# Central Queensland Coal Project

# Appendix 6a – Groundwater Model Report Summary

Central Queensland Coal

CQC SEIS, Version 3

October 2020

# Groundwater Technical Report Summary

## Central Queensland Coal

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# 1. Introduction

Eco Logical Australia (ELA) was engaged by Central Queensland Coal (CQC) to develop a technical summary of the Numerical Groundwater Model and Groundwater Assessment report (Modelling report) developed by HydroAlgorithmics (2020) for the Central Queensland Coal Project (CQC Project) to act as a stand- alone detailed executive summary. ELA's summary of the Groundwater Modelling work focussed on the methodology and findings of the report. Site background information (i.e. physical and geological setting) is not included in this summary and can be found in the main technical report prepared by HydroAlgorithmics (2020).

# 2. Technical Summary

## 2.1 Scope and objectives

The scope of works and main objective of the modelling report was to support a response to comments on the amended 2019 SEIS v2 submitted for the CQC Project. Comments were received from several agencies, including the Queensland Department of Agriculture and Fisheries (DAF), Department of Environment and Science (DES) and Department of Natural Resources, Mines and Energy (DNRME).

The development of the report also included consideration of a peer review (undertaken by AGE) of previous modelling work undertaken by CDM Smith, a peer review (also undertaken by AGE) of the current HydroAlgorithmics (2020) model, as well as a detailed reconciliation against groundwater-related requirements as published in the IESC Information Guidelines.

## 2.2 Groundwater data sets and dependent assets

The numerical groundwater model has been developed on the basis of the following datasets and sources at minimum, detailed in the sections below.

### 2.2.1 Groundwater monitoring data

The groundwater monitoring network installed within ML 80187, ML 700022 and surrounds has been progressively developed as part of initial exploration and groundwater investigation programs (i.e. 2010-11, 2011-12 and 2014-20), through to targeted and detailed groundwater investigations, bore census and baseline monitoring network installations (and extensions) in 2017 and 2018, supplementary groundwater investigations and continued baseline groundwater monitoring in 2019. The extensive groundwater investigations supported improvements to the groundwater modelling and assessments and future validation, including the most recent extensive groundwater monitoring which included:

- Monthly and ongoing baseline monitoring (water level and quality).
- Monthly groundwater baseline monitoring at select landholder bores.
- Regular groundwater level recording at exploration bores, selected water holes / pools across the CQC Project area.
- Data logging of alluvial groundwater levels to monitor response to streamflow recharge.
- Select monitoring of the basement aquifers.

In addition to the above, several site-specific groundwater investigations were undertaken in 2019 to support the groundwater monitoring datasets including:

- Transient Electromagnetic (TEM) ground survey to explore groundwater associated with surficial geology (Groundwater Imaging, 2019).
- Open end permeability and packer testing at two exploration drill holes (AMEC, 2019).
- Core sampling from two exploration drill holes and laboratory permeability testing (GES, 2020).

Groundwater monitoring and assessment has been undertaken across the site, with a focus on the geological units listed below, in order to further inform the groundwater model for the CQC Project:

- Cenozoic Deposits (Quaternary Holocene Estuarine Alluvium, Quaternary Alluvium and Quaternary Pleistocene Alluvium / Regolith)
- Styx Coal Measures (Overburden, Coal Seams, Interburden and Underburden)

### 2.2.2 Groundwater use

Groundwater use data that was considered in the development of the numerical model included:

- Water information located on ML 80187 and ML 700022, mainly comprising exploration bores, a wind pump (WP001) and bore Mm1 located on site.
- Data and information from government database searches that revealed several bores (Table 5-7, Section 5.2.3 of the main report), located in several catchment areas around the site.
- A landholder bore survey, which identified two bores labelled 187278 and BH20, within a 10-kilometre radius from the CQC Project.

### 2.2.3 Groundwater dependent ecosystems

Environmental groundwater use considered in the development of the numerical model included Subterranean, Aquatic and Terrestrial groundwater dependent ecosystems (GDEs), all of which are present in the vicinity of the Project. Stygofauna are present within some parts of the alluvial aquifers of the region. Aquatic GDEs comprise groundwater fed creeks and their associated aquatic ecosystems. Terrestrial GDEs include riparian vegetation and Wetland 1, where there is utilisation of sub-surface groundwater.

### 2.2.4 Groundwater level

Baseline conditions are critical in the development of a numerical model and the extensive groundwater monitoring network in the vicinity of the CQC Project provides a reasonable spatial distribution of groundwater level information. Reports prepared by CDM Smith (2018) and AMEC (2019) present an inferred water table elevation as well as general groundwater flow directions with the groundwater level estimated to occur between 10 to 30 metres below ground level. A review of the data in the immediate vicinity of the CQC Project generally shows minimal head separation between the upper stratigraphic sequences of the Early Cretaceous (Styx Coal Measures) and Cenozoic sediments. There is, however, the potential for localised upward pressure from the lower Early Cretaceous units. Isotope analysis undertaken suggest that these gradients can potentially be a result of the groundwater system near the Tooloombah Creek pinch point (the location where Tooloombah Creek passes between Mount Brunswick and Mount Mamelon) receiving recharge from surface water.

The temporal groundwater levels show a general correlation with the rainfall, which is evident when the groundwater levels are plotted against the cumulative rainfall departure and is especially evident for the below average rainfall experienced since 2017. Data obtained from the monitoring bores also shows correlated responses in relation to seasonal fluctuation, periodic fluctuations such as when aquifer testing was undertaken, as well as low amplitude fluctuations (5 to 10 cm) in the groundwater table associated with high and low tides at certain bores close to tidal areas.

### 2.2.5 Groundwater quality

The baseline water quality has been assessed and evaluated against commentary made in the draft Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results (DES, December 2018) for each corresponding lithological unit and is summarised below.

- **Quaternary alluvium**: 'The water appears suitable for most purposes, although EC and TN may exceed QWQG aquatic ecosystem surface water quality guidelines, and pH (lower range values) may be below the guidelines in places.'.
  - The pH of the groundwater ranges from slightly acidic (6.5) to slightly alkaline (8.0), with the salinity generally ranging from 469 to 12,362 µS/cm, except for one bore (BH25) where the salinity ranges from 17,416 to 34,804 µS/cm (ref: Table 5-10).
- **Quaternary Pleistocene Alluvium / Regolith**: '… there are occurrences of excessive salinity. EC, pH (upper range values) and TN may exceed QWQG aquatic ecosystem surface water quality guidelines.'
  - The pH of groundwater ranges from slightly acidic (5.9) to slightly alkaline (8.6), with the salinity of the groundwater ranging from <1,000 µS/cm to > 47,000 µS/cm.
- **Tertiary Sediments**: Water quality only available from two bores. The pH from these bores fall in the neutral range and the salinity range is between 7,750 and 9,680 µS/cm.
- **Styx Coal Measures**: 'The water quality is poor for irrigation because sodium levels are excessive for sensitive crops (SAR >8), and EC may exceed irrigation guidelines in some bores. The water should be tested before giving to stock as there are occurrences of excessive salinity. Groundwater EC exceeds QWQG aquatic ecosystem surface water quality guidelines, and TN and pH (upper range values) may do so also.'
  - In general, the pH of bores drilled into the Styx Coal Measures range from being slightly acidic (6.8) to slightly alkaline (8.2). However, there are several bores with very high alkalinity (pH 10.9 to 12).
  - The salinity concentrations are classed as high with concentrations generally exceeding 14,000 µS/cm.
- **Permian Measures**: 'Groundwater EC exceeds QWQG aquatic ecosystem surface water quality guidelines, as TN frequently does, and pH (upper range values) may also.'
- **Surface water**: The salinity (EC) ranges of the Styx River are large at surface water sampling point St2 (4,884-37,800 µS/cm; 20th-80th%iles) reflecting the effects of tides and discharge of freshwater to sea following rainfall events. Since the installation of the Tooloombah Creek Gauging Station (ToGS01) in September/October 2019, and during the prevailing dry conditions in the second half of 2019, recorded salinity (EC) levels in the pool upstream of ToGS01 were shown to be gradually increasing and over a three-month period and had more than doubled from 4,000 µS/cm to approximately 9,000 µS/cm.

- **Isotope sampling**: isotopic analysis of the Tooloombah Creek and Deep Creek surface water samples indicates that, consistent with the findings of Gonfiantini (1986), the ratio of residual isotopes $O^{-18}$ to $H^{-2}$ increases (relative to the groundwaters sampled) and is well below the Global Meteoric Water Line (GMWL) and the Local Meteoric Water Line (LMWL) indicating the water undergoes evaporation (i.e. progressively enriched with heavier isotopes). Stable isotope sampling was supplemented by leaf water potential (LWP) measurements. In relation to GDEs, CDM Smith (2018f) relevantly observed that much of the soil profile is very dry and well below the agronomic wilting point (i.e. less than -1.5 MPa) for LWP, noting that native tree species can often tolerate soil moisture potentials well below this level. Radioactive isotope results and relative comparison to chloride and bicarbonate/chloride concentrations (CDM Smith, 2018f) indicates that there is a greater potential for groundwater contributions to Tooloombah Creek than Deep Creek, albeit potentially not in any significant quantities.

### 2.2.6 Aquifer hydraulic properties

Hydraulic properties for the Project have been assessed through a combination of aquifer testing as well as literature reviews and information obtained from previous modelling undertaken. The results from these assessments are provided in Tables 5-17, 5-18, 5-19, 5-20, 5-21 and 5-22 of the main report.

### 2.2.7 Environmental values and water quality objective guidelines

Environmental values (EVs) and water quality objectives (WQOs) for QLD waters are prescribed in Schedule 1 of the *Environmental Protection (Water and Wetland Biodiversity) Policy 2019*, which replaced the *Environmental Protection (Water) Policy 2009* on 1 September 2019. WQOs are long-term goals for water quality management that protect EVs. WQOs are typically based on national water quality guidelines, with a general focus and objective to further characterise and establish appropriate water quality guidelines at a regional and site-specific scale. The Styx River catchment is part of Basin 127 and is generally consistent with the Styx Surface Water Basin. The environmental values for surface waters and groundwaters specific to the CQC Project are published in the Styx River, Shoalwater Creek and Water Park Creek Basins Environmental Values and Water Quality Objectives (DEHP, 2014).

