Project No 254 (King Vol UWIR and dewatering assessment)

PO Box 788
(27 Scheu Street)
INNISFAIL
Queensland 4860
AUSTRALIA
Phone 617 4061 3103
Fax 617 4061 8094

Project 254 King Vol UWIR and dewatering assessment
December 2017

KING VOL UNDERGROUND WATER IMPACT REPORT
AND DEWATERING ASSESSMENT
AUCTUS RESOURCES PTY LTD
## CONTENTS

1  **INTRODUCTION** …………………………………………………………………………………… 9  
   1.1 Assumptions and limitations ……………………………………………………………………… 9  
   1.2 Revision of the UWIR ……………………………………………………………………………… 9

2  **LEGISLATIVE REQUIREMENTS OF A UWIR** ……………………………………… 14  
   2.1 Water Act 2000 (QLD) ……………………………………………………………………………… 14  
      2.1.1 Section 376 …………………………………………………………………………………… 14  
   2.2 EPOLA Act ………………………………………………………………………………………… 16  
   2.3 UWIR guideline …………………………………………………………………………………….. 16  
   2.4 Report structure …………………………………………………………………………………….. 16

3  **PROJECT AREA** …………………………………………………………………………………… 17  
   3.1 Project description ………………………………………………………………………………… 17  
   3.2 Climate ……………………………………………………………………………………………… 19  
   3.3 Catchment hydrology ……………………………………………………………………………… 20  
   3.4 Water plans ………………………………………………………………………………………… 22  
   3.5 Groundwater management areas ……………………………………………………………….. 22

4  **UNDERGROUND WATER EXTRACTIONS (PART A)** ………………………………… 23  
   4.1 Quantity of water already produced …………………………………………………………….. 23  
   4.2 Quantity of water to be produced in the next three years …………………………………… 27  
      4.2.1 Method of extraction ………………………………………………………………………… 27  
      4.2.2 Estimate based on borefield capacity ……………………………………………………… 27  
      4.2.3 Estimate based on 2017 numerical model ………………………………………………… 27
5  AQUIFER INFORMATION AND UNDERGROUND WATER FLOW (PART B).....32

5.1 Overview of aquifers..............................................................................................32
5.2 Chillagoe Formation – western limestone............................................................37
  5.2.1 Description.......................................................................................................37
  5.2.2 Underground water flow and aquifer interactions .......................................40
  5.2.3 Underground water level trend analysis .....................................................44
5.3 Chillagoe Formation – eastern limestone.............................................................46
  5.3.1 Description.......................................................................................................46
  5.3.2 Underground water flow and aquifer interactions .......................................46
  5.3.3 Underground water level trend analysis .....................................................46
5.4 Chillagoe Formation – arkose...............................................................................47
  5.4.1 Description.......................................................................................................47
  5.4.2 Underground water flow and aquifer interactions .......................................47
  5.4.3 Underground water level trend analysis .....................................................48

6  PREDICTIONS OF GROUNDWATER IMPACTS (PART C) .................................49

6.1 Model setup............................................................................................................49
6.2 Model code / platform .........................................................................................49
6.3 Model domain .......................................................................................................49
  6.3.1 Layers.........................................................................................................52
6.4 Model boundary conditions ..................................................................................52
  6.4.1 Seepage faces...............................................................................................52
  6.4.2 Recharge.......................................................................................................52
  6.4.3 Underground mine development...................................................................53
6.5 Hydraulic parameters and model inputs...............................................................54
  6.5.1 Observations.................................................................................................56
6.6 Calibration results..................................................................................................56
  6.6.1 Objective.......................................................................................................56
  6.6.2 Methodology.................................................................................................56
  6.6.3 Results..........................................................................................................57
Project No 254 (King Vol UWIR and dewatering assessment)

6.7 Sensitivity ......................................................................................................... 59

6.8 Predictive Model for Impact Assessment ......................................................... 61

6.8.1 Model setup ................................................................................................. 61

6.8.2 Immediately affected area ........................................................................... 61

6.8.3 Long term affected area ............................................................................. 65

6.9 Annual review of the predictions ...................................................................... 72

7 IMPACTS TO THE ENVIRONMENTAL VALUES (PART D) ............................... 73

7.1 Definition of EVs ............................................................................................. 73

7.1.1 Biological integrity of ecosystems ................................................................. 74

7.1.2 Beneficial use in production of foods ........................................................... 85

7.1.3 Beneficial use in aquaculture ........................................................................ 85

7.1.4 Beneficial use in agriculture ......................................................................... 85

7.1.5 Suitability for primary, secondary or visual recreational use ......................... 85

7.1.6 Suitability of the water for supply as drinking water .................................... 85

7.1.7 Suitability of the water for industrial use ..................................................... 85

7.1.8 Cultural and spiritual values of the water .................................................... 85

7.2 Past impacts on EVs ........................................................................................ 86

7.3 Predicted impacts on EVs ............................................................................... 86

7.4 Nature and extent of the impacts on GDEs ...................................................... 86

7.5 Nature and extent of the impacts on stock watering ........................................ 90

7.6 Nature and extent of the impacts on springs of interest ................................... 94

7.7 Impacts to formation integrity and surface subsidence ........................................ 94

8 WATER MONITORING STRATEGY (PART E) .................................................. 95

8.1 Rationale and strategy ...................................................................................... 95

8.2 Monitoring record ............................................................................................ 95
8.3 Monitoring program and timetable ................................................................. 96
  8.3.1 Monitoring locations ............................................................................... 96
  8.3.2 Water level monitoring ........................................................................... 97
  8.3.3 Water quality monitoring ........................................................................ 99
  8.3.4 Ecological monitoring of GDEs .............................................................. 101
  8.3.5 Reporting .............................................................................................. 101

9 SPRING IMPACT MANAGEMENT STRATEGY (PART F) ....................... 102
  9.1 Springs of interest ..................................................................................... 102
  9.2 Spring inventory ........................................................................................ 102
  9.3 Connectivity between the spring and aquifer ......................................... 104
  9.4 Spring values ............................................................................................ 104
  9.5 Management strategy .............................................................................. 104

10 CONCLUSIONS ............................................................................................. 105

11 CERTIFICATION OF UWIR ................................................................. 107

12 REFERENCES .............................................................................................. 108
  12.1 Legislation and policy ............................................................................ 108
  12.2 Publications and reports ......................................................................... 108

13 APPENDIX A – CALIBRATION HYDROGRAPHS .................................... 112
TABLE OF FIGURES

Figure 3.1: Location of ML 20658 .................................................................................. 18
Figure 3.2: Long term averages of temperature and rainfall ........................................ 19
Figure 3.3: Full record of monthly rainfall and CRD at Rookwood (028009) ............... 20
Figure 3.4: Historical daily discharge of Walsh River at Rookwood ............................. 21
Figure 4.1: Produced groundwater extraction at King Vol Mine ................................. 24
Figure 4.2: Production and monitoring bores ............................................................... 26
Figure 4.3: Predicted annual underground inflow volumes (ML) .................................. 29
Figure 4.4: Predicted rates of underground inflow (ML/day) ...................................... 30
Figure 4.5: Predicted cumulative underground inflow (ML) ......................................... 31
Figure 5.1: Solid geology ......................................................................................... 35
Figure 5.2: Cross section .......................................................................................... 36
Figure 5.3: Rainfall recharge ..................................................................................... 42
Figure 5.4: Pre-development groundwater elevation contours ................................... 43
Figure 5.5: Groundwater level hydrograph for bores screened in the western limestone distal from operations ................................................................. 44
Figure 5.6: Groundwater level hydrograph for bores screened in the western limestone proximal to operations ................................................................. 45
Figure 5.7: Groundwater level hydrograph for a bore screened in the eastern limestone .............................................................................................................. 47
Figure 5.8: Groundwater level hydrograph for bores screened in the arkose .......... 48
Figure 6.1: Extent of model domain ............................................................................ 50
Figure 6.2: Model mesh within mine area .................................................................. 51
Figure 6.3: Extent of underground mine development (after Auctus Resources, 2017) 53
Figure 6.4: Modelled parameter zones ....................................................................... 55
Figure 6.5: Calibration – modelled vs. observed groundwater levels ....................... 57
Figure 6.6: Groundwater Level Elevations - Mungana Decline Monitoring Bores ............... 63
Figure 6.7: Predicted underground mine inflow rates (ML/day) ......................................... 65
Figure 6.8: Location of registered bores .................................................................................. 66
Figure 6.9: Map showing the predicted impact above trigger threshold in IAA in year 1 of operations .................................................................................................................... 67
Figure 6.10: Map showing the predicted impact above trigger threshold in IAA in year 2 of operations .................................................................................................................... 68
Figure 6.11: Map showing the predicted impact above trigger threshold in IAA in year 3 of operations .................................................................................................................... 69
Figure 6.12: Map showing the predicted total impact in LTAA at end of mining .............. 71
Figure 7.1: Registered bores, springs, and potential groundwater dependent ecosystems (GDEs) ................................................................................................................................. 75
Figure 7.2: Aquatic GDE indicator site on Archies Creek at WP028 (Image: Auctus) ....... 77
Figure 7.3: Aquatic GDE indicator site on Bowler Creek at WP015 (Image: Auctus) ....... 78
Figure 7.4: Indicators of aquatic groundwater dependent ecosystems (GDEs) ............. 79
Figure 7.5: Indicators of terrestrial groundwater dependent ecosystems (GDEs) .... 82
Figure 7.6: Indicators of subterranean groundwater dependent ecosystems (GDEs) .... 84
Figure 7.7: Extent of predicted zone of influence in context of potential GDEs .............. 89
Figure 7.8: Extent of predicted zone of influence in relation to registered bores ............ 91
Figure 8.1: Existing and proposed monitoring bores .......................................................... 98
Figure 9.1: Stewart Spring (Nov, 2017; image: Auctus) .................................................... 103
Figure 9.2: Pooled water nearby Stewart Spring (WP002, marked on Figure 7.4; image: NRA, 2017a) ......................................................................................................................... 103
LIST OF TABLES

Table 3.1: Discharge of Walsh River at Rookwood ........................................................ 21
Table 4.1: Summary of production bores ....................................................................... 23
Table 4.2: Summary of produced groundwater extraction ............................................. 25
Table 4.3: Predicted annual dewatering volumes for life of mine .................................. 29
Table 5.1: Stratigraphy and lithology of the King Vol region ........................................... 33
Table 5.2: Informal lithofacies of the Chillagoe Formation (from western-most to eastern-most) (information derived from RLA (2008)) .................................................. 34
Table 5.3: Details of groundwater bores screened in the western limestone facies of the Chillagoe Formation ................................................................. 38
Table 5.4: Hydraulic properties of the western limestone facies .................................... 39
Table 5.5: Groundwater levels before and after development, with drawdown .............. 42
Table 5.6: Pre-development (2008–2016) linear trends in water level ........................... 45
Table 6.1: Summary of initial hydraulic parameters ....................................................... 54
Table 6.2: Simulated depth dependence within the Chillagoe Formation ....................... 54
Table 6.3: Calibration statistics ...................................................................................... 58
Table 6.4: Calibrated hydraulic parameters ................................................................... 59
Table 6.5: Sensitivity scenarios ..................................................................................... 60
Table 6.6: Bores in the vicinity of King Vol Mine ............................................................ 70
Table 7.1: Pre-development depth to groundwater level in monitoring bores ............... 81
Table 7.2: Predicted drawdown at various times for GDE indicator sites ....................... 87
Table 7.3: Groundwater quality at King Vol compared to stock watering (beef cattle) guideline values ......................................................................................... 92
Table 8.1: Lengths of monitoring records for King Vol bores ....................................... 96
Table 8.2: Monitoring timetable (derived in part from Table G18 of the EA) .................. 99
Table 8.3: Monitoring parameters (derived from Table G19 of the EA) ......................... 100
Table 9.1: Spring inventory results ................................................................................ 102
1 INTRODUCTION

Auctus Resources Pty Ltd (Auctus) requested that Rob Lait and Associates (RLA), in conjunction with Australasian Groundwater and Environmental Consultants (AGE), undertake an underground water impact report (UWIR), to support the underground extension of the King Vol Mine in North Queensland. RLA has extensive involvement with hydrogeological assessments of the King Vol Mine and this report builds upon comprehensive knowledge of existing groundwater conditions.

The UWIR is required by the Department of Environment and Heritage Protection (DEHP) to meet the legislative requirements of the Environmental Protection (Underground Water Management) and Other Legislation Amendment Act 2016 (EPOLA Act), which amends the Environmental Protection Act 1994 (EP Act), and Chapter 3 of the Water Act 2000 (Water Act). The EPOLA Act details specific methods and information that DEHP considers necessary for provision to the administering authority, in accordance with section 126A of the EP Act.

1.1 Assumptions and limitations

The predictions of groundwater inflow to the underground mine and associated drawdown presented in this UWIR are based on a groundwater numerical flow model that contains certain assumptions (Section 6). Production bores are currently used to dewater the mine, however, the predictive simulation did not include these bores, as the mine development (to 680 mbGL) is well below the current production bore depth (200 mbGL). If this situation changes in the future, an alteration of the model may be required. The predictions are reliant on the current mine plan, and may change if operations vary significantly from planned development.

1.2 Revision of the UWIR

The first version of this UWIR (dated September 2017) was submitted and assessed by DEHP in September 2017. Feedback was provided by DEHP, comprising ten items that required attention in the revised version of the UWIR (document authored by Jacob Toe of DEHP, dated 20th of October 2017). This final version of the 2017 UWIR has addressed the written feedback from DEHP, including: adding sections to the UWIR for clarification; revising model scenarios in direct response to the DEHP’s concerns; incorporating findings of a field investigation into groundwater dependent ecosystem (GDE) indicators undertaken by Natural Resource Assessments Pty Ltd (NRA) in October 2017 (NRA, 2017a); and presenting findings from a geochemical investigation into the types of water present in the water bodies on site (NRA, 2017b). Specific changes are outlined below to identify which parts of the UWIR have been updated.
Section 3.1: Project description

This section has been reworded to address comment no. 1 from DEHP. It now clearly states that the analysis undertaken as part of the UWIR addresses the entire life of mine (up to 2024) and the full extent of proposed mine development to 680mBGL, including groundwater inflow to proposed mine voids at the deepest level.

Section 4.2: Quantity of water to be produced in the next three years

This section has been updated to address comments no. 2 and no. 4 from DEHP. It was previously unclear what quantity of the predicted underground inflow was proposed to be extracted. It was also unclear whether the numerical model simulated water take from depths below the current production bores, which are approximately 200 m deep. It was further requested that the model depict the worst case scenario on site, i.e. that the model be set up in a conservative manner.

The revised section includes updated dewatering estimates from the numerical model and a more detailed explanation of the derivation of those values. It is made clear that the proposed dewatering volumes are the entire predicted inflows to the underground mine, and for the full mine development plan to 680 mBGL, over seven years. The basis of the predictions and their conservative nature are now better explained.

Section 6.4: Model boundary conditions

This section has been changed to address comments no. 9 and no. 10 from DEHP, in which it was stated that predicted drawdown areas should be assessed using a 0.2 m drawdown contour. This change addresses the way GDEs have been assessed, and therefore, it is also relevant to comments no. 6 through no. 8.

The section has been revised to reflect the change in model boundary conditions, namely from a zero recharge scenario in the predictive model, to a predictive scenario where recharge is applied at 2% of rainfall. It is important to note that there has been no change to the model setup, calibration, framework or mesh, and the characteristics of the aquifers have not been altered in any way. The calibration phase of the model already had recharge applied and has not been changed.

This adjustment to the model boundary conditions was made in response to DEHP’s request for an estimate of the area where predicted drawdown would reach 0.2 m, in line with the default spring impact threshold. Previously, drawdown was presented using a 5 m drawdown contour because:

a) 5 m is the applicable bore trigger threshold for consolidated formations such as those at King Vol Mine (DEHP, 2016a); and

b) there is significant seasonal variation in groundwater level in this area, thus, 5 m is a reasonably detectable change in the groundwater level.
Initially, the predictive model included zero recharge, meaning that any change in groundwater level was not balanced by naturally occurring rainfall. This created areas within the model, but distal from the mine, where outputs were dominated by noisy fluctuations in water level that were unrelated to the dewatering. In order to produce a representative model output for 0.2 m of drawdown, recharge in the predictive model was applied at a rate of 2% of rainfall. The resultant output is a coherent 0.2 m drawdown contour surrounding the mining area (Section 6.8).

The change to the recharge boundary condition in the predictive model is justified for several reasons. First, zero recharge is probably unrealistic, and was only used as a means of providing a very conservative (worst case scenario) prediction. Second, addition of recharge at 2% of rainfall is assessed to be representative of actual conditions determined on site (Section 5.2.2), and the model calibration is not very sensitive to recharge (Section 6.7). Third, whilst recharge within the predictive model provides a slightly less conservative prediction of impacts, there is a slight increase in the predicted inflows to the underground mine, which are interpreted to be the dewatering volumes required. Last, the predicted drawdown can still be considered a conservative over-estimate, due to the way the mine development has been applied in the model. RLA and AGE consider this minor amendment to the model to provide representative predictions in response to DEHP’s request for provision of a 0.2 m drawdown contour.

As a result of the application of recharge to the predictive model, the areal extent of the predicted drawdown is slightly less than what was predicted in the previous UWIR. This is a product of the predictions being slightly less conservative. However, with the updated assessment of potential impacts on GDEs (Section 7.4), based in part on the work of NRA (NRA, 2017a; NRA, 2017b), the overall approach of the revised UWIR remains precautionary.

Section 6.8: Predictive Model for Impact Assessment

This section has been changed to address comments no. 9 and no. 10 from DEHP, in which it was stated that predicted drawdown areas should be assessed using a 0.2 m drawdown contour. The maps in this section showing the predicted impact areas at various points have been updated, and any comments about the areal and vertical extent of drawdown have been revised to reflect the predictions.

Section 6.9: Annual review of the predictions

This section has been reworded to address comment no. 3 from DEHP. In the previous version of the UWIR, no recommendation was made for annual revision of the impact predictions. As Section 376(2) of The Water Act 2000 requires that an annual review must be submitted if the predicted decline in water level exceeds the bore trigger threshold, regardless of the presence or absence of bores, this recommendation has been revised. Section 6.9 now includes a discussion of the proposed annual review.
Section 7.1.1: Biological integrity of ecosystems

This section has been reworded to address comment no. 5 from DEHP. Previously, insufficient evidence of the moderately disturbed nature of the terrestrial ecosystems at King Vol Mine existed, thus, statements regarding biological integrity of ecosystems were not well supported. The revised UWIR now uses new information made available through a field survey (NRA, 2017a) to form an assessment of the overall condition of the ecology.

