. Properties&lt;&gt;Field measurements. Some key coarse discretisation. Reviewed by hydrogeo.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Some.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor coverage.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Some usage info.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baseflow estimates.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeframe=3-10x. Stresses=2-5x. Mass balance&lt;1%. Properties&lt;&gt;Field measurements. Some key coarse discretisation. Reviewed by hydrogeo.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td></td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>Lots.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good aquifer geometry.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good usage info.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Local climate info.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>K measurements Hi-res DEM.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good performance stats. Long-term trends replicated. Seasonal fluctuations OK. Present day data targets. Head and flux targets.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeframe~calibration. Similar stress periods. Similar stresses to those in calibration. Steady state prediction consistent with steady state calibration. Good verification.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timeframe&lt;3x. Stresses&lt;2x. Mass balance&lt;0.5% Properties~Field measurements. Some key coarse discretisation. Reviewed by modeller.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count</td>
<td></td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Count: 6
8 Groundwater Model and Data Limitations

The IESC *Uncertainty analysis – Guidance for groundwater modelling within a risk management framework* (2018) identifies four key sources of scientific uncertainty affecting groundwater model simulations:

- Structural/conceptual.
- Parameterisation.
- Measurement error.
- Scenario uncertainties.

These four sources of scientific uncertainty have been qualitatively assessed with regards key aspects of the CVM groundwater model, as presented in Table 8-1.

Overall, the model captures depressurisation due to active mining. The model is numerically stable with no mass balance error. The model shows a good fit between observed and modelled groundwater levels (Section 2.6.1). A depth dependence function was used for hydraulic conductivity, with the calibrated values showing a good fit to observed data as presented in Section 2.7. Overall, the model is considered fit for purpose to achieve the objectives outlined in Section 1 based on the data provided and the project timeframe.

In case of future use of the model, updates could be conducted to further refine the model if it was deemed that an increase in model confidence level was required, but the applicability of this would be dependent on the purpose of the future modelling and availability of data to inform future changes. As it stands, the current model is deemed fit for purpose for the Project impact assessment.
Table 8-1  Groundwater Model and Data Limitations