The following EVs have been considered as part of the development of the conceptual model:

- Aquatic Ecosystems – No known springs or seeps are located within the CQC Project area, but the aquatic ecosystems that exist within Deep Creek and Tooloombah Creek are being considered by Eco Logical Australia (2020a) separate to numerical groundwater modelling report.
- Irrigation – Groundwater is not currently being used for irrigation purposes within the CQC Project area and irrigation is mainly sourced from surface water sources within the Styx river catchment.
- Farm supply / use – Groundwater is not being used for farm supply, mainly due to unsuitable water quality within the Styx Coal Measures and Quaternary Pleistocene Alluvium.
- Stock (Drinking) Water – Groundwater is currently being used for stock watering (mainly associated with grazing) purposes.
- Aquaculture – Groundwater is not used for aquaculture and was therefore excluded.
- Human Consumer – Poor water quality of the groundwater in the open cut extent and basement rocks generally make the water not suitable for human consumption.

- Primary, Secondary and Visual Recreation – Groundwater is not used for primary, secondary and/or visual recreation and no EVs for these are known or proposed for the Project area.
- Drinking Water – Groundwater quality is not suitable for human consumption.
- Industrial Use - The Project would utilise groundwater that report to the sumps within the open cut in ML 80187. The groundwater is anticipated to be of relatively poor water quality, but would be suitable for industrial use and therefore preferentially used in the mine site water balance.
- Cultural and Spiritual Value - There are no known EV's for cultural or spiritual values within the Project area, nor any WQOs proposed.

## 2.3 Conceptual groundwater model

### 2.3.1 Conceptual model development

Figure 1-1 presents a schematic representation of the hydrogeological conceptual model for the CQC Project and incorporates the following main hydrogeological units:

- Quaternary and Pleistocene Alluvium / Regolith: These units are considered unconfined aquifers. In terms of conceptualisation, a separation has been identified between the Quaternary (Holocene) Alluvium and the Quaternary Pleistocene Alluvium / Regolith on the basis of their hydraulic properties and differences observed regarding composition and compaction (the Holocene epoch is considered to be less compacted).
- Styx Coal Measures: The coal measures are generally considered as being confined aquifers, with the expectation to be less confined where the coal measures sub-crop near the surface / regolith. In the shallower overburden, interburden and the seams itself, no clear discernible water level reductions or propagation can be observed. However, based on recommendations from a peer review, depth dependence in the coal seams has been incorporated and considered.
- Permian Sequence (Back Creek Group, Boomer Formation and Carmila Beds): These units are generally considered to be confined aquifers. They are considered to be less confined, however, in areas where these units sub-crop near surface / regolith. For the purpose of the Project, the Back Creek Group has been separated as a discrete deep groundwater system for the purpose of separation of direct impacts on the overlying target coal seams. This deep system has been assigned a low sensitivity ranking based on the poor water quality, limited groundwater yields and limited potential for interaction with GDEs.

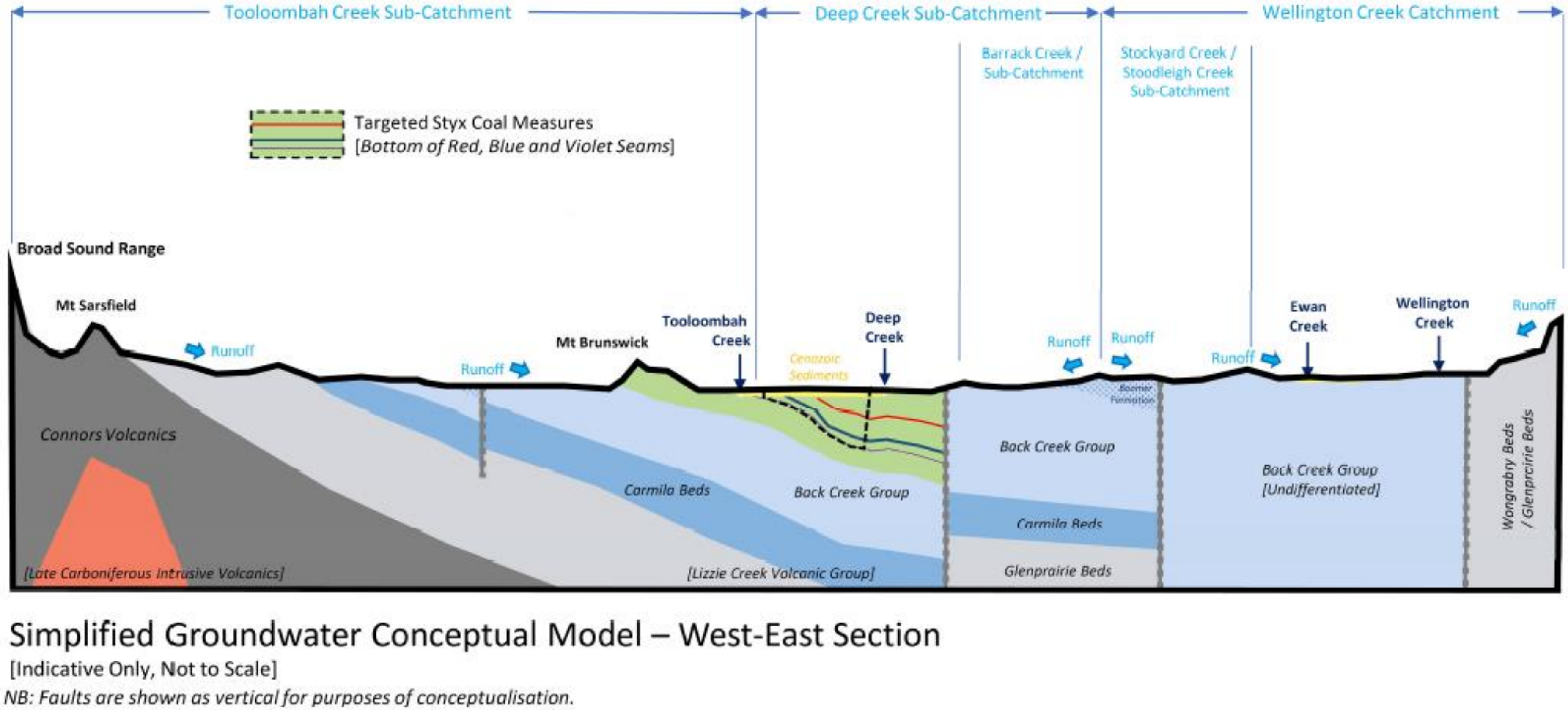


**Figure 1-1: Simplified Conceptual Groundwater Model (HydroAlgorithmics, 2020)**

The conceptual hydrogeological model is described generally in CDM Smith (2018) and has been reviewed and updated based on updates to the regulatory framework and additional data acquired to characterise the hydrological and landscape setting, geology, soils and geomorphology, and groundwater datasets and dependent assets (including groundwater connectivity and dependence). Based on a review of all of the information, and generally consistent with the four (4) Aquifer Class / Chemistry Zones in the draft *Regional Groundwater Chemistry Zones: Fitzroy-Capricorn-Curtis Coast and Burdekin-Haughton-Don Regions Summary and Results (DES, December 2018)*, the data supports four conceptual groundwater systems as follows:

- **Alluvial (Holocene) Groundwater System** – including alluvial (narrow-channel) sediments within the deep cut infills of Tooloombah Creek and Deep Creek as well as estuarine sediments toward the Styx River mouth downstream of the CQC Project.
- **Alluvial (Pleistocene) Groundwater System** – including Cenozoic sediments (beyond the Holocene alluvial sediments) overlying the Early Cretaceous Styx Coal Measures, however, precise subdivision of the Quaternary Pleistocene Alluvium from the weathered Early Cretaceous (i.e. regolith of the sedimentary rocks) is physically less clear at depth.
- **Sedimentary Rock Groundwater System** – including the shallow rock Early Cretaceous Styx Coal Measures, including relatively higher permeability coal seams/plies, albeit reducing permeability with depth.
- **Sedimentary and Fractured (Basement) Rock Groundwater Systems** – including shallow and deep rock groundwater bearing structures and the Permian Measures of the Back Creek Group to Carmila Beds and Lizzie Creek Volcanic Group to Connors Volcanic Group.

The conceptual groundwater model layers and initial hydraulic parameter targets have been determined, with consideration of the conceptual and numerical groundwater models developed in CDM Smith (2018), and form the basis of the design, construction and calibration of the updated numerical groundwater model. The conceptual model layers and hydraulic parameters used in the design of the model are summarised in Table 1-1. Relative comparisons with the previous (CDM Smith, 2018) model are highlighted in green (increased or added values) and red (decreased values).