Section 7.1.1.1: Aquatic ecosystems

This section has been revised to address comments no. 5 and no. 8 from DEHP. The previous version of the UWIR relied on the mapping of GDEs available from the GDE Atlas. This section now reflects the revised understanding of potential GDEs present at the site developed through a field survey and a geochemical analysis of water types (NRA, 2017a; NRA, 2017b). In addition, the discussion of groundwater-surface water interaction has also been adjusted to reflect the findings of these investigations. Remnant pools in surface water bodies have now been identified in the field, allowing for a better understanding of groundwater-surface water interaction.

Section 7.1.1.2: Terrestrial ecosystems

This section has been changed to address comment no. 7 from DEHP. The previous assertion that terrestrial ecosystems within the predicted drawdown area were unlikely to be reliant on groundwater has been removed. In response to new field observations of mature *Melaleuca* and *Brachychiton* species in and around the ML (NRA, 2017a), the definition of terrestrial GDEs has been adjusted. The revised UWIR acknowledges the presence of likely terrestrial GDEs within the zone of influence of dewatering. Accordingly, relevant recommendations are made for monitoring.

Section 7.1.1.3: Subterranean ecosystems

This section has been changed to address comment no. 6 from DEHP. The previous assertion that there were no subterranean GDEs expected to be impacted by the exercise of underground water rights at King Vol has been removed. The definition of, and impact assessment for, subterranean GDEs has been adjusted to reflect new information provided, including ecological mapping of the area (NRA, 2006; NRA, 2011a; NRA, 2011b). The revised UWIR acknowledges the presence of potential subterranean GDEs within the predicted drawdown area. Accordingly, relevant recommendations are made for monitoring.
Section 7.4: Nature and extent of the impacts on GDEs

This section has been significantly rewritten in response to new information provided, and the changes address comment no. 10 from DEHP. Previously, the UWIR relied on the 5 m drawdown contour as an indication of dewatering impacts, whereas the revised UWIR relates to areas within the 0.2 m drawdown contour area. Further, the potential impact on GDEs is now assessed within this area. These changes in the assessment come in response to a revised understanding of GDEs on site, based on the presence of GDE indicators (NRA, 2017a), and they replace generalised statements with site-specific information. This is a precautionary approach, and is more conservative than the previous version of the UWIR. Accordingly, a monitoring program designed to detect potential impacts to GDEs is designed and recommended for King Vol Mine (Section 8).

Section 7.5: Nature and extent of the impacts on stock watering

This section has been updated to address comment no. 5 from DEHP. The reference to certain environmental values being absent at the site has been removed, and this change is based on a revised conceptualisation of GDEs at the site from new information provided through field investigations (NRA, 2017a).

Section 8: Water monitoring strategy (Part E)

This section has been revised to include recommendations to enable better monitoring of potential impacts on GDEs, including the installation of new monitoring bores.

Section 9.1: Springs of interest

This section has been revised to address comment no. 9 from DEHP. As stated above, the previous UWIR used a 5 m drawdown area to assess potential impacts from dewatering. This was in line with the guideline requirements for impacts to other bores, but is inadequate to assess potential impacts to springs. In response, the revised UWIR includes maps of the 0.2 m drawdown contour derived from a model run with recharge that is 2% of rainfall. It is now noted in Section 9.1 that Stewart Spring, the closest spring to King Vol Mine, is approximately 6 km outside the 0.2 m drawdown contour.

Comment no. 9 from DEHP also indicated that additional survey of springs in the area is desirable, and that further details would be needed to support the impact assessment of Stewart Spring. To this end, the revised UWIR now references the new information available on ecological indicators near Stewart Spring (NRA, 2017a), and the quality of the water at these sites relative to groundwater (NRA, 2017b).
2 LEGISLATIVE REQUIREMENTS OF A UWIR

2.1 Water Act 2000 (QLD)

2.1.1 Section 376
The statutory requirements for an UWIR, as detailed in section 376 of the Water Act, must be addressed in all cases. This section of the act is transcribed as boxed text below.

Section 376 of the Water Act (2000):
1) An underground water impact report must include each of the following—
   a) for the area to which the report relates—
      i) the quantity of water produced or taken from the area because of the exercise of any previous relevant underground water rights; and
      Example for paragraph (a)(i)—
      If the report is prepared by a mining tenure holder before it exercises its underground water rights, the quantity of water produced or taken from the area would be shown in the report as zero.
      ii) an estimate of the quantity of water to be produced or taken because of the exercise of the relevant underground water rights for a 3-year period starting on the consultation day for the report;
   b) for each aquifer affected, or likely to be affected, by the exercise of the relevant underground water rights—
      i) a description of the aquifer; and
      ii) an analysis of the movement of underground water to and from the aquifer, including how the aquifer interacts with other aquifers; and
      iii) an analysis of the trends in water level change for the aquifer because of the exercise of the rights mentioned in paragraph (a)(i); and
      iv) a map showing the area of the aquifer where the water level is predicted to decline, because of the taking of the quantities of water mentioned in paragraph (a), by more than the bore trigger threshold within 3 years after the consultation day for the report; and
      v) a map showing the area of the aquifer where the water level is predicted to decline, because of the exercise of relevant underground water rights, by more than the bore trigger threshold at any time;
      Note—
      If the underground water impact report or final report is approved, the mapped areas mentioned in subparagraphs (iv) and (v) establish immediately affected and long-term affected areas under section 387.
c) a description of the methods and techniques used to obtain the information and predictions under paragraph (b);

d) a summary of information about all water bores in the area shown on a map mentioned in paragraph (b)(iv), including the number of bores, and the location and authorised use or purpose of each bore;

da) a description of the impacts on environmental values that have occurred, or are likely to occur, because of any previous exercise of underground water rights;

db) an assessment of the likely impacts on environmental values that will occur, or are likely to occur, because of the exercise of underground water rights—
   i) during the period mentioned in paragraph (a)(ii); and
   ii) over the projected life of the resource tenure

e) a program for—
   i) conducting an annual review of the accuracy of each map prepared under paragraph (b)(iv) and (v); and
   ii) giving the chief executive a summary of the outcome of each review, including a statement of whether there has been a material change in the information or predictions used to prepare the maps;

f) a water monitoring strategy;

g) a spring impact management strategy;

h) if the responsible entity is the office—
   i) a proposed responsible tenure holder for each report obligation mentioned in the report; and
   ii) for each immediately affected area—the proposed responsible tenure holder or holders who must comply with any make good obligations for water bores within the immediately affected area;

i) other information or matters prescribed under a regulation.

2) However, if the underground water impact report does not show any predicted water level decline in any area of an affected aquifer by more than the bore trigger threshold during the period mentioned in subsection (1)(b)(iv) or at any time as mentioned in subsection (1)(b)(v), the report does not have to include the program mentioned in subsection (1)(e).

3) In this section—

   **environmental value** see the Environmental Protection Act 1994, section 9.
2.2 EPOLA Act

There are two important amendments of the EPOLA Act that influence the implementation of a UWIR.

Amendment of s 87 (Amendment of s 376 (Content of underground water impact report))

Clause 33 of the EPOLA Act amends section 87 of the Water Reform and Other Legislation Amendment Act 2014, which in turn amends section 376 of the Water Act. The EPOLA Act states that UWIRs must include a description of impacts to environmental values, both past and future, that are anticipated from the exercise of underground water rights.

Amendment of s 215 (Other amendments)

Clause 7 of the EPOLA Act amends section 215 of the EP Act such that the regulator may deem impacts identified in a UWIR to be grounds for amendment of the environmental authority (EA) applicable to the resource activity. (Explanatory notes for EPOLA Act).

2.3 UWIR guideline

A guideline (DEHP, 2016a) was devised to provide additional information for proponents in responding to section 376 of the Water Act, including the changes made in accordance with the EPOLA Act. The guideline provides background on the methods appropriate for a UWIR and recommends the following outline:

- Part A: Information about underground water extractions resulting from the exercise of underground water rights;
- Part B: Information about aquifers affected, or likely to be affected;
- Part C: Maps showing the area of the affected aquifer(s) where underground water levels are expected to decline;
- Part D: An assessment of the impacts to the environmental values from the exercise of underground water rights;
- Part E: A water monitoring strategy; and
- Part F: A spring impact management strategy.

2.4 Report structure

In order to conform to the most recent recommendations of the regulators and to address the statutory requirements for UWIRs, this report is aligned with the structure derived from the UWIR guidelines (DEHP, 2016a) indicated above. Parts A through F are clearly identified within the heading titles of the report, and the relevant section of the Water Act is provided in the text.
3 PROJECT AREA

3.1 Project description

King Vol Mine is a mining development northwest of Chillagoe, conducted within mining lease (ML) 20658 (granted 2015, expires 2036) and under EA EMPL0056913 (Figure 3.1). The deposit is predominantly zinc, with minor lead, silver and copper mineralisation. The mineralisation is associated with skarn alteration within limestone of the Chillagoe Formation (Auctus Resources, 2017).

Depth of underground mining at the end of the current plan of operations at King Vol Mine is 180 mBGL. The proposed underground extension would see life of mine (LoM) operations to a final depth of 680 mBGL, and less than half this depth will be achieved in the first three years of mining (Auctus Resources, 2017). The extension is planned to develop and produce ore at a rate of up to 450,000 t/yr, over the 7-year mine life, with mined waste rock between 80,000 t/yr and 180,000 t/yr (Auctus Resources, 2017). This UWIR includes the assessment based on the mine plan for the entire life of mine (up to 2024) and the full extent of proposed mine development to 680 mBGL.

The King Vol Mining method will be a top-down method with open stoping and pillars. The mine will be extended from existing underground operations, accessed via a decline from the existing box cut. Development of other mine infrastructure within ML 20658, such as haul roads, run of mine (ROM) pad and waste rock depositaries will be required. The proposed disturbance footprint is 41 ha (Auctus Resources, 2017).

Stopes will be developed from a central decline on the eastern side of the resource. Stoping will be progressed sequentially from upper layers to lower layers upon the completion of each ore drive. Backfilling will be undertaken as required, using potentially acid forming (PAF) waste preferentially over non-acid forming (NAF) waste.

Unprocessed ore produced from King Vol Mine will be transferred approximately 25 km southeast to Mungana / Red Dome (another Auctus operation) for processing.
3.2 Climate

The King Vol area is located within the inland tropics of North Queensland and experiences a warm dry winter (May to September) and a hot and rainy summer (October to April). Annual rainfall in the coastal tropics is typically high, but reduces in inland locations due to orographic effects. Rainfall in this region is also very variable, because of the influence of monsoons. In response, rivers and creeks are highly ephemeral, and may only contain disconnected remnant pools during the cooler months.

The closest Bureau of Meteorology (BoM) station to King Vol Mine is Rookwood (BoM station number 028009), situated approximately 25 km northwest of Chillagoe. The average annual rainfall at this location is 849 mm (1961 to 2016 data). Rainfall is highest in January and February, and maximum temperatures at nearby station 031108 indicate that November and December are the hottest months (Figure 3.2).

The complete monthly rainfall record for this station is provided in Figure 3.3, along with cumulative rainfall departure (CRD). The CRD method is a summation of the monthly departure of rainfall from the long-term average monthly rainfall. A rising trend in the CRD plot indicates periods of above average rainfall, whereas a falling slope indicates periods when rainfall is below average. Groundwater level trends which do not correlate to the CRD (with or without a lag) suggest the trend is not due to natural climatic variations.

Figure 3.2: Long term averages of temperature and rainfall
3.3 Catchment hydrology

The Chillagoe area is situated in the Walsh River sub-catchment of the Mitchell River. To the south of ML 20658, the Walsh River flows west and then northwest, to its confluence with the Mitchell River about 100 km away. Surface waters of the Mitchell River catchment discharge to the Gulf of Carpentaria further to the northwest.

The closest river gauge on the Walsh River to ML 20658 is Rookwood (site number 919310A), which is situated 1.5 km downstream of the river crossing at Burke Developmental Road (E211282, N8120400). Gauge records exist for the Walsh River at Rookwood from 13 October 1967 to 26 October 2016, and discharge statistics are provided in Table 3.1. Annual discharges for the last four years are relatively low compared to the preceding high discharge years from 2007 to 2012 (Figure 3.4). Despite this, high rainfall in January and February 2017 led to flooding of the Walsh River and site access to King Vol Mine was disrupted at that time. The upstream catchment for the Walsh River at this point is approximately 5,000 km², and flow is partly regulated by upstream diversions from Tinaroo Falls Dam. Despite this, the discharge is still ephemeral, with mean daily discharge typically lower than 10 m³/s (cumec) for two months of the year, followed by one or two months of no flow. This dry period is usually from July to October (Table 3.1).
Table 3.1: Discharge of Walsh River at Rookwood

<table>
<thead>
<tr>
<th>Month</th>
<th>Max (cumecs)</th>
<th>Min (cumecs)</th>
<th>Mean (cumecs)</th>
<th>Median (cumecs)</th>
<th>Mean (cumecs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>2271.1</td>
<td>0.0</td>
<td>103.6</td>
<td>11.6</td>
<td>105.3</td>
</tr>
<tr>
<td>Feb</td>
<td>3293.3</td>
<td>0.0</td>
<td>160.1</td>
<td>52.3</td>
<td>148.3</td>
</tr>
<tr>
<td>Mar</td>
<td>4081.4</td>
<td>0.1</td>
<td>112.4</td>
<td>28.9</td>
<td>114.3</td>
</tr>
<tr>
<td>Apr</td>
<td>639.1</td>
<td>0.0</td>
<td>14.7</td>
<td>5.0</td>
<td>14.5</td>
</tr>
<tr>
<td>May</td>
<td>117.6</td>
<td>0.0</td>
<td>3.5</td>
<td>1.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Jun</td>
<td>35.9</td>
<td>0.0</td>
<td>1.3</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>Jul</td>
<td>3.1</td>
<td>0.0</td>
<td>0.5</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Aug</td>
<td>1.9</td>
<td>0.0</td>
<td>0.3</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Sep</td>
<td>3.6</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Oct</td>
<td>47.1</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Nov</td>
<td>217.8</td>
<td>0.0</td>
<td>2.4</td>
<td>0.0</td>
<td>2.3</td>
</tr>
<tr>
<td>Dec</td>
<td>1033.0</td>
<td>0.0</td>
<td>17.7</td>
<td>0.7</td>
<td>17.9</td>
</tr>
</tbody>
</table>

Figure 3.4: Historical daily discharge of Walsh River at Rookwood
3.4 Water plans
The Chillagoe area is part of the Water Resource Plan Area for the Mitchell River Catchment ([https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0013/109120/mitchell-area-map.pdf](https://www.dnrm.qld.gov.au/__data/assets/pdf_file/0013/109120/mitchell-area-map.pdf)). The Water Plan (Mitchell) 2007 (previously the Mitchell water resource plan – WRP) specifies water management areas, trading zones, and criteria for deciding water licence applications within the Mitchell River catchment. The purpose of the plan, amongst other things, is to regulate the taking of both overland flow water and groundwater.

3.5 Groundwater management areas
ML 20658 lies on the border of the Chillagoe Groundwater Management Area (GMA) and the Great Artesian Basin (GAB) GMA (Water Plan (Mitchell) 2007). For the purposes of this UWIR, the management criteria and ecological outcomes specified for the Chillagoe GMA will be adopted, as the aquifers present in the King Vol Mine area are not GAB aquifers. The major units present at King Vol Mine are the Devonian Hodgkinson Formation, the Silurian-Devonian Chillagoe Formation, and the Proterozoic Dargalong Metamorphics (Section 5.1); whereas the important stratigraphic formations of the GAB are the Hutton Sandstone and the Cadna-owie-Hooray aquifer, or their stratigraphic correlatives, which are of Jurassic to Cretaceous age.

The nearest GAB sediments are the Gilbert River Formation and the Wallumbilla Formation of the Carpentaria Basin, which crop out approximately 20 km to the west of the ML. It is clear that groundwater at King Vol Mine is not connected to the GAB aquifers, as it is hosted within the Hodgkinson Province, and therefore it is relevant to the Chillagoe GMA.

The only prescribed watercourse within the vicinity of King Vol Mine is the Walsh River, and, as the mine is more than 1 km from the river, the groundwater resources at the mine are not considered “water within the watercourse” (Water Plan (Mitchell) 2007).
4 UNDERGROUND WATER EXTRACTIONS (PART A)

This section of the report addresses section 376(a) of the Water Act.

4.1 Quantity of water already produced

Prior to 2010, the mineral resources at King Vol were developed as a prospect by the previous proponent, Kagara Ltd. However, no groundwater extraction is recorded as having occurred at the site prior to transfer of the lease to Auctus in 2015.

In September, October and November of 2016, three new production bores were drilled at King Vol Mine (Table 4.1). The production bores were completed within limestone of the Chillagoe Formation and the drill logs for these bores show that this lithofacies is cavernous from 100 m to 200 m depth (RLA, 2017; Section 5.1).

In the following months, a total of at least 136.3 ML was produced from two of the bores (Table 4.2). The effect of this dewatering is evident in groundwater hydrographs of monitoring bores within the immediate vicinity (RLA, 2017; Section 5). From May 2017 onwards, the extraction rate has decreased (Figure 4.1 and Table 4.2), as drawdown responded to the depletion in storage. The total production volume to date is in the order of 300 ML (Figure 4.1).