<table>
<thead>
<tr>
<th>Type</th>
<th>Part</th>
<th>Status</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural/Conceptual</td>
<td>Grid and Model Extent</td>
<td>Fit for purpose</td>
<td>The model has an unstructured Voronoi grid that includes detailed cell refinement around site, neighbouring mines and along drainage features.</td>
</tr>
<tr>
<td></td>
<td>Layers</td>
<td>Fit for purpose</td>
<td>Top of layer 1 incorporates site LiDAR data</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fit for purpose</td>
<td>Representation of alluvium based on CSIRO (2015) regolith mapping and refined based on site drill data.</td>
</tr>
<tr>
<td>Conceptualisation</td>
<td></td>
<td>Fit for purpose</td>
<td>The local structure of the geology is based on detailed data at site (CVM Mine geology model), and regional model geometry (outside of site) interpolated based on neighbouring mines geology models (Winchester South, Lake Vermont, Moorvale South and Olive Downs South) and geological mapping. Geophysical surveys across the Project Area have identified minor faulting in the CVM area. Faulting is typically confined to the coal seams of the Moranbah Coal Measures. Thrust faults are the dominant structural feature in the Project Area and show throws range between 3 and 15m and average 6.6m. Therefore, no geological structures (i.e. faults) have been included within the Project area in the model other than through layer displacements from the site geological model. The most significant geological structures in the area is the Jellinbah Fault Zone which is located remote from the site and will not be intersected by mining. Therefore, its influence on the groundwater regime in the CVM area is likely to be very limited.</td>
</tr>
<tr>
<td>Conceptualisation</td>
<td></td>
<td>Fit for purpose</td>
<td>Ecological Service Professionals (ESP, 2020) undertook an environment assessment of the condition of the aquatic ecosystems in the vicinity of the Project Area in April 2020. This data on known GDEs (location and interaction) have been considered and incorporated.</td>
</tr>
<tr>
<td>Conceptualisation</td>
<td></td>
<td>Fit for purpose</td>
<td>The Permian coal measures outcrop along the western edge of the site. Therefore, how this is captured within the model influences the model predictions. The structure of the coal seams was checked to ensure it matches observed and mapped geology. The predictions of drawdown adjacent to mining was checked and the model shows a good fit between modelled and observed trends.</td>
</tr>
<tr>
<td>Type</td>
<td>Part</td>
<td>Status</td>
<td>Comment</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------------------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Conceptualisation</td>
<td>Saturated Extent of Alluvium and Regolith</td>
<td>Fit for purpose</td>
<td>Site monitoring network includes 4 bores mapped within alluvium that were used to inform saturated extent of alluvium locally at site and for calibration targets. The model slightly under or over-predicts groundwater levels in alluvium, but generally within 5 m of observed levels. For the extent alluvium in the vicinity of the Project Area (i.e., alluvium along Harrow Creek and Cherwell Creek) a slope analysis and Google satellite images were used. Any additional data or study on alluvium extent and thickness at CVM should be reviewed and captured (where relevant) in future updates of the model. Such improvements are not deemed required for the Project impact assessment however.</td>
</tr>
<tr>
<td>Parameterisation</td>
<td>Hydraulic Conductivity – Depth Dependence</td>
<td>Fit for purpose, future improvements possible</td>
<td>Field testing of hydraulic conductivity (horizontal and to a lesser extent vertical) has been conducted in the area. Hydraulic conductivity test results from the other sites within the model domain were also considered. The data shows a general decline in hydraulic conductivity with depth that is replicated in the model. Further conductivity tests and measurements of storage properties can improve model calibration and refine model predictions, but are not deemed required for the Project impact assessment.</td>
</tr>
<tr>
<td></td>
<td>Spoil Properties</td>
<td>Fit for purpose, future improvements possible</td>
<td>Limited site-specific data is available for the spoil. Spoil properties were adopted using the previous studies.</td>
</tr>
<tr>
<td></td>
<td>Rivers</td>
<td>Fit for purpose, future improvements possible</td>
<td>Isaac River stage height is changed temporally in the historical calibration model based on observed levels from government stream gauges, and long term annual average level assumed in the predictive model. Watercourses within and in the vicinity of the Project Area such as Harrow Creek and Cherwell Creek are ephemeral and only flow briefly after rainfall. Therefore, river stage height of zero was assigned to these watercourses in the model. Measurements of flow rates and stage height in the rivers can help with improving the model calibration and refining the model predictions, but are not deemed required for the Project impact assessment.</td>
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<td>Measurement Error</td>
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<td>Bore logs and construction details available for most site bores, and long-term site water level data available for various units.</td>
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<td>Landholder Bore Data Quality</td>
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<td>Impacts on registered landholder bores are influenced by the assumptions of the bore design, target geology and use.</td>
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<td>Timeseries water level data from the site as well as the neighbouring mines (Winchester South, Moorvale South, Olive Downs South and Lake Vermont, Peak Downs, Moranbah South) for the alluvium and Permian coal measures.</td>
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<td>Transient warm-up (1988-2008) and transient (2008 to 2020) calibration model set up and a depth dependence function used and calibration to water levels conducted using automated (PEST) and manual methods.</td>
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<td>Uncertainties</td>
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<td>Model captures approved and proposed open cut mining at CVM. The model also includes future mining at Sarajii, Peak Downs and Grosvenor mainly based on publicly available data. The actual future mine progression for these sites may vary.</td>
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<td>Uncertainty analysis has been conducted by stochastic modelling using an adapted Monte Carlo method with modern software packages. The Latin Hypercube Sampling (LHS) method was used to create random realisations from parameter and PEST++ was used to orchestrate the model runs. The uncertainty analysis quantified the variability in predictions with changes in maximum predicted drawdowns, mine inflows, impact on alluvium flow and impacts on surface water flow.</td>
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9 Conclusions