**Table 1-1: Conceptual model hydraulic parameters (HydroAlgorithmics, 2020)**

| Model Layer | | Hydraulic Conductivity | | Specific Yield | Specific Storativity |
|---|---|---|---|---|---|
| | | $K_{Horizontal}$ [m/day] | $K_{Vertical}$ [m/day] | $S_y$ [-] | $S_s$ [1/m] |
| 1 | Styx Coal Measures Overburden / Interburden (Out-of-Pit Emplacement Final Landform) | 1# | 0.1 | 0.005 | 0.000005 |
| 2– 3 | Qa, Qhe/s, Qhe/m, Qhcm | 10 **(x2~)** | 0.41 | 0.02 **(x2)** | 0.000013+ **(x2~)** |
| | Qpa, Qr, Qf > Kx | 4.1 | 0.41 | 0.01 | 0.000013+ **(x2~)** |
| | Regolith / Weathered Kx, Pb, Pbm, Pc | 1 | 0.1 | 0.005 | 0.000013+ **(x2~)** |
| | TQr, Ta, Td | **1** | **0.1** | **0.01** | **0.000013+** |
| 4 | Regolith / Weathered Kx, Pb, Pbm, Pc, Cp | 1 | 0.1 | 0.005 | 0.000013+ **(x2~)** |
| | | 0.02 | 0.002 **(÷10)** | 0.005 | 0.000005 |

| Model Layer | | Hydraulic Conductivity | | Specific Yield | Specific Storativity |
|---|---|---|---|---|---|
| | | $K_{Horizontal}$ [m/day] | $K_{Vertical}$ [m/day] | $S_y$ [-] | $S_s$ [1/m] |
| 5 | Styx Coal Measures (Overburden / Interburden – Upper) | | | | |
| 6 | Coal (G1-R Lower Aggregate) | 0.22-0.002* (Up to x70) | 0.075 (x25) | 0.005 | 0.000005 |
| 7 | Styx Coal Measures (Interburden – Mid) | 0.003 | 0.0015 (÷2) | 0.005 | 0.000005 |
| 8 | Coal (P-B Lower 2 Aggregate) | 0.22-0.002* (Up to x70) | 0.075 (x25) | 0.005 | 0.000005 |
| 9 | Styx Coal Measures (Interburden – Lower) | 0.003 | 0.0015 (÷2) | 0.005 | 0.000005 |
| 10 | Coal (V Upper 1-V Lower 2 Aggregate) | 0.22-0.002* (Up to x70) | 0.03 (x10) | 0.005 | 0.000005 |
| 11 | Styx Coal Measures (Underburden) | 0.004 | 0.002 (÷2) | 0.005 | 0.000005 |
| 12 | Back Creek Group / Boomer Formation | 0.004 (x10) | 0.002 (÷2) | 0.005 | 0.000005 |
| 12 | Glenprairie / Wangrabry Beds | 0.0004 | 0.0002 (÷2) | 0.005 | 0.000005 |
| 13 | Lizzie Creek Volcanic Group / Carmila Beds | 0.0004 | 0.0002 (÷2) | 0.005 | 0.000005 |
| 14 | Intrusive Rocks / Connors Volcanic Group | 0.00001 | 0.00001 | 0.005 | 0.000005 |

* It is known in Eastern Australian coal basins that seam permeability typically reduces with depth. A depth dependent (horizontal) hydraulic conductivity ($K_H$) linear reduction has been applied with a lower bound capped to no more than two orders of magnitude lower than the upper bound value, at the deepest point of the open cut.

^ Where the depth dependent $K_H$ is reduced to be equivalent to $K_V$, it has also been reduced accordingly, at a ratio of 2:1 to ensure $K_H > K_V$.

[+] Application of physical upper limit for unconsolidated materials as determined by Rau *et al*. (2018).

[#] Based on Hawkins (1998).

The development of the conceptual model also considered the broad conceptualisation of the following aspects:

### BASEMENT ROCK

The basement rock was based on interpretation of the available geological mapping and in consultation with CQC's geologists. Reference is made to the mapped structures and faults within the basement rock at the interface of the Early Cretaceous Styx Coal Measures and the Permian Measures to the east/north-east of the CQC Project.

### FRESHWATER-SALINE WATER INTERFACE (GHYBEN-HERZBERG RELATIONSHIP)

The location of the steady-state interface between oceanic saltwater and inland (fresher) groundwaters can be conceptually based on the generalisation that discharge of inland fresh water is maintained toward the ocean (Verruijt, A., 1968) and the Ghyben-Herzberg Relationship used to relate the depth of the interface below sea level to the height of the free groundwater surface. Applying the relationship at the Ogmore Road Bridge (several kilometres downstream of the CQC Project) and assuming approximately 1-2 m of freshwater head (assuming average – static conditions above the long term mean sea level), the theoretical depth of the seawater interface could be expected to be at approximately -40 to -80 mAHD. Considering the inferred groundwater level (phreatic surface) further inland at the Tooloombah Creek and Deep Creek confluence (north of the CQC Project) is 7 mAHD, it would then equate to a 280 mAHD interface depth. Furthermore, noting that the static water level (SWL) at the deepest northern extent of the proposed open cut is in the order to 12 to 17 mAHD, it would then equate to a -480 to -680 mAHD interface depth.

For relative comparison, the bottom of the proposed open cut at the deepest point is at approximately -152 mAHD. The predicted groundwater drawdown extent (i.e. 1 - 2 m contours) in the Styx Coal Measures as a result of the CQC Project does not extend as far as the historic Ogmore mine workings (8 km downstream) and would not result in any superposition effects. Therefore, is not expected to result in any discernible change to the location of the freshwater-saltwater interface.

### ECO-HYDROGEOLOGICAL MODELS

Hydrological (interflow) concepts are based on the flow duration curves developed by WRM Water and Environment (2020). It is recognised that other factors (e.g. downstream rock bar control, and the potential for upstream bottlenecking/storage of flows prior to discharge at the Tooloombah Creek and Mamelon Creek confluence in the unconsolidated alluvial sediments) may result in extended interflow/pool persistence within the downstream reach of Tooloombah Creek.

It is also recognised that seasonal and extended dry conditions may control the saturated water elevation and thus the direction of flow between a watercourse and aquifer at different points in space and time. For example, when the hydraulic gradient of the aquifer is towards the watercourse, the stream may be considered gaining, and conversely, if the hydraulic gradient of the aquifer is away from the watercourse, the stream may be considered losing. Depending on the season/period under investigation, the channel system can be hydraulically connected to the aquifer or have a leaking streambed through which water can infiltrate to the subsurface. The extent of this interaction depends on physical characteristics of the channel system and channel bed composition (e.g. streams commonly contain a silt layer in the bed which reduces conductance between the stream and the aquifer). This mechanism is explicitly considered in the numerical groundwater model through the use of river cells to simulate gaining and losing conditions.

### BASELINE CONDITIONS

The following baseline conditions are assumed for the conceptualisation:

- Diffuse rainfall recharge occurs across the Styx River catchment at varying rates;
- flood recharge events occur during large and sustained streamflow events and are expected to result in the highest rates of recharge;
- average areal actual evapotranspiration (annual) for the CQC Project and surrounds is estimated to be approximately 715 mm/year;
- the Styx Coal Measures do not appear capable of producing significant quantities of useable groundwater and is generally of poor quality;
- local groundwater tends to mound beneath the hills to the west (Figure 5-3 of the main report), with ultimate discharge to local drainages and/or loss by evapotranspiration through geological outcrops and vegetation where the unconfined water table is nearer to the ground surface in lower lying/incised areas;

- the Styx Coal Measures are not highly transmissive due to the aggregated seam/ply thicknesses being in the order of metres spread across the mining interval;
- for the purposes of this assessment and conservatism, faulting is not assumed to be a no flow barrier;
- rainfall runoff is likely to be the primary source of stream flow across the CQC Project; and
- wetlands in the vicinity of the CQC Project are unlikely to be dependent on or connected to the regional groundwater table (measured at 10 mbgl and greater).

### CONDITIONS DURING MINING

During operations, the following may be expected:

- During mining, the potentiometric heads in the sedimentary rock groundwater system would be reduced in the vicinity of the open cut mine extents, but the localised water table may rise beneath above-ground and in-pit backfilled waste rock emplacement mounds;
- drawdowns within the coal measures would occur immediately around the active open cut excavations;
- up-dip coal seams of the Styx Coal Measures, which are not mined, are also expected to receive some enhanced rainfall recharge where they subcrop or outcrop in the west / south-west;
- drawdown would tend to propagate along the strike of the mined coal seams of the Styx Coal Measures; and
- groundwater sourced from the coal measures and/or via enhanced recharge would report to the open cut sumps as groundwater inflows.

### POST MINE CLOSURE CONDITIONS

Voids would be backfilled during mine closure. Until the voids are backfilled to the pre-mine groundwater table and re-saturated, the backfilled open cut would continue to draw in groundwater (at a reducing rate) from the surrounding geological units (predominantly the Styx Coal Measures). However, enhanced (fresher) rainfall recharge (and evapotranspiration) in backfilled spoil and localised water table rise beneath final landforms could be expected to maintain a localised groundwater sink for several decades and beyond within the extent of the open cut at the CQC Project.

### CONCEPTUAL MODEL WATER BALANCE

CDM Smith (2018f) presented the steady state groundwater recharge input rate within the previous model domain to be in the order of 5.4 GL/annum (14.7 ML/day), which when compared to the conservatively predicted cumulative abstraction volume over the 18-year mine life (on an average annualised basis) is approximately 5.7%.

The evapotranspiration rate presented in CDM Smith (2018f) for the steady state calibrated model was -10.8 ML/day (approximately 74% of all model outputs). It is considered that such declines in groundwater storage by historic and present anthropogenic use, and future uses including the CQC Project, would be balanced (in most part) by changes to throughflow or enhanced recharge and, therefore, declines in total groundwater storage would be temporary until a new steady-state is reached.

## 2.4 Numerical model

### 2.4.1 Modelling approach

The following presents a summary of the modelling approach undertaken by HydroAlgorithmics, including the consideration of previous numerical groundwater modelling studies and research findings for the development of the CQC Project groundwater model.

