HORSE PIT EXTENSION EPBC ACT REFERRAL

APPENDIX F – PART n3OF 9

Groundwater Impact Assessment Report 2021
5.2 Hydraulic Properties

As part of this groundwater assessment, hydraulic testing was conducted on major geological units within the Project Area. Relevant nearby hydraulic testing was also conducted in 2017 for the Olive Downs Project groundwater assessment, in 2019 for the Moorvale South Project groundwater assessment, and in 2019 for the Winchester South Project groundwater assessment.

Project site hydraulic testing includes slug (rising and falling head) tests performed on monitoring network bores completed in 2009 (URS, 2009), 2019 (AGE, 2019) and 2020 (HFS, 2020). Additionally, two test production bores were drilled in 2020 (one into the Rangal Coal Measures, one into the Tertiary Basalt) with the intent of completing additional hydraulic testing (pumping tests) in support of the Project’s groundwater assessment. Following installation however, the yields from these two production bores were found to be insufficient for the completion of the intended hydraulic testing program.

The Winchester South Project hydraulic testing included slug tests on the monitoring network, core sample from the interburden of the coal seams, as well as downhole packer tests targeting major faults in the Project Area. The Olive Downs Project and Moorvale South Project assessments included laboratory geotechnical testing of core samples for vertical (Kv) and horizontal (Kh) hydraulic conductivity, and field testing using methods such as monitoring bore slug testing, packer testing for horizontal hydraulic conductivity, pumping tests, as well as documenting airlift yields. Across July 2019 step and constant rate pumping tests were conducted at two bores as part of the Moorvale South Project assessment.

Two pumping test have been carried out near the Moorvale South Project site, 5 km north east of the Project. The purpose of these tests was to establish characteristics of the Isaac River alluvial aquifers and the coal seam aquifers of the Rangal Coal Measures (Golder Associates, 2019). This information contributes to the understanding of the connectivity between the deep and shallow aquifers, the interaction between the shallow aquifer and the Isaac River and the flow dynamics within the aquifers.

This section presents a summary of the available field hydraulic data and comparison to reported hydraulic properties within external sources.

5.2.1 Hydraulic Data

The database of available field results for horizontal (Kh) and vertical (Kv) hydraulic conductivity is presented graphically as Figure 5-3. Tests from the Project Area are provided as a separate classification on the plot. The data are also presented separately for each test method as results can vary based on the type of testing and analysis undertaken.

Figure 5-3 shows that the hydraulic conductivity of the alluvium is variable, ranging from $10^2$ to almost $10^4$ metres per day (m/day), which reflects the heterogeneous nature of the alluvial sediments. Hydraulic testing of the alluvium within the Project Area itself also showed found hydraulic conductivity to be at the lower end of this scale, with values ranging from 0.09 m/d to 1.25 m/d. Pumping tests conducted in 2019 as part of the Moorvale South Project assessment reported hydraulic conductivity values in the range of 2.1 – 2.7 m/day, which is in the range of values provided by slug testing conducted across the Study Area.

Hydraulic conductivity testing of the Tertiary basalt within the Study Area is limited to slug testing of Project monitoring bores. Hydraulic conductivity of the Tertiary Basalt is highly variable, ranging from $5.18 \times 10^{-3}$ to 3.19 m/d, which reflects the heterogenous nature of the basalt as controlled by the degree of weathering and/or nature of fractures / vesicules.
The Rewan Group sediments exhibit a low hydraulic conductivity, typically less than $10^{-4}$ m/day, similar to the interburden/overburden material of the Rangal Coal Measures. Interburden/overburden testing shows a hydraulic conductivity of at least an order of magnitude less than that of coal seams at similar depths.

The coal seams of the Permian coal measures generally record higher hydraulic conductivity than the majority of the interburden/overburden for tests. This is due to the dual porosity of the coal seams, with a primary matrix porosity and a second (dominant) porosity provided by fractures (joints and cleats), which supports the concept of the coal seams themselves forming the dominant groundwater zones of the Permian units.

Slug tests were performed in 2009, 2019 and 2020 on Project monitoring bores targeting the coal seams of the Moranbah Coal Measures. The testing reported the following horizontal hydraulic conductivities (Kh) ranges (Figure 5-3):

- 0.26–0.33 m/d for the Q Seam;
- 0.024 – 0.16 m/d for the P Seam;
- 0.007 – 0.33 m/d for the H Seam; and
- 0.025 – 0.59 m/d for the D Seams

The hydraulic conductivity of non-coal Permian units tested (interburden) was generally found to be lower than the coal seam permeabilities with hydraulic conductivity values of 0.026 m/d and 0.034 m/d reported. No Project vertical hydraulic conductivity (Kv) data exists for the Moranbah Coal Measures and as such anisotropy has not been calculated.

Permeability testing of Permian units has also been undertaken across the Study Area. Moorvale South Project site pumping tests in 2019, performed on the Leichhardt and Vermont Seams of the Rangal Coal Measures, reported hydraulic conductivity ranges between 0.5 – 1.5 m/day, and 0.5 – 1.2 m/day, respectively. These values are generally higher than within the Project Area but align with previous testing of the Permian coal measures across the Study Area.

**Figure 5-3** shows that the hydraulic conductivity of the Permian coal measures as well as the Rewan Group generally declines with depth, due to increasing overburden pressure reducing the aperture of secondary porosity features. Anisotropy for the Rangal Coal Measures interburden material was more variable, with Kv ranging between 11% and 76% of Kh. During the Olive Downs Project groundwater assessment, core samples were collected within the coal seam roof/ floor material and proximal to fault zones, where practicable (i.e. for competent samples). Results for these samples indicated a Kv of between 50% to 160% of Kh. Comparison of Kh and Kv indicates that within the Rewan Group the Kv is around 10% to 40% of Kh.
Figure 5-3  Summary of Results for All Hydraulic Testing
5.2.2 Hydraulic Conductivity Ranges

A histogram of the spread of horizontal hydraulic conductivity (Kh) from the field testing at CVM, as well as at the Winchester South Project, Olive Downs Project and Moovale South Project, is presented in Figure 5-4. The results are compared to the range of documented values for each relevant units as presented within a literature review previously completed by HydroSimulations (2018) based on a number of other studies within the Bowen Basin.

![Histogram of Horizontal Hydraulic Conductivity Distribution](image)

The comparison shows that the field results for alluvium, regolith, basalt, Rangal Coal Measures and Fort Cooper Coal Measures within the Study Area and immediate surrounds fall within the range of field data collected through other studies across the Bowen Basin. Results from the Moorvale South Project site recorded some lower readings for the Rewan Group than previously identified in literature. Results for the Moranbah Coal Measures from the CVM Project site recorded higher readings than previously identified in literature. Review of Figure 5-3 shows that within the Moranbah Coal Measures the higher readings are attributed to the H seam where hydraulic conductivities are generally an order of magnitude greater than measured within the Q, P and D coal seams. As discussed in Section 4.2.3.1 the H seam is generally thicker than the other seams, which may result in wider cleats and fissures within the unit.
5.2.3 Faulting

As discussed in Section 4.2.3.3, significant faulting is not present at CVM or in the Project Area, however extensive faulting has been mapped within the Permian coal measures east of the Project (see Figure 4-2). As identified by Jourde et al. (2002), faulting can result in higher permeabilities within strata parallel with the fault plane, and lower permeabilities within strata perpendicular to the fault plane. However, this can also be dependent on whether faults are currently active (Paul et al., 2009). Faulting has been inactive within the Bowen Basin for over 140 million years (Clark et al., 2011), indicating that the fault zones are less likely to act as conduits to flow; this relates to filling of the fractured pore spaces over time through hydrothermal alteration and mineralisation (Uysal et al., 2000). Drill core logs from within the Study Area and the Project Area show that where fractures and faults have been geologically logged, many fractures are “healed” with calcite and siderite. This indicates that although the system contains a fracture network, many of the existing fractures are cemented, which reduces the effective permeability of the fracture when compared to any open fracture network.

Downhole hydraulic testing undertaken, was conducted in the Permian coal measures for the Winchester South Project. Fault zones were confirmed to be intersected at these drill holes due to the presence of fracturing, calcite infills, and slickensides in core obtained from the drill holes, all of which are considered an indicative marker of faulting. Testing results showed relatively low hydraulic conductivity values ranging from $6.93 \times 10^{-5}$ to $2.07 \times 10^{-3}$ m/day, and in line with those presented in Figure 5-5. These properties indicate that the faulting zones intercepted and tested are ‘healed’ and not pathways for preferential groundwater flow.

As discussed in Section 5.2.1, laboratory geotechnical analysis of core samples of interburden immediately above and below coal seams proximal to a fault zone has previously been undertaken in support of groundwater assessments in the Study Area. The samples recorded vertical hydraulic conductivity of 50% to 160% of horizontal hydraulic conductivity; i.e. although some samples show a typical $K_v$ of somewhat less than $K_h$, some samples also suggest greater $K_v$ than $K_h$ which may be indicative of preferential vertical flow pathways associated with faulting. However, it was also noted that these areas of increased $K_v$ are limited vertically, with samples collected from the same drill hole at horizons further above and below the fault zone (interburden and Rewan Group) returning a lower $K_v$ of between 11% and 76% of $K_h$.

The impact of faults on groundwater flow within the Study Area was also assessed as part of the Bowen Gas Project. Kinnon (2010) assessed the movement of water and gas across a series of faults in the Bowen Basin using stable isotope and water quality analysis to assess zones of potential recharge, water mixing and flow pathways. Higher gas production rates were also observed on either side of a major fault, with differences in isotopic compositions of produced water for wells north and south of the major fault line at similar depths, implying little communication across the fault boundary, and suggesting that the fault acts as a horizontal permeability barrier to water and gas flow. The results of the study showed that compartmentalisation was evident and that this was due to the structural geology (faulting) in the basin.

Based on a detailed literature review of the effect of faulting on groundwater flow, Coffey (2014) has developed a conceptual model for fault zone hydraulic characterisation in the Bowen Basin (Figure 5-5), largely based on Jourde et al. (2002) and Flodin et al. (2001). This conceptualisation provides a means of inferring hydraulic conductivities of the fault core and the fault damage zone from regional hydraulic conductivity, with the fault core typically one to three orders of magnitude lower conductivity than the regional host rock, and the damage zone approximately an order of magnitude higher.
5.3 Groundwater Distribution, Flow, Recharge and Discharge

5.3.1 Alluvium

5.3.1.1 Distribution and Flow

Due to the apparent heterogeneity and discontinuity of the Quaternary alluvium or Tertiary sediments pre-mining groundwater flow directions were not calculated as part of the original EIS project (URS, 2009). The groundwater flow direction was determined as likely to be topographically controlled, flowing from higher to lower elevations (URS, 2009).

Alluvial groundwater levels are currently monitored at six bores (refer to Table 5-1 and Figure 5-1) as part of the Project. Water levels have been periodically monitored at these sites since 2008. Routine monitoring of these bores commenced in July 2019 to support the Project and establish baseline levels over time.

The majority of available groundwater monitoring data for the alluvium relates to the area of this aquifer along the upstream parts of Cherwell Creek on the CVM ML immediately south of the Project Area. Monitoring data from one monitoring bore is also available for the alluvium associated with Horse Creek in the north of the Project (MB20CVM01A). Available monitoring data shows groundwater elevations in the alluvium are approximately 225 to 224.25 mAHD in the upstream (west) parts of the Cherwell Creek alluvium, and 213.3 to 212 mAHD in the downstream (east) parts of the alluvium, where it extends across CVM south of the Project. Groundwater elevations for bores within alluvium near to the Project Area are displayed in Figure 5-6.
Quarterly alluvium aquifer monitoring records date back to June 2008 for bore PZ08-S located south of the Project Area near Cherwell Creek, and generally show groundwater levels between 216 and 220 mAHD (11 to 14.5 m below top of casing (mbTOC)). Some fluctuation is evident in the data, possibly related to climatic trends.