Table 4.1: Summary of production bores

<table>
<thead>
<tr>
<th>Bore</th>
<th>Easting GDA zone 55</th>
<th>Northing GDA zone 55</th>
<th>Aquifer unit</th>
<th>Depth (mBGL)</th>
<th>Elevation (mAHD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVPB01</td>
<td>207005</td>
<td>8125462</td>
<td>Chillagoe Formation (west limestone)</td>
<td>189</td>
<td>263.15</td>
</tr>
<tr>
<td>KVPB02</td>
<td>207184</td>
<td>8125276</td>
<td>Chillagoe Formation (west limestone)</td>
<td>200</td>
<td>254.54</td>
</tr>
<tr>
<td>KVPB03</td>
<td>206870</td>
<td>8125630</td>
<td>Chillagoe Formation (west limestone)</td>
<td>198</td>
<td>260.72</td>
</tr>
</tbody>
</table>
Project No 254 (King Vol UWIR and dewatering assessment)

Figure 4.1: Produced groundwater extraction at King Vol Mine
## Table 4.2: Summary of produced groundwater extraction

<table>
<thead>
<tr>
<th>Date</th>
<th>Time period (days)</th>
<th>Pumping rate (L/s)</th>
<th>Extracted volume (ML)</th>
<th>Cumulative volume (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>KVPB01</td>
<td>KVPB02</td>
<td>KVPB03</td>
</tr>
<tr>
<td>28/01/2017</td>
<td>33</td>
<td>8.3</td>
<td>0.0</td>
<td>15.6</td>
</tr>
<tr>
<td>28/02/2017</td>
<td>31</td>
<td>8.8</td>
<td>0.0</td>
<td>16.6</td>
</tr>
<tr>
<td></td>
<td>no data for March or April</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/05/2017</td>
<td>28</td>
<td>0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>16/06/2017</td>
<td>27</td>
<td>0</td>
<td>6</td>
<td>UNK</td>
</tr>
<tr>
<td>23/06/2017</td>
<td>7</td>
<td>0</td>
<td>5.5</td>
<td>15</td>
</tr>
<tr>
<td>30/06/2017</td>
<td>7</td>
<td>0</td>
<td>5</td>
<td>15.47</td>
</tr>
<tr>
<td>7/07/2017</td>
<td>7</td>
<td>0</td>
<td>4.13</td>
<td>14.61</td>
</tr>
<tr>
<td>14/07/2017</td>
<td>7</td>
<td>0</td>
<td>4.93</td>
<td>12.8</td>
</tr>
<tr>
<td>21/07/2017</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>13.02</td>
</tr>
<tr>
<td>28/07/2017</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>12.72</td>
</tr>
<tr>
<td>4/08/2017</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>13.49</td>
</tr>
<tr>
<td>11/08/2017</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>13.47</td>
</tr>
<tr>
<td>12/08/2017</td>
<td>1</td>
<td>17.5</td>
<td>0</td>
<td>13.35</td>
</tr>
<tr>
<td>17/08/2017</td>
<td>5</td>
<td>12.12</td>
<td>0</td>
<td>11.1</td>
</tr>
<tr>
<td>22/08/2017</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>9.8</td>
</tr>
<tr>
<td>27/08/2017</td>
<td>5</td>
<td>6.9</td>
<td>0</td>
<td>9.4</td>
</tr>
<tr>
<td>29/08/2017</td>
<td>2</td>
<td>6.5</td>
<td>0</td>
<td>9.1</td>
</tr>
</tbody>
</table>

UNK - unknown pumping rate - pump was operating but meter was not functioning
Production and monitoring bores
4.2  Quantity of water to be produced in the next three years

4.2.1  Method of extraction

The current production bores penetrate to a depth of approximately 200 mBGL, whereas proposed mining will be to a depth of 680 mBGL. Therefore, at a minimum, additional underground dewatering is expected to be carried out from within the mine workings to remove seepage and inflows from the underground mine. As a proactive measure, Auctus is currently investigating the possibilities for deeper dewatering and water supply bores. Groundwater is also expected to be removed as moisture within the ore and waste rock, and via ventilation.

4.2.2  Estimate based on borefield capacity

The designed extraction rate from each existing production bore was 20 L/s (Section 4). With three bores at constant capacity, this equates to a combined total of 5,184 ML/day (1892 ML/year) extracted for dewatering via the borefield. Extrapolated to three years at a continuous rate, this is approximately 5,680 ML (RLA, 2017). However, it is now evident that the designed extraction rate is no longer achievable as groundwater storage in caverns has been diminished through recent production. Therefore, the estimate for dewatering based on the borefield capacity requires adjustment for reliable mine water management. This adjustment was undertaken using the numerical model outputs as a representative indication of the dewatering volumes required (discussed below).

4.2.3  Estimate based on 2017 numerical model

A numerical groundwater flow model for the King Vol Mine was developed for this UWIR using FEFLOW. The full details of this model are provided in Section 6. The FEFLOW model simulates groundwater flow in the aquifers around the mine and also simulates mine development based on the progressive deepening of the shaft and development of drives over the planned life of the mine. This includes simulation of the complete mining plan to 680 mBGL over seven years. The mine voids are simulated within the model as drains, into which there is groundwater inflow. The model removes all water that enters the drains, and thus the voids of the mine are simulated in the model as continuously dry, due to passive dewatering. Through this understanding, it is logical to use the predicted inflows to the underground workings as an estimate of the volume of water required for dewatering.

The predicted underground inflow from the FEFLOW model is provided below as annual totals (Table 4.3; Figure 4.3), instantaneous rates (Figure 4.4), and cumulative volumes (Table 4.3; Figure 4.5). The model predicts groundwater inflow volumes to underground workings of 2,929 ML, 3,421 ML, and 4,668 ML for years, 1, 2 and 3 of the simulation, respectively (Figure 4.3), and a total inflow volume over the life of the mine of 29,558 ML (Table 4.3). As these volumes represent the expected inflow to the underground mine, they are the predicted volume required for the dewatering take at King Vol Mine. These dewatering volumes are derived from a predictive model that incorporates recharge equal to 2% of rainfall. They are slightly higher than the initial model predictions, which included no recharge.
The assumptions inherent in these model predictions are summarised in Section 6. These dewatering rates are considered conservative and representative, and are a reasonable estimate of the anticipated volume of water that will be removed from the aquifers as a result of the proposed mine expansion. The estimates are considered conservative because they represent a scenario where inflows are overestimated, due to the way the voids are modelled. The proposed mine plan includes the progressive back-filling of voids, whereas the model does not include any simulation of back-filling. This means that more water is allowed to enter the voids in the model simulation than is likely in reality. In addition, the active dewatering that currently occurs at the mine via existing production bores is only represented in the model within the historical calibration period, and is not relied upon for dewatering in the model predictions. Overestimation of dewatering take in this way enables responsible planning for mine water management.

The predicted dewatering rates are validated to a certain extent through comparison with the dewatering pattern observed at Mungana underground mine (Mungana). Mungana is an analogous underground mine operated by Auctus, which is located to the southeast of King Vol Mine, and is hosted within similar carbonate aquifers (e.g. fractured limestones). The observed inflows to underground workings at Mungana, while being higher than the predicted inflows, are intermittent. As the mine development intercepts discrete fractures, the groundwater in these features must be removed through dewatering, however, flows abate after the storage of the fractures are depleted. A similar pattern of variable dewatering is expected at King Vol Mine due to the fractured nature of the host rock.
### Table 4.3: Predicted annual dewatering volumes for life of mine

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual dewatering volume (ML)</th>
<th>Cumulative dewatering volume (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>2929</td>
<td>2929</td>
</tr>
<tr>
<td>2019</td>
<td>3421</td>
<td>6350</td>
</tr>
<tr>
<td>2020</td>
<td>4668</td>
<td>11017</td>
</tr>
<tr>
<td>2021</td>
<td>5099</td>
<td>16116</td>
</tr>
<tr>
<td>2022</td>
<td>4653</td>
<td>20769</td>
</tr>
<tr>
<td>2023</td>
<td>4443</td>
<td>25212</td>
</tr>
<tr>
<td>2024</td>
<td>4346</td>
<td>29558</td>
</tr>
</tbody>
</table>

### Figure 4.3: Predicted annual underground inflow volumes (ML)
Project No 254 (King Vol UWIR and dewatering assessment)

Figure 4.4: Predicted rates of underground inflow (ML/day)
Project No 254 (King Vol UWIR and dewatering assessment)

Figure 4.5: Predicted cumulative underground inflow (ML)
5 AQUIFER INFORMATION AND UNDERGROUND WATER FLOW (PART B)

This section of the report addresses section 376(b)(i) to 376(b)(iii) of the Water Act.

5.1 Overview of aquifers

The King Vol lead copper silver deposit is hosted in a fault-bounded block of deformed limestone, chert, arenite and mudstone of the Chillagoe Formation. The Chillagoe Formation is a member of the Palaeozoic Hodgkinson Province, and is stratigraphically below the Hodgkinson Formation (Table 5.1). The sequence of the Chillagoe Formation at King Vol Mine forms a narrow, northwest-southeast trending band of steeply dipping beds that are bordered to the southwest by the Palmerville Fault, and to the northeast by the Walsh Fault (Figure 5.1). The Palmerville Fault is a regionally significant structure, demarcating the contact between the Hodgkinson Province and the Mesoproterozoic Dargalong Province (south and west of the fault; Figure 5.1).

The recognised stratigraphy of the area is provided in Table 5.1. Within ML 20658 there are four lithofacies of the Chillagoe Formation mapped in at the 1:250,000 scale (Department of Mines and Energy, 1996; Figure 5.1). These are arenite (SDc/a1), chert (SDc/c), limestone (SDc/l), and breccia (SDc/b). These units are very similar to the informal lithofacies of the Chillagoe Formation as identified by Auctus, which are shown in Table 5.2 (RLA, 2008). A semi-quantitative cross section of the strata (Figure 5.2) shows that the mineralisation is present within a series of narrow lodes that dip steeply to the west. The ore is mainly associated with the limestone within the Chillagoe Formation sequence, which includes arkose, limestone, shale and chert (Auctus Resources, 2017; Figure 5.2).

The groundwater present within the Chillagoe Formation near King Vol Mine is influenced by the secondary porosity of structural features, such as faults and fractures, and solution features (RLA, 2017). The dominant aquifer is the western limestone lithofacies (Table 5.2), which hosts cavities at depths between 100 m and 200 m below the ground level (mBGL). More minor solution of the limestone is observed at the surface, with the development of solution pipes to shallow depths, i.e. close to the watertable (RLA, 2017). Despite these solution features, all the lithological units at King Vol have decreasing permeability with depth, and there are no known major fractures in the rocks below 100 m. The arkose and the eastern limestones are also considered aquifers, whereas the intermediate shale (ISH) and the chert are aquitards (Table 5.2).

The interaction between groundwater of the Chillagoe Formation and that hosted in other units is inhibited by a lack of hydraulic connectivity across the major geological contacts and the Palmerville Fault and the Walsh Fault (Figure 5.1). The Mulgrave Formation and the Dargalong Metamorphics to the southwest of the Palmerville Fault are crystalline or clay-rich rocks (Table 5.1) that are considered to be aquitards (RLA, 2017).
The Hodgkinson Formation to the northeast of the Walsh Fault has significantly lower permeability than the Chillagoe Formation (RLA, 2017). The faults themselves are deeply weathered, and are associated with shear zones and highly deformed rock. Thus, the conceptual model of the King Vol site is one of limited-to-no connectivity between the Chillagoe Formation and surrounding areas. This conceptual understanding is the basis for the framework of the FEFLOW model (Section 6).

There is no other aquifer of significance in the area, and therefore, the lithofacies of the Chillagoe Formation are the only aquifers explored in detail below. The intermediate shale and chert lithofacies (Table 5.2) are not described in detail as they host no monitoring bores and are not viable aquifers.

**Table 5.1: Stratigraphy and lithology of the King Vol region**

<table>
<thead>
<tr>
<th>Age</th>
<th>Province</th>
<th>Formation</th>
<th>Lithology</th>
<th>Map symbol</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carboniferous</td>
<td>Kennedy Province</td>
<td>Pratt Volcanics</td>
<td>welded rhyolitic ignimbrite</td>
<td>Cp/x</td>
<td>4, 5</td>
</tr>
<tr>
<td>Devonian</td>
<td>Hodgkinson Province</td>
<td>Hodgkinson Formation</td>
<td>greywacke with minor mudstone</td>
<td>Dhk/a1</td>
<td>3, 4, 5</td>
</tr>
<tr>
<td>Silurian to Early Devonian</td>
<td>Hodgkinson Province</td>
<td>Chillagoe Formation</td>
<td>limestone, chert, metabasalt, arenite, mudstone and minor siltstone, conglomerate, breccia, lithic sandstone, andesite and skarns</td>
<td>SDc/</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>Ordovician-Silurian</td>
<td>Hodgkinson Province</td>
<td>Mulgrave Formation</td>
<td>quartzose greywacke</td>
<td>Om/a</td>
<td>4, 5</td>
</tr>
<tr>
<td>Mesoproterozoic</td>
<td>Yambo Subprovince</td>
<td>Dargalong Metamorphics</td>
<td>predominantly biotite gneiss</td>
<td>PLdd</td>
<td>1, 3, 5</td>
</tr>
</tbody>
</table>

*Citations:*
3. RLA (2008)
5. Geoscience Australia (2017)
Table 5.2: Informal lithofacies of the Chillagoe Formation (from western-most to eastern-most) (information derived from RLA (2008))

<table>
<thead>
<tr>
<th>Lithofacies name</th>
<th>Lithology</th>
<th>Aquifer or aquitard</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>western limestone</td>
<td>mostly limestone with abundant intercalated basic volcanic units</td>
<td>aquifer</td>
<td>this unit is rarely associated with the mineralisation</td>
</tr>
<tr>
<td>intermediate shale (ISH)</td>
<td>interbedded sandstones, siltstones and shales</td>
<td>aquitard</td>
<td></td>
</tr>
<tr>
<td>eastern limestone</td>
<td>limestone, marble (hosts sulphide-rich ore)</td>
<td>minor aquifer</td>
<td>dips steeply to the west; may be contiguous with western limestone to the south of the deposit</td>
</tr>
<tr>
<td>arkose</td>
<td>arkosic sandstone, greywacke sandstone</td>
<td>aquifer</td>
<td>is present in the sequence in at least two locations, to east and west of the mineralised eastern limestone</td>
</tr>
<tr>
<td>chert</td>
<td>chert</td>
<td>aquitard</td>
<td></td>
</tr>
</tbody>
</table>
Project No 254 (King Vol UWIR and dewatering assessment)

Figure 5.2: Cross section
5.2 Chillagoe Formation – western limestone

5.2.1 Description

As described above in Section 5.1, the western limestone lithofacies of the Chillagoe Formation is comprised predominantly of limestone, but with pervasive interbedding of basic volcanic rocks. These strata are observed to have viable primary and secondary porosity, and are considered the most productive aquifer at the site. The western limestone is only associated with the mineralisation at King Vol Mine at a small number of locations, whereas the bulk of the deposit is hosted within alteration of the eastern limestone. The two limestone facies may be contiguous outside the ML.

As the stratigraphic units of the King Vol Mine area are very steeply dipping (Section 5.1; Figure 5.2), the surface expression of the units (Figure 5.1) is a close approximation of the aquifer distribution. With the orientation of the strata dip towards the west, it is logical to infer some aquifer distribution at depth beyond the western contact boundary shown in Figure 5.1. The thickness or depth of the western limestone is not mapped further here, as the sub-vertical orientation of the geological units dictates that their vertical extent is at least 700 mBGL, and is not highly variable in the lateral direction (Figure 5.2).

There are six operational monitoring bores and three production bores screened in the western limestone lithofacies of the Chillagoe Formation (Table 5.3; Figure 4.2). The production bores are all approximately 100 m deeper than the monitoring bores, and their bore logs indicate significant solution cavities at this deeper level (RLA, 2017).

Constant rate pumping tests were conducted on the three production bores (KVPB01, KVPB02, and KVPB03) in 2016. The drawdown and recovery data were analysed to produce estimates of hydraulic parameters, and to understand possible boundary effects present (RLA, 2017). Boundary effects may include both barriers that increase drawdown (e.g. faults that are infilled with clay minerals) and recharge boundaries that contribute water to the groundwater system and decrease drawdown (e.g. surface water features).

The analysis revealed changes in the slope of the drawdown trends at all three bores, at \( t = 1,000 \) minutes in bores KVPB01 and KVPB02, and at \( t = 360 \) minutes in bore KVPB03 (RLA, 2017). This indicates a boundary effect causing a reduction in flow. Considering that the aquifer units are constrained within a relatively narrow band trending northwest-southeast, the most likely boundary is considered to be the extent of the aquifer (RLA, 2017). The extent of the aquifer could be limited to the western limestone lithofacies, or the Chillagoe Formation as a whole. This means that as pumping progresses, the cone of influence reaches the edge of the aquifer in the southwest and northeast directions and ongoing groundwater flow must be drawn from regions of the aquifer that are along strike (RLA, 2017).
Table 5.3: Details of groundwater bores screened in the western limestone facies of the Chillagoe Formation

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Aquifer</th>
<th>Status</th>
<th>Type</th>
<th>Easting GDA55</th>
<th>Northing GDA55</th>
<th>Elevation (mAHĐ)</th>
<th>Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVGT001</td>
<td>west limestone</td>
<td>No longer in use</td>
<td>Monitoring</td>
<td>206782.7</td>
<td>8125472.8</td>
<td>262.4</td>
<td>35</td>
</tr>
<tr>
<td>KVMB1A</td>
<td>west limestone</td>
<td>Operational</td>
<td>Monitoring</td>
<td>206816.7</td>
<td>8125556.0</td>
<td>254.3</td>
<td>100</td>
</tr>
<tr>
<td>KVMB1B</td>
<td>west limestone</td>
<td>Operational</td>
<td>Monitoring</td>
<td>206930.4</td>
<td>8125464.7</td>
<td>257.0</td>
<td>100</td>
</tr>
<tr>
<td>KVMB2A</td>
<td>west limestone</td>
<td>Operational</td>
<td>Monitoring</td>
<td>207352.4</td>
<td>8124822.6</td>
<td>246.5</td>
<td>57</td>
</tr>
<tr>
<td>KVMB2B</td>
<td>west limestone</td>
<td>Operational</td>
<td>Monitoring</td>
<td>207347.6</td>
<td>8124871.6</td>
<td>247.3</td>
<td>100</td>
</tr>
<tr>
<td>KVMB3</td>
<td>west limestone</td>
<td>Operational</td>
<td>Monitoring</td>
<td>208138.2</td>
<td>8123765.9</td>
<td>243.5</td>
<td>100</td>
</tr>
<tr>
<td>KVMB4B</td>
<td>west limestone</td>
<td>Operational</td>
<td>Monitoring</td>
<td>206445.5</td>
<td>8126152.1</td>
<td>251.6</td>
<td>75.5</td>
</tr>
<tr>
<td>KVPB01</td>
<td>west limestone</td>
<td>Operational</td>
<td>Production</td>
<td>207005.2</td>
<td>8125462.3</td>
<td>263.1</td>
<td>189</td>
</tr>
<tr>
<td>KVPB02</td>
<td>west limestone</td>
<td>Operational</td>
<td>Production</td>
<td>207184.1</td>
<td>8125275.9</td>
<td>254.5</td>
<td>200</td>
</tr>
<tr>
<td>KVPB03</td>
<td>west limestone</td>
<td>Operational</td>
<td>Production</td>
<td>206869.5</td>
<td>8125630.2</td>
<td>260.7</td>
<td>198</td>
</tr>
</tbody>
</table>
Recovery data from the three pumping tests are variable. The ability of the groundwater level to recover to pre-pumping levels at bores KVPB01 and KVPB03 is limited, with residual drawdown resulting from the presence of solution cavities and the impact of the aquifer boundaries (RLA, 2017). Recovery performance at KVPB02 is faster and probably reflects the fact that there are fewer cavernous sequences within the limestone at that location (RLA, 2017).