- Previous numerical groundwater flow models: Central Queensland Coal Project Groundwater Technical Report (CDM Smith, 2017); and the Central Queensland Coal Project Appendix A6 – Groundwater Technical Report (CDM Smith, 2018e).
- CQC Project numerical groundwater flow model (with improvements) - Table 7-1 in the main report provides detail of the model improvements. These improvements were also made cognisant of the evolution and ongoing improvements made recently by the Office of Groundwater Impact Assessment (OGIA) to enhance the understanding of groundwater flow systems for the prediction of impacts elsewhere in QLD coal basins.
- Uncertainty analysis methods – Details of the uncertainty analysis methodologies proposed by HydroAlgorithmics to improve the previous models were presented and discussed with the DES, where HydroAlgorithmics outlined the combination of statistical methods (e.g. Monte Carlo, etc.) and scenario-based analyses initially proposed, including a preliminary list of relevant parameterisations for investigation and/or analysis:
    1. Tidal Boundary Condition Range (incorporating Sea Level Rise Predictions);
    2. Rainfall Recharge Totals (incorporating Climate Change Scenario Range and Adopted Alluvium / Regolith (%) Recharge);
    3. Maximum evapotranspiration (ET) Rate and Extinction Depths;
    4. Hydraulic Conductivity Zones (Pilot Points) – Alluvium / Styx Interburden / Coal Seams / Basement Aquifer (Vertical & Horizontal);
    5. Geological Structure (Fault) Zone of Hydraulic Conductivity [Enhanced or Reduced];
    6. Depth Dependence (Depth Function) in Coal Seams;
    7. Specific Storage and Specific Yield Parameters;
    8. Spoil Properties in Backfilled Voids; and
    9. Predictive Sensitivity for Increased Landholder Pumping.

#### GROUNDWATER MODELLING GUIDELINES

The numerical groundwater modelling for the CQC Project has been guided by the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). The complexity in the groundwater systems has been characterised during the groundwater model conceptualisation and broader conceptualisations made to simplify the representation of the systems to allow consideration of relevant environmental values and water quality objectives. Relevantly, the model design and construction has considered the updates to the regulatory framework and additional data acquired to characterise the hydrological and landscape setting, geology, soils and geomorphology, and groundwater datasets and dependent assets (including groundwater connectivity and dependence).

The depth and high salinity of the groundwater systems at the CQC Project, coupled with targeted groundwater investigations and the lack of groundwater users all indicate that the groundwater systems are not significant aquifers in the Project area.

### MODEL SOFTWARE

The following software was used in the development and running of the numerical groundwater model:

- MODFLOW-USG Software
- AlgoMesh Software
- USG-Transport Software
- AlgoCompute Platform and HGSUQ Software

Central Queensland Coal provided the 2018 CQC Geological Model to assist with the numerical groundwater flow model build. Beyond the 2018 CQC Project Geological Model, HydroAlgorithmics has used all available drill logs from the groundwater monitoring investigations and surficial geology mapping data and information.

## 2.4.2 Model set-up

### MODEL DOMAIN, MESH & LAYERS

The numerical groundwater flow model domain and mesh refinement is shown in Figure 1-2 and summarised below.

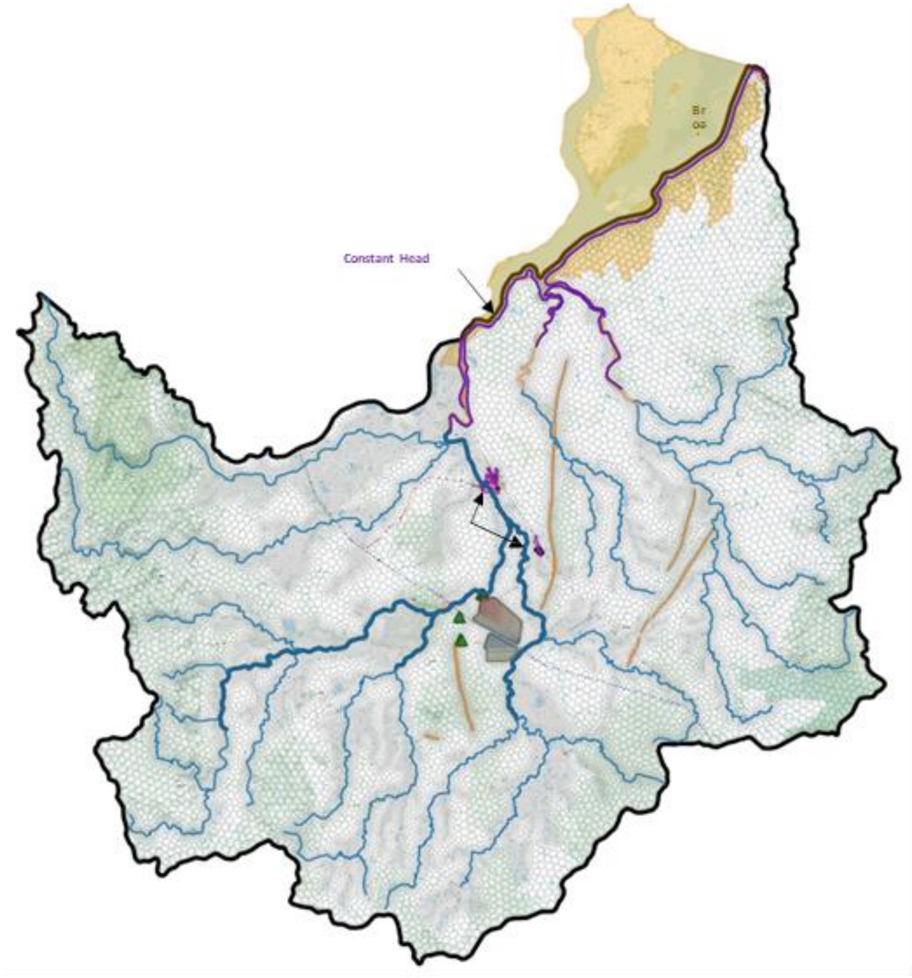


**Figure 1-2: Numerical model domain (HydroAlgorithmics, 2020)**

Model layer geometry has been built consistent with the conceptual groundwater model, with a zoomed-in and vertically exaggerated cross-section of the model layers for the Styx Coal Measures, presented in Table 1-2.

The details relating to each of the modelled layers can be summarised as follows:

- **Layer 1** – This layer is set up as an inactive layer for potential future use and modelling of elevated landforms such as waste rock dumps and modelling post mining scenarios such as groundwater mounding beneath these elevated landforms.
- **Layers 2 to 4** – These layers have been developed and refined to allow for improved groundwater connectivity analysis. Along the reaches of Tooloombah Creek and Deep Creek, in the vicinity of the Project, the Quaternary Alluvium (Qa) has been included in Layer 2, extending laterally consistent with the available surficial geology mapping. Similarly, along the Styx River and Styx River mouth, the mapped Estuarine Deposits (Qhe/s, Qhe/m and Qhcm) have been included in Layer 2. Where the mapped Quaternary units are absent, a 10 m regolith layer is applied in Layer 2. In the far south-east of the model domain, the mapped Tertiary sediments (Ta, Td, TQr) are included in Layer 2. For the purposes of refined groundwater connectivity analysis, and assessment of potential groundwater dependent ecosystems, where the base of the weathering surface (i.e. BHWE surface from the geological model) extended to depths greater than 10 m thickness (Layer 2), the additional profile has been partitioned to incorporate the deeper (lower) mapped Qpa unit / regolith in Layers 3 and 4 (as a 50:50 split) to the base of weathering. Layers 3 and/or 4 include the weathered subcrops of the Early Cretaceous and Permian units.
- **Layers 5 to 11** – These layers represent the Early Cretaceous Styx Coal Measures have been separated and the coal seams aggregated to allow the model to apply separate coal and interburden permeabilities.
- **Layers 12 to 14 and Basement** - The bottom (or basement) layers of the model comprise the Permian Back Creek Group (including Boomer Formation), Lizzie Creek Volcanic Group (including Carmila Beds) and underlying Connors Volcanic Group. All layers throughout the model domain are cut off at a minimum elevation of -1000 mAHD.

**Table 1-2: Numerical groundwater model layers and relationship to geology and stratigraphy (HydroAlgorithmics, 2020)**

| Group | Sub-group | Model Layer | Unit / Geology | Lithology | Indicative Thickness | |
|---|---|---|---|---|---|---|
| Upper | | 1 | Inactive Layer for Elevated Landforms (e.g. Out-of-pit Waste Rock Emplacements) | Predominantly (Bulk) Kx (Broken Overburden / Interburden) | Up to 75 m | |
| Upper | | 2 | Quaternary / Tertiary / Weathered Regolith (Early Cretaceous / Permian / Volcanics) | Qhe/s, Qhe/m, Qhcm, ; Qa ; Qpa, Qr, Qf > Kx ; Ta ; Kx ; Pb, Pbm ; Pc, Pv, Cp | 10 m* | 20.2 m |
| Upper | | 3 | Quaternary / Tertiary / Weathered Regolith (Early Cretaceous / Permian / Volcanics) | Qa ; Qpa ; Ta ; Kx ; Pb, Pbm ; Pc, Pv, Cp | 5 m* | 20.2 m |
| Upper | | 4 | Weathered Regolith (Early Cretaceous / Permian / Volcanics) | Kx ; Pb, Pbm, Pvw ; Pc, Pv, Cp | 5.2 m* | 20.2 m |
| Middle | Early Cretaceous – Styx Coal Measures | 5 | Overburden / Interburden (Upper) | Kx (Overburden) | 43.6 m* | 242.1 m |
| Middle | Early Cretaceous – Styx Coal Measures | 6 | Coal Seams (Aggregated to Red Seam) | Kx (Coal) | 2.6 m* [3.0 m^] | 242.1 m |
| Middle | Early Cretaceous – Styx Coal Measures | 7 | Interburden | Kx (Interburden) | 55.8 m* | 242.1 m |
| Middle | Early Cretaceous – Styx Coal Measures | 8 | Coal Seams (Aggregated to Blue Seam) | Kx (Coal) | 4.3 m* [4.5 m^] | 242.1 m |
| Middle | Early Cretaceous – Styx Coal Measures | 9 | Interburden | Kx (Interburden) | 21.3 m* | 242.1 m |
| Middle | Early Cretaceous – Styx Coal Measures | 10 | Coal Seams (Aggregated to Violet Seam) | Kx (Coal) | 2.2 m* [2.1 m^] | 242.1 m |
| Middle | Early Cretaceous – Styx Coal Measures | 11 | Underburden | Kx (Underburden) | 112.3 m* | 242.1 m |
| Bottom | Permian | 12 | Back Creek Group (including Boomer Formation) and Glenprairie/Wangrabry Beds | Pb, Pbm, Pvw | 859 m – 1,005 m* | |
| Bottom | Volcanics | 13 | Carmila Beds / Lizzie Creek Volcanic Group | Pc, Pv, Cp | 859 m – 1,005 m* | |
| Bottom | Volcanics | 14 | Intrusive Rocks / Connors Volcanic Group | CPvo, CMzg *[West Only]* | 859 m – 1,005 m* | |
| Basement (to -1000 mAHD) | | | | | | |

* Median Model Cell Thickness.
^ Area-Weighted Average Layer Thickness.