Monthly data from alluvial monitoring bores is presented in Figure 5-7 and shows a declining trend of approximately 0.25 to 0.3 m over the second half of 2019 at two bores, again likely related to dry recent climate trends. Since June 2020 monitoring bores Pz07s, PZ08s and MB19CVM01A have been reported as dry, which is likely to be related to the drier than average climate conditions. MB20CVM01A (located in the north of the Project Area) and MB19CVM09A (located to the south of the Project Area) show generally declining groundwater elevations in correspondence to drier than average condition. A slight recovery in groundwater elevations was observed in both bores in early 2021, in response to wetter than average climatic conditions reported.

Groundwater elevation data for the Isaac River Alluvium has been collected as part of the Winchester South Project, Moorvale South Project and Olive Downs Project groundwater assessments, which are located to the east / southeast of the Project Area. A potentiometric surface for the Isaac River alluvium from water level observations collected during these groundwater assessments is displayed in Figure 5-8. Groundwater elevations were found to range from around 179 mAHDD in the northern end of the Winchester South Project Area, and between approximately 162 mAHDD to 166 mAHDD to the south-east, increasing with proximity to the Isaac River. This suggests losing stream conditions as discussed in Section 5.3.7. The water levels in the Isaac River alluvium clearly follow the flow direction of the Isaac River, with south-easterly flow gradients.
Inferred Groundwater Level and Flow Direction in Isaac River Alluvium

LEGEND

- Alluvial Groundwater Elevation (mAHD)
- Major Watercourse
- Minor Watercourse
- Project Mining Lease Boundary
- Existing CVM Pits
- Horse Pit Extension Project Area
- Horse Pit Future Mining Footprint
- Mapped Extent of Quaternary Alluvium
- Inferred Extent of Tertiary Quaternary Alluvium (TQA)

Groundwater Monitoring Bores

- Isaac River Alluvium
5.3.1.2 Recharge and Discharge

Recharge to the alluvium is considered to be mostly from stream flow or flooding (losing streams), with direct infiltration of rainfall also occurring where there are no substantial clay barriers in the shallow subsurface. Short term monitoring data available for monitoring bores MB19CVM09A and MB20CVM01A show a response in groundwater elevations with climate. As shown in Figure 5-7 groundwater levels generally decline during drier than average conditions before showing slight recovery in response to wetter than average conditions experienced at the start of 2021.

Long term monitoring data available for monitoring bore Pz08-S does not show any correlation between groundwater elevations and climatic conditions at this location. Groundwater levels at Winchester South Project bore Knob Hill 2 were found to generally show trends similar to rainfall, whereas groundwater levels at Winnet Bore were observed as unresponsive to climate, remaining relatively stable to slightly increasing from April 2012 to July 2019. The lack of response to rainfall trends may relate to the presence of surficial clays restricting groundwater recharge, as discussed in Section 4.2, or that rainfall was not sufficient to wet the unsaturated zone within the alluvium above the water table as well as providing vertical groundwater flow towards the water table. Similar variable trends have been observed in alluvial bores located at Winchester South Project located to the south east of the Project Area.

Recharge rates have been estimated using chloride mass balance (CMB) calculations. The CMB calculations were based on available water quality results (chloride concentrations) collected from the monitoring bores at CVM and other monitoring bores within the Study Area. The CMB calculation assumed average annual rainfall of 564 mm based on SILO Grid point data (Latitude: -22.10, Longitude: 148.05) as discussed in Section 3.1. The calculations also assumed a mean annual rainfall chloride flux of 3 milligrams per litre (mg/L), which is consistent with the values used as part of the Winchester South (SLR, 2020) and Olive Downs (Hydrosimulations. 2018b) numerical groundwater models. Outliers were excluded from the calculations and were identified as readings more than four standard deviations above the mean (USEPA, 2009). Using the CMB method recharge rates for the various alluvium unit have been calculated:

- Isaac River Channel Alluvium – 3 mm/yr
- Isaac River Flood Plain Alluvium – 1.3 mm/yr
- Other alluvium – 1.3 mm/yr
- Tertiary sediments – 0.1 mm/yr

Groundwater within the alluvium is discharged as evapotranspiration from riparian vegetation growing along the Isaac River, as well as potential baseflow contributions after significant rainfall and flood events. Groundwater within the alluvium is also discharged through the landholder use of bores in the region.

Geological logs in the Study Area indicate that the alluvium is underlain by low hydraulic conductivity stratigraphy (i.e. claystone, siltstone and sandstone), which restricts the rate of downward leakage to underlying formations. Localised perched water tables within the alluvium are evident where waterbodies continue to hold water throughout the dry period (e.g. pools in the Isaac River and floodplain wetlands) and occur where clay layers slow the percolation of surface water.
5.3.2 Tertiary Basalt

5.3.2.1 Distribution and Flow

Due to the apparent heterogeneity and discontinuity of the Tertiary basalt pre-mining groundwater flow directions were not calculated as part of the original EIS project (URS, 2009). The groundwater flow direction was determined as likely to be topographically controlled, with local flow from higher to lower elevations (URS, 2009).

Tertiary basalt groundwater levels are currently monitored at six bores (refer to Table 5-1 and Figure 5-1) as part of the Project. Monitoring records date from mid-2008 to mid-2017 for bore PZ03-S located west of the Project Area where the Horse Pit has been mined through, and shows relatively stable groundwater levels of 223.5 m AHD (22.5 mbTOC) between late 2013 and mid-2016 after which mining in Horse Pit eventually approached the bore (Figure 5-10). Groundwater levels declined to 221 m AHD prior to the bore being absorbed by mining activities in mid-2017.

Monitoring records date from mid-2008 to mid-2013 for bore PZ06-S located south of the Project Area, and show relatively stable groundwater levels of 215.8 m AHD (26.2 mbTOC) until monitoring ceased.

No groundwater level data is available for the basalt aquifer between mid-2017 and early 2019, however monitoring of this aquifer recommenced following the establishment of three new monitoring bores south of the Project in early 2019. Monthly monitoring of these bores since late 2019 shows slightly declining trends at bores MB19CVM03T (225.4 to 224.6 m AHD) and MB19CVM05T (207.4 to 203.6 m AHD), although bore MB19CVM07T is comparatively steady at 220.2 to 219.9 m AHD over this time. A slight recovery of groundwater levels is noted between December 2020 and February 2021 corresponding with wetter than average conditions over this period. The declining trends and slight recovery may be indicative of several influences including settling of the bores following drilling, recent climatic trends or impacts from mining activities.

Two additional bores, monitoring bore MB20CVM02A and pumping bore CVMPB07_01 were established in late 2020. Routine monitoring of these bores commenced in April 2021 to support the Project and establish baseline levels over time. Groundwater elevations recorded are consistent with the other Project monitoring bores, ranging from 221.5 m AHD (CVMPB07_01) and 210.8 m AHD (MB20CVM02A).

Groundwater elevations for the Tertiary basalt are displayed in Figure 5-9. The elevations are based on measurements from the Project’s basalt monitoring bores. Basalt groundwater elevations range from around 224.6 m AHD to the south west of the Project Area to 202.5 m AHD to the east. Figure 5-9 includes the inferred extent of the basalt as interpreted from the aeromagnetic geophysical surveys (URS, 2008; Section 4.2.1.3). Flow within the basalt is therefore believed to be localised to these extents.
5.3.2.2 Recharge and Discharge

Recharge to the basalt aquifers is likely to be via surface infiltration and overland flow in areas where the basalt is exposed and/or no substantial clay barriers occur in the shallow subsurface. Recharge may also occur via vertical seepage from overlying alluvium aquifers in areas where underlying low hydraulic conductivity stratigraphy (i.e. claystone, siltstone and sandstone) is absent.

Using the CMB method (refer Section 5.3.1.2) a recharge rate for the Tertiary basalt has been calculated as 1.7 mm/yr.

Groundwater discharge occurs primarily via evapotranspiration. Discharge via baseflow to minor tributaries of Cherwell Creek (in areas intersected by the basalt) may also occur after significant rainfall and flood events. Vertical seepage through the basalt is limited by the underlying low hydraulic conductivity overburden of the Blackwater Group and other aquitards.

5.3.3 Regolith

5.3.3.1 Distribution and Flow

The regolith is not expected to form a significant aquifer at CVM in relation to the Project. Bore PZ12-S, located in the east of the Project area, has quarterly water level records available from early 2014 to early 2021 (Figure 5-11). The records show falling groundwater levels from 24.5 m TOC (217.7 m AHD) at the commencement of monitoring down to 26.5 m TOC (215.7 m AHD) in mid-2016; however, levels have been generally stable since that time and even show a slight recovery to approximately 25.9 m bTOC (216.3 m AHD) in the most recent data.
Additional monitoring bores were installed within the regolith in mid to late 2020. Figure 5-11 presents monthly water levels recorded at bore MB20CVM06T located to the south of the Project Area and CVMB16_02 located on the north eastern boundary of the Project Area. Figure 5-11 shows generally stable groundwater levels ranging between 13.82m bTOC (218.1 mAH) and 11.94m bTOC (220.1 mAH). Water level measurements of additional monitoring bore CVMB16_01 commenced in April 2021, at which time the bore was recorded to be dry. The depth to the base of the screen at CVMB16_01 is 13.9m bTOC (224.08m AHD).

![Figure 5-11 Hydrograph of Regolith Groundwater Trends](image)

Exploration drilling across the Winchester South Project Area suggested that the regolith is not commonly saturated. Groundwater monitoring conducted within the Study Area includes four monitoring bores intersecting the regolith (GW06s, GW12s, GW16s and GW21s at the Olive Downs Project). The location of these bores is shown in Figure 5-2. Of these bores, two (GW06s and GW16s) have remained dry (unsaturated) between June 2017 and February 2019. However, bore GW12s which is located along Ripstone Creek, records a saturated thickness of around 23 m in the regolith, while bore GW21s has a saturated thickness of less than 1 m.

Overall, the regolith within the Project Area and Study Area is considered to be largely unsaturated, with the presence of water restricted to lower elevation areas along the Isaac River and the lower reaches of its tributaries (i.e. Cherwell Creek and Cherwell Creek). Flow within the regolith where it is saturated is a reflection of topography, flowing towards nearby drainage lines.
5.3.3.2 Recharge and Discharge

Water within the regolith, where it is saturated, occurs at depths of approximately 12 mbgl to 26 mbgl. As discussed in Section 4.2, the regolith material comprises low hydraulic conductivity strata (i.e. clay and claystone), which restricts rainfall recharge. This is shown by the general lack of response to climatic conditions in both Project monitoring bores. This is consistent with observations within regolith monitoring bores (GW12s and GW21s) in the Winchester South Project Area, where groundwater levels have remained relatively stable between June 2017 and February 2019, despite above average rainfall, although not substantial, from October to December 2017 and over February 2018. This lack of response in monitoring bores within the Study Area may also be due to rainfall being insufficient to wet the unsaturated zone above the water table as well as providing vertical groundwater flow towards the water table.

Using the CMB method (refer Section 5.3.1.2) a recharge rate for the regolith has been calculated as 0.1 mm/yr.

Groundwater discharge occurs primarily via evapotranspiration, with some baseflow to streams from the regolith under wet climatic conditions. Vertical seepage through the regolith is limited by the underlying low hydraulic conductivity of the Blackwater Group overburden and other aquitards.

5.3.4 Rewan Group

5.3.4.1 Distribution and Flow

The closest bores to the Project Area screened within the Rewan Group is bore RN141383 (MB3), which is part of the Eagle Downs Mine monitoring network and is located 17km south east of the Project. VWP GW01d (at the Olive Downs Project) is approximately 5 km to the east of the Winchester South Project boundary, on the western side of the Isaac River. The location of both bores is shown in Figure 5-2. The unit thickens towards the Isaac River, and can be up to 300 m thick within the Study Area. In general, the occurrence of the unit can vary regionally based on the structural setting. The Rewan Group comprises low hydraulic conductivity lithologies and is typically considered an aquitard.