The numerical groundwater model developed for the Project successfully achieved the modelling objectives, as outlined in Section 1. Model calibration statistics are within suggested guidelines (Middlemis et al., 2001) and mass balance errors remain low, through the model calibration and predictive modelling. Model construction considers all available data, including the current site mine plan and site geological model for the Project Area. The uncertainty analysis has demonstrated a low likelihood for the Project to impact on alluvial water levels, with drawdown to layers mostly contained within the Project Area. The model serves as a suitable representation of possible transient groundwater conditions within the Study Area, over the life of the Project, however, the uncertainty in predictions should be acknowledged.

Limited site-specific information on aquifer storage and specific yield parameters were available during calibration. As more site-specific hydraulic data becomes available, new data should be compared with the calibrated parameters achieved and the validity of the model calibration should be assessed. Additional site-specific data is expected to “tighten” uncertainty bounds for model prediction results. Predictive sensitivity indicates that mine inflows are most sensitive to the specific yield values of the Permian units. However, calibration sensitivity to these parameters is relatively low. Future work should consider opportunities to further constrain values of these parameters. However, as it stands, the model is deemed fit for purpose for the Project impact assessment without such improvements.
10 References


GHB, 2017, Caval Ridge Mine Numerical Groundwater Model, Prepared for BHP, Project number 31/34006/03, December 2017


(DO NOT DELETE SECTION BREAK)
APPENDIX A

Calibration Residuals
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APPENDIX B

Calibration Hydrographs
The images depict line graphs showing water level data over time for different locations.

**2372-VWP2**
- Observed values are marked with dots.
- Simulated values are represented by a line.

**2372-VWP3**
- Similar to 2372-VWP2.

**2372-VWP4**
- Similar to 2372-VWP2.

**2375-MB2**
- Similar to 2372-VWP2.

**2375-VWP1**
- Similar to 2372-VWP2.

**2375-VWP2**
- Similar to 2372-VWP2.

**2375-VWP3**
- Similar to 2372-VWP2.

**2393-MB1**
- Similar to 2372-VWP2.
APPENDIX C

Hydraulic Parameters and Recharge Zone Distribution
LEGEND

- Model Boundary
- Project Mining Lease Boundary
- Surrounding Mines
- Model Grid

Parameter Zone
- Duaringa Formation
- Regolith
- Regolith under Alluvium
- Tertiary Basalt
- Weathered Permian

FIGURE C-2

Hydraulic Parameter Zone Distribution
Layer 2

H:\Projects-SLR\620-BNE\620.13593 BHP - Horse Pit Approvals\07 CADGIS\ArcGIS\Groundwater Appendix C\62013593 C-2 Hydraulic Zone Distribution (Layer 2).mxd
Hydraulic Parameter Zone Distribution
Layer 4

FIGURE C-4
**LEGEND**

- Model Boundary
- Project Mining Lease Boundary
- Surrounding Mines
- Model Grid

Parameter Zone
- RCM-interburden
- Faults

Hydraulic Parameter Zone Distribution
Layer 6

FIGURE C-6
Hydraulic Parameter Zone Distribution
Layer 7

FIGURE C-7

Legend:
- Model Boundary
- Project Mining Lease Boundary
- Surrounding Mines
- Model Grid
- Parameter Zone
  - Vermont Seam
  - Faults

Scale: 1:470,000
GDA 1994 MGA Zone 55
07-May-2021
620.13593
LEGEND

- Model Boundary
- Project Mining Lease Boundary
- Surrounding Mines
- Model Grid
- Parameter Zone
  - FCCM Seams
  - Faults

Hydraulic Parameter Zone Distribution
Layer 10

Scale: 1:470,000
GDA 1994 MGA Zone 55
07-May-2021
620.13593

FIGURE C-10
APPENDIX D

Cumulative Drawdown Predictions
Maximum Cumulative Drawdown in Quaternary Alluvium (Layer 1)