Geological structure and faulting included within the model mesh has been based on the available geology mapping and cross-sections within the Styx River catchment. Lateral connection groups have been used to create horizontal flow connections across the faults. Sensitivity and uncertainty analyses explore alternative hydraulic properties along the faults.

The numerical groundwater model covers an area of approximately 1,600 km$^2$ extending approximately 57 km north to south and 54 km east to west and is generally defined by:

- Tooloombah Creek/Deep Creek sub-catchments;
- Granite Creek/Montrose Creek sub-catchments;
- Wellington Creek catchment (including Stoodleigh Creek sub-catchment); and
- bounded by parts of the Broad Sound and adjoining estuarine systems gazetted as a Declared Fish Habitat Area.

## BOUNDARY CONDITIONS & STRESS PERIODS

The numerical model was also set up to include the following stresses and model boundary conditions:

- No-flow and fixed head boundaries - No flow boundary conditions have been applied in all layers at the topographic ridges of the Styx River catchment (i.e. elevation of the water table is topographically controlled). A fixed head boundary condition has been applied using the constant head package (CHD) at the Styx River mouth and along the mapped estuarine reach of the Styx River (i.e. to the railway crossing). The distribution of active cells has been adjusted from the previous modelling to ensure the fixed head is applied above the base. Based on a review of tidal influence and long-term sea level records (Section 3.3), the chosen elevation of the fixed head boundary applied was 3.5 mAHD.
- Inactive and pinched-out areas - Select layers are pinched out within the model domain where non-existent; for example, the Styx Coal Measures (Layers 4-11) do not exist in the far west of the model domain, nor beyond the fault / interface with the Back Creek Group in the east.
- Water courses and drainage features - All the key river (and drainage) reaches located within the model domain have been assigned as river cells and partitioned consistent with the conceptual groundwater model. As an improvement to the numerical groundwater model, river cells (with Stage Depth > 0 m) are used instead of drain cells. Conductance values have been applied to river cells based on an average bed area for each of the key river (and drainage) reaches.
- Recharge (rainfall & flood) - Transient recharge is applied based on a constant proportion of rainfall for the averaging period. Consistent with the conceptualisation, where the less consolidated Cenozoic Sediments (i.e. Quaternary Alluvium) are present, higher recharge rates have been applied relative to the mapped Quaternary Pleistocene Alluvium.

  Episodic flood events would not be applied to the predictive model, however, allowing for a conservative impact assessment.
- Evapotranspiration - Two evapotranspiration maximum rates have been applied across the model domain at the surface:
  1. 1,239 mm/year in mapped (Qhe) Quaternary Estuarine Alluvium based on BOM pan evaporation multiplied by a conversion coefficient of 0.7 for lake evaporation; and
  2. 715 mm/year in all other areas based on average areal actual evapotranspiration (annual) at the CQC Project.

  The evapotranspiration rates are reduced linearly with depth to ET extinction depths, dependent on the lithology (i.e. mapped unconsolidated sediments), the mapped high, moderate and low potential GDE areas, and vegetation cover.
- Historic mining and investigations - The model stress periods for the transient pre-calibration have been assigned as closely as possible to be generally consistent with the historic mining sequence.

The transient simulation period for the groundwater model has been extended specifically to increase the calibration datasets and allow for cumulative assessment of historic mine workings. Several model variants are being used and temporal discretisation varied accordingly to reflect available baseline datasets, refined baseline datasets and details of other stressors (i.e. historic mine workings, future mine design and long-term use). Additional model variants are used to allow separate reporting and quantification of Project effects, alone from cumulative effects, utilising null model runs for comparison.

The model stress periods applied in the model vary from monthly to annually, five yearly and for an overall period of 400 years. Throughout these stress periods, Adaptive Time Stepping was used to attain the appropriate time steps to ensure numerical convergence for the transient model.

### MODEL CALIBRATION

The calibration of the model focussed on matching historical groundwater level observations with the predicted groundwater levels. At the time of developing the model, no reliable baseflow or streamflow data was available to use in the calibration of the model. The current status of mining did not allow for calibration of the model against mine inflow or dewatering data sets. The steady state calibration of the model was undertaken by using the average of measured groundwater levels from various sources across the site. The transient calibration of the model was focussed around using data mainly recorded for the period from 2010 to 2019.

A variable recharge factor was applied across the model domain that is consistent with the developed conceptual model, with a moderate recharge (1.3%) applied to the Quaternary Alluvium.

Initial hydraulic properties were assigned for each layer based on the updated conceptual groundwater model with ranges consistent with aquifer testing and literature reviews undertaken. The initial anisotropy factor and specific yield were assigned consistent with the core permeability and porosity test work undertaken.

Model calibration for the steady-state and transient modes gave scaled root mean square (SRMS) errors of 3.49% and 2.01%, respectively and indicate good overall model calibration across the model domain and indicative vertical head gradients are generally consistent.

The modelled water balance used during the numerical model estimated an overall net water surplus of 0.003 ML/day, with recharge forming the biggest input (51 ML/day) and evapotranspiration (-67 ML/day) the biggest output.

It is reported that groundwater levels within ML80187 area are in the region of 10 mbgl, which also includes the deep cut and incised watercourses, as well as topographical lower lying areas. The modelling of groundwater-surface water interactions is included in the model for the determination of changes to baseflow and/or enhanced leakage along defined watercourse reaches.

The overall confidence level classification of the numerical model is considered to be Class 2 (*The Australian Groundwater Modelling Guidelines - Barnett et al., 2012*), and capable of a number of specific uses, and most relevantly:

- is capable of providing estimates of dewatering requirements for mines and excavations and the associated impacts;
- is capable of providing impact predictions of proposed developments in medium value aquifers;
- is capable of predicting long-term impacts of proposed developments in low value aquifers; and
- is capable of evaluating to inform management of medium risk impacts.

## 2.5 Numerical modelling predictions

### 2.5.1 Predictive modelling approach

A general mine schedule / mine plan was provided by Central Queensland Coal with the assumption that mining will commence during July 2020 and be completed by June 2038, with Mine Closure achieved by June 2039.[1]

The predictive modelling approach considered the following:

- Initial Conditions – conditions were based on the end of the initial transient calibration period (September 2019) and a monthly prelude transient prediction period (up to commencement of mining). This was done to ensure continuity in the transient prediction model runs.
- Stress period lengths - stress periods varied from monthly to annual to five yearly and 400 years, using Adaptive Time Stepping to optimise model convergence.
- Climate – The climate conditions are kept constant within the predictive model runs which allows for a conservative assessment. Climate change predictions are, however, addressed as part of the uncertainty analysis.

The following key processes were included and incorporated into the predictive modelling. Given that pre-stripping and construction, including vegetation clearing, activities are mostly occurring at or above natural ground surface, this has not been included in the predictive modelling.

#### PIT EXCAVATION

The active open cut mining areas are simulated using drain cells with the invert elevation guided by model layer geometry as well as provided mine progression plans. No additional drain cells have been modelled to facilitate any advanced dewatering that might be required. This might have an impact on timing of the effect that drawdown might have but is not expected to impact the maximum predicted drawdown extent and footprint, should advanced dewatering be adopted (at present it is not proposed).

#### EXTERNAL WASTE LANDFORMS

Given the temporary nature of the out-of-pit waste rock landforms that are re-handled, the elevations of the backfill spoil emplacements were not altered beyond the final rehabilitated landform, despite the differences in elevation. This is considered to be of no material consequence to the numerical groundwater model predictions during mining as the groundwater table would generally be in excess of tens of metres deep during the operational life and lower due to the advancing open cut mining areas.

#### PIT BACKFILL

The backfilling process is simulated by applying Time-varying Material (TVM) properties to reflect the changes in the host rock properties (pre-mining) to reflect the backfill spoil (broken, less consolidated rock), and was applied generally consistent with the backfill schedule provided. Minor adjustments were made to align with the incremental period plot (drain) scheduling (based on a monthly stress period) and final landform design. The adopted hydraulic properties (higher permeabilities) applied to spoil

[1] Note that the HydroAlgorithmics (2020) report states the Project starts in 2020, which was adopted for assessment purposes (due to the timing of the initial model setup) and will be subject to refinement by Central Queensland Coal following approval.

were made consistent with the conceptualisation. In addition to the TVM properties applied, a higher infiltration rate (enhanced rainfall recharge in spoil) was accommodated in the groundwater model by assigning a higher rainfall recharge percentage (i.e. 5% of rainfall). However, it is noted that the evapotranspiration rates and depths from the surface remained unchanged.

#### COAL REJECTS

The total proportion of coal rejects would not be expected to have a considerable effect on the hydraulic properties applied to the spoil in the groundwater model simulation and, therefore, has not been changed.

#### WATER STORAGE DAMS

No allowance was made for additional recharge or recirculation of water from onsite storage dams.

#### FINAL LANDFORM DESIGN

The final landform (after backfilling) generally reflects the pre-mining ground surface levels across the mined area. The elevated final rehabilitated landforms beyond the in-pit backfill spoil emplacement areas have been simulated in Layer 1 of the numerical groundwater model with elevations of up to approximately 75 m above the pre-mining ground surface levels. The following characteristics have been applied to such areas:

1. Higher permeability of the spoil (broken, less unconsolidated rock);
2. higher infiltration rate (enhanced rainfall recharge in spoil); and
3. higher evapotranspiration surface (absolute), however the evapotranspiration rates and depths from the surface remain unchanged.