5.3.4.2 Recharge and Discharge

Groundwater elevations for Olive Downs Project monitoring VWP’s GW01d (logger P3 and P4) are shown in Figure 5-12. Excluding recovery/stabilisation trends following construction and data considered to be erroneous, the graph shows that groundwater elevations within the Rewan Group have remained stable to slightly declining from 2017 to 2019. Groundwater elevations within the Rewan Group are above those recorded within the deeper Permian coal measures, indicating a downward hydraulic gradient. Figure 5-12 also presents trends for nested alluvial bore GW01s (at the Olive Downs Project), which show alluvial groundwater levels above the Rewan Group groundwater elevation. This indicates a downward gradient from the overlying alluvium. However, as outlined above, due to the low hydraulic conductivity of the Rewan Group stratigraphy (Section 5.2), the unit is considered an aquitard, restricting groundwater flow. No site data is available for the low permeability Rewan Group and therefore recharge estimates have not been calculated.
5.3.5 Permian Coal Measures Interburden

5.3.5.1 Distribution and Flow

Within the Project Area, two monitoring bores are established within the overburden/interburden (PZ08-D and PZ12-D), the location of these monitoring bores is shown on Figure 5-1. Groundwater occurrence within the Permian coal measures interburden is largely restricted to weathered horizons or to secondary porosity through fractures (Section 5.2).

Groundwater monitoring of the Permian Coal measure interburden has been undertaken in the east of the Project Area (PZ12-D) since early 2014. Groundwater monitoring of the Permian Coal measure interburden was also undertaken to the southwest of the Project Area (PZ08-D), immediately northwest of Heyford Pit, between mid 2008 and late 2019.

Figure 5-13 shows that groundwater elevations gradually declined within PZ12-D until early mid 2020 after which they have slightly recovered. The data potentially indicates a subdued response to mining activities from Horse Pit located directly to the west. Although limited, the data for PZ08-D shows a gradual increase in groundwater elevations from 203.5 mAHD in June 2008 to 214.8 mAHD. This may be indicative of increase recharge from rehabilitated areas associated with the nearby Heyford Pit. Water levels remained relatively stable since the start of monitoring indicating no influence from climate conditions or proximal mining activities.
Recharge to the Permian coal measures occurs at subcrop. Due to the low hydraulic conductivity of the interburden material, groundwater largely flows horizontally within the coal measures, along the bedding plane of the coal seams in the direction of the hydraulic gradient to the east. Groundwater discharge occurs via evaporation and abstraction from active mine areas.

### 5.3.6 Permian Coal Measures Coal Seams

#### 5.3.6.1 Distribution and Flow

Within the Study Area the coal seams of the Permian coal measures underlie the Rewan Group and surficial cover, and outcrop along the ridgelines to the east and west. The coal seams of the Moranbah Coal Measures subcrop throughout the west and portions of the northern section of the Project Area. Throughout the remainder of the Project Area the coal seams underlie the surficial cover. Groundwater occurrence within the Permian coal measures is largely restricted to the more permeable coal seams that exhibit secondary porosity through fractures and cleats ([Section 5.2](#)). Regionally groundwater flow is to the east, consistent with local topography (GHD, 2017). Differences in piezometric heads within the confined coal seam aquifers of the Moranbah Coal Measures drive groundwater flow eastwards across the Bowen Basin, from the slightly more elevated subcrop areas on the western flank of the Basin to the less elevated subcrop areas on the eastern flank (GHD, 2017). However, mining activities throughout the region have created locally modified groundwater flow systems within the Permian coal measures that are superimposed on these regional flow gradients.
Monitoring bores within the Project Area comprise two bores within the Q Seam (Pz04 and Pz07-D), seven within the P Seam (monitoring bores PZ06-D, PZ09, PZ11-D, MB20CVM03P, pumping bore CVMPB07_02 and VWP sensors CVMVWP07_R01_V1 and CVMVWP15_01_V2), eight within the H Seam (monitoring bores PZ10, MB19CVM06P, MB19CVM08P, MB19CVM10P and VWP sensors CVMVWP_01_V1, CVMVWP07_R01_V2, CVMVWP15_01_V3 and CVMB16_02), and nine within the D Seam (monitoring bores PZ01, PZ03-D, PZ05, MB19CVM02P, MB19CVM04P, MB20CVM05P and VWP sensors CVMP01_01_V2, CVMVWP07_R01_V3 and CVMVWP15_01_V4).

Using combined water level monitoring data from the target coal seams a potentiometric surface map was generated for the Moranbah Coal Measures as part of the original CVM EIS project (URS, 2009; recreated in Figure 5-14). The contours show pre-mining groundwater flow within the Permian coal measures to be west to east across the Project Area north of Cherwell Creek, consistent with recharge of the coal seams where they subcrop to the west of the Project (URS, 2009).

Groundwater monitoring of the Q Seam has been undertaken in the east of the Project Area (PZ04) and to the south of the Project Area in the vicinity of Heyford Pit (PZ07-D), since mid 2008. Groundwater elevations for current Q Seam monitoring bores are displayed in Figure 5-15. Groundwater elevations within the Q Seam bores are similar, ranging from 210.2 mAHD to 209.6 mAHD.

An insufficient number of data points are available to generate potentiometric contours for the Q Seam given it is not widespread across the CVM and Project areas, existing only towards the east of the CVM mining leases. An inferred groundwater flow to the south east has been estimated (Figure 5-15) based on the saturated heads generated as part of the calibration of the Project numerical model (Appendix 8). It is understood that the Q Seam has yet to be intercepted by existing mining activities at Horse Pit. The inferred groundwater flow direction is therefore indicative of the influence of mining activities associated with Peak Downs Mine located further to the south east of the Project Area.
Groundwater monitoring of the P Seam has been undertaken to the south of the Project Area, in the vicinity of Heyford Pit, since 2008. Groundwater elevations for current P Seam monitoring bores are displayed in Figure 5.16. Groundwater elevations within the P Seam range from 209.99 mAHDb (MB20CVM03P) to 175.2 mAHDb (PZ11-D). An insufficient number of data points are available to generate potentiometric contours for the P Seam. End of calibration (December 2020) saturated heads, calculated as part of the numerical model (Appendix B), have been generated to provide an indication of localised groundwater flow in the Project Area. It is understood that the P Seam has yet to be intercepted by mining at the existing Horse Pit. It is therefore believed that the local groundwater flow direction in the areas north of Cherwell Creek will be easterly in line with regional flow. This is supported by the calibration saturated heads which show an inferred groundwater flow direction to the south east across the Project Area (Figure 5.16). The lower groundwater elevations in the P Seam at monitoring bore PZ09, potentially indicate a localised south / south westerly flow direction in the area south of Cherwell Creek, towards the existing Heyford Pit, where the P Seam has been intercepted. This is also supported by the calibration saturated heads for the P Seam in these areas (Figure 5.16).

Groundwater monitoring of the H Seam has been undertaken immediately south of the Project Area since 2019. Groundwater elevations within the H Seam monitoring bores range from around 209.63 mAHDb to the east of Horse Pit in the north of the Project Area to 191.84 mAHDb to the south east. Groundwater elevations for H Seam monitoring bores are displayed in Figure 5.17. Groundwater elevations in the H Seam potentially indicate flow in a south westerly / westerly direction towards the southern extents of Horse Pit and towards Heyford Pit where the seam has been intercepted during mining activities. End of calibration (December 2020) saturated heads calculated as part of the numerical model (Appendix B) have been generated to provide an indication of localised groundwater flow in the Project Area. As shown in Figure 5.17, the calibrated saturated heads indicate localised groundwater flow to the south west, towards the southern area of Horse Pit and towards Heyford Pit. Based on the calibration data, the influence of mining activities on groundwater elevations in the north of the Project Area appears to be limited, with local flow direction inferred to be west to east in line with regional flow.

Groundwater monitoring of the D Seam has been undertaken immediately south of the Project Area since 2008. Groundwater elevations within the D seam currently range from 199.34 mAHDb (PZ01) to 191.5 mAHDb (MB20CVM05P). Groundwater elevations for D Seam monitoring bores are displayed in Figure 5.18. End of calibration (December 2020) saturated heads have been generated as part of the numerical model (Appendix B) to provide an indication of localised groundwater flow in the Project Area. Given that the D Seam is currently mined at both Horse Pit and Heyford Pit it is believed that the local groundwater flow direction will be east to west towards the active mining areas. This is supported by the calibration saturated heads which show an inferred groundwater flow direction to the west across the Project Area (Figure 5.18).

Within the Project Area no monitoring bores target the regionally shallower Rangal Coal Measures or Fort Cooper Coal Measures as these units are not present within or in the vicinity of the CVM leases or the Project.

Within the Study Area the Rangal Coal Measures are targeted by the Winchester South Project, with 12 Project groundwater monitoring bores that intersect the Permian coal measures within the Project Area. Five of the bores are established within the Leichhardt Seam (C2105R, C2136, R2008, R2010R, R2032), four within the Vermont Seam (G2304R, G2307, R2035, R2055), and three within the interburden (R2009R, R2034R, R2054). Groundwater levels within the Rangal Coal Measures coal were found to range from 189.65 mAHDb to 165.95 mAHDb.
LEGEND

Surface Geology
- Qa-QLD (Qa)
- Qr-QLD (Qr)
- Qr\b-QLD (Qr\b)
- Suttor Formation (Tu)
- Suttor Formation? (Tu?)
- TQa-QLD (TQa)
- Tb-QLD (Tb)
- Td-QLD (Td)
- Fort Cooper Coal Measures (Pwt)
- Moranbah Coal Measures (Pwb)
- Back Creek Group (Pb)

Mapping units
- Mining Lease
- Existing CVM Pits
- Horse Pit Future Mining Footprint
- Horse Pit Extension Project Area
- Major Watercourse
- Minor Watercourse
- P Seam Monitoring Bore
- Calibrated Saturated Head
- Inferred Groundwater Flow Direction

Map Scale: 1:100,000

P Seam Elevations December 2020
D Seam Elevations December 2020

FIGURE 5-18

LEGEND

Surface Geology

- Qa-QLD (Qa)
- Qr-QLD (Qr)
- Q\r\b-QLD (Qr\b)
- TQa-QLD (TQa)
- Tb-QLD (Tb)
- Fort Cooper Coal Measures (Pwt)
- Moranbah Coal Measures (Pwb)
- Back Creek Group (Pb)

Mining Lease

Existing CVM Pits

Horse Pt Future Mining Footprint

Horse Pt Extension Project Area

Major Watercourse

Minor Watercourse

D Seam Monitoring Bores

Calibrated Saturated Heads

Inferred Groundwater Flow Direction

GDA 1994 MGA Zone 55

Scale: 1:70,000

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www.slrconsulting.com

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Groundwater levels in the Fort Cooper Coal Measures of range from 31.9 mbgl to 32.7 mbgl (165.5 mAHD to 168 mAHD) within the Study Area. Seven monitoring bores, as part of the Eagle Downs Mine monitoring network located directly to the east of the Project Area, are screened within the Fort Cooper Coal Measures. Groundwater levels within this unit to the east of the Project Area range from approximately 187 mAHD (MB1) to 196.74 mAHD (MB4).

5.3.6.2 Recharge and Discharge

Groundwater level trends for monitoring bores intersecting the Moranbah Coal Measures coal seams within the Project Area are presented in Figure 5-19 to Figure 5-22.

Figure 5-19 shows that groundwater elevations have remained relatively stable at approximately 213m AHD since the start of monitoring indicating no influence from climate conditions or proximal mining activities.

Figure 5-20 shows generally stable elevations from 2008 to mid 2013, after which they steadily decline in response to the progression of the Heyford Pit. The relatively stable elevations observed prior to mining indicate that groundwater response at this location is independent from climate, potentially indicating more confined conditions. Groundwater elevations at 2020 monitoring bore MB20CVM03P and test production bore CVMPB07_02 were recorded at 210 mAHD and 208.4 mAHD respectively. This is approximately 35m higher than observed at bores PZ09 and PZ11-D located to the south of the Project Area, indicating a general hydraulic gradient towards Heyford Pit.