The drawdown and recovery data from the constant discharge tests were also analysed to derive estimates of aquifer transmissivity and storage coefficient using the Theis method for confined aquifers (Theis, 1935). The transmissivity of the western limestone ranges from 22.8 m²/day to 122 m²/day (Table 5.4; RLA, 2017). Using some assumptions about the viable saturated thickness of the aquifer, hydraulic conductivity appears to be in the order of 0.1 m/day to 0.5 m/day (Table 5.4). This value is in the middle of the very wide generalised range of hydraulic conductivity values for carbonate aquifers such as limestone, which can be as low as 0.0001 m/day in cemented limestones, or as great as 1000 m/day in highly karstified rocks (Freeze & Cherry, 1979; Heath, 1983). At the time of writing, there are no other known published values of hydraulic conductivity for the Chillagoe Formation.

The heterogeneous nature of the western limestone lithofacies is demonstrated by the differing recovery rates of the three production bores, and by their varying hydraulic properties (Table 5.4).

### Table 5.4: Hydraulic properties of the western limestone facies

<table>
<thead>
<tr>
<th>Bore</th>
<th>Transmissivity (T)[m²/day]†</th>
<th>Storage coefficient (S)[dimensionless]†</th>
<th>Hydraulic conductivity (K)[m/day]*</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVPB01</td>
<td>22.8</td>
<td>2.70 x 10⁻³</td>
<td>0.13</td>
</tr>
<tr>
<td>KVPB02</td>
<td>59.5</td>
<td>3.77 x 10⁻⁶</td>
<td>0.35</td>
</tr>
<tr>
<td>KVPB03</td>
<td>122</td>
<td>1.87 x 10⁻²</td>
<td>0.72</td>
</tr>
<tr>
<td>Average</td>
<td>68.1</td>
<td>7.13 x 10⁻³</td>
<td>0.40</td>
</tr>
</tbody>
</table>

† T and S values from RLA (2017)

*The two values of K are estimates only. They were derived using assuming two values for saturated thickness of the aquifer (b) of 170 m and 270 m, based on the maximum depth of the unsaturated zone (30 m), the depth of the bores (200 m), plus an optional aquifer thickness below the bores (100 m).
5.2.2 Underground water flow and aquifer interactions

As explained in previous sections, the western limestone facies is hydraulically connected to the other lithofacies of the Chillagoe Formation, but has limited or no connectivity with underground water from other formations due to the effect of geological contacts and fault weathering. This assertion is confirmed by the similarity of the hydrograph trends for the various lithofacies (Figure 5.5 through Figure 5.8).

The majority of the groundwater bores at King Vol Mine are completed in the western limestone facies of the Chillagoe Formation. As there are insufficient data points to produce water table maps for the other lithofacies of the Chillagoe Formation, there are groundwater level elevation contours presented in Figure 5.4 that are derived from data from all the Chillagoe Formation monitoring bores. The levels from the production bores are not used in this map, as they represent a deeper part of the aquifer (discussed further below).

There are some key observations regarding the pre-development groundwater elevations (Table 5.5) that aid in the conceptual understanding of the system. First, the shallower monitoring bores (depths range from 35 m to 100 m; Table 5.3), show a pre-development pattern of groundwater flow in the Chillagoe Formation along strike from the northwest to the southeast (Figure 5.4).

Groundwater elevations around the production area (228 mAHD) are consistent, with a higher elevation in the arkose to the west (234 mAHD), and a lower elevation in the limestone of the southeast (219 mAHD). This pattern is to be expected, as it aligns with surface water drainage towards the Walsh River, which is 2.7 km south of ML 20658.

Second, the deeper production bores (about 200 m deep) have different groundwater levels from the shallower monitoring bores. It is difficult to determine the precise pre-development groundwater levels for the production bores as they were completed and developed at different times in late 2016. As a result, the most reliable level readings are from KVPB02, as it was installed first. The earliest water levels for KVPB01 and KVPB03 are affected by significant airlifting during bore installation, and are not representative of true pre-development conditions.

In November 2016 the groundwater elevation in KVPB02 was 235.6 mAHD, higher than the groundwater elevation in the shallower bores at the same time (228 mAHD). This demonstrates an upward hydraulic gradient from the lower level to the upper level within the western limestone before development.

Since development and production of groundwater at the three dewatering bores, up to 50 m of drawdown is recorded in bores proximal to operations (Table 5.5; Figure 5.6) and more than 100 m of drawdown is recorded to date in KVPB02 (Figure 5.6). As dewatering has significantly changed the groundwater levels within the area of the production bores, the vertical gradient has switched from upward to downward, and local groundwater flow directions are towards the production area (post-development drawdown is mapped in Section 6). However, the regional flow from northwest to southeast is not disrupted.
The conceptual model of inflows and outflows to the system includes rainfall recharge to the Chillagoe Formation over the summer and autumn months, with regional flow input from further northwest, regional outflow to the southeast, and a minor seasonal component of outflow (baseflow) to drainage features (e.g. Walsh Creek). Base flow does not occur perennially or ubiquitously, as flow in Walsh River is known to be ephemeral (Section 3.3).

Recharge to the groundwater system can be characterised from direct rainfall recharge through the soil zone to the water table. Rainfall recharge through the soil zone will only be possible when soil moisture deficits are overcome and the soil profile reaches saturation (field capacity).

Groundwater hydrographs from the monitoring bores show that groundwater levels do rise rapidly in the order of 5 m to 10 m in response to significant climatic events. Groundwater levels also demonstrate that recharge episodes are infrequent, leading to long term declines in groundwater levels over prolonged dry periods between soaking rainfall events.

A soil moisture analytical model was used to estimate rainfall recharge rates to the shallow groundwater system. Monthly rainfall and evaporation was used. The soil moisture balance also assumed:

- field capacity – 250 mm; and
- maximum monthly recharge capacity – 12 mm replicating increased runoff under intense rainfall events.

Figure 5.3 shows the components of the soil moisture balance and the estimated capped effective recharge. Recharge only occurs when the soil moisture deficit reaches zero. The extended record of monthly rainfall data shows the period between 2008 to 2011 was wetter than normal. This wetter period potentially produced a larger number of recharge events which is consistent with the monitoring bore hydrograph responses. The below average rainfall recorded from 2011 onwards results in fewer recharge events and explains the declining groundwater levels recorded at the site.
Project No 254 (King Vol UWIR and dewatering assessment)

**Figure 5.3: Rainfall recharge**

**Table 5.5: Groundwater levels before and after development, with drawdown**

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Aquifer</th>
<th>Elevation (mAHD)</th>
<th>Pre-development groundwater elevation (mAHD)</th>
<th>Post-development groundwater elevation (mAHD)</th>
<th>Drawdown* (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVMB1A</td>
<td>West Limestone</td>
<td>254.3</td>
<td>228.2</td>
<td>176.6</td>
<td>51.6</td>
</tr>
<tr>
<td>KVMB1B</td>
<td>West Limestone</td>
<td>257.0</td>
<td>228.2</td>
<td>178.0</td>
<td>50.2</td>
</tr>
<tr>
<td>KVMB2A</td>
<td>West Limestone</td>
<td>246.5</td>
<td>228.1</td>
<td>227.5</td>
<td>0.6</td>
</tr>
<tr>
<td>KVMB2B</td>
<td>West Limestone</td>
<td>247.3</td>
<td>228.2</td>
<td>227.6</td>
<td>0.7</td>
</tr>
<tr>
<td>KVMB3</td>
<td>West Limestone</td>
<td>243.5</td>
<td>219.3</td>
<td>221.1</td>
<td>-1.8</td>
</tr>
<tr>
<td>KVMB4B</td>
<td>West Limestone</td>
<td>251.6</td>
<td>229.2</td>
<td>197.4</td>
<td>31.8</td>
</tr>
<tr>
<td>KVMB6B</td>
<td>East Limestone</td>
<td>258.8</td>
<td>228.2</td>
<td>190.0</td>
<td>38.2</td>
</tr>
<tr>
<td>KVMB7</td>
<td>Arkose</td>
<td>253.0</td>
<td>226.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVMB7R</td>
<td>Arkose</td>
<td>253.0</td>
<td>228.3</td>
<td>229.3</td>
<td>-1.0</td>
</tr>
<tr>
<td>KVMB8</td>
<td>Arkose</td>
<td>258.0</td>
<td>233.7</td>
<td>242.1</td>
<td>-8.3</td>
</tr>
<tr>
<td>KVPB01</td>
<td>West Limestone</td>
<td>263.1</td>
<td>225.1</td>
<td>185.2</td>
<td>39.9</td>
</tr>
<tr>
<td>KVPB02</td>
<td>West Limestone</td>
<td>254.5</td>
<td>235.6</td>
<td>185.8</td>
<td>49.8</td>
</tr>
<tr>
<td>KVPB03</td>
<td>West Limestone</td>
<td>260.7</td>
<td>223.0</td>
<td>180.7</td>
<td>42.3</td>
</tr>
</tbody>
</table>

*Drawdown is the change in groundwater level between November 2016 to April 2017 (positive = decrease; negative = increase)
Pre-development groundwater elevation contours
5.2.3 Underground water level trend analysis

The full historical records of groundwater levels from bores screened in the western limestone facies of the Chillagoe Formation show that seasonal fluctuations were characteristic in these bores prior to development. This indicates direct rainfall recharge to the aquifer. The peak in groundwater level is in April, lagging a few months behind the peak in rainfall in January (Section 3.2) and streamflow in February (Section 3.3).

Non-parametric tests of water level trends have not been conducted in this UWIR due to the limitations of the data that can cause bias in the results, including: strong seasonality, a long gap in the record, and irregular frequency. Visual inspection indicates that there is a natural, gradual decline in groundwater level from 2012 to 2015, corresponding to a decrease in CRD (Figure 5.5 and Figure 5.6). This is confirmed by weakly correlative linear trends in bores with groundwater level records spanning 2008 to 2016 (Table 5.6).

Since dewatering production began in early 2017, the water levels in bores within this aquifer have decreased to varying degrees depending on proximity to operations (Figure 5.6). There is no recent long term drawdown trend in bores KVMB2A/2B, and KVMB3 (Figure 5.5), which are 0.5 km and 1.8 km from the production bores, respectively (Figure 4.2). There is one anomalous data point recorded on the 12th of December 2016 for each of KVMB2A, KVMB2B, and KVMB3 (Figure 5.5). These data appear anomalous as there are no continued drawdown effects for those bores in the following monitoring data.

![Groundwater level hydrograph for bores screened in the western limestone distal from operations](image)
Figure 5.6: Groundwater level hydrograph for bores screened in the western limestone proximal to operations

Table 5.6: Pre-development (2008–2016) linear trends in water level

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Aquifer</th>
<th>Trend (m/yr)</th>
<th>$R^2$ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVMB1A</td>
<td>West Limestone</td>
<td>-0.6</td>
<td>0.23</td>
</tr>
<tr>
<td>KVMB1B</td>
<td>West Limestone</td>
<td>-0.7</td>
<td>0.42</td>
</tr>
<tr>
<td>KVMB2A</td>
<td>West Limestone</td>
<td>-0.9</td>
<td>0.59</td>
</tr>
<tr>
<td>KVMB2B</td>
<td>West Limestone</td>
<td>-0.9</td>
<td>0.56</td>
</tr>
<tr>
<td>KVMB3</td>
<td>West Limestone</td>
<td>-0.3</td>
<td>0.22</td>
</tr>
<tr>
<td>KVMB4B</td>
<td>West Limestone</td>
<td>-0.5</td>
<td>0.31</td>
</tr>
<tr>
<td>KVMB6B</td>
<td>East Limestone</td>
<td>-0.8</td>
<td>0.51</td>
</tr>
<tr>
<td>KVMB7</td>
<td>Arkose</td>
<td>-0.6</td>
<td>0.54</td>
</tr>
</tbody>
</table>
5.3 Chillagoe Formation – eastern limestone

5.3.1 Description
The eastern lithofacies of the Chillagoe Formation recognised at King Vol Mine is present in a sub-vertical unit between the arkose and the shale (Figure 5.2). It is lithologically similar to the western limestone and may be contiguous with it to the south of the deposit. Minor marble and several sulphide-rich ore bands are present in the eastern limestone. Due to the viable primary porosity of this unit, it is considered a minor aquifer (RLA, 2017).

As the stratigraphic units of the King Vol Mine area are very steeply dipping (Section 5.1; Figure 5.2), the surface expression of the units (Figure 5.1) is a close approximation of the aquifer distribution. With the orientation of the strata dip towards the west, it is logical to infer some aquifer distribution at depth beyond the western contact boundary shown in Figure 5.1. In addition, the thickness or depth of the eastern limestone lithofacies is not mapped further here, as the sub-vertical orientation of the geological units dictates that their vertical extent is at least 700 mBGL, and is not laterally variable (Figure 5.2).

5.3.2 Underground water flow and aquifer interactions
As there is only one groundwater monitoring bore in the eastern limestone, the data from it are combined with those from other lithofacies to produce a water table map. An interpolated watertable map derived from all the Chillagoe Formation data is provided in Figure 5.4. The discussion of aquifer connectivity and groundwater flow in Section 5.2.2 applies to the eastern limestone unit.

5.3.3 Underground water level trend analysis
A single monitoring bore (KVMB6B) is completed within the eastern limestone 200 m northwest of KVPB03 (Figure 4.2). The groundwater level hydrograph for this bore (Figure 5.7) shows a very similar pattern to that of western limestone bores close to the production bores (Figure 5.6), reaffirming the connectivity between these units. There is a gradual decline in pre-development water level from 2008 (Table 5.6) reflecting the drier climate after 2010 (Figure 5.7). The groundwater recharge response to the high rainfall year of 2010-2011 is recorded in bore KVMB6B (Figure 5.7), and drawdown of at least 38.2 m related to dewatering is evident from late 2016 (Table 5.5).
5.4 Chillagoe Formation – arkose

5.4.1 Description

As the stratigraphic units of the King Vol Mine area are very steeply dipping (Section 5.1; Figure 5.2), the surface expression of the units (Figure 5.1) is a close approximation of the aquifer distribution. With the orientation of the strata dip towards the west, it is logical to infer some aquifer distribution at depth beyond the western contact boundary shown in Figure 5.1. In addition, the thickness or depth of the arkose is not mapped further here, as the sub-vertical orientation of the geological units dictates that their vertical extent is at least 700 mBGL, and is not laterally variable (Figure 5.2).

5.4.2 Underground water flow and aquifer interactions

As there are only three groundwater monitoring bores completed in the arkose, the data from it are combined with those from other lithofacies to produce a water table map. An interpolated water table map derived from all the Chillagoe Formation data is provided in Figure 5.4. The discussion of aquifer connectivity and groundwater flow in Section 5.2.2 applies to the arkose unit.
5.4.3 Underground water level trend analysis

Three monitoring bores, KVMB7, KVMB7R, and KVMB8, are completed within the arkose. Bore KVMB7R replaced KVMB7 in November of 2016 and it is situated in a band of arkose to the east of operations, whereas KVMB8 screens a separate layer of the arkose further to the west of the production bores (Figure 4.2).

The groundwater level hydrographs for KVMB7 (Figure 5.8) shows a pre-development pattern that is similar to that of other bores completed in the Chillagoe Formation, reaffirming the connectivity between these units. There is a gradual decline in pre-development water level from 2008 (Table 5.6) reflecting the drier climate after 2010. The groundwater recharge response to the high rainfall year of 2010-2011 is recorded in bore KVMB7, with smaller fluctuations also evident in preceding seasons (Figure 5.8).

In contrast to the bores screened in the limestone, water levels in bores KVMB7R, and KVMB8 show no drawdown response to dewatering (Figure 5.8). There has been an increase in the water level of approximately 8 m in bore KVMB8 since the beginning of 2017. This is possibly linked to either rainfall recharge from high rainfall events in January and February or a lower hydraulic conductivity at this bore resulting in a longer period of stabilisation. The groundwater level in KVMB8 stabilised in April, which is typically the peak in hydrographs from other bores (e.g. Figure 5.5). The groundwater level patterns indicate that although there is limited hydraulic connectivity between the limestone and the arkose, the impacts of groundwater abstraction to date are not observed at KVMB8 in the west or KVMB7 in the east.

![Figure 5.8: Groundwater level hydrograph for bores screened in the arkose](image-url)
6 PREDICTIONS OF GROUNDWATER IMPACTS (PART C)

This section of the report addresses sections 376(b)(iv) to 376(e) of the Water Act.

6.1 Model setup

The model development has followed the general process outlined in the Australian Modelling Guidelines (Barnett et al., 2012). This process is outlined below:

- review data and develop conceptual model;
- constructing numerical flow model;
- calibrating the numerical flow model;
- scenario predictions; and
- reporting.

6.2 Model code / platform

The finite-element simulation package FEFLOW (Diersch, 2008), was used to simulate the impact of the mining operations on the groundwater regime. FEFLOW is a high-end groundwater flow package, capable of simulating two and three-dimensional density-coupled groundwater flow, mass and heat transport in saturated and unsaturated media. FEFLOW is used worldwide as a high-end groundwater modelling tool at universities, research institutes, government offices and engineering companies. It is applied worldwide for groundwater-related tasks within the mining sector.

6.3 Model domain

The general shape and extent of the model domain was developed to be of sufficient size and extent so as not to be influenced by physical boundary conditions. The full extent of the numerical model mesh is shown in Figure 6.1. The numerical model has been developed in GDA94, Zone 55.

General mesh refinement was applied within the extent of the Chillagoe Formation. Further refinement was placed around the footprint of the proposed underground mine using the LoM plan as the basis for spatial extent (Figure 6.2). The LoM plan and schedule was provided by Auctus. The final model mesh consists of 7418 mesh elements per layer and 3724 nodes per slice.
King Vol UWAR (G1880A)

Extent of model domain

DATE
27/11/2017

FIGURE No.
6.1
6.3.1 Layers
The model was divided into 33 layers in order to represent the depth of underground mine development. Within FEFLOW, each model layer extends over the entire model domain and the thickness is typically 25 m for each layer.

The natural topographic surface layer was used as the basis for the top of layer 1 in the model. The base of the model was simulated at -500 mAH.D. The surface topography was modelled through the use of a high resolution (cells 30 m by 30 m) digital elevation model (DEM). This DEM was ground-truthed through comparison with survey data obtained in the field at various sites. The results show a good match to the surveyed data.

Model layers were assigned as unconfined (phreatic) with “free and movable” assigned to slice 1 and “fixed” assigned to the remainder of the layers.

6.4 Model boundary conditions

6.4.1 Seepage faces
Time constant seepage faces were applied broadly to layer 1 to allow groundwater to be removed from the model domain. Seepage faces within FEFLOW behave as drains in the numerical model and have flow constraints that allow water to be removed from the model, not added. Therefore a simulated seepage face will not add groundwater to the model to maintain a constant head. The seepage faces were applied to help constrain groundwater elevations to topography.