### 2.5.2 Groundwater inflows

The model also allowed for a predicted groundwater take and / or direct groundwater inflows into the open cut area of the mine, with no water take proposed from either the Deep Creek or Tooloombah Creek located approximately 150 m from the open cut. The average inflows modelled (combined inflow / take from Open cut 1 and 2) varies  from less than 0.01 ML/d to 1.12 ML/d. Predicted inflows steadily increase in Open Cut 2 (i.e. the North Pit) during the first 2 to 3 years of the CQC Project as the pit is developed and depth increases to the east. Predicted inflows remain generally between 1.0 ML/day and 1.2 ML/day for the next three years and gradually reduce to approximately 0.6 ML/day before the commencement of mining in Open Cut 1 (the South Pit). Combined inflows in Open Cut 1 and Open Cut 2 during the concurrent mining period then peak at just below 1.0 ML/day, before again steadily reducing to negligible inflows for the final years.

### 2.5.3 Groundwater drawdown

Modelled changes in predicted groundwater levels have been extracted from the numerical groundwater model runs and are presented in Attachment 14 and 15 of the main report. Modelled drawdown contours are shown in accordance with the bore trigger thresholds defined in the *Water Act 2000* to identify any bores that are likely to be impacted and would require further bore assessment.

The model results demonstrate that substantial drawdown occurs within the proposed open cut extent, and the surrounding network of groundwater monitoring bores provide varying levels of change to allow the development of appropriate triggers for investigation. An assessment of drawdown was undertaken for several time periods. In order to assess the drawdown extent a focus was placed on three main periods and assessed for discrete model layers as listed below:

- Three years after commencement of mining (Styx Coal Measures) - the maximum predicted groundwater level drawdown is largely contained within the Styx Coal Measures (Layers 6, 8 and 10), extending to lesser magnitudes (i.e. <2 m) beyond the open cut extent up to approximately 3.5 km in the north, 5 km in the north-east (at depth), and 3 km in the south-east.
- Ten years after commencement of mining (Cenozoic deposits) – The predicted drawdown extends to the north (west of the fault) and toward the historic mine workings at Bowman. Uncertainty Analysis, including parameter sensitivity analysis, suggest that drawdown could elongate further along the strike of the coal outcrop, however this is localised and not expected to encroach to any appreciable extent to the downstream reach of Tooloombah Creek (at the Deep Creek confluence) nor the Styx River.
- End of open cut mining (Cenozoic deposits) - Some temporal drawdown is predicted in the Cenozoic sediments in the near vicinity of the open cut mining operation, where the saturated water table is present (albeit gradual and localised), and is predicted to gradually recover post-mining
- End of open cut mining (Back Creek Group) - head gradients are maintained to the west of the open cut mining operations in the reach of Tooloombah Creek downstream of the Mamelon Creek confluence, and is greater than the predicted head plots in the overlying Cenozoic Deposits, when referring to the 20 mAHD head contour. The relevance of this existing head gradient is then evident when considering model baseline baseflow / leakage estimates and corresponding potential impacts along Tooloombah Creek

The numerical groundwater model also considered drawdown predictions at the following areas:

- Private landholder bores - Of the private landholder bores identified in the vicinity of the Project, only one bore (BH28) would be impacted beyond the 5 m bore trigger threshold as identified in the *Water Act 2000*, while at the remainder of the bores the predicted impact will be less than 0.5m.
- Springs, wetlands and GDEs – The model predicted drawdowns in the vicinity of the CQC Project range from 1.3 m to 4.6 m.
- Broad Sound Declared Fish Habitat Area - The predicted modelling results (<0.001m) at Well01, BH36 and BH37 supports the conclusion that there would be no decline in groundwater levels predicted at the nearest point of the Broad Sound Declared Fish Habitat Area.
- Groundwater Fauna locations / Stygofauna habitat - all 'Riverside' sampling locations that recorded stygofauna were located toward the Styx River mouth, downstream of the CQC Project. The maximum predicted drawdown varies from <0.001m to 53.9 m at STX093. Within the extent of the open cut and the extent of the modelled drawdown impact, any stygofauna present is expected to be impacted on a local scale.

### 2.5.4 Baseflow to surface water features

Model predicted baseflow changes and/or enhanced leakage as a result of the CQC Project have been determined by calculating the averaged differences in flux in model cells along specified watercourse reaches. Model predicted flux along the three Tooloombah Creek reaches demonstrate that the changes primarily relate to model reach 2 (defined as upstream of the Deep Creek confluence to Mamelon Creek confluence) in the vicinity of the CQC Project, and to a far lesser extent both upstream of the Mamelon Creek Confluence and downstream of the Deep Creek confluence. The averaged differences in flux along Deep Creek relate to the reach downstream of the Brussels Creek confluence, in the vicinity of the CQC Project. The predicted changes in Barrack Creek are of little to no consequence (during mining and post-mining) and therefore further partitioning of Deep Creek would be superfluous.

A brief summation is provided below for the Styx River, Tooloombah Creek, Deep Creek and other watercourses/drainage lines. It is noted that the predicted water levels at observed pools on Tooloombah and Deep Creek for the recent rains (post model calibration) provide good validation for the model, but model water levels that are lower than observed, suggesting the predicted baseflow may over-estimate actual impacts.

- Styx River – The model predicted changes in the reaches downstream of the CQC Project are less than 0.0003 $m^3/s$ over a combined length of 6.1 km. Given the influence rainfall runoff has on the downstream reached of the Styx river, these predicted model changes are considered negligible.
- Tooloombah Creek - The model predicted changes are less than 0.0002 $m^3/s$ over a combined length of 1.7 km. Given the influence rainfall runoff has on the downstream reach of Tooloombah Creek, these predicted model changes are considered negligible.
- Deep Creek – The model predicted changes are less than 0.005 $m^3/s$ to 0.006 $m^3/s$ over a combined length of 17.5 km. A proportion of this baseflow is subject to the onset of gradual indirect effects of predicted drawdown. However, it is noted that if drawdown occurs within the losing zones beneath the unsaturated zone at Deep Creek (this may occur during extended dry periods), leakage from Deep Creek would not eventuate at that time.

The mass water balance error achieved a target threshold of <0.5% mass balance closure error in all cases.

### 2.5.5 Post mine closure predictions

The model considered post-closure equilibrium groundwater levels. The results indicate that water levels in the Cenozoic deposits / regolith would substantially recover to levels close to pre-mining conditions, with some localised mounding under final landforms that have been constructed above natural surface level, with some net gain effects evident in the baseflow conditions of Tooloombah Creek and Deep Creek after approximately 150 years. Recovery results in the Styx Coal Measures and Back Creek Group would recover to head conditions similar to pre-mining conditions. Overall, it was found that the regional groundwater flow direction towards the coast are maintained.

The assessment of cumulative impacts, including impacts relating to the historic mine workings at Ogmore and Bowman, concluded that the predictive cumulative modelling results demonstrate there is unlikely to be any superposition effects, thus, the predicted cumulative drawdown impacts at private landholder bores, springs, wetlands, groundwater dependent ecosystems, Broad Sound Declared Fish Habitat Area and on recorded groundwater fauna locations / stygofauna habitat and riparian vegetation are equivalent to the CQC Project alone.

### 2.5.6 Uncertainty analysis

The uncertainty analysis was undertaken following a range of scenario-based analyses and statistical methods. The uncertainty analysis focussed on the following:

- Parameter identifiability - Each of the parameters identified including $K_{HORIZONTAL}$/%Infiltration, $K_{HORIZONTAL}$, $K_{HORIZONTAL}/K_{VERTICAL}$, $S_s$ and $S_y$ have been specifically investigated across all layers as part of the quantitative Uncertainty Analysis (UA) (Attachment 11 of the main report)
- Quantitative uncertainty analysis - Uncertainty Analysis (Attachment 11 of the main report) results for hydraulic conductivity zones indicate the improved numerical model predictions are on the lower side of the UA 50%ile (i.e. as likely as not to exceed), but it is noted that the SRMS error diverges as the UA %ile increases. For specific storage ($S_s$) and specific Yield ($S_y$) it is noted that relative to other hydraulic parameters in the model layers, the applied $S_s$ values appear to be generally of low identifiability.
- Scenario based sensitivity analysis – Scenarios included 1) Tidal boundary condition range analysis which concluded that that the differences in maximum predicted groundwater drawdown for both conditions are negligible; 2) Rainfall recharge applied a -20% and +20% variance to rainfall infiltration (refer below); 3) Geological structure zone of hydraulic conductivity concluded that the differences in maximum predicted groundwater drawdown in Layer 2 is localised while negligible in Layer 8.
- Qualitative analysis – The qualitative analysis assessed the following 1) Maximum ET rate and extinction depths which showed that model runs with lesser extinction depths and higher maximum ET had little to no consequence; 2) Depth dependence, the quantitative UA did not enforce depth-dependence; 3) Soil properties were not included in the uncertainty analysis based on the recommendations from the peer review to apply higher permeability and storage properties to the fill material

Climate change and climate variability was incorporated into the numerical groundwater modelling and focussed on:

- Climate variability – climate variability was not incorporated in the forward prediction modelling but was included and assessed in the uncertainty analysis.
- Climate Change predictions - It was found that the average change in groundwater take/inflow over the life of the CQC Project varied as follows with the following changes; 1) -20% rainfall recharge: average predicted take/inflows reduced on average by 15.7%; and 2) +20% rainfall recharge: average predicted take/inflows increased on average by 16.9%.
- Sea level rise projections - The 0.8 m increase in sea level, as adopted by the QLD Government and considered in the model, is within the range of modelled constant head boundary conditions assessed as part of the uncertainty (sensitivity) analysis.