Figure 5-21 shows that groundwater elevations appear to correlate with climate conditions. Groundwater elevations within monitoring bores MB19CVM06P and MB19CVM08P have remained relatively similar since the start of monitoring, with elevations consistently around 10m lower within MB19CVM10P. This difference may be due to the influence of mining operations on MB19CVM10P at the nearby Heyford Pit or could be indicative of the level of connectivity with the overlying material at both locations.

Figure 5-22 shows that groundwater elevations with D Seam monitoring bores were relatively stable in monitoring bores PZ03-D and PZ01 prior to and during the early phases of mining of Horse Pit. PZ03-D was mined through as Horse Pit progressed in early 2019. Drawdown within PZ01 related to Horse Pit activities was first observed in late 2017, with groundwater elevations having steadily declined since. Declining groundwater levels have been observed in MB20CVM05P since installation in 2019. MB19CVM04P located directly to the south west of Horse Pit has been recorded as dry since installation in early 2019. Similarly, MB19CVM02P, located directly to the northwest of Heyford Pit, is recorded as dry since installation in early 2019. The declining groundwater elevations and ‘dry’ observations in Project monitoring bores confirm the dewatering of the D Seam from current mining activities within the Project Area.
Figure 5-19    Hydrograph for Q Seam Bores

Figure 5-20    Hydrograph for P Seam Bores
Figure 5-21  Hydrograph for H Seam Bores

Figure 5-22  Hydrograph for D Seam Bores
Groundwater level trends for monitoring bores intersecting the Rangal Coal Measures coal seams within the Winchester South Project area are presented in Figure 5-23. Trends for the underlying Fort Cooper Coal Measures unit in landholder bores close to this Project are presented in Figure 5-24. Groundwater level trends for monitoring bores included in the Eagle Downs Mine monitoring network intersecting the Fort Cooper Coal Measures are presented in Figure 5-25. Groundwater levels at these bores can be seen to be relatively stable since 2015. Bore R2032 recorded a 3 m water level drop from approximately 188.5 mAHD to 185.2 mAHD in March 2019. This change coincides with the routine monitoring event in March 2019, and is likely a result of the logger being set at a different level. Groundwater levels have been relatively stable since, with a slight increase observed towards the end of 2019.

Groundwater within the Permian coal measures is confined and sub-artesian. For the shallower coal measures, groundwater elevations are generally at or below groundwater elevations within the overlying unconfined sediments, indicating a downward hydraulic gradient. However, with increased depth of cover and pressure the hydraulic gradient within the Permian coal measures reverses. This coincides with a decrease in hydraulic conductivity with depth as discussed in Section 5.2.

Recharge to the Permian coal measures occurs where the unit occurs at subcrop. Using the CMB method (refer Section 5.3.1.2) a recharge rate for the weathered Permian units has been calculated as 0.1 mm/yr. Due to the low hydraulic conductivity of the interburden material, groundwater largely flows horizontally within the coal measures, along the bedding plane of the coal seams. Groundwater discharge occurs via evaporation and inflow from active mine areas.

Figure 5-23 Hydrograph of Rangal Coal Measures Coal Groundwater Trends
Figure 5-24  
Hydrograph for Bores within the Fort Cooper Coal Measures

Figure 5-25  
Hydrograph for Eagle Downs Mine Monitoring Bores within the Fort Cooper Coal Measures
5.3.7 Groundwater Interaction with Watercourses

In central Queensland, highly seasonal rainfall results in intermittent stream flow, limited groundwater recharge and deep water tables. In this environment, the most appropriate way to assess surface water and groundwater interaction is by comparing stream stage elevation data to the underlying groundwater elevation in a nearby monitoring bore. The Isaac River at Deverill (130410A) stream gauge provides a long-term record of stream stage for the Isaac River near to the Project. The location of the stream gauges is shown in Figure 3-3. The Water Monitoring Information Portal (WMIP) data indicate that at Station 130410A surface water (flowing and ponded) elevations generally remain around 170 mAHD. The gauge has recorded a maximum stream elevation of 180 mAHM, which has been recorded five times since 1968, in March 1979, March 1988, April 1989, January 1991 and February 2008.

The closest bore to the Project with long-term groundwater level monitoring in the Isaac River alluvium is registered bore RN13040180, which is approximately 40 km downstream of the stream gauge. The bore is located approximately 80 m from the Isaac River, along Carfax Road. Water levels in this bore follow the rainfall residual mass curve, indicating that rainfall derived recharge (including from stream flow) is a key source of water to this aquifer (Figure 5-26). From 1970 to present, water levels within the alluvium at RN13040180 were recorded between 12 mbgl to 18 mbgl.

Sharp peaks have been recorded occasionally in the dataset and appear to correlate with times of high flow in the Isaac River, however, there does not appear to be a definitive relationship between river level/magnitude of discharge and magnitude of fluctuation in groundwater level. This is in part a reflection of the intermittent water level data (where data at times corresponds to high river levels is often not recorded due to flooding).

![Groundwater Level in RN13040180 against Isaac River Levels](image)

The Isaac River is largely a losing system with stream-stage above that of the local groundwater levels, resulting in the water draining through the alluvial sediments to the local groundwater system. Occasional periods of baseflow to the river from the underlying alluvium may occur after prolonged rainfall events or following flood events. Under these conditions, recharged alluvial sediments will drain to the river as the hydraulic gradient reverses and sustains stream-flow for a short period after the rainfall event.
5.4 Baseline Water Quality

This section reports on the chemical characteristics and resulting possible beneficial uses of groundwater within the various geological units across the wider Study Area. Water quality results for surface water (Isaac River) and leachate analysis of potential spoil and reject materials at the Project are also discussed below. Appendix A2 presents the groundwater quality data collected at site, as well as other publicly available data.

5.4.1 Water Type

The proportions of the major anions and cations were used to determine the hydrochemical facies of groundwaters sampled. The anion-cation balance from the CVM monitoring bores is shown on the Durov plot in Figure 5-27.

The results for these monitoring bores generally indicate that Na and Cl are the dominant major ions in groundwater across the Project Area. Surficial alluvial and basalt generally display a more mixed water type, with higher proportions of magnesium and bicarbonate ions. The dominant water types in the basalt and unconsolidated alluvium therefore generally Na-Mg-Cl and Na-Mg-Cl-HCO₃. Regolith strata showed a similar water type but a greater proportion of the Cl ion.

Non coal Permian bores also showed mixed water types of Na-Cl-HCO₃ (PZ012-D) and Na-Mg-Cl (PZ08-D).

Within the Moranbah Coal Measures only P seam monitoring bores consistently recorded a Na-Cl water type. Water types of the Q seam, H seam, D seam were more variable with the distribution of the major ions appearing to be associated with the depth of the bore. In general, deeper bores, typically in the east of the Project Area, displayed Na-Cl water types, with shallower bores showing water types with higher proportions of calcium or magnesium ions. This is likely to be due to greater recharge from overlying surficial deposits in the shallower areas, the greater thickness of the unweathered material preventing the mobilisation of salts into the coal seams in the deeper locations. As the shallower bores are closer to the base of weathering, seepage of mobilised salts during recharge is more likely to occur. Within the deeper deposits, recharge from overlying units is likely to be less, with major ions distribution more influenced by secondary salinity mechanisms.

From Durov plot it is also clear that the H seam bores are strongly alkaline, which also accounts for a greater proportion of carbonate to bicarbonate ions. This contrasts to all other aquifers in the Project Area which are neutral to slightly acidic and therefore have a greater proportion of bicarbonate to carbonate ions.

Studies undertaken in the Winchester South Project showed similar results with alluvial bore Knob Hill 2 displaying a mixed water type which differs from the two nearby alluvial monitoring bores that are both Na-Cl type; this suggests some degree of compartmentalisation in the alluvial aquifer. Bore R2010, R2032, R2035, and R2054, screened in the Rangal Coal Measures (Leichhardt Seam, Vermont Seam, & interburden) all reported three consecutive readings of Sodium at or close to LOR resulting in the water type plotting as HCO₃-Cl type. Sodium levels have since returned to average with the cause of the low concentrations unknown, but should be considered anomalous, with the Rangal Coal Measures being classified as a Na-Cl water type, which is consistent with other samples in the Study Area.

Major ion data collected from the Eagle Downs Mine, Winchester South Project, Moorvale South Project, and Olive Downs Project sites, and publicly available sources is presented in Figure 5-28, along with data for the Isaac River at Deverill (station 130410A).
Figure 5-27  Durov Plot of CVM Bores
5.4.2 Salinity

Salinity is a key constraint to water management and groundwater use and can be described by total dissolved solid (TDS) concentrations.

Figure 5.29 presents the TDS data associated with waters screened in the various geological horizons for CVM monitoring bores, registered bores and publicly available data. Salinity ranges represented on Figure 5.29 are defined by the Food and Agriculture Organization of the United Nations (FAO).

The graph shows that surface water within the Isaac River is largely fresh, while water within the alluvium is fresh to saline with an average TDS of 556 milligrams per litre (mg/L) (marginal) and ranging between 10 mg/L and 5,620 mg/L. Where water is present within the regolith material, it is generally highly saline, but can be brackish to moderately saline with an average TDS of 7,101 mg/L and ranging between 1,110 mg/L and 18,600 mg/L. Water present in the Tertiary basalt is generally moderately saline with an average TDS of 3,538 mg/L, but can be fresh to highly saline ranging between 656 mg/L and 16,526 mg/L.

Water within the Permian Moranbah Coal Measures is generally saline within the coal seams and moderately saline to saline interburden units, but can range between fresh and highly saline. Coal seam units of the Moranbah Coal Measures record an average TDS of 7,598 mg/L, ranging between 720 mg/L and 24,704 mg/L. The interburden units of the Permian coal measures record an average TDS of 5,349 mg/L, ranging between 1,520 mg/L and 9,126 mg/L.
Water within the Permian Rangal Coal Measures is generally saline within the coal seams and saline interburden units but can range between fresh and highly saline. Coal seam units of the Rangal Coal Measures record an average TDS of 6,212 mg/L, ranging between 923 mg/L and 16,400 mg/L. The interburden units of the Permian coal measures record an average TDS of 3,436 mg/L, ranging between 421 mg/L and 18,400 mg/L.

![Figure 5-29 FAO (2013) Salinity Ranking by Unit – CVM](image)

Note: RCM = Rangal Coal Measures, MCM = Moranbah Coal Measures

**Figure 5-29  FAO (2013) Salinity Ranking by Unit – CVM**

Available long-term trends in salinity within the alluvium and Isaac River within the Study Area are presented in **Figure 5-30**. The salinity in the alluvium and Isaac River has been described by electrical conductivity rather than TDS. As discussed above, salinity within the alluvium can be highly variable spatially. As demonstrated by **Figure 5-30**, salinity can also vary at one location temporally. Results for government alluvial bore RN13040180 indicates electrical conductivity (EC) can range between 199 µS/cm and 7,400 µS/cm (fresh to saline). **Figure 5-30** also presents EC as recorded at Isaac River station 130410A since 2011, which ranges between 7 µS/cm and 1,773 µS/cm (fresh to brackish).

The water quality data for the alluvium occasionally shows an inverse correlation in EC to rainfall residual mass curve, with rising EC recorded during periods of declining/below average rainfall and vice versa. However, due to the lack of temporal readings, there is no clear correlation between groundwater salinity in the alluvium at RN13040180 and stream flow and salinity of the Isaac River.
Spatial distribution of TDS is shown in Figure 5-31 for the Study Area, which is based on measured TDS and calculated TDS from available EC data in the CVM monitoring network, and from the Eagle Downs Mine monitoring network, Winchester South Project, Moorvale South Project and Olive Downs Project groundwater assessments. The figure depicts mostly fresh water quality localised along the Isaac River, with brackish to moderately saline water along the river and tributaries. Alluvial monitoring bores for the Project support this showing generally brackish to saline water along Cherwell Creek upstream of the Isaac River. The salinity within the coal measures appears to increase with depth. Bores within the coal measures near the subcrop areas in the west generally record moderately saline water quality, which increases to saline quality where the coal measures are deepest near the Isaac River. This information supports the coal measures being largely recharged by rainfall where they occur at subcrop.