6.4.2 Recharge
Areal recharge across the model domain from rainfall infiltration has been applied to the model.

In this instance, the groundwater level hydrographs for the monitoring bores were assessed to determine an appropriate application of temporal recharge. A recharge estimate was determined based on monthly rainfall, average monthly evaporation and a soil moisture algorithm (see Section 5.2.2). On a monthly basis, the aquifers at the site appear to respond only to the larger rainfall events in excess of 250 mm per month. The effective recharge during these periods of high rainfall was capped to 12 mm/month on the assumption that significant run-off would occur during periods of high, intensive and prolonged rainfall.

Further work may be carried out in future to refine these estimates of groundwater recharge.
Effective recharge was applied to the historical period from 2008 to 2017 using the soil moisture algorithm output discussed above (see Section 5.2.2). In the previous version of the UWIR, it was assumed that no recharge would occur after the historical period (2017 onwards). This assumption provided a conservative approach, resulting in over-prediction of drawdown. In response to a requirement to present the 0.2 m drawdown predictions graphically, a refinement of the model was carried out. A recharge rate (2% of rainfall) was applied to the predictive model for this latest version of the UWIR. This boundary condition is still considered conservative, as the recharge rate is relatively low and drawdown is predicted through the over-estimation of mine inflows (refer below). In addition, alteration of recharge in the calibration phase had little effect on the model’s ability to simulate observed groundwater levels (Section 6.7).

6.4.3 Underground mine development

The LoM underground mine development (Figure 6.3) was obtained from data provided by Auctus. The depth of mine development was applied as a time variant seepage faces to the corresponding model layer (see Section 6.4.1 for discussion on the application of seepage faces within FEFLOW). The schedule for this development was also based upon information provided by Auctus. The seepage faces allow groundwater to exit the model, and thus these mine voids are simulated as effective drains from the time they are created to the end of LoM. This represents a conservative approach compared to reality, where the voids would be progressively backfilled, lowering the seepage rates.

Figure 6.3: Extent of underground mine development
(after Auctus Resources, 2017)
6.5 Hydraulic parameters and model inputs

Table 6.1 summarises the hydraulic parameters used to initially represent the various model layers.

**Table 6.1: Summary of initial hydraulic parameters**

<table>
<thead>
<tr>
<th>Model layer</th>
<th>Material</th>
<th>Horizontal hydraulic conductivity (m/d)</th>
<th>Vertical hydraulic conductivity (m/d)</th>
<th>Specific yield (%)</th>
<th>Specific storage (m^3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>$5 \times 10^{-2}$</td>
<td>$5 \times 10^{-3}$</td>
<td>0.1</td>
<td>$1 \times 10^{-4}$</td>
</tr>
<tr>
<td>1 - 33</td>
<td>Other lithology</td>
<td>$8.64 \times 10^{-3}$</td>
<td>$8.64 \times 10^{-3}$</td>
<td>0.1</td>
<td>$1 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

The parameter zones used to define the Chillagoe Formation and the other lithology are shown in Figure 6.4. This parameter zone is consistent with the mapped geology (Figure 5.1) and represents the conceptual understanding presented in Section 5.1 that the interaction between groundwater of the Chillagoe Formation and that hosted in other units is inhibited by a lack of hydraulic connectivity across the major geological contacts and the Palmerville Fault and the Walsh Fault.

Within the Chillagoe Formation, a depth dependence was applied to both the horizontal and vertical hydraulic conductivity parameters. This depth dependence is summarised in Table 6.2 and is consistent with the conceptualisation discussed in Section 5.1.

**Table 6.2: Simulated depth dependence within the Chillagoe Formation**

<table>
<thead>
<tr>
<th>Model layer</th>
<th>Elevation (mAHD)</th>
<th>Horizontal hydraulic conductivity (m/d)</th>
<th>Vertical hydraulic conductivity (m/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 3</td>
<td>250+</td>
<td>$5 \times 10^{-2}$</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>4</td>
<td>225 - 250</td>
<td>$4.8 \times 10^{-2}$</td>
<td>$4.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>5</td>
<td>200 – 225</td>
<td>$4.6 \times 10^{-2}$</td>
<td>$4.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>6</td>
<td>175 – 200</td>
<td>$4.4 \times 10^{-2}$</td>
<td>$4.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>7</td>
<td>150 – 175</td>
<td>$4.2 \times 10^{-2}$</td>
<td>$4.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>8</td>
<td>125 – 150</td>
<td>$4.0 \times 10^{-2}$</td>
<td>$4.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>9</td>
<td>100 – 125</td>
<td>$3.8 \times 10^{-2}$</td>
<td>$3.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>10</td>
<td>75 – 100</td>
<td>$3.6 \times 10^{-2}$</td>
<td>$3.6 \times 10^{-3}$</td>
</tr>
<tr>
<td>11</td>
<td>50 – 75</td>
<td>$3.4 \times 10^{-2}$</td>
<td>$3.4 \times 10^{-3}$</td>
</tr>
<tr>
<td>12</td>
<td>25 – 50</td>
<td>$3.2 \times 10^{-2}$</td>
<td>$3.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>13 - 33</td>
<td>-500 - 25</td>
<td>$3.0 \times 10^{-2}$</td>
<td>$3.0 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
King Vol UAVR (G1880A)

Modelled parameter zones

DATE
29/11/2017

FIGURE No:
6.4
6.5.1 **Observations**

A series of observation points (total of 15) was provided by Auctus and these are consistent with the bores shown in Figure 4.2 and summarised in Table 4.1 and Table 5.3.

Based on the location of the observation points (Figure 4.2) and the model layering, each bore location was assigned to a model layer commensurate with its screened depth.

6.6 **Calibration results**

6.6.1 **Objective**

The objective of the calibration was to modify the model inputs such that the model reproduces the historical observed groundwater behaviour (heads and flows) to a sufficient level. The calibration also provides the starting groundwater levels for the predictive model.

Due to necessary simplifications in creating the model, not every observation can be accurately simulated in the model. However, it is necessary that the general groundwater level behaviour is captured across the model domain. A descriptor for assessment of the model-wide level of fit is the Scaled Root Mean Square (SRMS). This measure looks past individual bores and looks at the overall fit of the model. If the ratio of the RMS error to the total head loss in the system is small, the errors are only a small part of the overall model response (Anderson and Woessner, 1992). Barnett *et al.*, (2012) suggest that a SRMS of under 10% indicates that a model is calibrated sufficiently.

The SRMS is just one measure and does not form the only metric for successful calibration. The calibrated model parameters need to be realistic and reflect the conceptual understanding and field data collected.

6.6.2 **Methodology**

The observations for the calibration include groundwater levels (heads), and pumped discharge estimates (discharge). This is an ideal situation as calibrating to different observations types (i.e. heads and flows) helps to reduce the parameter non-uniqueness as there is a smaller range of parameter combinations that can match all three of those observation types, rather than heads alone.

Due to model run times the calibration has involved only manual techniques to understand how the model components perform with the likely ranges of parameters.

The groundwater model was calibrated to transient conditions to ensure the seasonal response to stresses (e.g. rainfall) was replicated. This is particularly important where rainfall is known to be highly seasonal with contrasting wet and dry periods.
The calibration adopted monthly stress periods from 1 January 2008 to 1 January 2017 using monthly rainfall as an input (Section 3.2) and the results of the soil moisture balance spreadsheet model (Section 6.4.2). By adjusting aquifer parameters (hydraulic conductivity [horizontal and vertical], specific yield and specific storage), the calibration improved the match between observed and simulated water levels.

Available groundwater level data were used to calibrate the model. Figure 4.2 shows the monitoring sites used in the calibration process.

### 6.6.3 Results

Figure 6.5 compares the observed and calculated water levels from the transient model graphically, with Table 6.3 presenting statistics from the calibration process. Appendix A provides hydrographs for each bore comparing the observed and simulated groundwater levels from the transient model.

![Figure 6.5: Calibration – modelled vs. observed groundwater levels](image)
Table 6.3: Calibration statistics

<table>
<thead>
<tr>
<th>Calibration performance measure</th>
<th>Weighted value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum of residuals (SR) (m)</td>
<td>2524.25</td>
</tr>
<tr>
<td>Mean sum of residuals (MSR) (m)</td>
<td>5.58</td>
</tr>
<tr>
<td>Scaled mean sum of residuals (SMSR) (%)</td>
<td>4.85</td>
</tr>
<tr>
<td>Sum of squares (SSQ) (m²)</td>
<td>54326.34</td>
</tr>
<tr>
<td>Mean sum of squares (MSSQ) (m²)</td>
<td>120.19</td>
</tr>
<tr>
<td>Root mean square (RMS) (m)</td>
<td>10.96</td>
</tr>
<tr>
<td>Root mean fraction square (RMFS) (%)</td>
<td>0.46</td>
</tr>
<tr>
<td>Scaled RMFS (SRMFS) (%)</td>
<td>0.92</td>
</tr>
<tr>
<td>Scaled RMS (SRMS) (%)</td>
<td>9.52</td>
</tr>
</tbody>
</table>

The RMS error calculated for the calibrated model is 10.96 m. The total observed head loss within the model domain is 115 m; therefore, the ratio of RMS to the total head loss (SMRS) is 9.52%. This indicates a good calibration of the model and is below the 10% SRMS specified in the Australian guidelines (Barnett et al., 2012).

It is important to note that there are a number of observations (late 2016 and early 2017) that are influenced by pumping from dewatering bores PB01, PB02 and PB03. Dewatering bores PB01, PB02 and PB03 have been drilled into a cavernous aquifer with relatively high transmissivity (average of 68 m²/day) and high storage (see Table 5.4 and Section 5.2.1).

Pumping tests from these bores show the influence of boundary effects on the data indicating a finite extent to the cavernous aquifer. Recent pumping data from dewatering bores PB01, PB02 and PB03 shows that the yield from these bores is reducing. This reduction in yield is thought to be as a result of the depletion in storage of the cavernous aquifer.

This cavernous aquifer has not been represented within the model as its distribution and extent is not accurately known. If an attempt was made to represent this in the model it is highly likely that a better calibration could be achieved. However, given that the cavernous aquifer is depleting and that the extent is finite, the influence of such a feature would only relate to short term mine water management and short term potential underground inflows.
Representation of a cavernous aquifer within the model would not influence long term drawdown resulting from mining, nor the longer term predicted inflow rates to the underground mine.

The transient calibration model is able to replicate long-term trends, in particular responses to rainfall events and localised pumping (Appendix A). Table 6.4 summarises the calibrated hydraulic parameters for each of the hydrostratigraphic units within the model domain.

<table>
<thead>
<tr>
<th>Model layer</th>
<th>Horizontal hydraulic conductivity (m/d)</th>
<th>Vertical hydraulic conductivity (m/d)</th>
<th>Specific yield (%)</th>
<th>Specific storage (m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 3</td>
<td>4 x 10$^{-2}$</td>
<td>4.0 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>4</td>
<td>3.8 x 10$^{-2}$</td>
<td>3.8 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>5</td>
<td>3.6 x 10$^{-2}$</td>
<td>3.6 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>6</td>
<td>3.4 x 10$^{-2}$</td>
<td>3.4 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>7</td>
<td>3.2 x 10$^{-2}$</td>
<td>3.2 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>8</td>
<td>3.0 x 10$^{-2}$</td>
<td>3.0 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>9</td>
<td>2.8 x 10$^{-2}$</td>
<td>2.8 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>10</td>
<td>2.6 x 10$^{-2}$</td>
<td>2.6 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>11</td>
<td>2.4 x 10$^{-2}$</td>
<td>2.4 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>12</td>
<td>2.2 x 10$^{-2}$</td>
<td>2.2 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
<tr>
<td>13 - 33</td>
<td>2.0 x 10$^{-2}$</td>
<td>2.0 x 10$^{-3}$</td>
<td>0.01</td>
<td>1 x 10$^{-5}$</td>
</tr>
</tbody>
</table>

6.7 Sensitivity

A sensitivity analysis was carried out to assess the response of the model to varying input parameters. The objective of the sensitivity analysis was to rank the input parameters in terms of their influence on the predicted results. The model parameters were adjusted to encompass the range of likely uncertainty in key parameters (invariably ± 1 order of magnitude from the calibrated value). Table 6.5 summarises the sensitivity analyses completed and the change in SRMS (calibration measure) as a result of the parameter change.
The analysis shows that the model is most sensitive to changes in specific storage and hydraulic conductivity. An order of magnitude increase in specific storage provides a SRMS of 10.84%. The calibrated specific storage of the model ($1 \times 10^{-5}$) is already at the lower end of the likely parameter range (based on the pumping test interpretations) and therefore a lower bound sensitivity was not carried out. An increase in specific yield (unconfined storage parameter) has minimal effect (increase of 0.3%) on the SRMS of the model calibration.

The effective recharge to the model was increased and decreased by 20% during the model sensitivity analysis. The results show relative insensitivity to recharge in the order of 0.3%. The hydraulic conductivity (both horizontal and vertical) of the Chillagoe Formation was increased and decreased by a multiple of five during the model sensitivity analysis. On both occasions the change led to a worse calibration statistic indicating that the model is performing well in terms of representing the bulk rock mass of the Chillagoe Formation.

The model represents a complex, heterogeneous geological system through the simulation of a homogenous rock mass in the Chillagoe Formation. The cavernous aquifer present at the site has not been represented within the model as the distribution and extent is not accurately known. The implementation of more complex geology and structure within the model would improve calibration and predictions, however this would be at the expense of a usable and practical impact assessment tool.

**Table 6.5: Sensitivity scenarios**

<table>
<thead>
<tr>
<th>Sensitivity analysis</th>
<th>Model layer</th>
<th>Material</th>
<th>Change</th>
<th>Change in SRMS (%) Basecase 9.52%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>Increase Sy by multiple of 10</td>
<td>+0.31%</td>
</tr>
<tr>
<td>2</td>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>Increase Ss by multiple of 10</td>
<td>+1.32%</td>
</tr>
<tr>
<td>3</td>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>Decrease capped effective recharge by 20% of recharge</td>
<td>-0.30%</td>
</tr>
<tr>
<td>4</td>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>Increase capped effective recharge by 20% of recharge</td>
<td>+0.30%</td>
</tr>
<tr>
<td>5</td>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>Increase Kh and Kv by multiple of 5</td>
<td>+0.41%</td>
</tr>
<tr>
<td>6</td>
<td>1 - 33</td>
<td>Chillagoe Formation</td>
<td>Decrease Kh and Kv by multiple of 5</td>
<td>+1.19%</td>
</tr>
</tbody>
</table>
6.8 Predictive Model for Impact Assessment

6.8.1 Model setup

The numerical model used to predict the impact of the development on the groundwater system was based on the calibrated model. The underground mine was simulated as a series of seepage faces (see Section 6.4.3) corresponding to the mined depth and the model layering. These boundary conditions were temporally controlled to represent the development of the mine to the proposed depth of 680 mBGL over the whole LoM period. The seepage faces representing the underground mine were initially applied in monthly timesteps.

The seepage faces representing the underground mine development are kept active all the way through the predictive simulation. This is a further conservative representation allowing for greater drawdown and groundwater inflows than would be expected to occur, as the mine plan in reality includes progressive backfilling.

The modelled extent of the Chillagoe Formation is represented in Figure 6.4. The model provides a simplified representation of the geology of the Chillagoe Formation and does not include the various lithofacies mapped at the site (Figure 5.1 and Table 5.1). Given this simplified representation, it assumes that the whole of the Chillagoe Formation will act as one hydraulically connected unit in a horizontal and vertical sense. It is known that this is not the case in reality and that various lithofacies of the Chillagoe Formation are conceptually understood to behave as aquitards or low permeability units. This model assumption is a further conservative approach to the prediction of impacts.

6.8.2 Immediately affected area

6.8.2.1 Drawdown

The immediately affected area (IAA) is defined as the area where predicted drawdown exceeds the applicable bore trigger threshold (5 m in the case of consolidated formations at King Vol Mine) within the first three years. Due to the presence of potential GDEs in the area, the assessment of potential impact in this case is also addressed through determining the areas where drawdown exceeds the spring trigger threshold of 0.2 m. Both contours are retained in mapping for clarity.

The predicted groundwater drawdown in response to the underground mine development at King Vol Mine is shown in Figure 6.9, Figure 6.10 and Figure 6.11 for years 1, 2 and 3 respectively.
The drawdown contours show that at the end of year 1 (Figure 6.9), there is a maximum drawdown of 82 m within the mine area. The 5 m drawdown contour (equivalent to the bore trigger threshold) is some 1,300 m to 1,500 m from the mine area. The 0.2 m drawdown contour (equivalent to the spring trigger threshold) is approximately 1,700 m to 2,500 m from the mine area. There are no registered groundwater bores or known springs within the 0.2 m drawdown contour at the end of year 1. There are three subterranean and three terrestrial GDE indicator sites (as mapped by NRA, 2017a) within the 0.2 m drawdown contour at the end of year 1.

At the end of year 2 the maximum predicted drawdown is 126 m (Figure 6.10). The 5 m drawdown contour (equivalent to the bore trigger threshold) is some 1,800 m to 2,200 m from the mine area. The 0.2 m drawdown contour (equivalent to the spring trigger threshold) is about 2,000 m to 2,700 m from the mine area. There are four subterranean, one aquatic, and six terrestrial GDE indicator sites (as mapped by NRA, 2017a) within the 0.2 m drawdown contour at the end of year 2.

The drawdown contours at the end of year 3 (Figure 6.11), show a predicted drawdown with a maximum of 170 m within the mine area. This represents further dewatering and depressurisation due to the progression of mining. Along the strike of the Chillagoe Formation (that is, northwest-southeast), the 5 m and 0.2 m drawdown contours are approximately 2,700 m and 3,100 m from the mining area, respectively. There are four subterranean, one aquatic, and seven terrestrial GDE indicator sites (as mapped by NRA, 2017a) within the 0.2 m drawdown contour at the end of year 2. There are no registered groundwater bores or known springs within the 0.2 m drawdown contour at the end of year 2 or 3.

It is important to note that the numerical model assumes a certain degree of hydraulic connectivity between the shallow water bearing layers (i.e. strata above 100 mBGL) and the mined ore body (as deep as 700 mbGL). Information available from the Mungana / Red Dome site shows that during underground mine development the response to dewatering was laterally limited, with bores in close proximity to the mine experiencing more than 100 m of drawdown (Figure 6.6), but bores more than 200 m away having a much lower drawdown. Recovery of water levels close to the decline at Mungana is also greater than 100 m (Figure 6.6). When there was a hiatus in extraction in 2013, recovery to pre-development groundwater levels at Mungana took approximately two years (Figure 6.6).