## 2.6 Groundwater impact assessment

The following sub-sections have been prepared in line with the DEHP TOR Guideline – Water and considered the aspects discussed below.

### 2.6.1 Impacts to groundwater quantity

The impacts associated with groundwater quantity and associated surface water flows focussed on the following:

DURING MINING:

1. Direct inflow to the Styx Coal Measures – during mining there will be a constant loss of groundwater, with groundwater inflows steadily reducing to negligible inflow as the backfilled material recharges.
2. Local change in groundwater flow directions – during mining the open cut will act as a groundwater sink and result in a temporary change in groundwater flow direction in close proximity to the open cut operations, but regional groundwater flow directions will remain similar to pre-mining conditions, until the groundwater system recovers at the completion of mining.
3. Direct inflow to the Alluvium - inflows from higher permeability surficial Quaternary alluvium (Qa) (of generally better (surface water) quality when compared to the Quaternary Pleistocene alluvium [Qpa] unit), if exposed in the highwall (or low wall) of the open cut, would be intercepted prior to it reaching the floor of the open cut and pumped back to the nearest drainage line.
4. Indirect inflow to the Alluvium - As mining progresses, an increase in natural leakage of groundwater from the alluvium/regolith to the underlying Early Cretaceous/Permian rock would be expected. The removal (excavation) of alluvium/ regolith within the pit extent during mining would also reduce rainfall recharge temporarily but would resume upon backfilling and is discussed below.
5. Changes in hydraulic properties - there would be a change in hydraulic properties across the open cut mining footprint from the ground surface where waste rock infills the excavations to the floor of the mined coal seams, as well as the out-of-pit emplacements during mining.
6. Changes in water balance - Recognising the model discretisation (Section 7.7.6), as well as surface water flows, the magnitude of predicted water losses (0.005-0.006 $m^3$/s) as a consequence of the indirect groundwater inflows from the associated alluvium relating to the 17.5 km length of the defined watercourse is negligible when compared to stream flow volumes and the localised effects of surface water catchment excision by the CQC Project.

POST CLOSURE / EQUILIBRIUM:

1. In the long-term, all voids would be backfilled and groundwater levels would substantially recover over many decades. Localised mounding is predicted to occur where the final landform surfaces are elevated above the existing surface, and the resulting net gain effects evident in the predicted changes in baseflows and/or lesser leakage in Tooloombah Creek and Deep Creek.
2. Changes in local groundwater flow directions – Local groundwater flow direction is modelled to return to pre-mining conditions

### 2.6.2 Impacts to groundwater quality

Similarly, the potential impacts on groundwater quality focussed on the following:

DURING MINING:

1. Changes in local groundwater quality - Given the similarity of higher (albeit variable) salinity for the various source groundwaters, no appreciable change in groundwater salinity is expected as a consequence of mining.

2. Hydrocarbon / other chemicals - limited potential for groundwater contamination to occur as a result of hydrocarbon and other chemical contamination.

POST MINING / EQUILIBRIUM

There is expected to be no appreciable change in groundwater quality as a result of the CQC Project.

The potential impacts on environmental values considered the following:

- Aquatic ecosystems – there is a limited potential for groundwater to support or impact aquatic ecosystems.
- Irrigation - predicted water losses in Tooloombah Creek and Deep Creek as a consequence of the indirect groundwater inflows are considered to be negligible.
- Farm supply / stock water – Only a single bore (BH28) is predicted to be impacted beyond the 5m drawdown threshold and no appreciable change in groundwater salinity is expected as a consequence of mining.
- Human consumer / drinking water – Due to the quality of the groundwater in the vicinity of the project and its general suitability for human consumption, not potential impact is expected as a result of mining.
- Industrial use - groundwaters are anticipated to be of relatively poor water quality however would be suitable for industrial use and therefore preferentially used in the mine site water balance.

## 2.7 Monitoring and management

As part of the numerical modelling a draft groundwater monitoring program is proposed based on the DES recommendations and has been designed to be undertaken on a quarterly basis with the view to review and revise the program as more data is collected during the life of the mine.

The groundwater monitoring program developed focussed on the following:

- Groundwater pit inflow – monitoring would include the monitoring of water levels and water quality in the pit sumps, but also record data on the volumes of water abstracted
- Private landholder bores – Periodic monitoring of groundwater levels
- Styx river (Tide monitoring – Ogmore bridge) – continuation of monitoring of depth to water surface
- Tooloombah Creek (Surface water flow gauging) – continuation of surface water level and flow measurements
- Deep Creek (Surface water flow gauging) - continuation of surface water level and flow measurements.
- Wetlands 1 & 2 – continuation of the monitoring of groundwater levels at monitoring bores WMP 25 and WMP 26.
- Quarternary Alluvium, Pleistocene Alluvium and Styx Coal Measures – continuation of existing monitoring program of the monitoring bores installed in these lithological units, with the consideration for the installation of additional monitoring bores. This is discussed in more detail in Section 10.1.7 of the main report.
- Back Creek Group – Existing monitoring program should be continued with consideration of the installation of additional monitoring bores as well as VWP monitoring locations

- Groundwater level triggers - Preliminary triggers have been developed at each groundwater monitoring bore reflecting either a proportion (e.g. approximately 75%) of the maximum predicted groundwater drawdown, or where less than 2 m, a default trigger in the unconsolidated aquifers of 2 m, and a default trigger in the consolidated aquifers of 5 m
- Groundwater quality triggers – The groundwater quality triggers are developed cognisant of the environmental values and water quality objectives and has been presented in detail in Tables 10-2 to Table 10-5 in the main report.

A detailed water management plan will be prepared as part of the project and will focus on the following:

- Erosion and sediment control
- Trigger action response plan

A Mineral Waste Management Plan would be developed and include, but may not necessarily be limited to:

- Characterisation of waste rock and coal rejects and production quantities and volumes.
- Identification of appropriate performance measures (e.g. to prevent or minimise the migration of pollutants beyond the excavated pit extent or seepage from out-of-pit emplacements).
- Reject disposal management, including material handling methodologies, scheduling and water management.
- Rehabilitation strategies both in the short-term and long-term, with consideration of backfilling activities, final landforms, flood interactions (if any) and post-mine closure equilibrium groundwater levels.
- Ongoing mine water (e.g. collected from dewatered fine rejects prior to rehabilitation) and groundwater monitoring, assessment, review and improvement of performance.

A project specific groundwater dependent ecosystem monitoring and management plan and receiving environment monitoring program have been prepared by Eco Logical Australia (2020b, c). The numerical groundwater model would be subject to review at least every three years from the commencement of open cut mining, in line with the indicative review timeframes prescribed for UWIRs in Qld.

# 3. Review of Numerical Modelling Report – AGE Consultants

Australian Groundwater and Environmental Consultants Pty LTD (AGE) completed a peer review of the CQC Project numerical groundwater model constructed by HydroAlgorithmics (HA).

Some of the key findings from this peer review completed by AGE are presented below.

### HYDROGEOLOGICAL CONCEPTUALISATION

The key findings in relation to the hydrogeological conceptualisation are:

- The conceptual model presented is plausible and has identified the surface water and groundwater interactions and components responsible for bulk water movement within the identified aquifers.
- Substantial additional data has been collected in comparison with previous models (including CDM Smith 2018) and the completion of the previous groundwater impact assessment. However, some data limitations in relation to stream flow data in both Tooloombah and Deep Creek have been identified. Monthly groundwater level data is also limited with groundwater level loggers currently only installed in a small number of recent bore installations. The collation of additional data would greatly assist in quantifying surface water and groundwater interaction in the vicinity of the CQC Project.
- The segregation of the hydrostratigraphic units is an improvement on previous models, particularly the separation of the three major coal seams, overburden, interburden and underburden units. The permeability of the coal seams has also been presented as reducing vertically and it is very well documented.
- The anisotropy ratios in the aquifer parameters used in the conceptualisation is considered conservative, while the introduction of spatial variability in aquifer parameters have only been used to explain observed data. This approach is consistent with good modelling practices.
- Seawater intrusion and density dependent flow have been assessed and are presented in the findings of the HA report. Seawater intrusion is unlikely to affect the potential impacts associated with the CQC Project. The observed density differences and their potential impacts, as well as salinity adjusted groundwater levels are not represented in the model.
- Faulting is represented in the conceptual model. While it is not assumed to be a barrier in the model, the hydraulic conductivity contrast introduced is sufficiently limiting drawdown propagation impacts.
- Streamflow in the Tooloombah and Deep Creeks are highly ephemeral, however the presence of persistent pools suggest that the alluvial strata remains close to fully saturated.
- The conceptual model presents some estimates of evapotranspiration and total groundwater volume, but no detailed presentation of model inflow and outflow terms or magnitude of key discharge components has been presented.