Due to limitations of the routine monitoring of ephemeral water bodies, surface water quality sampling is not currently conducted as part of the Project. Sampling of surface water features (Cherwell Creek) is therefore limited to discharge events and during periods of flow.

Surface water quality sampling was conducted as part of the Winchester South Project at nine locations within the Study Area throughout 2019. The surface monitoring network monitors the Isaac River, Ripstone Creek, and several un-named drainage features associated with the Winchester South Project. Over the monitoring period, the data indicate that both EC is higher at the upstream site compared to the downstream sites for both the Isaac River and the un-named drainage feature that traverses centre of the Winchester South Project Area. Similar results were observed during aquatic ecology surveys completed for the Project in December 2019 and April 2019 (ESP, 2020). Sites upstream of the Project were generally found to be more saline than sites downstream of the Project.
Figure 5-30  Isaac River Salinity Versus Alluvium Salinity
5.4.3 Beneficial Groundwater Use

The Project lies within the Isaac Connors Groundwater Management Area (GMA – Zone 34) of the Fitzroy Basin under the Water Plan (Fitzroy Basin) 2011. Groundwater at the Project includes alluvial groundwater under GMA Groundwater Unit 1 and water within the hard rock aquifers in GMA Groundwater Unit 2 (sub-artesian aquifers). The management objective of the Water Plan (Fitzroy Basin) 2011 is to maintain the 20th, 50th and 80th percentiles water quality results in order to preserve or enhance groundwater quality for its recognised uses. In the case of Isaac groundwaters, these values include aquatic ecosystems, irrigation, farm supply/use, stock watering, primary recreation, drinking water as well as being of cultural and spiritual value.

In order to understand the groundwater resources within the Project and Study Area, available water quality data have been compared to the:

- Fitzroy Basin Zone 34 groundwater quality objectives for deep and shallow water;
- Australian Drinking Water Guidelines (ADWG) (NHMRC, 2011);
- ANZECC (2000) guidelines for aquatic ecosystems, irrigation (long-term and short-term) and stock water supply.

Comparing the data to relevant guideline levels, the summary results indicate that, where present, water within the alluvium at the Project is generally suitable for stock water supply and short-term irrigation (Appendix A2). However, the alluvial groundwater generally exceeds guideline levels for drinking water (i.e. TDS, chloride and sodium), freshwater aquatic systems, and long-term irrigation (boron and iron). The alluvial groundwater also records concentrations of fluoride above the Fitzroy Plan Water Quality Objectives (WQO) for Zone 34 (shallow).

Results for the Winchester South Project indicate that water within the Quaternary alluvium (not present in the Project Area) is generally suitable for stock water supply, long-term irrigation and short-term irrigation. However, the Quaternary alluvial groundwater generally exceed guidelines levels for drinking water (i.e. TDS, chloride and sodium), freshwater aquatic systems, and long-term irrigation (chromium, iron, and manganese). The alluvial groundwater also records concentrations of total and dissolved iron and manganese above the Fitzroy Plan Water Quality Objectives (WQO) for Zone 34 (shallow).

Results from the Project, Moorvale South Project and Olive Downs Project groundwater assessments show that, where water is present within the regolith material, it exhibits poorer quality compared to the alluvium and is not considered a suitable groundwater resource for livestock, irrigation, drinking water or aquatic ecosystems. The water within regolith material was found to exceed the Fitzroy Plan WQO (Zone 34 –shallow) for EC, chloride, calcium, sodium, hardness, magnesium, sulfate, copper and manganese.

Water within Tertiary basalt within the Project Area is generally suitable for stock water supply and short-term irrigation (Appendix A2). However, the basalt groundwater generally exceed guidelines levels for drinking water (i.e. TDS, chloride, sodium, total iron, total and dissolved manganese and dissolved arsenic), freshwater aquatic systems, and long-term irrigation (total boron, total iron and total and dissolved manganese). The basalt groundwater also records concentrations of bicarbonate, total and dissolved manganese and dissolved iron manganese above the Fitzroy Plan Water Quality Objectives (WQO) for Zone 34 (shallow).
Water within the interburden of the Permian coal measures is generally suitable for stock water supply. Groundwater quality within the Project coal seams is variable, with TDS values generally increasing with seam depth. Comparison of results to the guideline levels indicates the Moranbah Coal Measures (interburden and coal) are not considered a suitable groundwater resource for irrigation, drinking water or aquatic ecosystems. Groundwater within the coal measures (coal) recorded concentrations of:

- Bicarbonate (D Seam) and sodium (D Seam) above the Fitzroy Plan WQO (Zone 34 – deep);
- EC levels (P Seams), concentrations of sulfate (D Seam), total manganese (D Seam), sodium (P Seam), chloride (P and D Seam) and magnesium (D Seam) above the Fitzroy Plan WQO (Zone 34 – shallow); and
- Concentrations of sodium (D Seam) sulphate (P, H and D seams), fluoride (Q and D seams), dissolved iron (Q, P, H and D seams), calcium (P and H seams), EC levels (D Seam) and pH units above the Fitzroy Plan WQO (Zone 34 – shallow and deep).

Similar results were reported for the Winchester South Project, with the interburden of the Permian coal measures generally suitable for stock water supply. In contrast, groundwater within the coal seams generally exhibit a higher TDS, which is on average higher than the guideline level for beef cattle but below the guideline level for sheep. Comparison of results to the guideline levels indicates the Rangal Coal Measures (interburden and coal) are not considered a suitable groundwater resource for irrigation, drinking water or aquatic ecosystems. Groundwater within the coal measures (coal and interburden) record concentrations of bicarbonate above the Fitzroy Plan WQO (Zone 34 – deep), and fluoride above the Fitzroy Plan WQO (Zone 34 – shallow and deep).

Groundwater chemistry results from the Eagle Downs Mine monitoring network suggest that water within the Fort Cooper Coal Measures could be suitable for stock water supply and short term irrigation. It is noted however that not all analytes are available for a complete assessment of the suitability for this unit.

5.4.4 Leachate Analysis

Leachate analysis was undertaken for the Project by Terrenus Earth Sciences (2021). The analysis was conducted on weathered overburden (clay), overburden (sandstone and siltstone), and interburden (claystone, sandstone, coal with some claystone, mudstone, and siltstone) material representative of future spoil material. Some of the overburden and interburden samples were also noted to be carbonaceous. Analysis was also conducted on material representative of future spoil material, and carbonaceous claystone and siltstone (coal seam roof and floor) representative of potential rejects material, as well as composite samples representing coarse rejects. It is important to note that the results from the geochemistry assessment represent an ‘assumed worst case’ scenario as the samples are pulverised prior to testing, and therefore have a very high surface area compared to materials in the field and do not account for mixing during emplacement.

Within the Study Area leachate analysis was also conducted by Terrenus Earth Sciences (2017) for the Olive Downs Project EIS, and the Winchester South Project Area by EGi (2012) and Terrenus Earth Sciences (2019), and is considered relevant to the Project given the similar geological setting.

Terrenus Earth Sciences (2021 undertook a desktop review of geochemical data sourced from samples collected and analysed from the CVM EIS (URS 2007; Terrenus 2009); from samples collected in 2013 at the commencement of mining (PW Baker 2013); and from samples collected since 2013 by BMA and BHP Minerals Closure Planning. In 2020 a sampling program was completed to supplement the existing data set.

A total of 474 samples were reviewed by Terrenus Earth Sciences (2021) as part of the desktop assessment. Analysis of these samples found the following:
• 453 samples (96% of all samples) were identified as non-acid forming (NAF)
• 5 samples (1% of all samples) were identified as ‘uncertain classification’ with 4 likely to be NAF, and one likely to be potentially acid forming
• 9 samples (<2% of all samples) were identified as potentially acid forming (PAF)
• 2 samples (<1% of all samples) were identified as low capacity PAF

Analysis by Terrenus Earth Sciences (2021) of 81 samples collected as part of the 2020 sampling program found the following:

• pH ranged from 5.9 to 8.9 with a median value of 9.5
• EC ranged from 163 µS/cm to 1730 µS/cm with a median value of 391 µS/cm
• Sulfur concentration ranged from 9 mg/L to 512 mg/L with a median value of is 46 mg/L
• Al concentration ranged from 0.01 mg/L to 1.8 mg/L with a median value of 0.09 mg/L
• As concentrations ranged from 0.001 mg/L to 0.875 mg/L with a median value of 0.042 mg/L.
• Analytes for which all samples tested were below LOR include Be, Bi, P, Sn, Th and Zr; and analytes for which concentrations were generally below LOR (i.e. 80% or more were below LOR) include Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb, Ti, U and Zn
• Other analytes tested include:
  • B ranged from 0.05 mg/L to 0.30 mg/L with a median concentration of 0.12 mg/L
  • Ba ranged from 0.001 mg/L to 0.0172 mg/L with a median concentration of 0.009 mg/L
  • Mn ranged from 0.001 mg/L to 0.092 mg/L with a median concentration of 0.004 mg/L
  • Mo ranged from 0.004 mg/L to 0.282 mg/L with a median concentration of 0.039 mg/L
  • Sb ranged from 0.001 mg/L to 0.032 with a median concentration of 0.004 mg/L
  • Se ranged from 0.010 mg/L to 0.100 mg/L with a median concentration of 0.030 mg/L
  • V ranged from 0.001 mg/L to 0.090 mg/L with a median concentration of 0.020 mg/L
  • W ranged from 0.001 mg/L to 0.002 mg/L with a median concentration of 0.001 mg/L

Analysis by Terrenus Earth Sciences (2019) tested 38 samples and found the following:

• 29 samples were identified as NAF with very low Sulfur (<0.1 %)
• 7 samples were identified as NAF
• 2 samples were identified as ‘uncertain classification’ with one likely to be NAF, and one likely to be potentially acid forming
• pH is generally 8.7 and ranges between 6.3 and 10.1.
• EC is generally 601 µS/cm and ranges between 110 µS/cm and 2,410 µS/cm.
• Sulfur content is generally 37 mg/L and ranges between 2 mg/L and 319 mg/L.
• Aluminium concentrations are all below the limit of reporting (LOR) of <0.2 mg/L in the 2019 sampling, with values between <0.01 mg/L and 0.15 mg/L observed in 2012.
• Arsenic concentrations between <0.001 mg/L and 0.4 mg/L.
• Metals concentrations were all below the laboratory limit of reporting for Be, Cd, Co, Hg, Ni, Pb, and V.
• Metals concentrations above the LOR were identified for the following:
  o Ba with all 2019 values below LOR of <0.2, and 2012 values between 0.06 mg/L and 0.94 mg/L.
  o B with a majority of samples below LOR ranging between <0.05 mg/L and 0.4 mg/L.
  o Cr with all values below with the exception of one 2012 sample with a concentration of 0.08 mg/L.
  o Cu with all 2019 values below LOR of <0.02, and 2012 values between
  o Fe with all 2019 values below LOR of <0.2, and 2012 values between 0.001 mg/L and 0.1 mg/L.
  o Mn with values between <0.001 mg/L and 0.07 mg/L.
  o Se with a majority below LOR, and 10 samples between 0.01 mg/L and 0.02 mg/L.