Whilst the King Vol model provides a conservative approach and assumes and represents vertical hydraulic connection, it is highly likely that this connection will not be as effective as modelled, and that the shallower water bearing layers will not depressurise to the full extent simulated during mine development.
6.8.2.2 Impacted bores

The registered groundwater bores in the vicinity of King Vol Mine are 45684, 45685, 45687, 45689, and 15174 (Table 6.6). These bores are used for stock watering (beef cattle). They are all situated on Lot 4, Plan BW18, in the shire of Mareeba, and were originally attributed to Pratt Pastoral Holding. Assessment of bore location (Figure 6.8) and screen lithology (Table 6.6) indicates that only bores RN45684 and RN45689 are completed in the Chillagoe Formation. As there is limited connectivity between the Chillagoe Formation and other aquifers (RLA, 2017; Section 5.1), it is unlikely that bores 45685, 45687, or 15174 could be impacted by exercise of underground water rights at King Vol Mine. Notwithstanding this, all five bores within the 20 km radius are assessed for potential impact in Section 7.5.

There is no industrial use by nearby mines of groundwater (refer to Section 7.1.7).
6.8.2.3 **Underground inflow**

The predicted rates of seepage to the underground mine during the life of mine is shown in Figure 6.7. The model predicts inflows in the order of 2 ML/day (23 L/s) to 15 ML/day (174 L/s).

The predictive model does not represent pumping from the dewatering bores during the simulation. The dewatering bores have previously extracted groundwater at rates from 15 L/s to 30 L/s, with initial mine development yielding dry working conditions. The initial predicted groundwater seepage and the actual pumping rates are comparable. In this regard the model is providing a reasonable verification to additional site data.

As discussed previously, the model is considered to be a conservative tool for the purposes of impact assessment, this is due to:

- the seepage faces representing the underground mine development remain active all the way through the predictive simulation, despite plans for progressive backfilling; and
- the Chillagoe Formation as modelled will act as one hydraulically connected unit in a horizontal and vertical sense. It is known that this is not the case in reality and that various lithofacies of the Chillagoe Formation are conceptually understood to behave as aquitards or low permeability units. Furthermore the vertical hydraulic connection is likely to be less than what is represented in the model.

Given the conservative approach summarised above, it is highly likely that the actual seepage rates to the underground mine will be less than predicted. For comparison, the current typical rate of extraction at King Vol Mine, which provides dry conditions underground, is approximately 14 L/s or 15 L/s. Therefore, the inflow predictions are considered to be overestimates.
6.8.3 Long term affected area

The long-term affected area (LTAA) is defined as the area where predicted drawdown exceeds the applicable bore trigger threshold (5 m in the case of consolidated formations at King Vol Mine) at any time. Due to the presence of potential GDEs in the area, the assessment of potential impact over the life of mine is also addressed through determining the areas where drawdown exceeds the spring trigger threshold of 0.2 m. Both contours are retained in mapping for clarity.

The predicted groundwater drawdown in response to the underground mine development to the full life of mine at King Vol Mine is shown in Figure 6.12 for the LTAA. There are no registered groundwater bores within the 5 m drawdown contour.

The drawdown contours show that at the end of mining (Figure 6.12), there is a maximum predicted drawdown of 244 m within the mine area. The 5 m drawdown contour (equivalent to the bore trigger threshold) is some 3,200 m to 4,000 m from the mine area. The 0.2 m drawdown contour (equivalent to the spring trigger threshold) is about 3,500 m to 4,500 m from the mine area. There are no registered groundwater bores or known springs within the 0.2 m drawdown contour at the end of mining. There are eleven subterranean, two aquatic, and fourteen terrestrial GDE indicator sites (as mapped by NRA, 2017a) within the 0.2 m drawdown contour at the end of mining.
Location of registered bores
Map showing the predicted impact above trigger threshold in IAA in year 1 of operations.
Map showing the predicted impact above trigger threshold in IAA in year 2 of operations
Map showing the predicted impact above trigger threshold in IAA in year 3 of operations
### Table 6.6: Bores in the vicinity of King Vol Mine

<table>
<thead>
<tr>
<th>Bore RN</th>
<th>Original bore name</th>
<th>Drilled date</th>
<th>Easting GDA z55</th>
<th>Northing GDA z55</th>
<th>Distance to King Vol (km)</th>
<th>Depth (m)</th>
<th>Screen depth (m)</th>
<th>Lithology</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>45684</td>
<td>RAYMONDS BORE</td>
<td>1/01/1973</td>
<td>203955</td>
<td>8128833</td>
<td>4.5</td>
<td>21.94</td>
<td>15.9 m to 21.9 m</td>
<td>Limestone</td>
<td>Chillagoe Formation</td>
</tr>
<tr>
<td>45685</td>
<td>NOLANDS WELL</td>
<td>1/01/1910</td>
<td>210775</td>
<td>8135521</td>
<td>10.7</td>
<td>9.14</td>
<td>7 m to 8 m</td>
<td>volcanics</td>
<td>Nychum Volcanics</td>
</tr>
<tr>
<td>45687</td>
<td>NO 3</td>
<td>1/01/1946</td>
<td>207886</td>
<td>8116925</td>
<td>8.6</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
<td>unknown</td>
</tr>
<tr>
<td>45689</td>
<td>HOUSE WELL</td>
<td>1/01/1900</td>
<td>217225</td>
<td>8113868</td>
<td>15.5</td>
<td>7.62</td>
<td>unknown</td>
<td>limestone</td>
<td>unknown</td>
</tr>
<tr>
<td>15174</td>
<td>WOTAN JOB NO 1832</td>
<td>14/04/1962</td>
<td>203268</td>
<td>8134378</td>
<td>9.7</td>
<td>21.3</td>
<td>19 m to 20 m</td>
<td>gravel and sand</td>
<td>unknown</td>
</tr>
</tbody>
</table>

All these bores were originally attributed to Pratt Pastoral Holding and are within the same cadastral lot:
- Shire: 4880 Mareeba
- Lot: 4
- Plan: BW18
- Parish: 1960 Gavin
- County: Bolwarra
Map showing the predicted total impact in LTAA at end of mining

DATE
29/11/2017

FIGURE No.
6.12
6.9 **Annual review of the predictions**

Annual review of model predictions and reporting is required if the predictions indicate the bore trigger threshold may be exceeded at any time. The results of this predictive model indicate that no bores in the vicinity will be impacted by exercise of underground water rights at King Vol. Notwithstanding this, it is recommended that a review of the model be undertaken on an annual basis, within the reporting associated with the UWIR (refer to Section 8.3.5 for details). This review will consist of comparison of predicted drawdown and inflow rates with observed drawdown and inflow rates, and comparison of the actual mine progression against that used within the predictive model. The review will assess the need, or otherwise, to update and/or recalibrate the model with newly available data.
7 IMPACTS TO THE ENVIRONMENTAL VALUES (PART D)

This section of the report addresses sections 376(da) and (db) of the Water Act.

7.1 Definition of EVs

An environmental value is defined in section 9 of the EP Act to be:

a) a quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety; or

b) another quality of the environment identified and declared to be an environmental value under an environmental protection policy or regulation.

The Environmental Protection (Water) Policy 2009 (Qld; EPP Water) provides a framework to protect and/or enhance the suitability of Queensland waters for various beneficial uses. Groundwater resources of the King Vol Mine area are located within the Mitchell River catchment (Sections 3.2 and 3.5). This area is not listed in Schedule 1 of the EPP Water, therefore, the environmental values listed in section 6(2) of the EPP Water may apply, which are:

(a) for high ecological value waters—the biological integrity of an aquatic ecosystem that is effectively unmodified or highly valued;

(b) for slightly disturbed waters—the biological integrity of an aquatic ecosystem that has effectively unmodified biological indicators, but slightly modified physical, chemical or other indicators;

(c) for moderately disturbed waters—the biological integrity of an aquatic ecosystem that is adversely affected by human activity to a relatively small but measurable degree;

(d) for highly disturbed waters—the biological integrity of an aquatic ecosystem that is measurably degraded and of lower ecological value than waters mentioned in paragraphs (a) to (c);

(e) for waters that may be used for producing aquatic foods for human consumption—the suitability of the water for producing the foods for human consumption;

(f) for waters that may be used for aquaculture—the suitability of the water for aquacultural use;

(g) for waters that may be used for agricultural purposes—the suitability of the water for agricultural purposes;
(h) for waters that may be used for recreation or aesthetic purposes, the suitability of the water for—

(i) primary recreational use; or

(ii) secondary recreational use; or

(iii) visual recreational use;

(i) for waters that may be used for drinking water—the suitability of the water for supply as drinking water;

(j) for waters that may be used for industrial purposes—the suitability of the water for industrial use;

(k) the cultural and spiritual values of the water.

A description of each environmental value is provided below, and those that may be impacted by exercise of water rights at King Vol Mine are discussed further in Sections 7.4 through 7.6. Additionally, impacts to formation integrity and subsidence are assessed in Section 7.7.

**7.1.1 Biological integrity of ecosystems**

According to the Groundwater Dependent Ecosystems Atlas (GDE Atlas), there are ecological areas within and in close vicinity to ML 20658 that have medium and high potential for interaction with groundwater. These areas include aquatic, terrestrial and subterranean ecosystems that may be partially dependent on groundwater (Figure 7.1).

The environment at the King Vol site is slightly disturbed, due to the history of beef cattle grazing in the region, and associated clearing. The slight disturbance is demonstrated by the presence of weeds at most sites surveyed across the area, but only as non-dominant vegetation (NRA, 2017a). In general, the vegetation communities are in good condition (NRA, 2017a). Additionally, the consistent groundwater quality at the site between 2008 and 2017 (NRA, 2017b) indicates that disturbance to biological integrity of any potential GDE reliant on the groundwater would be minimal. The consistent background groundwater quality is also reflective of the fact that recharge zones are only slightly disturbed.

The ecosystems relevant to groundwater EVs at King Vol Mine are defined below.
Registered bores, springs, and potential groundwater dependent ecosystems (GDEs)

DATE
29/11/2017

FIGURE No.
7.1
7.1.1.1 Aquatic ecosystems

Potential aquatic GDEs near King Vol are mapped within the GDA Atlas and the Queensland Spring Database to consist of a single spring, Stewart Spring, and the Walsh River and its tributaries on the southern side, which are at least 2.7 km south of the mine lease (Figure 7.1). Springs are addressed in Sections 7.6 and 9, whereas other GDEs are defined in this section. A recent field investigation (NRA, 2017) also identified aquatic GDE indicators at several more locations close to King Vol (Figure 7.4), including:

- a standing pool within the drainage line of Archies Creek to the northwest of the ML (Figure 7.2);
- a standing pool within the drainage line of Bowler Creek to the south of the ML (Figure 7.3); and
- a flowing pool within an unnamed drainage line close to Stewart Spring.

The presence of surface water and wetland indicator species (WIS), such as Melaleuca leucadendra, in these aquatic ecosystems indicates a possible connection to groundwater (NRA, 2017a). In addition, the presence of abundant fish species in the pools indicates they are permanent rather than ephemeral (NRA, 2017a). In addition, survey data along the Walsh River and at points on other watercourses indicates that the drainage features of the area have undulating beds, allowing for pools to develop in discrete areas of lower topography.

The connectivity between groundwater and surface water was further investigated by comparing the surface water quality of these sites with the groundwater quality from bores KVMB003 and KVMB004B (NRA, 2017b). The groundwater is a calcium-bicarbonate type water, with significant magnesium (NRA, 2017b). The water at the pools near Stewart Spring and Archie Creek has a similar major ion composition to the groundwater, although there is significantly less magnesium in the surface water (NRA, 2017b). The water from the pool in Bowler Creek bears some geochemical similarity the groundwater (NRA, 2017b). In contrast, the water sampled from the GDE indicator sites at Walsh River bears more similarity to existing records for Walsh River surface flows than it does to groundwater (NRA, 2017b).

Additional supporting evidence also indicates that there is some degree of connectivity between the groundwater in the Chillagoe Formation and the overlying creeks, including:

- the fresh groundwater quality in the Chillagoe Formation (electrical conductivity typically between 500 µS/cm to 600 µS/cm; RLA 2017);
- the southeastward groundwater flow direction toward the Walsh River; and
- the aquifer characteristics demonstrating viable groundwater flow.
Although the streamflow characteristics of the Walsh River at Rookwood (Section 3.3) indicate that there are no dry season flows, the presence of remnant pools observed in dryer months (e.g. NRA, 2017a) indicates that baseflow (i.e. groundwater discharge) could be occurring at discrete sections of the river reaches. Thus, there is expected to be some aquatic ecosystem dependence on groundwater in the areas where water similarity is confirmed (namely Archies and Bowler Creek, and the unnamed drainage line near Stewart Spring; Figure 7.4).

Therefore, an assessment of potential impacts on the biological integrity of potential aquatic GDEs is required (refer to Section 7.4).
Project No 254 (King Vol UWIR and dewatering assessment)

Figure 7.3: Aquatic GDE indicator site on Bowler Creek at WP015 (Image: Auctus)
Indicators of aquatic groundwater dependent ecosystems (GDEs)

King Vol UWR (G1880A)

DATE
29/11/2017

FIGURE No.
7.4
7.1.1.2 Terrestrial ecosystems

Within ML 20568 there is an area mapped in the GDE Atlas as having low potential for terrestrial ecosystem dependence on groundwater (Figure 7.1). This area coincides closely with the outcrop of the Chillagoe Formation (Figure 5.1). Potential impacts to terrestrial GDEs are assessed in Section 7.4, and field observations at King Vol Mine are outlined below.

The majority of terrestrial GDE indicator sites identified close to King Vol Mine (Figure 7.5) are consistent with regional ecosystem (RE) 9.11.8a (NRA, 2017a), despite not being recorded as such in the most recent RE database (DSITI, 2016). RE 9.11.8a is defined as: semi-evergreen vine thicket on limestone rock outcrops, commonly containing Gyrocarpus americanus (helicopter tree), Brachychiton chillagoensis (Chillagoe kurrajong), and other species (DSITI, 2016). This discrepancy in RE mapping and observations in the field indicates that the GDE Atlas may also be inconsistent in the area (NRA, 2017a). Conversely, several sites within the GDE Atlas areas mapped as potential GDEs were found not to host vegetation communities indicative of GDEs (NRA, 2017a).

The potential terrestrial GDEs around King Vol are limited in extent to areas characterised by limestone outcrop, and are easily distinguished from surrounding areas, which are RE 9.11.3d (NRA, 2017a). In this sense, the source aquifer for potential GDEs in RE 9.11.8a areas is conceptualised as the Chillagoe Formation, and is therefore hydraulically connected, to some degree, to the King Vol Mine.

RE 9.11.3d is defined as: low woodland to low open woodland of Melaleuca citro lens (scrub teatree) and/or M. stenostachya or Terminalia spp., possibly with Eucalyptus cullenii (Cullen's ironbark) (DSITI, 2016). The areas of RE 9.11.3d are not suspected to be terrestrial GDEs.

A terrestrial GDE indicator site (WP009; Figure 7.5) was identified on the Walsh River flood plain, with the WIS Melaleuca leucadendra present (NRA, 2017a). This was the only site identified by NRA (2017) to be a potential terrestrial GDE that was not RE 9.11.8a.

The potential terrestrial GDE areas of RE 9.11.8a contain Brachychiton spp., which provides a reliable indication of groundwater reliance. Brachychiton spp. are known to preference deep water sources over shallow ones and use a fast growing tap root for groundwater uptake (Bijoor et al., 2012). The unsaturated zone in the area of King Vol Mine was typically 19 m to 29 m deep before development (Table 7.1). Although there is insufficient data to understand the typical tap root depths for Brachychiton spp., it is possible that they are utilising groundwater (NRA, 2017a). The maximum normal root depth for ecosystems in tropical savannah is approximately 15 m (Eamus et al., 2006), however, Brachychiton spp. tap roots may be deeper than this.
In addition, *Brachychiton* spp. is also susceptible to air embolisms, potentially causing mortality (Choat *et al.*, 2005). The presence of mature trees of this species in the area indicates that they may be accessing groundwater during dry periods to prevent air embolisms (NRA, 2017a).

**Table 7.1: Pre-development depth to groundwater level in monitoring bores**

<table>
<thead>
<tr>
<th>Bore</th>
<th>95th Percentile of depth to water (mBGL) (2008 to mid-2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVGT001</td>
<td>29</td>
</tr>
<tr>
<td>KVMB1A</td>
<td>24</td>
</tr>
<tr>
<td>KVMB1B</td>
<td>27</td>
</tr>
<tr>
<td>KVMB2A</td>
<td>19</td>
</tr>
<tr>
<td>KVMB2B</td>
<td>19</td>
</tr>
<tr>
<td>KVMB3</td>
<td>25</td>
</tr>
<tr>
<td>KVMB4A</td>
<td>21</td>
</tr>
<tr>
<td>KVMB4B</td>
<td>29</td>
</tr>
<tr>
<td>KVMB7</td>
<td>27</td>
</tr>
</tbody>
</table>
Indicators of terrestrial groundwater dependent ecosystems (GDEs)
7.1.1.3 Subterranean ecosystems

There are well-known caves within the carbonate sequences of the Chillagoe Formation, such as those in the Chillagoe - Mungana Caves National Park more than 20 km southeast of King Vol. These caves are mostly above the watertable, but their ecosystems support species such as children’s python, huntsman spiders and several species of bats (Zawada, 2000). Presence of water in these caves is generally ephemeral, occurring for only a few days immediately after rainfall events. This water represents the percolation of deep drainage through the unsaturated zone to the watertable below. Limestone formations are often associated with karst features, meaning voids created in the land surface and sub-surface by the slow dissolution of the limestone by rain water.

Areas around the King Vol ML that are mapped as high potential subterranean GDEs (Figure 7.1) were investigated for indicators. Twelve sites within these areas were found to correlate to areas of limestone outcrops where solution features and/or fractures were evident (NRA, 2017a). Many of these sites were also characterised by mature *Brachychiton* spp. and/or *Gyrocarpus* spp. with roots embedded into fractures and solution features (NRA, 2017a). Three sites identified as apparent cavities in the rocks were mapped, including one location (WP033) where pooled water within the cavity was observed (Figure 7.6; NRA, 2017a). Although there is not yet a clear relationship between these sites and a reliant ecosystem, it is known that there are environmentally sensitive areas close to King Vol ML that may be linked to subsurface habitats, for example, habitat areas for the Greater Large-eared Horseshoe Bat (NRA, 2011a; 2011b). In addition, the subterranean indicator sites are situated within outcrop of the Chillagoe Formation, and thus the source aquifer is the focus of the dewatering. Therefore, as a precautionary measure, these sites are assessed for potential impacts from drawdown in Section 7.4.
Indicators of subterranean groundwater dependent ecosystems (GDEs)
7.1.2 **Beneficial use in production of foods**
Groundwater is not used for production of foods for human consumption in the vicinity of the King Vol Mine area.