### NUMERICAL GROUNDWATER MODEL REPORTING

The groundwater modelling reporting was considered to be detailed and set out in a logical sequential order. Key findings in relation to the modelling included:

- The report prepared by HA stated that the model achieved, and even exceeds, the targeted Class 2 level of confidence. AGE has concluded that the model can be considered a Class 2 model given the targeted confidence level has been achieved for the majority of the modelling guideline criteria. Exceptions to this finding include the adequacy of streamflow data, which should be assigned a Class 1 level of confidence. Further exceptions relate to the soils and land use self-assessment, which has been assessed to meet the Class 3 level of confidence. AGE concluded that it appears the available data has not been used to parameterise the evaporation package, which has led to the estimation of the evaporation losses to 8 m below ground level, even for areas cleared for grazing.
- The model extent and model mesh are considered appropriate and fit for purpose to be used in the EIS for the CQC Project.
- The assessment of the model boundary conditions concluded that the coastal boundary is appropriately represented by a constant head boundary. The use of the MODFLOW river package to describe the creek boundary conditions is defensible but could benefit from additional sensitivity runs. Evapotranspiration loss has been assigned an extinction depth of 8 m across the majority of the model domain and additional sensitivity runs are suggested to confirm the sensitivity of this model parameter.
- The exclusion of the extraction of groundwater from landholder bores are considered a reasonable simplification due to the limited volumes extracted for stock and domestic use.
- The MODFLOW drain package has been used to represent the proposed open cut mining and is an appropriate approach for the likely dewatering method (pumped sump) within the working pit.
- Advanced dewatering has not been represented in the model but is currently under consideration regarding whether this approach will be adopted.
- Model calibration comprised a steady state calibration to represent initial conditions and two transient calibrations with the 1919 to 2010 transient calibration providing realistic water levels. The calibration only included groundwater levels but did not consider flux or head differences. The head difference was, however, compared to modelled equivalents post calibration.
- Progressive backfilling was considered in the model using the time-varying material (TVM) package, but no long-term simulation of water levels in the residual voids has been considered.
- The modelled water balance has been presented with the dominant output represented by evapotranspiration.
- Limited information has been provided regarding how the model calibration was achieved. The HA reporting suggests that the model was calibrated manually before undergoing automated calibration using PEST software. The current calibration relies on absolute groundwater level observations only, hence is likely to present a relatively high degree of non-uniqueness compared to a calibration that has been achieved using a range of different observation data types. However, the calibrated Scaled RMS (SRMS) that has been reported for the transient calibration is low (2%), which suggests the model replicates observed heads relatively well.
- The prediction models used (transient and transient null) are consistent with the Australian guidelines. The inflow patterns presented are plausible with initial rapid inflows predicted during the early stages of mining, gradually reducing over time as areas are backfilled. It was found that the predicted inflows from the creeks were coincidental following the sensitivity testing of different river bed conductance in the model.

- A parameter sensitivity / identifiability analysis, in accordance with the IESC guidelines has been undertaken, but it seems that parameters including river bed conductance have not been assessed.
- Stochastic uncertainty analysis has been undertaken. It has been noted that in some cases the parameter ranges explored in the uncertainty analysis are restrictive, along with a very narrow calibration constraint (exclusion of runs where SRMS exceed 3%).
- Scenario analysis confirm that for some scenarios the predictions are relatively sensitive to the river bed conductance parameter.

### REVIEW OF MODEL FILES

A review of the model files showed no significant discrepancies between the model reporting and model files; however, some minor discrepancies were observed between the model water balance produced by HA and the AGE re-run of the transient model. The differences are attributed to the use of different solvers, however errors were substantially less than the 1% threshold that is typically considered acceptable.

### IESC UNCERTAINTY ANALYSIS GUIDANCE NOTE REVIEW CHECKLIST

The IESC Uncertainty Analysis Guidance noted includes a review checklist, which is recommended to be applied to projects that include an uncertainty assessment. AGE concluded that generally the modelling undertaken partially meets the requirements laid out in the IESC guidelines. There are however some aspects that have been identified in which the assessment is not clear cut. These include:

- Development of models commensurate with the overall risk – It was considered that a more integrated surface water and groundwater model should be undertaken. This is, however, likely addressed by the separate model being developed by Eco Logical Australia (ELA), a summary of which is provided in Section 4 of this report.
- Has calibration minimised non-uniqueness – with the calibration of the model only considering groundwater levels, the model is likely to be prone to non-uniqueness. The non-uniqueness has been assessed through the development of a large number of alternative parameter calibration sets as part of the uncertainty analysis, however not all parameters were included and the parameter ranges were considered too narrow. This has been addressed, to some extent, through two additional scenario assessments.

### OVERALL CONCLUDING REMARKS

AGE is of the view that the modelling has been undertaken in a professional and rigorous manner that meets current industry standards and the guiding principles set out in the Australian Groundwater Modelling Guidelines and IESC Uncertainty Analysis Guidance Note. The AGE peer review has not identified any fundamental flaws in the work which are likely to significantly effect model predictions. AGE have identified the following opportunities for improvement in the model, and suggest these are addressed at minimum in the first numerical model review iteration (based on the commitment made by HydroAlgorithmics to undertake a model review at least every three years from the commencement of open cut mining):

- "Re-calibration of the groundwater flow model to observed head differences in nested monitoring facilities and to estimated baseflow at the Tooloombah Creek and Deep Creek gauges"; and
- "Re-running the predictive uncertainty analysis including the river bed conductance parameter, assessing a wider range of parameter values and adopting a higher SRMS cut off."

# 4. Technical study to assess the groundwater and surface water interaction – Eco Logical Australia

## 4.1 Analytical modelling

Following completion of the numerical groundwater modelling, and to support the SEIS approval process, Eco Logical Australia completed technical studies to increase the understanding of groundwater – surface water interactions that occur in the CQC Project area and characterise the relationship with identified riparian vegetation and GDEs (Eco Logical Australia, 2020d). These studies follow an assessment undertaken by 3D Environmental (2020), which developed conceptual models for four defined GDE assessment areas at Tooloombah Creek and Deep Creek. The 3D Environmental (2020) conceptualisation considers that soil moisture is dependent on bank storage as a recharge mechanism to surface water and GDEs. The conceptual models consider that seasonal rainfall and flooding provides recharge to the shallow alluvial groundwater system in the creek bed via lateral infiltration, with water returning to the creek through baseflow from the alluvial unconformity during the dry season. A potential hydraulic connection was reported to exist between the surface water pools at Tooloombah Creek and the alluvial groundwater system due to observed salinity changes in the pools, however this has not been confirmed.

Eco Logical Australia (2020d) assessed the available hydrogeological data for the CQC Project and data obtained from the alluvial drilling program, undertaken at three transects across Tooloombah Creek and Deep Creek, in the vicinity of the 3D Environmental (2020) GDE assessment areas. Drilling sediment samples were collected to the base of the alluvium and at various depths within the Styx Coal Measures. The samples were submitted to a NATA accredited laboratory to undergo testing for particle size density (PSD) to allow estimation of hydraulic conductivity (K; m/s) of the sediments, soil moisture content and salinity. The data obtained was used to inform analytical modelling undertaken to:

- verify the feasibility of bank storage as a recharge mechanism;
- identify whether moisture within the alluvial sediments can support GDEs in the region;
- assess the feasibility for groundwater to feed and sustain surface water pools in the region; and
- estimate potential groundwater discharge volumes and rates from the alluvial aquifer to the Tooloombah Creek and Deep Creek assessment areas, assuming lateral flow occurs from bank storage.

The analytical modelling results support the 3D Environmental (2020) conceptualisation. Tooloombah Creek and Deep Creek contain transmissive alluvial sediments in sporadic, discontinuous pockets, with hydraulic conductivities that are suitable to allow groundwater uptake by terrestrial vegetation (K = $10^{-5}$ to $10^{-7}$ m/s). Bank storage is critical, specifically at Tooloombah Creek, which suggests bank storage groundwater flows towards the creek, feeds surface water pools to ensure they are persistent during the dry months and sustains soil moisture to support riparian vegetation and GDEs. Salinity within the alluvium does not exceed 7800 EC at Tooloombah Creek and 3060 EC at Deep Creek North, therefore moisture can be considered reasonable for GDEs to use (assuming water up to 10,000 EC is suitable for tree use).

Deep Creek shows groundwater flow is enhanced away from the creek, hence the pools located on the far eastern side of Deep Creek are prone to drying during the winter months as bank storage would rapidly return to the creek (from the west) or continue to flow away from the creek (on the east). The results suggest the Deep Creek surface water pools are not groundwater fed and the observed increase in salinity can be explained purely from evaporative concentration of salts.

Chloride data from rainfall and groundwater sampling during the alluvial drilling program was reviewed to estimate groundwater recharge, using the chloride mass balance method, to verify and refine the groundwater recharge parameters for the site and to inform the integrated groundwater – surface water numerical model. The average recharge rate was calculated at:

- 5.5 mm/year for Tooloombah Creek catchment area (2 ML/year or 0.7% of the annual average rainfall for the region); and
- 17.4 mm/year for the Deep Creek catchment (5.2 ML/year or 2.2% of the annual average rainfall).

An average recharge rate of 9.8 mm/year was estimated for both catchments; i.e. the entire CQC Project area (6.5 ML/year and 1.2% of the annual average rainfall for the region). This recharge rate is consistent with the recharge value implemented in the CQC Project numerical groundwater model by HydroAlgorithmics (2020).

## 4.2 Proposed numerical modelling

The numerical MODFLOW-SURFACT model developed by HydroAlgorithmics (2020) simulates mine dewatering impacts, most notably drawdown in the coal measures and overlying alluvium, and associated depletion of groundwater baseflow to the creeks. The latter are represented as river (RIV) boundaries, rather than drains (DRN), in order to allow for possible groundwater recharge under 'losing' conditions as well as discharge under 'gaining' conditions. The model results are currently presented for large reaches of each key watercourse, hence have some limitations for assessing potential impacts to GDEs. A finer scale resolution would be required to predict changes in connectivity status (e.g. gaining to losing) during mine operations and post closure.

The implementation of an adaptive management approach to the impacts of mine dewatering on GDEs will be supported by local-scale models of representative sites of significant ecological value, where fundamental datasets are either already available or can easily be collected. This may be achieved through the development of local scale 2D cross-section models based on the Eco Logical Australia (2020d) and 3D Environmental (2020) technical studies and conceptualisations. The models would be developed in an appropriate numerical code (i.e. MODFLOW or FEFLOW) with the use of drain boundary conditions to represent the mine pit and allowing the simulation and prediction of baseflow depletion and episodic recharge via bank storage and/or floodplain recharge. These processes may be used to further understand the potential impacts to the water balance that supports key GDEs associated with the CQC Project.

Alternatively, based on the HydroAlgorithmics (2020) report, predicted changes to groundwater – surface water interaction may potentially be able to be exported from the numerical groundwater model at a much finer scale. Should the model be available for interrogation, a detailed appraisal of how well the numerical model represents the local scale site conceptual models is proposed. The fine-scale flux change predictions made by the model should only be considered reasonable if the observed hydraulic gradients and local heterogeneity are appropriately represented.

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