Analysis by Terrenus Earth Sciences (2018) found the analysis of the 27 samples tested as being representative of spoil material (as a bulk material) had the following outcomes:
• All samples were identified as NAF with most showing very low Sulfur content (<0.1%).
• One sample returned ‘uncertain’ results, due to conflicting results.
• pH is generally 9.0 and ranges between 5.4 and 9.7, with only one reading below pH 7.
• EC is generally 400 µS/cm and ranges between 158 µS/cm and 1,050 µS/cm.
• Sulfur content is generally 27 mg/L and ranges between 4 mg/L and 92 mg/L.
• Aluminium concentrations are around 0.3 mg/L and range between <0.2 mg/L and 0.5 mg/L.
• Arsenic concentrations are around 0.12 mg/L and range between <0.02 mg/L and 0.5 mg/L.
• Metals concentrations were all below the laboratory LOR for Ba, Be, B, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn.

Analysis of the eight samples tested by Terrenus Earth Sciences (2018) as being representative of potential reject material found:
• Six of the eight samples were identified as NAF, with five classified as having very low sulfur content (<0.1%).
• One sample returned ‘uncertain’ results, due to conflicting results.
• One sample was classified as potentially acid forming (PAF) – derived from carbonaceous claystone of the Lower Leichhardt Seam roof at a depth of 104 m below surface.
• pH is generally 8.9 and ranges between 6.9 and 9.6.
• EC is generally 293 µS/cm and ranges between 120 µS/cm and 554 µS/cm.
• Sulfur content is generally 49 mg/L and ranges between 6 mg/L and 206 mg/L.
• Aluminium concentrations are around 0.4 mg/L and range between <0.2 mg/L and 1.0 mg/L.
• Arsenic concentrations are around 0.07 mg/L and range between <0.02 mg/L and 0.22 mg/L.
• Metals concentrations were all below the laboratory LOR for Ba, Be, B, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn.

Overall, the geochemical assessments found that:

• potential spoil material is expected to be overwhelmingly NAF, with excess acid neutralising capacity (ANC) and has a negligible risk of developing acid conditions;
• spoil is predicted to generate low to moderate salinity surface run-off and seepage with low soluble metal/metalloid concentrations;
• approximately 30% of potential reject material has a relatively low degree of risk associated with potential acid generation. However, the magnitude of any localised acid, saline or metalliferous drainage would be buffered by the presence of the alkaline NAF spoil. As a bulk material (of relatively small total quantity), coal reject is regarded as posing a generally low risk of environmental harm and health-risk.
5.5 Groundwater Usage - Anthropogenic

A search of the Queensland Government’s Groundwater Bore Database (GWBD) and the Bureau of Meteorology’s National Groundwater Information System (NGIS) was carried out for registered bores within the Study Area. The search indicated that there are 310 registered bores, of which 177 bores (57%) are used for groundwater monitoring and investigations, and 83 bores (27%) are used for water supply. The remainder of bores have an unknown use or resulted from exploration activities (Table 5-4).

<table>
<thead>
<tr>
<th>Use</th>
<th>Count</th>
<th>Percent of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater monitoring (mine monitoring, water resource investigation etc)</td>
<td>177</td>
<td>57</td>
</tr>
<tr>
<td>Water Supply</td>
<td>83</td>
<td>27</td>
</tr>
<tr>
<td>Unknown</td>
<td>33</td>
<td>11</td>
</tr>
<tr>
<td>Exploration (petroleum, gas, coal, stratigraphic etc)</td>
<td>17</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>310</td>
<td>100</td>
</tr>
</tbody>
</table>

5.5.1 Field Bore Censuses

Three field bore censuses have been carried out within the Study Area:

- A field bore census was conducted for the Project in 2020, targeting properties in the immediate vicinity of CVM. Results are provided in Appendix A3.
- A field bore census was conducted for the Moorvale South Project in 2019 (Golder Associates, 2019).
- A field bore census was conducted as part of the Olive Downs Project groundwater assessment in 2017 (HydroSimulations, 2018a).

Across the three bore census, a total of 157 bore locations were assessed. Of the 157 bores:

- 64 bores were found to be existing and in use;
- 44 bores are existing but not in use;
- 8 bores were of unknown status (could not access); and
- 41 bores were abandoned and destroyed.

Of the existing and unknown bores with water use information available, 56 are used for stock water supply, 31 are used of groundwater monitoring and 6 are used for domestic water supply. For the existing and unknown bores with geological information available, 24 intersect alluvium, 12 are within regolith material, four intersect Tertiary basalt material and 37 intersect Permian coal measures (Rangal Coal Measures, Blackwater Group and Back Creek Group).

For the 26 bores surveyed as part of the Project’s 2020 bore census (i.e. a subset of those discussed above):

- 17 bores were found to be existing and in use;
- seven bores are existing but not in use (abandoned);
- one bore was decommissioned; and
• one bore was destroyed.

Of the existing and unknown bores with water use information available surveyed in the Project’s bore census, one is used for Quarry water supply (gravel washing and dust suppression), four are used for stock water supply, 12 are used of groundwater monitoring and one is used for domestic water supply.

For the existing and unknown bores with geological information available, two intersect alluvium, one is within regolith material, four intersect Tertiary basalt and seven intersect Permian coal measures (Rangal Coal Measures, Blackwater Group and Back Creek Group).

Results of the 2020 Project bore census conducted at CVM (Appendix A3) found groundwater use in the area to be limited due to low yields, with many bores abandoned in favour of utilisation of connection to the water supply from the Eungella-Bingegang pipeline. Based on the bore census results, it has been determined that groundwater is not privately extracted from the Moranbah Coal Measures within 5km of the Project. Given the increasing depth to the Moranbah Coal Measures further from the Project, it is considered unlikely groundwater extraction is undertaken from the unit further east. Correlation of the total depths for the surveyed bores against the model layer elevations (Section 6) show that water extraction in the surveyed bores is primarily from the shallower Fort Cooper Coal Measures where it overlies the Moranbah Coal Measures. The census results show groundwater take from private extraction is relatively insignificant with estimated yields for assessed stock water bores ranging from 1.6 to 4.7ML/yr and yields from the one quarry water supply bore estimated at 6.57 ML/yr.

Figure 5-32 shows the locations and uses of bores detailed in the combined bore censuses. Full results of the Olive Downs Project and Moorvale South Project bore census surveys are provided in the full groundwater assessment reports (Hydrosimulations, 2018a; and Golder Associates, 2019 respectively).

5.5.2 Mine Pit Inflows

Groundwater inflows from the Permian coal measures to the Mine’s active pits are generally small in volume and do not typically need to be actively managed via advance dewatering or other groundwater management methods, with evaporation from the pit walls and floors accounting for most of the groundwater. Small volumes of groundwater inflow requiring management, when they occur, which are generally managed via the use of in-pit sumps to capture water that is then used for dust suppression purposes or circulated via the Mine water management system for use in coal washing.

Groundwater Inflow estimates for Horse Pit and Heyford Pit at CVM are provided in Table 5-5 below based on BMA’s annual Associated Water Take reporting to DoR. Estimates are based on BMA’s site water balance calculations using site climate data, pit inflow, pit storage and outflow data.

Table 5-5 Estimated Groundwater Inflow at CVM 2018/2019 (BMA, 2019)
Associated mine water data for CVM, Peak Downs mine and Saraji mine are presented in **Table 5-6**.

**Table 5-6  Estimated Cumulative Groundwater Inflow at CVM, Peak Downs and Saraji 2017 to 2020 (BMA, 2020)**

<table>
<thead>
<tr>
<th>Tenure</th>
<th>Name of section of mine</th>
<th>Date From</th>
<th>Date To</th>
<th>Volume (ML)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML1775</td>
<td>CVM, Peak Downs and Saraji</td>
<td>July 2017</td>
<td>July 2018</td>
<td>6,199</td>
</tr>
<tr>
<td></td>
<td></td>
<td>July 2018</td>
<td>July 2019</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>July 2019</td>
<td>July 2020</td>
<td>9,063</td>
</tr>
</tbody>
</table>
5.6  Groundwater Usage – Environmental

5.6.1  Groundwater Dependent Ecosystems

A GDE is one in which the plant and/or animal community is dependent on the availability of groundwater to maintain its structure and function.

5.6.1.1  National Atlas of Groundwater Dependent Ecosystems

Desktop mapping of potential aquatic and terrestrial GDEs indicates that areas with possible high, moderate and low potential for groundwater interaction occur in the vicinity of the Project Area (BoM, 2017). Isolated areas of high and moderate potential GDE’s occur within the Project Area, with low potential GDE’s identified predominantly around the Project Area boundaries. The GDE Atlas classifies ecosystems based on the potential for dependence on groundwater through multiple lines of scientific evidence. Ecosystems have been mapped as either:

- High potential for groundwater dependence (indicating a strong possibility the ecosystem is interacting with groundwater);
- Moderate potential for groundwater dependence; or
- Low potential for groundwater dependence (indicating it is relatively unlikely the ecosystem will be interacting with groundwater and will include ecosystems that are not interacting with groundwater).

Surface ecosystems near the Project that may be reliant on the surface expression of groundwater are shown in Figure 5-33. The desktop GDE mapping indicates:

- Terrestrial vegetation associated with the Isaac River and downstream extent of Cherwell Creek are mapped as having a high potential to be dependent on subsurface expression of groundwater.
- Aquatic habitat associated with the Isaac River, Cherwell Creek and downstream extent of Harrow Creek is mapped as having a high potential to be dependent surface expression of groundwater.
- Terrestrial vegetation and aquatic habitat associated with a number of palustrine wetlands surrounding the Olive Downs Project is mapped as having a moderate potential to be associated with the surface expression of groundwater.
- All other terrestrial vegetation and aquatic habitat within the Project locality, is broadly mapped as having a low to moderate potential of being associated with the presence of groundwater (BoM, 2017).

5.6.1.2  CVM GDE Studies

A remote sensing terrestrial GDE assessment was undertaken by 2rog (2021) as part of broader GDE assessments across BHP tenements within the region. Using the IESC recommended remote sensing approach, Landsat ETM imagery was selected following relatively wet and dry seasons and was analysed to identify areas of vegetation that were shown to be persistently wetter and greener than the surrounding areas. No potential terrestrial GDEs were identified in the vicinity of CVM using the remote sensing method, with the closest terrestrial GDE mapped using the IESC approach located approximately 45km to the east of the Project Area.
Ecological Service Professionals (ESP, 2020) undertook a field environment assessment of the condition of the aquatic ecosystems in the vicinity of the Project Area in April 2020. The results of aquatic indicators surveyed as part of the assessment were consistent with results from previous aquatic ecology surveys at CVM and in the broader region. Field assessments concluded that aquatic habitat condition at mapped potential surface-expression GDE sites in the vicinity of the Project were representative of ephemeral waterway and wetland sites, with no obvious surface-expression of groundwater at these sites. The assessment found that the aquatic ecological value of mapped potential surface-expression expression GDEs was low to moderate at wetland sites and waterway sites. No differences were observed in aquatic ecological indicators between sites on mapped potential surface-expression GDEs compared with those that are not mapped (ESP, 2020).

E2M Consulting (E2M) undertook a field survey in December 2020 to verify and characterise the presence, extent and condition of potential terrestrial and aquatic GDEs in the vicinity of the Project Area (E2M, 2021b). Possible GDEs within and/or directly adjacent to the disturbance footprint were found to be vegetation communities occurring on Land Zone 3 (Quaternary alluvial systems) and containing canopy species known elsewhere to have dependence on groundwater (e.g. *E. tereticornis, E. camaldulensis*). Within the Project Area, possible terrestrial GDE communities were found to be restricted to RE 11.3.2 and RE 11.3.25 (E2M, 2021a). Mapped as a low potential GDE in the GDE Atlas, the field assessment classified RE 11.5.3 as a potential GDE due to the species potential able to access groundwater between 10 to 20mbgl. Field survey information was then compared to depth to groundwater (depth to water table) predictions from the Project groundwater model (see Section 6) with respect of literature information on rooting depths of the observed species. This analysis has identified that for the most part, the pre-Project water table lies beyond the reach of the observed vegetation communities, and therefore those communities can not be considered GDEs. Exceptions to this are the riparian vegetation along Horse Creek to the north of the Project Area and Caval and Cherwell Creeks to the south of the Project Area (including on areas of ML 1775), which were found to contain communities that, on the basis of species type and predicted water table depth, may be considered GDEs. However, E2M (2021b) also found that in these particular areas, the vegetation communities observed were likely to be facultive and be dependant on surface water flow within their respective watercourses.