7.1.3 **Beneficial use in aquaculture**
Groundwater is not used for aquaculture purposes in the vicinity of the King Vol Mine area.

7.1.4 **Beneficial use in agriculture**
Groundwater is not used for irrigation purposes in the vicinity of the King Vol Mine area. No bores licensed specifically for irrigation purposes are located within a 10 km radius of the site.

Groundwater is commonly used for livestock (beef cattle) watering on properties neighbouring the King Vol Mine. This groundwater is sourced from the Chillagoe Formation, the Nychum Volcanics, and other unknown aquifers, potentially including an alluvial sequence (Table 6.6). The potential impact to this environmental value is assessed in Section 7.5.

7.1.5 **Suitability for primary, secondary or visual recreational use**
Groundwater is not used for primary, secondary, or visual, recreational use in the vicinity of the King Vol Mine area.

7.1.6 **Suitability of the water for supply as drinking water**
Groundwater is not used as a drinking water supply in the vicinity of the King Vol Mine area. According to anecdotal information, domestic use from farm bores is precluded due to the hardness of the water (a natural characteristic of groundwater from limestone aquifers).

7.1.7 **Suitability of the water for industrial use**
The groundwater extraction at King Vol Mine will be used for industrial purposes and mining activities on site. There are no other industrial users of any significance in area. The neighbouring mine, Solomons Mine, does not actively dewater for mining activities.

Industrial water quality requirements should to be considered on a case-by-case basis (ANZECC/ARMCANZ, 2000). The groundwater at King Vol is of suitable quality for these local industrial processes and minor changes in quality would not have an impact on beneficial use. This environmental value will be maintained through protection of other values, such as the environmental value for livestock watering, which has well defined guideline values.

7.1.8 **Cultural and spiritual values of the water**
There are no known environmental values in relation to cultural and spiritual values of groundwater within the King Vol area.
7.2 Past impacts on EVs
Environmental impacts that occurred within the ML in the past have not been reported. However, the slightly disturbed ecosystem that exists at the site based on the development of the area, with a significant grazing history of beef cattle, indicates that some moderate changes to the groundwater level and quality may have occurred in the last 200 years. As there have not been major development of the ore deposits at King Vol prior to 2016, the condition of the groundwater monitored from 2008 to mid-2016 is considered reliably representative of background conditions.

7.3 Predicted impacts on EVs
Those environmental values that are not impacted by exercise of water rights at King Vol Mine are identified and explained in Section 7.1 and are:

- Beneficial use in production of foods;
- Beneficial use in aquaculture;
- Suitability for primary, secondary or visual recreational use;
- Suitability of the water for supply as drinking water;
- Suitability of the water for industrial use; and
- Cultural and spiritual values of the water.

The potential impacts on the remaining environmental values are explored below.

7.4 Nature and extent of the impacts on GDEs
Potential impacts from the exercise of underground water rights on GDEs can include changes to both groundwater levels and groundwater quality; they may be permanent or temporary; and they must be considered in both spatial and temporal contexts (DEHP, 2016b). This section assesses potential impacts on aquatic, terrestrial and subterranean GDEs, whereas springs (one type of aquatic GDE) are addressed in Sections 7.6 and 9.

The source aquifer of relevance for this UWIR for potential GDEs is the outcropping limestone unit of the Chillagoe Formation (refer to geological map in Figure 5.1), as this is associated with the RE identified in the field (Section 7.1.1.2), and is the target aquifer for the dewatering. This is a conservative assumption, and is based on the site context, as the formations in and around ML 20568 are vertically extensive (Section 5).
Given the sensitive nature of some ecological areas nearby King Vol ML (NRA, 2011a; NRA, 2011b), and the strong association of mapped RE 9.11.8a with potential terrestrial GDEs, it is considered appropriate that a precautionary approach to GDE impact assessment is used. Therefore, it is assumed that ecological function is in some way reliant on groundwater at each of the GDE indicator sites identified in the field (Figure 7.4; Figure 7.5; and Figure 7.6). As such, the model predictions of groundwater drawdown surrounding the mine (Section 6.8) indicate that these GDEs will be affected by reduced access to groundwater (Table 7.2; Figure 7.7). Some potential GDEs are closer to mine operations, where drawdown is predicted to be tens of metres (Table 7.2). These areas would experience total loss of groundwater input. However, that is not to say that all water would be diverted from these communities. Surface runoff, infiltration and deep drainage would all remain unaltered by exercise of underground water rights. Other potential GDE sites that are close to the LoM 0.2 m drawdown contour may experience only a minor reduction in groundwater availability during the dry season (Table 7.2). Because the drawdown predictions are conservative (Section 6), it is possible that no impact may be observed at these sites. The monitoring program is discussed in Section 8.

Table 7.2: Predicted drawdown at various times for GDE indicator sites

<table>
<thead>
<tr>
<th>Way point (NRA, 2017a)</th>
<th>Terrestrial</th>
<th>Aquatic</th>
<th>Subterranean</th>
<th>Yr 1 drawdown (m)</th>
<th>Yr 2 drawdown (m)</th>
<th>Yr 3 drawdown (m)</th>
<th>LoM drawdown (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>010</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6.4</td>
</tr>
<tr>
<td>014</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11.8</td>
</tr>
<tr>
<td>015</td>
<td></td>
<td>✓</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13.4</td>
</tr>
<tr>
<td>016</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>20</td>
</tr>
<tr>
<td>017</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>3.9</td>
<td>12.2</td>
<td>53.3</td>
</tr>
<tr>
<td>018</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>3.1</td>
<td>10.9</td>
<td>50.4</td>
</tr>
<tr>
<td>019</td>
<td>✓</td>
<td></td>
<td></td>
<td>0.2</td>
<td>10</td>
<td>22.4</td>
<td>73.1</td>
</tr>
<tr>
<td>020</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>11.6</td>
<td>33.3</td>
<td>54.6</td>
<td>121.1</td>
</tr>
<tr>
<td>021</td>
<td>✓</td>
<td></td>
<td></td>
<td>57.1</td>
<td>93.8</td>
<td>128.3</td>
<td>203</td>
</tr>
<tr>
<td>022</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>61</td>
<td>100</td>
<td>136</td>
<td>211.7</td>
</tr>
<tr>
<td>023</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>3.9</td>
<td>13.1</td>
<td>58.3</td>
</tr>
<tr>
<td>024</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>19.3</td>
</tr>
<tr>
<td>026</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>3.1</td>
<td>11.8</td>
<td>53.7</td>
</tr>
<tr>
<td>027</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>0</td>
<td>0.9</td>
<td>7.8</td>
<td>44.4</td>
</tr>
<tr>
<td>028</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>1.4</td>
<td>8.8</td>
<td>46.6</td>
</tr>
<tr>
<td>030</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.6</td>
</tr>
<tr>
<td>031</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4.6</td>
</tr>
<tr>
<td>032</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.3</td>
</tr>
<tr>
<td>033</td>
<td>✓</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5.1</td>
</tr>
</tbody>
</table>
As outlined in Section 7.1.1, potential terrestrial GDEs are limited to those mature trees whose roots can reach the watertable. The watertable is moderately deep at King Vol Mine (Table 7.1) and could only be accessed by deep-rooted trees far exceeding the typical root depth expected for ecosystems in tropical savannah, which is approximately 15 m (Eamus et al., 2006). If dieback of deep-rooted species occurs as a consequence of the lowering of the watertable, there is the potential for understory species that are reliant on canopy cover to also be indirectly affected, despite not being dependent on groundwater themselves. The ecological responses anticipated as a result from drawdown are outlined in detail in a GDE impact assessment (NRA, 2017c).

As an assessment of the potential duration of drawdown effects, the groundwater level data available from a nearby Auctus operation at Mungana were analysed. The mine lease at Mungana is also located within the province of the Chillagoe Formation, and the underground development is analogous to King Vol, with progressive dewatering from within the underground workings. It is therefore an ideal proxy to assess recovery. When dewatering was active at Mungana, bores immediately above operations were drawn down by more than 100 m over a period of 2.5 years. However, when pumping ceased, recovery to pre-development groundwater levels took approximately two years (e.g. Figure 6.6). A similar rapid rate of recovery is expected at King Vol Mine.

As there is impact predicted for GDEs from the exercise of underground water rights at King Vol Mine, monitoring additional to that required under the EA conditions for groundwater compliance and the Receiving Environment Monitoring Program (REMP) is needed. This is outlined in Section 8.
Extent of predicted zone of influence in context of potential GDEs

DATE
29/11/2017

FIGURE No.
7.7
7.5 Nature and extent of the impacts on stock watering

Groundwater is commonly used for livestock (beef cattle) watering on properties neighbouring the King Vol Mine. However, most of the bores are distal from operations and completed in other geological formations (source aquifers). As a result, there are no bores situated within the IAA or the LTAA (Section 6). The predicted drawdown in relation to the bore locations is shown in Figure 7.8 and the model assumptions and uncertainty are discussed in Section 6.

Bores 45684 and 45689 are used for stock (beef cattle) watering and are screened in the Chillagoe Formation and are therefore linked to the groundwater at King Vol Mine. However, they are 4.5 km and 15.5 km from the zone of operations and are therefore very unlikely to be impacted. Bore 45684 is indeed the closest bore to the mine and is still outside the LoM 0.2 m drawdown contour (Figure 7.8). Bore 45685 is completed in the Nychum Volcanics and is therefore not hydraulically connected to the Chillagoe Formation. Bore 45685 is also more than 10 km away and is outside the LoM 0.2 m drawdown contour. Bores 45687 and 15174 are screened in unidentified formations, although their lithologies and locations indicate that they are not completed in the Chillagoe Formation. These bores are also out outside the LoM 0.2 m drawdown contour and are not expected to be impacted by exercise of underground water rights (Figure 7.8).

As the groundwater in the region is used for stock watering, the water quality must be protected to maintain this value. Water quality objectives (WQOs) for livestock (beef cattle) watering may be adopted as appropriate for protecting the environmental value of groundwater use for agriculture near the site. In this case the ANZECC/ARMCANZ (2000) guidelines for stock watering are the most suitable parameters (Table 7.3). Maintenance of water quality at a level below the guideline values effectively preserves environmental values for groundwater used in agriculture. As the groundwater salinity at King Vol is between 500 µS/cm and 600 µS/cm (RLA, 2017), and the exercise of underground water rights is not expected to change the groundwater quality in or around the site, there is no impact to the environmental value of stock watering from changes in water quality. A statistical comparison of the groundwater quality at the site with the stock watering guideline values (Table 7.3) demonstrates this concept well. All the 95th percentiles for monitoring sites are below the guideline values (Table 7.3). The 95th percentiles of lead concentrations in KVPB1 and KVPB3 marginally exceed the stock watering guideline, however, this water will not be used for stock watering and will be retained on site.
Extent of predicted zone of influence in relation to registered bores

DATE
29/11/2017

FIGURE No:
7.8
Table 7.3: Groundwater quality at King Vol compared to stock watering (beef cattle) guideline values

<table>
<thead>
<tr>
<th>Bore</th>
<th>number of records</th>
<th>Aluminium - total</th>
<th>Arsenic - Total</th>
<th>Cadmium - Total</th>
<th>Cobalt - Total</th>
<th>Copper - total</th>
<th>Electrical Conductivity</th>
<th>Fluoride</th>
<th>Hardness (CaCO3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td></td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>µS/cm</td>
<td>µg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>Guideline value</td>
<td>5</td>
<td>0.5</td>
<td>0.01</td>
<td>1</td>
<td>1</td>
<td>7,463</td>
<td>2,000</td>
<td>note A</td>
<td>note B</td>
</tr>
</tbody>
</table>

**Notes:**
- General – guideline values also exist for uranium, mercury, and chromium, but these analytes are not monitored
- A – the value of 7463 µS/cm is derived from a total dissolved solids guideline of 5,000 mg/L using a conversion factor 0.67
- B – no guideline value is presented for hardness, but the value for calcium is 1,000 mg/L
Table 7.3 continued:

<table>
<thead>
<tr>
<th>Bore</th>
<th>number of records</th>
<th>Lead - Total</th>
<th>Molybdenum - Total</th>
<th>Nickel - filtered</th>
<th>Nitrate</th>
<th>pH</th>
<th>Selenium - Total</th>
<th>Sulphate</th>
<th>Zinc - Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
<td>mg/L</td>
<td>mg/L</td>
<td>µg/L</td>
<td>mg/L</td>
<td>pH units</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
<td>mg/L</td>
</tr>
<tr>
<td>Guideline value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GW KVMB001A</td>
<td>47</td>
<td>0.021</td>
<td>0.0029</td>
<td>1.3</td>
<td>0.46</td>
<td>7.5</td>
<td>0.004</td>
<td>13.8</td>
<td>0.18</td>
</tr>
<tr>
<td>GW KVMB001B</td>
<td>48</td>
<td>0.008</td>
<td>0.0025</td>
<td>3.3</td>
<td>0.75</td>
<td>7.5</td>
<td>0.004</td>
<td>20.8</td>
<td>0.17</td>
</tr>
<tr>
<td>GW KVMB002A</td>
<td>48</td>
<td>0.013</td>
<td>0.0025</td>
<td>1.0</td>
<td>0.70</td>
<td>7.6</td>
<td>0.004</td>
<td>5.0</td>
<td>0.05</td>
</tr>
<tr>
<td>GW KVMB002B</td>
<td>50</td>
<td>0.002</td>
<td>0.0025</td>
<td>3.0</td>
<td>0.09</td>
<td>7.5</td>
<td>0.005</td>
<td>12.0</td>
<td>0.02</td>
</tr>
<tr>
<td>GW KVMB003</td>
<td>49</td>
<td>0.004</td>
<td>0.0025</td>
<td>1.0</td>
<td>0.69</td>
<td>7.5</td>
<td>0.005</td>
<td>5.3</td>
<td>0.04</td>
</tr>
<tr>
<td>GW KVMB004B</td>
<td>46</td>
<td>0.045</td>
<td>0.0025</td>
<td>1.0</td>
<td>0.05</td>
<td>7.5</td>
<td>0.003</td>
<td>7.0</td>
<td>0.30</td>
</tr>
<tr>
<td>GW KVMB006B</td>
<td>44</td>
<td>0.084</td>
<td>0.0025</td>
<td>1.0</td>
<td>0.54</td>
<td>7.4</td>
<td>0.003</td>
<td>12.0</td>
<td>0.28</td>
</tr>
<tr>
<td>GW KVMB007</td>
<td>36</td>
<td>0.004</td>
<td>0.0025</td>
<td>1.6</td>
<td>0.13</td>
<td>7.4</td>
<td>0.003</td>
<td>6.3</td>
<td>0.03</td>
</tr>
<tr>
<td>GW KVMB007R</td>
<td>7</td>
<td>0.007</td>
<td>0.0010</td>
<td>0.9</td>
<td>0.03</td>
<td>6.9</td>
<td>0.005</td>
<td>5.9</td>
<td>0.04</td>
</tr>
<tr>
<td>GW KVMB008</td>
<td>8</td>
<td>0.005</td>
<td>0.0017</td>
<td>0.5</td>
<td>0.02</td>
<td>7.1</td>
<td>0.005</td>
<td>48.0</td>
<td>0.04</td>
</tr>
<tr>
<td>GW KVPB1</td>
<td>3</td>
<td>0.900</td>
<td>0.0005</td>
<td>1.0</td>
<td>0.04</td>
<td>7.4</td>
<td>0.004</td>
<td>11.0</td>
<td>4.98</td>
</tr>
<tr>
<td>GW KVPB2</td>
<td>6</td>
<td>0.003</td>
<td>0.0009</td>
<td>1.0</td>
<td>0.00</td>
<td>7.0</td>
<td>0.005</td>
<td>9.4</td>
<td>0.17</td>
</tr>
<tr>
<td>GW KVPB3</td>
<td>6</td>
<td>0.180</td>
<td>0.0088</td>
<td>0.5</td>
<td>0.01</td>
<td>7.1</td>
<td>0.005</td>
<td>32.4</td>
<td>0.69</td>
</tr>
</tbody>
</table>

notes:
C – the guideline value for total nickel is compared to available data, which are for filtered nickel
D – this guideline value pertains to Nitrite + Nitrate (as N), whereas the data are nitrate concentrations (as NO₃)
E – this guideline value is for aquatic ecosystem health (ANZECC/ARMCANZ, 2000)
7.6 Nature and extent of the impacts on springs of interest

There is only one mapped spring within a 20 km radius of the King Vol Mine, and that is Stewart Spring, on the far side of the Walsh River from ML 20658, and outside the LoM 0.2 m drawdown contour (Figure 7.1; DSITI, 2015). Springs are discussed in more detail in Section 9, where it is established that the source aquifer for Stewart Spring is not the Chillagoe Formation, but the Pratt Volcanics. This unit is hydraulically separated from the Chillagoe Formation by several flow barriers, including the extent of the Dargalong Metamorphics.

There is no anticipated impact on this spring or any environmental values associated with springs from the exercise of underground water rights at King Vol Mine.

7.7 Impacts to formation integrity and surface subsidence

A structural integrity assessment and geotechnical characterisation of the rock types at King Vol was undertaken to provide a basis for mine stoping design (Entech Pty Ltd, 2016). A conservative approach of stoping with 20 m level spacing was recommended, although the rock is considered competent enough for spacing of 35 m or 40 m, given its lithological characteristics. This, in addition with "rigorous back-analysis for initial stoping areas" (Entech Pty Ltd, 2016), ensures minimal risk of subsidence or damage to formation integrity. With regard to an assessment of subsidence risk, the report states:

"Caving and subsidence assessments indicated that caving is highly unlikely (but not impossible) to occur at the planned stoping dimensions. Subsidence is highly unlikely with planned stoping and ore drive development occurring in fresh to transitional materials, and the upper most level(s) will be fully support. [sic]"

It is therefore determined that there is no significant risk of damage to formation integrity or surface subsidence at King Vol Mine, and a subsidence monitoring program is not necessary.
8 WATER MONITORING STRATEGY (PART E)

This section of the report addresses section 376(f) and section 378 of the Water Act.

8.1 Rationale and strategy

This underground water monitoring strategy is designed to monitor changes in the IAA and the LTAA. The monitoring program has two objectives, first, to observe groundwater level changes in order to measure drawdown as a result of exercise of underground water rights for comparison with predicted drawdown values, and second to observe the changes in availability of groundwater for GDEs. This second objective will also be supported by a Groundwater Dependent Ecosystem Monitoring Program (NRA, 2017d), which will entail the measurement of the changes in ecological parameters that are expected as a secondary impact from the reduced access to groundwater.