### 5.6.1.3 Other relevant GDE Studies

In the vicinity of the Project Area, a detailed desktop assessment of potential GDEs was undertaken for the nearby Moorvale South Project in June 2019 (Kleinfelder, 2019), and field verification of GDE mapping was also undertaken as part of the Olive Downs Project EIS (DPM Envirosciences, 2018a). These studies found that the majority of the terrestrial vegetation associated with the Isaac River, Phillips Creek, North Creek and Cherwell Creek is unlikely to be dependent on groundwater, given the vegetation communities present along these features are known to occur more widely across the landscape and are not restricted to areas where they could potentially access groundwater. DMP Envirosciences (2018a) note that areas of RE 11.3.25, RE 11.3.27 and RE 11.3.4 along the Isaac River which contain Queensland Blue Gum (*Eucalyptus tereticornis*) and River Oak (*Casuarina cunninghamiana*) have the potential to be reliant on access to groundwater (Doody et al., 2018). Based on the depth to groundwater within the Study Area being greater than 10 mbgl, DPM Envirosciences (2018a) concluded that these communities have a low likelihood of being reliant on access to groundwater. The depth to groundwater in the vicinity of mapped terrestrial GDE’s within the Project Area is also greater than 10 mbgl, and in line with the DPM Envirosciences (2018a) findings, also unlikely to be reliant on access to groundwater.
Consistent with the IESC (Doody et al., 2018) Assessing Groundwater-Dependent Ecosystems: IESC Information Guidelines Explanatory Note, the ephemeral nature of the aquatic habitat associated with Isaac River, Phillips Creek, North Creek and Cherwell Creek indicates that these habitats have a low likelihood of being dependent on groundwater. Conditions within the Project Area are similar to those as part of these previous studies, with a low likelihood of being dependent on groundwater also expected.

Similarly, investigations by Kleinfelder (2019) found that due to the shallow rooting and drought resistance of the dominant tree species, it is unlikely any of the other REs present would be dependent on groundwater. It was found that certain species on the first banks of streams could be dependent on groundwater, but their drought resistance could mean little impact by changes to the groundwater flow.

A review of open-cut mines in the region of the as part of the Moorvale South Project assessment showed that none of the vegetation communities appeared to be impacted by the open-cut mines even when the mine had diverted watercourses upstream of the vegetation communities. This outcome shows the lack of dependence of most vegetation types in the region on groundwater and their drought resistance.

### 5.6.2 Stygoafauna

ESP (2020) undertook stygofauna sampling in April 2020 within the Project Area. Sampling was completed at thirteen bores. No stygofauna communities were recorded from bores sampled during the field survey. This was consistent with the findings of the desktop assessment which concluded that the aquifer formations in the vicinity of the Project are unlikely to support diverse stygofauna communities.

DPM Envirosciences (2018b) undertook stygofauna sampling in 2017 in the vicinity of the Project Area, as part of the Olive Downs Project groundwater assessment. DPM Envirosciences concluded the generally poor groundwater quality within the regolith material (indicated by EC levels up to 26,800 μS/cm) suggested the groundwater environment is unsuitable for stygofauna. DPM Envirosciences also concluded that the available water quality data for the relevant bores (GW01 and GW18) indicated that stygofauna could potentially occur in the unconsolidated sediments (alluvium) associated with the Isaac River. However, no stygofauna were encountered during sampling.

### 5.6.3 Springs

A spring vent is a point where there is a surface expression of groundwater, with groundwater flow occurring intermittently or continuously. The Queensland Government maintains an inventory of identified springs in the Queensland Springs Database (DES, 2019). No springs have been identified within the Study Area.

### 5.6.4 Internationally and Nationally Important Wetlands

A search of the EPBC Act ‘Protected Matters’ database (DEE, 2019) found that there are no Internationally or Nationally Important Wetlands within the Project Area. The closest wetlands of international importance are located approximately 220 km south-east of the Project and include those of the Shoalwater and Corio Bays Area. Lake Elphinstone is the closest nationally important wetland, located 70 km north (upstream) of the Project. Due to their distance from site, no internationally and nationally important wetlands will be impacted by the Project.
5.7 Conceptual Model

A conceptual model of the groundwater regime has been developed based on the review of the hydrogeological data for the Project and surrounds. It is important to note that the conceptual hydrogeological model presented herein represents an evolution of the hydrogeological understanding at CVM, with the conceptual model having first been developed during the CVM EIS (URS, 2009) and then further updated by GHD (2017).

The Project is located within the northern part of the Bowen Basin, which comprises Permian aged coal measures that have been folded into a syncline structure that strikes in a north-west to south-east direction. The geology of the Project site comprises the stratified sequences of the Moranbah Coal Measures at the westernmost extent of the syncline that dip towards the east. The Project targets the coal seams of the Moranbah Coal Measures, that occur at subcrop, and underlie the Rewan Group east of the Project site with depth increasing toward the Isaac River. The Triassic Rewan Group strata that unconformably overlie the coal measures east of the Project can reach up to 300 m thick within the Study Area. Surficial cover at the Project site includes the Cherwell Creek alluvium, a tributary of the Isaac River, as well as regolith material comprising Quaternary to Tertiary sediments and Tertiary Basalt. The main hydrogeological features at the Project include:

- Cainozoic sediments:
  - Quaternary alluvium – unconfined aquifer (water-bearing strata of permeable rock, sand, or gravel) localised along the eastern reaches of Cherwell Creek, becoming relatively prolific to the northeast and east of the Project;
  - Quaternary to Tertiary alluvium, colluvium and weathered units (regolith) – unconfined and largely unsaturated unit bordering alluvium;
  - Tertiary Basalt – variable groundwater bearing unit overlying Permian coal measures across much of the Project Area;
- Permian coal measures with:
  - Hydrogeologically ‘tight’ interburden units with aquitard properties; and
  - Coal sequences that exhibit water bearing properties associated with secondary porosity through cracks and fissures.

Along Cherwell Creek immediately adjacent the Project, the alluvium comprises between 6 to 9m of clay and silt which is underlain by up to 10m of fine to coarse sand and gravel. It should be noted that the surface alluvium extent is minor within the Project Area and there is no direct interception of the alluvium by the proposed pit extents.
The Isaac River alluvium occurs 10 km northeast of the Project at its closest, and comprises a heterogeneous distribution of fine to coarse grained sands interspersed with lenses of clays and gravels. The hydraulic properties of the alluvium vary due to the variable lithologic composition, with field tests from nearby resource project groundwater assessments indicating horizontal hydraulic conductivity can range between $1.4 \times 10^{-2}$ m/day and 8.7 m/day. Groundwater occurs within the alluvium at depths of around 11 mbgl to 17 mbgl, typically disconnected from the riverbed elevation. Regionally, groundwater flow within the alluvium is a subdued reflection of topography, with groundwater flowing in a south easterly direction consistent with the alignment of the Isaac River. However, local groundwater levels within the alluvium are highest close to the Isaac River, indicating a potential local flow direction away from the Isaac River. This also indicates potential losing conditions from the Isaac River to the underlying alluvium during flow periods. Spatially, the alluvium is variably saturated. Localised perched water tables are also evident where waterbodies continue to hold water throughout the dry period (e.g. pools in the Isaac River and wetlands) occurring where clay layers slow the percolation of surface water.

Recharge to the alluvium is considered to be primarily from stream flow or flooding (losing streams), with direct infiltration of rainfall also occurring rapidly where there are no substantial clay barriers in the shallow sub-surface. On a regional scale, discharge is via evapotranspiration from vegetation growing along creek beds and minor short duration baseflow events after significant rainfall/flooding. Infiltration to underlying formations is limited to areas with relatively high hydraulic conductivity units (e.g. coal seams). General downwards recharge to deeper units is limited by the low hydraulic conductivity (confining) coal measure interburden sequences and, east of the Project, the Rewan Group.

Water quality data for the alluvium within the Study Area indicates it can be fresh to saline and highly spatially and temporally variable. The alluvium across the Study Area is mostly suitable for stock water supply and irrigation but is not suitable for drinking water and freshwater aquatic ecosystems. Alluvial bores within the Project monitoring network were found to be on average, not be suitable for long-term irrigation, with concentrations of iron, chromium, and manganese exceeding guideline levels. Review of the Queensland GWDB and a landholder census indicates alluvial groundwater associated with the Isaac River is used by local landholders, predominantly for stock water supply. Based on previous ecological studies, it was identified that riparian vegetation along the Isaac River has a low likelihood of dependence on alluvial groundwater (DPM Envirosciences, 2018a).

Tertiary-Quaternary aged sediments (regolith) and basalt present across the Project Area form the base of the unconfined shallow groundwater system. The groundwater flow processes are similar to those of the alluvium, however the fluxes are expected to be significantly lower due to the dominance of clay within the sediments. Within the Study Area, near the Isaac River and creeks, water has been detected within the regolith material at depths of around 8 mbgl to 19 mbgl. Outside of these areas the regolith material was found to be largely unsaturated. Groundwater within the Tertiary Basalt at the Project site was generally encountered at the base of the unit at depths ranging of between 14 mbgl and 37 m bgl. Water quality data for the regolith indicates it is generally highly saline but can be brackish to moderately saline. Water within the regolith is generally of poor quality and not considered suitable for stock, irrigation, aquatic ecosystems or drinking water. Water quality within the basalt, where saturated, is generally of poor quality but is considered suitable for stock and short term irrigation.
In the Permian strata, groundwater is encountered mainly in the coal seams, and occasionally in the sandstone/siltstone units of lower hydraulic conductivity. As with the rest of the Bowen Basin, the coal seams are the main groundwater bearing units within the Permian sequences, with low hydraulic conductivity interburden generally confining the individual seams. The coal seams are dual porosity in nature with a primary matrix porosity and a secondary (dominant) porosity provided by fractures (joints and cleats). Hydraulic conductivity of the coal decreases with depth due to increasing overburden pressure reducing the aperture of fractures. Vertical movement of groundwater (including recharge) is limited by the confining interburden layers, meaning that groundwater flow is primarily horizontal through the seams with recharge only occurring at subcrop.

Review of fault behaviour within the Study Area and from external studies has identified that faults can increase vertical hydraulic conductivity parallel to the fault trace and reduce it perpendicular to the fault trace. However, any increases in vertical hydraulic conductivity is limited to small vertical horizons (<20 m) and is variable between faults dependent on localised hydrothermal activity and mineralisation in-filling pore spaces. Hydraulic testing of faults within the Study Area indicate that faulting zones intercepted are not pathways for preferential flow.

Regionally, groundwater within the Permian coal measures flows in a south-easterly direction. Review of water quality data indicates water within the Permian coal measures is generally saline within the Project Area but can range between fresh to highly saline. Groundwater within the coal measures of the Project Area is only considered suitable for some stock, with the type of stock dependent on the TDS range (i.e. beef cattle or sheep). Some bores screened within the interburden and the coal seams display highly variable concentrations of aluminium and nickel, exceeding the guidelines for stock watering.

A conceptual cross-section, made from the east-west section (see Figure 4-3) through the Project Area, of the hydrogeological system is presented in Figure 5-34 to Figure 5-36 illustrating the conceptual model of the area prior to, during and following the Project.
Figure 5-34 Conceptual Model of the Groundwater System Pre-Project
Figure 5-35  Conceptual Model of the Groundwater System During Project
Figure 5-36 Conceptual Model of the Groundwater System Post Project
6 Groundwater Simulation Model

6.1 Model Details

This section provides a summary of the design and development of the numerical groundwater model used to support this groundwater assessment. Full details of the numerical groundwater model are included within Appendix B.