There are no changes expected in water quality as a result of the exercise of underground water rights, and a moderate change in quality would not have a significant impact on environmental values or beneficial use (Section 7). Therefore, the compliance parameters placed on the groundwater through the conditions of the EA are appropriate for groundwater quality monitoring and management. As there is a sound record of background water quality, any potential deviations from baseline conditions will be discernible.

The predicted drawdown is outlined in Section 6. There is significant drawdown already observed and further declines predicted from the exercise of underground water rights at King Vol Mine. Therefore, the strategy behind the water level monitoring program is to assess the level of observed drawdown against predictions, ensuring that impacts do not exceed acceptable limits. To this end, there are slight modifications of the EA monitoring program with respect to groundwater levels, and these are presented below. In addition, installation of a groundwater monitoring bores that may be required at certain hold points is recommended, and the need for these sites is outlined below.

8.2 Monitoring record

The monitoring at King Vol Mine to date is in accordance with the EA requirements and includes additional baseline data that was collected regularly from 2008 to 2011 in eight bores (Table 8.1). Before operations began in 2016, monitoring frequency was increased to monthly for groundwater levels and quarterly for groundwater quality measurements, and new bores were included in the monitoring network (Table 8.1). Thus, there exists a comprehensive groundwater level and groundwater quality database for characterising the background conditions (RLA, 2017).
Table 8.1: Lengths of monitoring records for King Vol bores

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Water level records</th>
<th>Water quality records</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Earliest</td>
</tr>
<tr>
<td>GW KVGT01</td>
<td>16</td>
<td>11/11/2008</td>
</tr>
<tr>
<td>GW KVMB01A</td>
<td>53</td>
<td>20/10/2008</td>
</tr>
<tr>
<td>GW KVMB01B</td>
<td>57</td>
<td>10/09/2008</td>
</tr>
<tr>
<td>GW KVMB02A</td>
<td>57</td>
<td>10/09/2008</td>
</tr>
<tr>
<td>GW KVMB02B</td>
<td>56</td>
<td>10/09/2008</td>
</tr>
<tr>
<td>GW KVMB03</td>
<td>56</td>
<td>10/09/2008</td>
</tr>
<tr>
<td>GW KVMB04B</td>
<td>51</td>
<td>10/09/2008</td>
</tr>
<tr>
<td>GW KVMB06B</td>
<td>56</td>
<td>10/09/2008</td>
</tr>
<tr>
<td>GW KVMB07R</td>
<td>10</td>
<td>22/11/2016</td>
</tr>
<tr>
<td>GW KVMB08</td>
<td>10</td>
<td>22/11/2016</td>
</tr>
<tr>
<td>GW KVMB1</td>
<td>15</td>
<td>11/11/2008</td>
</tr>
<tr>
<td>GW KVPB1</td>
<td>6</td>
<td>23/11/2016</td>
</tr>
<tr>
<td>GW KVPB3</td>
<td>8</td>
<td>4/11/2016</td>
</tr>
</tbody>
</table>

8.3 Monitoring program and timetable

8.3.1 Monitoring locations

The existing groundwater bores will be accessed to monitor the groundwater at King Vol Mine (Figure 8.1). This monitoring suite is of suitable spatial extent and completed in formations with appropriate characteristics to adequately detect potential impacts, with the exception of one area (discussed further below). As high frequency baseline data collection was completed in 2011, the ongoing monitoring frequency is quarterly, in accordance with the EA.

Auctus will continue to measure groundwater levels and groundwater quality in all MB series bores in accordance with the requirements of the EA (Section 3.1; Table 8.2). Auctus will also monitor the three production bores at King Vol for groundwater level and groundwater quality.
In addition, it is recommended that a new groundwater monitoring bore (NMB-A) should be completed in the Chillagoe Formation to the northwest of the mine lease. The interim name allocated to this location until drilling is undertaken is NMB-A (new monitoring bore A). The location of NMB-A complements that of KVMB03, which is to the southeast, very close to the 0.2 m drawdown contour for year one (Figure 8.1). Thus, NMB-A would be positioned to detect drawdown at a similar time and magnitude to that expected in KVMB03, but to the northwest of the mine. It is recommended that this bore be installed as soon as possible, and the name changed in accordance with the convention for other King Vol monitoring bores. The proposed location as shown on Figure 8.1 may be moved within reason to allow for logistical and access constraints. As the model predictions are conservative, there may be no detectable drawdown at these sites within the first year. However, predicted drawdown at these sites by the end of the second year is between 8 m and 9 m, therefore, some discernible drawdown is likely to be recorded within two years.

It is also recommended that groundwater monitoring bores designed to detect drawdown further from the site be installed before the end of the second year. The two proposed locations are shown as NMB-B and NMB-C on Figure 8.1. The sites are placed close to the predicted 0.2 m drawdown contour for year 3. Thus, detectable drawdown is likely to be observed at these locations approximately two years after it is measured at KVMB03 or NMB-A. As the model predictions are an over-estimate of the predicted drawdown, drawdown may not be observed at these locations until after year 3. The completion of these monitoring bores before the end of the second year of proposed mining allows for the collection of appropriate background data.

### 8.3.2 Water level monitoring

Groundwater level monitoring in the bores at King Vol Mine listed in Table 8.2 shall be carried out monthly. Every third month the water quality will also be monitored, and the monthly monitoring of water levels will be synchronised with this event, such that water levels are obtained immediately before purging and sampling of the bore.

In addition, the installation of groundwater level data loggers (pressure transducers) is recommended for key monitoring sites, including: KVMB03, NMB-A, NMB-B and NMB-C (once completed). The benefit of data logger transducers is the provision of high-frequency data, especially across wet periods, when recharge is occurring (hence water levels are changing) and site access for manual measurements may be restricted.
### Table 8.2: Monitoring timetable (derived in part from Table G18 of the EA)

<table>
<thead>
<tr>
<th>Bore ID</th>
<th>Listed in EA (Table G18)</th>
<th>Monitoring frequency</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>KVMB01A</td>
<td>Yes</td>
<td>Monthly for water level (except RN45684)</td>
<td>Water level</td>
</tr>
<tr>
<td>KVMB01B</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVMB02A</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VMB02B</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVMB03</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVMB04B</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVMB06B</td>
<td>Yes</td>
<td>Quarterly for water quality</td>
<td>Water quality parameters listed in Table 8.3</td>
</tr>
<tr>
<td>KVMB07R</td>
<td>Yes (as KVMB07)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVMB08</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVPB1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVPB2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KVPB3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMB-A*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMB-B**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMB-C**</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*bore to be installed as soon as possible (water level only)

**bores to be installed before the end of year 2 (water level only)

### 8.3.3 Water quality monitoring

All samples for groundwater quality shall be collected after the bore is appropriately purged. The samples shall be preserved and forwarded to a NATA accredited water laboratory for analysis (RLA, 2017). The parameters to be analysed are the same as those listed in the EA and are provided in Table 8.3. Groundwater shall be sampled in accordance with the relevant guidelines and conventions (e.g. Sundaram et al., 2009; DEHP, 2010) and in compliance with Australian standards (AS/NZS 5667:11 1998).
Table 8.3: Monitoring parameters (derived from Table G19 of the EA)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Monitoring frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Conductivity (µS/cm)</td>
<td>µS/cm</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>pH units</td>
<td></td>
</tr>
<tr>
<td>Hardness (CaCO3)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Major cations and anions</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Sulphate</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Ammonia (as N)</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Fluoride</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Antimony – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Antimony – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Arsenic – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Arsenic – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Cadmium – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Cadmium – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Cobalt – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Cobalt – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Copper – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Copper – total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Lead – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Lead – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Molybdenum – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Molybdenum – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Selenium – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Selenium – Total</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Zinc – Diss</td>
<td>mg/L</td>
<td></td>
</tr>
<tr>
<td>Zinc – Total</td>
<td>mg/L</td>
<td></td>
</tr>
</tbody>
</table>
8.3.4 Ecological monitoring of GDEs

The monitoring of groundwater levels and quality provides information regarding the direct impact to other groundwater users that are potentially affected by drawdown, namely GDEs. In addition, to support the ongoing assessment of potential impacts to GDEs, a monitoring program has been designed to focus on GDE indicator sites within the LoM 0.2 m drawdown zone (NRA, 2017d). This monitoring will provide information on the condition of the GDEs through use of ecological parameters. Potential terrestrial GDEs will be assessed for changes to the condition of vegetation, and potential aquatic GDEs will be monitored through water analyses, as well as aquatic community observations (NRA, 2017d). The measurement of potential impacts to subterranean GDEs will be undertaken through the proxy of groundwater levels, as described above. Where potential subterranean GDEs exist between groundwater monitoring sites, spatial interpolation of data will be used to assist assessments. The ecological assessment of potential impacts to GDEs will be undertaken at sites in accordance with the validation survey (NRA, 2017a) at a frequency of twice a year, towards the end of the wet and dry seasons (NRA, 2017d).

8.3.5 Reporting

The implementation of the groundwater monitoring strategy described above must be reported to the Office of Groundwater Impact Assessment (OGIA). Condition G67 of the EA currently requires Auctus to provide an annual review of the Groundwater Management Program to the regulators (DEHP). This report shall also be submitted to OGIA and, with some additions listed here, will fulfill the reporting requirements related to this monitoring strategy. This report will therefore include assessment of groundwater levels from new bores, despite those bores not being required under EA conditions. The observed groundwater drawdown and inflows to the mine will be compared to the predictions from the numerical model for this report. Thus, a comparison of the observed impact to GDEs and that predicted in the model simulation will be presented.

Condition G60 of the EA stipulates that results from surface water monitoring undertaken as part of the Receiving Environment Monitoring Program (REMP) must be reported annually. The EA currently lists three points on the Bowler Creek for surface water compliance monitoring at King Vol Mine (Table G15). Where there are relevant findings, Auctus will incorporate information relating to surface water into the groundwater report. In addition, this monitoring report will present the findings from the GDE monitoring program (NRA, 2017d) to provide an indication of any changes in ecological condition at the potential GDE sites where drawdown may be observed.
9 SPRING IMPACT MANAGEMENT STRATEGY (PART F)

This section of the report addresses section 376(g) and section 379 of the Water Act.

9.1 Springs of interest

The UWIR guidelines (DEHP, 2016a) define a spring as a spring of interest if:

“the water level in an underlying aquifer is predicted, in an UWIR or final report, to decline by more than the spring trigger threshold at the location of the spring at any time and the cause of the predicted decline is the exercise of underground water rights. The spring trigger threshold is a decline of water level of 0.2 metres in the source aquifer, unless an alternative spring trigger threshold has been defined by regulation.”

9.2 Spring inventory

Auctus staff traverse the area of ML 20658 regularly and are very familiar with the landscape features. Based on their observations, there are no springs on the King Vol lease. During the GDE field verification survey of the King Vol site, which was focussed on potential areas as mapped in the GDE Atlas, no other springs were encountered at the site visited (NRA, 2017a).

There is only one mapped spring within a 20 km radius of the King Vol Mine, and that is Stewart Spring, on the far side of the Walsh River from ML 20658 (Figure 7.1; Figure 9.1; DSITI, 2015). The Queensland Government wetlands mapping identifies this spring as an active recharge spring containing fresh water (Table 9.1; DSITI, 2015). Stewart Spring was visited by ecologists to determine if the spring was flowing and to observe the associated terrestrial vegetation (NRA, 2017a). The spring was not flowing at the time (November, 2017), but the soil was damp at a level about 3 cm beneath the surface (NRA, 2017a). Nearby to the spring, a drainage line was identified, running north to the Walsh River. Discrete pools, some with flowing water, were observed in this drainage line, with mature WISs (NRA, 2017a; Figure 9.2), indicating long-lived, perennial features. The major-ion water chemistry of this water is very similar to that of local groundwater, with the exception of magnesium concentration (NRA, 2017b). All these factors indicate that there are potential aquatic GDEs in and around Stewart Spring. However, these surface water features and Stewart Spring itself are approximately 6 km outside the LoM 0.2 m drawdown contour (Figure 7.7).

<table>
<thead>
<tr>
<th>Spring name</th>
<th>Spring type</th>
<th>Water quality</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stewart Spring</td>
<td>active recharge spring</td>
<td>Fresh</td>
<td>-17.020278</td>
<td>144.293056</td>
</tr>
</tbody>
</table>
Project No 254 (King Vol UWIR and dewatering assessment)

Figure 9.1: Stewart Spring (Nov, 2017; image: Auctus)

Figure 9.2: Pooled water nearby Stewart Spring (WP002, marked on Figure 7.4; image: NRA, 2017a)
9.3 **Connectivity between the spring and aquifer**

There are no hydrological or hydrogeochemical records from Stewart Spring with which to undertake an integrated assessment and comparison with groundwater from ML 20568. However, as mentioned above, the major-ion signature of surface water 440 m from Stewart Spring is very similar to that of groundwater from King Vol bores, with the exception of magnesium concentration (NRA, 2017b). Stewart Spring is situated in an outcrop area of the Pratt Volcanics, close to where it is locally overlain by Tertiary-Quaternary sand, silt and gravel (Branch *et al.*, 1963). The Pratt Volcanics crop out to the west of the Palmerville Fault and is also separated from the Chillagoe Formation by the Dargalong Metamorphics (Figure 5.1). Therefore, the source aquifer for the spring is hydraulically separated and disconnected from the Chillagoe Formation. In addition, the LoM 0.2 m drawdown contour indicates a zone of influence around King Vol Mine that is distal from the spring’s location (approximately 6 km away; Figure 7.7). Stewart Spring is therefore highly unlikely to be impacted by mining activities at the King Vol Mine.

9.4 **Spring values**

In accordance with the UWIR guidelines (DEHP, 2016a), assessment of the risk to, and likely impact on, the ecosystem and cultural and spiritual values of springs are addressed under Part D (Section 7.6 of this UWIR).

9.5 **Management strategy**

There are no predicted impacts on springs from exercise of underground water rights at King Vol Mine (Section 7.6). Therefore, a management strategy for springs, including mitigation measures and reporting, is not required. It is recommended, however, that potential GDEs be regularly visited as part of the GDE monitoring program (refer to Section 8 for more details).
10 CONCLUSIONS

This UWIR has assessed the potential impact from the exercise underground water rights from the proposed development of an underground mine at King Vol (ML 20568) to a total depth of 680 mBGL within the Chillagoe Formation over seven years.

In addition to characterisation of the aquifers, groundwater system and environmental values through research and data analysis, a numerical groundwater flow model was developed to simulate the current operations, and to predict the potential changes to the groundwater regime. The numerical model inherits a conservative approach and provides the worst case scenario in terms of model drawdown and underground inflows. At the end of mining, the maximum predicted drawdown is 244 m within the immediate mine area. Along the strike of the Chillagoe Formation (that is, northwest-southeast), the 5 m and 0.2 m drawdown contours (equivalent to the bore trigger threshold and the spring trigger threshold, respectively) are approximately 4,000 m and 4,500 m from the mining area, respectively. There are no registered groundwater bores or known springs within the 0.2 m drawdown contour at the end of mining. There are eleven subterranean, two aquatic, and fourteen terrestrial GDE indicator sites (as mapped by NRA, 2017a) within the 0.2 m drawdown contour at the end of mining.

Based on rigorous observation of recovery at a nearby analogous site, drawdown is not expected to persist longer than two or three years after dewatering ceases.

An impact assessment was undertaken to identify potential risks to environmental values. Those environmental values that are **not** predicted to be impacted by exercise of water rights at King Vol Mine are:

- Biological integrity of aquatic, terrestrial and subterranean ecosystems outside of the LoM 0.2 m drawdown contour (including Walsh River);
- Ecosystem and cultural and spiritual values of identified springs (i.e. Stewart Spring);
- Beneficial use in production of foods;
- Beneficial use in aquaculture;
- Beneficial use in agriculture (including use from registered bores 45684, 45685, 45687, 45689, 15174);
- Suitability for primary, secondary or visual recreational use;
- Suitability of the water for supply as drinking water;
- Suitability of the water for industrial use; and
- Cultural and spiritual values of the water.
There are potential impacts to the biological integrity of GDEs within the zone of influence demarcated by the 0.2 m drawdown contour. The degree of ecological dependence is not directly quantified at this time. However, the field survey of sites revealing WISs and REs associated with GDEs, and the geochemical similarity between from surface waters and groundwater, indicates that there is some degree of dependence on groundwater. Some potential GDEs are closer to mine operations and would experience total loss of groundwater input, whereas others that are close to the 0.2 m drawdown contour would experience only a minor reduction in groundwater availability. This reduction will be monitored in the form of groundwater level monitoring and GDE observations outlined in Section 8, and will be compared to predictions of drawdown annually. The reduction in availability of underground water would be temporary, as groundwater levels would recover quickly to pre-development levels after dewatering ceases.

No spring management strategy is required for the King Vol Mine. The recommended groundwater monitoring, GDE monitoring, and reporting programs outlined in this UWIR are adequate to quantify acceptable impacts and detect unacceptable impacts; and are reconciled with the conditions of the current EA.
Project No 254 (King Vol UWIR and dewatering assessment)

11 CERTIFICATION OF UWIR

We certify that this underground water impact report has been prepared by Rob Lait and Associates Pty Ltd and Australasian Groundwater and Environmental Consultants Pty Ltd, as independent practising hydrogeologists, at the request of Auctus Resources Pty Ltd.

Rob Lait
Principal Hydrogeologist
Rob Lait and Associates Pty Ltd

Angela Bush
Senior Hydrogeologist

Daniel Barclay
Principal Hydrogeologist
Australasian Groundwater and Environmental Consultants
12 REFERENCES

12.1 Legislation and policy

*Environmental Protection Act 1994 (Qld)*

*Water Act 2000 (Qld)*

*Environmental Protection (Water) Policy 2009 (Qld)*

*Queensland Heritage Act 1992*

*Aboriginal Cultural Heritage Act 2003*

*Torres Strait Islander Cultural Heritage Act 2003*

*The Environmental Protection Regulation 2008*

*Environmental Protection (Underground Water Management) and Other Legislation Amendment Bill 2016*

*Explanatory notes for the Environmental Protection (Underground Water Management) and Other Legislation Amendment Bill 2016*  

*Water Plan (Mitchell) 2007 (Policy under the Water Act 2000)*

12.2 Publications and reports


Department of Science, Information Technology and Innovation (2016). “Regional Ecosystem Description Database (REDD), version 10.0.” Queensland Herbarium, Brisbane.


Natural Resource Assessments (NRA) (2011a). “EPBC Status Report – Figure 2: King Vol Protected Species Observations and Habitat” Job number 230101.02, Map prepared for Auctus Resources Pty Ltd. December 2011.


Project No 254 (King Vol UWIR and dewatering assessment)

13 APPENDIX A – CALIBRATION HYDROGRAPHS