6.1.1 Model Objectives

Numerical modelling was undertaken in support of the groundwater assessment for the Project to evaluate the potential impacts of the Project on the local groundwater regime. The objectives of the predictive modelling were to:

- Assess the groundwater inflow to the mine workings as a function of mine position and timing;
- Simulate and predict the extent and area of influence of dewatering, and the level and rate of drawdown at specific locations; and
- Identify areas of potential risk, where groundwater impact mitigation/control measures may be necessary.

6.1.2 Model Design

The numerical groundwater model was developed based on the conceptual groundwater model, presented within Section 5.7. Conceptualisation of the groundwater regime and the calibration of the model against observed data are key to achieving a reliable numerical model. Conceptualisation is a simplified overview of the groundwater regime (i.e. the distribution and flow of groundwater) based on available data and experience. Consistency between numerical model results and the conceptual understanding of the groundwater regime increases the credibility of the numerical model predictions.

The numerical model was developed using a Geographic Information System (GIS) in conjunction with MODFLOW-USG, which is distributed by the United States Geological Survey (USGS). MODFLOW-USG is a relatively new version of the popular MODFLOW code (McDonald and Harbaugh, 1988) developed by the USGS. MODFLOW is the most widely used code for groundwater modelling and has long been considered an industry standard.

The numerical groundwater model for the Project builds on the Olive Downs Project EIS model (the foundational regional Bowen Basin model) (HydroSimulations, 2018b). The foundational model was subsequently updated for the Moorvale South Project in 2019 (SLR, 2019b), for the Winchester South Project EIS in 2020 (SLR, 2020), and most recently for the Lake Vermont North Project (in conjunction with the Project). BMA has established groundwater data sharing agreements with the owners of each of these projects/mines, which allows for the sharing of groundwater data, models and documentation. Under these agreements, the groundwater models developed as part of each project/mine’s groundwater assessment have been adopted as a base for the Project groundwater assessment where relevant. Of note, the current update of the groundwater model reported herein is the first iteration to include data and information from the Lake Vermont North Project as well as a number of BHP sites (CVM, Poitrel, Daunia and Saraji).

A range of model updates were deemed required to ensure the regional Bowen Basin model is fit for purpose for the Project. The updates to the model design from that reported in SLR (2020) included:
- Model extent and grid – revised grid extent and refinement around CVM pits.
- Model layers – updated layers to deepest mined seams at CVM, capture stratification of alluvium and update model layers to match CVM geological model surfaces and update LiDAR data.
- Timing – updated calibration model to extend to December 2020 and refined timing to capture seasonality and mine progression changes.
- Boundary Conditions – updated model boundary conditions with revised grid extent and regional flows.
- Stresses – Maintained inputs, but with updates from more recent and site-specific data.

Previous groundwater modelling for CVM includes the GHD (2017) numerical groundwater model, developed for Associated Water Take reporting to DoR. The GHD (2017) model was built on the site geological model and reported on model calibration, predicted mine inflows, predicted drawdown extents. The GHD model however did not simulate cumulative impacts from the neighbouring mines. Elements of the GHD work have been included within the Project conceptual hydrogeological model as discussed in Section 5.7. However, for the purposes of the Project, minimal other elements from the GHD numerical model have been carried forward into the Project numerical model given the availability of the more recently updated regional Bowen Basin model.

6.1.3 Model Calibration

The numerical model includes a transient calibration (2008 to 2020). Both the steady-state and transient calibrations capture historical mining at Peak Downs, CVM, Saraji, Lake Vermont, Eagle Downs, Poitrel and Daunia Mines. Mining was represented in the model using the MODFLOW drain package, with the drain cells set to the base of the target coal seam for each pit, and within the target coal seam for underground mines. Calibration of the model was carried out with the objective being to replicate the groundwater levels measured in the CVM, Lake Vermont, Winchester South, Olive Downs Project, Moorvale South Project, Eagle Downs Mine and the Project monitoring networks and available privately-owned bores, in accordance with Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

Steady-state calibration for the model achieved a 6.7% scaled root mean square (SRMS) error, which is within the acceptable limits (i.e. 10%) recommended by the Australian groundwater modelling guidelines (Barnett et al., 2012). Observations from recently installed Project site bores have been included in the transient calibration statistics. Project site bore residuals were calculated as the difference between the observed water level and simulated head for the corresponding time period in the predictive model. With the Project site bore residuals included, the transient calibration achieved a 5.2% SRMS error, which is also within the acceptable limit of 10%. A detailed description of the calibration procedure is provided in Appendix B.

6.1.4 Model Performance and Limitations

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

The 2012 guide has replaced the model complexity classification of the previous guideline by a "model confidence level" (Class 1, Class 2 or Class 3 in order of increasing confidence) typically depending on:

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

It is generally expected that a model confidence level of Class 2 is required for mining environmental impact assessment. **Table 6-1** (based on Table 2.1, Barnett et al. 2012) summarises the classification criteria and shows a scoring system allowing model classification. Based on **Table 6-1**, the groundwater model developed for this Groundwater Assessment may be classified as primarily Class 2 (effectively “medium confidence”) with some items meeting Class 3 criteria, which is considered an appropriate level for this Project context.

**Table 6-1  Groundwater Model Classification Table**

<table>
<thead>
<tr>
<th>Class</th>
<th>Data</th>
<th>Calibration</th>
<th>Prediction</th>
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</tr>
</thead>
<tbody>
<tr>
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</table>

**6.1.5 Model Predictions**

Transient predictive modelling was undertaken to simulate both the proposed mining at the Project and surrounding mines from January 2021 to January 2056. The model timing used annual stress period durations as mining progressed into the future. Three numerical model scenarios were run:

• **Null Run** – No future mining within the Study Area.
• **Approved** – Approved and foreseeable mining within the Study Area.
• **Cumulative** – Approved and foreseeable mining plus the Project.
6.2 Predicted Groundwater Interception

The predicted inflows for Approved mining at Horse Pit plus the Project, and the total Horse Pit inflows are presented in Figure 6-1.

![Figure 6-1 Predicted Project Mine Inflows](chart)

The predicted average total inflow rate over the duration of mining is 198.1 ML/year (0.55 ML/day).

As shown, inflows to the Project are predicted to reach a maximum peak in year 2044, with 275.2 ML total inflow predicted for the year (0.75 ML/day). The average inflow rate due to the Project is 133.9 ML/year (0.36 ML/day). The predicted inflows are within the same order of magnitude as the groundwater inflows recorded at Horse Pit and Heyford Pit during 2018/2019 (Table 5-5). The modelled inflow volumes are therefore believed to realistic predictions for the Project.

The GHD (2017) model for CVM predicted an average inflow of 1,461 ML/year (4 ML/day) which is higher than the predicted inflows in the current model. The difference in the predicted inflows may relate to updates to the model structure from site geological information, the updates to the calibrated hydraulic properties based on more recent observation data (noting the GHD model’s reported calibration performance was relatively poor with an SRMS of 19% compared to 5.2% in the current model), and the implementation of the coal depth dependence function in the current model.

The Water Plan (Fitzroy Basin) 2011 groundwater area consists of the following (refer Section 2.1.2):

- Groundwater Unit 1 (containing aquifers of the Quaternary alluvium); and
• Groundwater Unit 2 (sub-artesian aquifers).

Planned mining operations at the Project will not intercept Quaternary alluvium. As such, all direct groundwater take predicted by the model is from Groundwater Unit 2.

6.3 Predicted Maximum Drawdowns

The process of mining reduces water levels in surrounding groundwater units due to interception of groundwater in the mined geology. The extent of the zone affected is dependent on the properties of the aquifers/aquitards and is referred to as the zone of drawdown. Aquifer drawdown is greatest at the working coal-face, and generally, gradually decreases with distance from the mining operations.

Maximum drawdown due to the Project is obtained by comparing the difference in groundwater levels for different aquifers in the Approved model run and the Cumulative model run. The maximum drawdown is a combination of the maximum drawdown values recorded at each model cell at any time over the duration of the predictive model. Figures showing predicted drawdowns feature the locations of privately-owned bores within the model domain. Discussion on the maximum predicted groundwater level drawdown at the privately-owned bores is included in Section 7.2. Predicted drawdown figures (Figure 6-2 to Figure 6-6) show where maximum drawdown impacts are predicted to exceed 1 m. In areas within the 1 m drawdown contour, the unit is considered impacted by drawdown. Figures include the locations of known private bores intercepting the relevant layers if present. Note that no private bores are predicted to be impacted as a result of mining activities at the Project.

No drawdown impacts are predicted for the Quaternary alluvium as a result of the Project. This prediction is consistent with the GHD (2017) model where no water table drawdown was predicted due to mining at CVM.

The maximum predicted drawdown associated with the Project within the regolith is shown in Figure 6-2. The drawdown extent within the regolith (Layer 2) is largely confined to the Project Area, and is influenced by the distribution of predicted saturated zones in the regolith. At the northern end of the CVM mining lease, 1 m drawdown influence is predicted to extend up to 2.9 km north of the lease boundary in the regolith. Review of SDSG mapping shows that the predicted drawdown intercepts basalt deposits located to the north east of the Project Area. As shown in Figure 6-2 no groundwater users are located within the predicted drawdown extent. In the vicinity of the Project Area there are therefore no known relevant potential receptors located within this zone.

The coal seams of the Moranbah Coal Measures are the primary groundwater bearing units intercepted by the Project, and will experience drawdowns as a direct result of mining at the Project. Groundwater level drawdown within the mined coal seams is influenced by unit structure and is confined to unit extents. Figure 6-3 to Figure 6-6 show the maximum predicted incremental drawdown for Q, P, H and D seam in the Moranbah Coal Measures. The figures show the extent of maximum predicted depressurization of the Permian coal measures is limited to the west of the Project area due to the structural geology (i.e. coal seams subcrop and the units do not exist west of the subcrop). The extents of maximum predicted incremental drawdown in the Moranbah Coal Measures seams are between 10 to 12 km to the east and north east of the Project boundary. The cone of depression is predicted to be steepest at the working coal face. The predicted drawdown extents are consistent with the previous predictions by GHD (2017) for the CVM operations.
FIGURE 6-3

Maximum Incremental Drawdown in Q Seam (Layer 12)
FIGURE 6-4

Maximum Incremental Drawdown in P Seam (Layer 14)
FIGURE 6-5

Maximum Incremental Drawdown in H Seam (Layer 16)

Legend:
- Drawdown Contours (m)
- Model Boundary
- Model Grid
- Project Mining Lease Boundary
- Surrounding Mines
- Horse Pit Expansion Project Area

Maximum Drawdown (m):
- 0
- 1 - 2
- 2 - 5
- 5 - 10
- 10 - 20
- 20 - 50
- 50 - 100
- 100 - 200

Solid Geology:
- Anakie Metamorphic Group (PLEa)
- Back Creek Group (Pb)
- Blackwater Group (Pw)
- Blenheim Subgroup (Pbe)
- Bundarra Granodiorite (Kgb)
- Burgrove Formation (Pwg)
- Clematis Group (Re)
- Du-BBG (Du)
- Fair Hill Formation, Fort Cooper Coal Measures (Pwf)
- German Creek Formation (Pbd)
- Ki-CQ (Ki)
- Lizzie Creek Volcanic Group (Pvz)
- MacMillan Formation (Pbn)
- Moolayember Formation (Rm)
- Moranbah Coal Measures (Pwb)
- Mount Rankin Formation (Ca)
- Peak Range Volcanics (Tp)
- Rangal Coal Measures, Bandanna Formation, Baralaba Coal Measures (Pwj)
- Retreat Supersuite (Dgr)
- Rewan Group (Rr)
- Silver Hills Volcanics (DCs)
- Anakie Metamorphic Group (PLEa)
- Blenheim Subgroup (Pbe)
- Bundarra Granodiorite (Kgb)
- Burgrove Formation (Pwg)
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