

# **Central Queensland Coal Project**

## **Appendix 6 – Groundwater Technical Report**

**Environmental Impact  
Statement**



Central Queensland Coal Project  
**Groundwater Technical  
Report**

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# 1 Introduction

## 1.1 This Report

This report presents the details of groundwater modelling undertaken to assist in the assessment of potential groundwater impacts associated with water affecting activities associated with the Central Queensland Coal Project.

Groundwater modelling is the only practical approach for assessing the combined potential effects of the Project on future groundwater conditions and dependent systems. This report provides a technical account of the conceptual and numerical groundwater modelling that has been conducted for the Project. The results from predictive simulations presented in this report are used in the Environmental Impact Statement (EIS) to inform the assessment of potential impacts on environmental values, which are addressed in Chapter 10 – Groundwater.

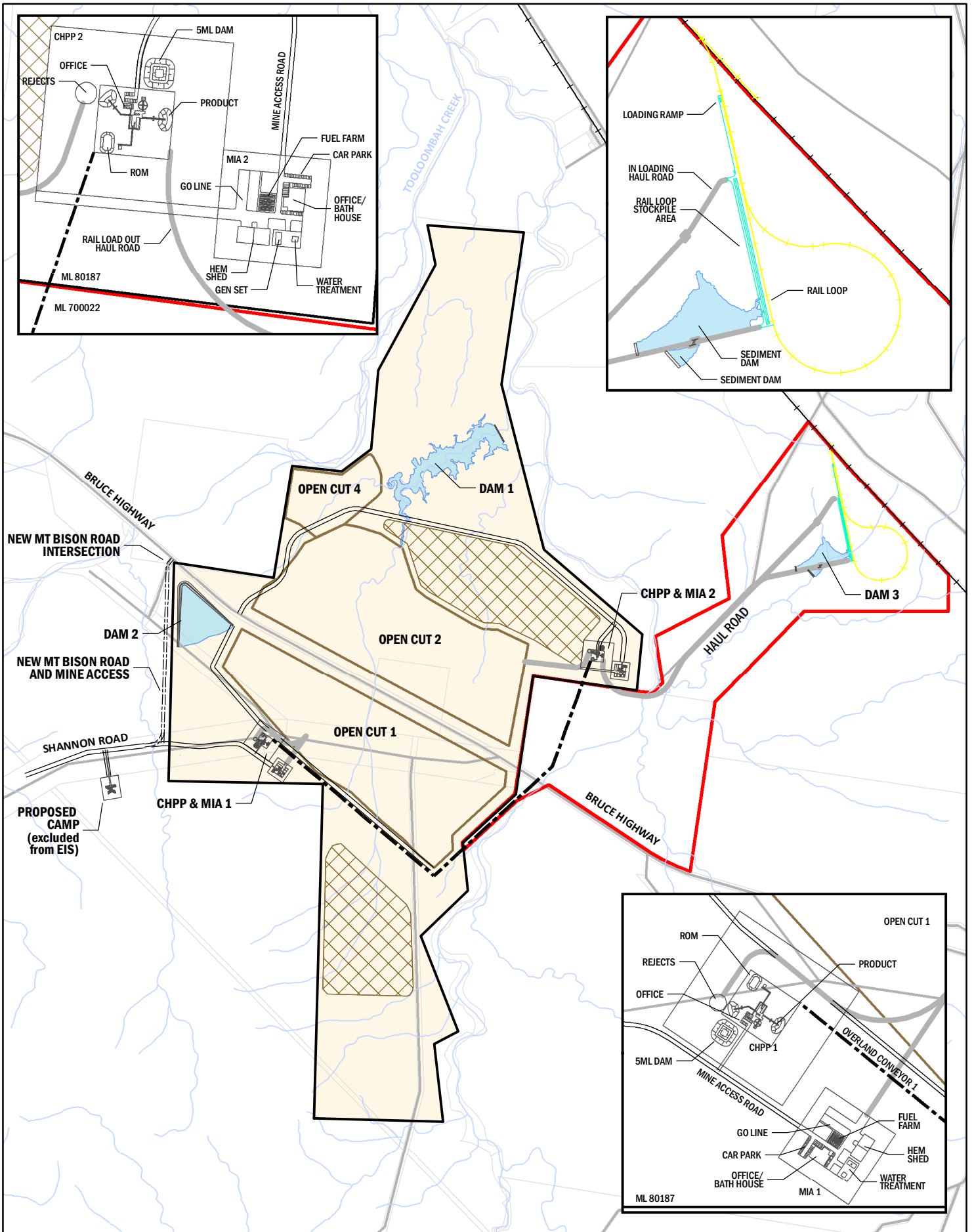
This report has three main sections:

- Data Analysis and Conceptualisation (Section 2) – reviews the datasets that support the groundwater modelling, and presents a conceptual hydrogeological model of the processes that control groundwater conditions in the project area, which then forms the basis of the numerical groundwater model.
- Model construction and calibration (Section 3) – describes how the numerical groundwater flow model is constructed, the hydrogeological processes that are represented by the model, and the ability of the model to simulate past groundwater conditions as an indication of its suitability for predictive simulations.
- Predictive Simulations (Section 4) – describes how the model is used to simulate the potential effects of the Project on groundwater conditions and presents the results of these simulations, including potential effects on water table elevation, groundwater pressure and groundwater flow, both during and after mining.

## 1.2 Modelling Objectives

The primary objectives of the groundwater modelling are to:

- Predict the potential drawdown of the water-table and change in groundwater pressure caused by mine water affecting activities (such as dewatering and depressurisation, water storages, and backfilling of mine voids) for
  - assessing potential effects on existing uses and environmental values; and
  - informing groundwater monitoring and management commitments.
- Predict the potential inflows of groundwater to the proposed open-cut mining operations for input to the Water Management Plan, which will be implemented throughout the life of the Project.
- Predict recovery of groundwater pressure and potential long-term changes in groundwater conditions after mining has ceased and the mine is rehabilitated.



**Figure 1**  
Proposed mine infrastructure locality plan



0 0.5 1 km

Scale @ A4 1:55,000  
Date: 10/08/17  
Drawn: Gayle B.

**Legend**

- ML 80187
- ML 700022
- Open-cut Mine Pit
- Dam Catchment
- Waste Dump Area
- Overland Conveyor
- Haul roads
- Rail Loadout Facility
- Rail Loop
- Proposed mine infrastructure
- Watercourse
- North Coast Rail Line
- Main road
- Cadastral boundary

DATA SOURCE  
QLD Open Source Data, 2017



## 1.3 Groundwater Modelling Guidelines

The practice of groundwater modelling in Australia has been influenced by guidelines developed by the Murray-Darling Basin Commission (Middlemis et al. 2001), widely known as the “MDBC guidelines”, and more recently by The Australian Groundwater Modelling Guidelines released by the National Water Commission (NWC; Barnett et al. 2012). The guidelines were designed to reduce the level of uncertainty surrounding modelling by promoting transparency in methodologies and encouraging consistency and best practice.

The NWC guidelines are similar to and broadly consistent with the earlier MDBC guidelines, providing information that is useful for all stakeholders in the outcomes of groundwater modelling: – from proponents of projects to regulators to professional groundwater modellers and members of the community. The groundwater modelling detailed in the subsequent sections has been undertaken in a manner consistent with the methods and recommendations of these guidelines.

## 1.4 Model Confidence Level Classification

The degree of confidence with which a model’s predictions can be used is a critical consideration for the Project. Several factors are typically considered to determine a model confidence level classification. The Australian Groundwater Modelling Guidelines (Barnett et al. 2012) define a system to classify the confidence level for groundwater models based on the following factors:

- available data;
- calibration procedures;
- calibration and prediction consistency; and
- level of stress (hydraulic stress in the model).

Models are classified as Class 1, 2 or 3 in order of increasing confidence. In general, a model will not fit entirely into one confidence level class because determining the most appropriate class depends upon multiple factors. The groundwater model developed for the Project is generally consistent with Class 1 confidence level, which applies to almost all new mining operations. The confidence classification scheme in the modelling guidelines does not allow for a Class 2 or 3 confidence level for large regional-scale models with long response and recovery times, and when the strata targeted for development and depressurisation are previously unstressed at that magnitude.

More generally, the Class 1 groundwater model developed for the Project is considered capable of providing appropriate physically-based predictions of relative responses to hydraulic stresses. On this basis, it is considered fit-for-purpose and an appropriate platform for assessing the potential effects of the Project on future groundwater conditions.



## 2 Data Analysis and Conceptualisation

### 2.1 Overview

The following provides an overview of groundwater data and analyses that have been conducted for the groundwater impact assessment in this EIS. These data and analyses provide the basis and support for the conceptual hydrogeological model presented in Section 2.3.8, which in turn provides the basis for the design of the numerical groundwater flow model described in Section 3. The numerical groundwater model is used in the EIS to predict the potential effects of the Project on groundwater conditions during and after mining, and those predicted effects are used in the groundwater impact assessment to evaluate the potential of the Project to impact upon groundwater environmental values (EVs).

### 2.2 Geology

#### 2.2.1 Styx Basin – general description

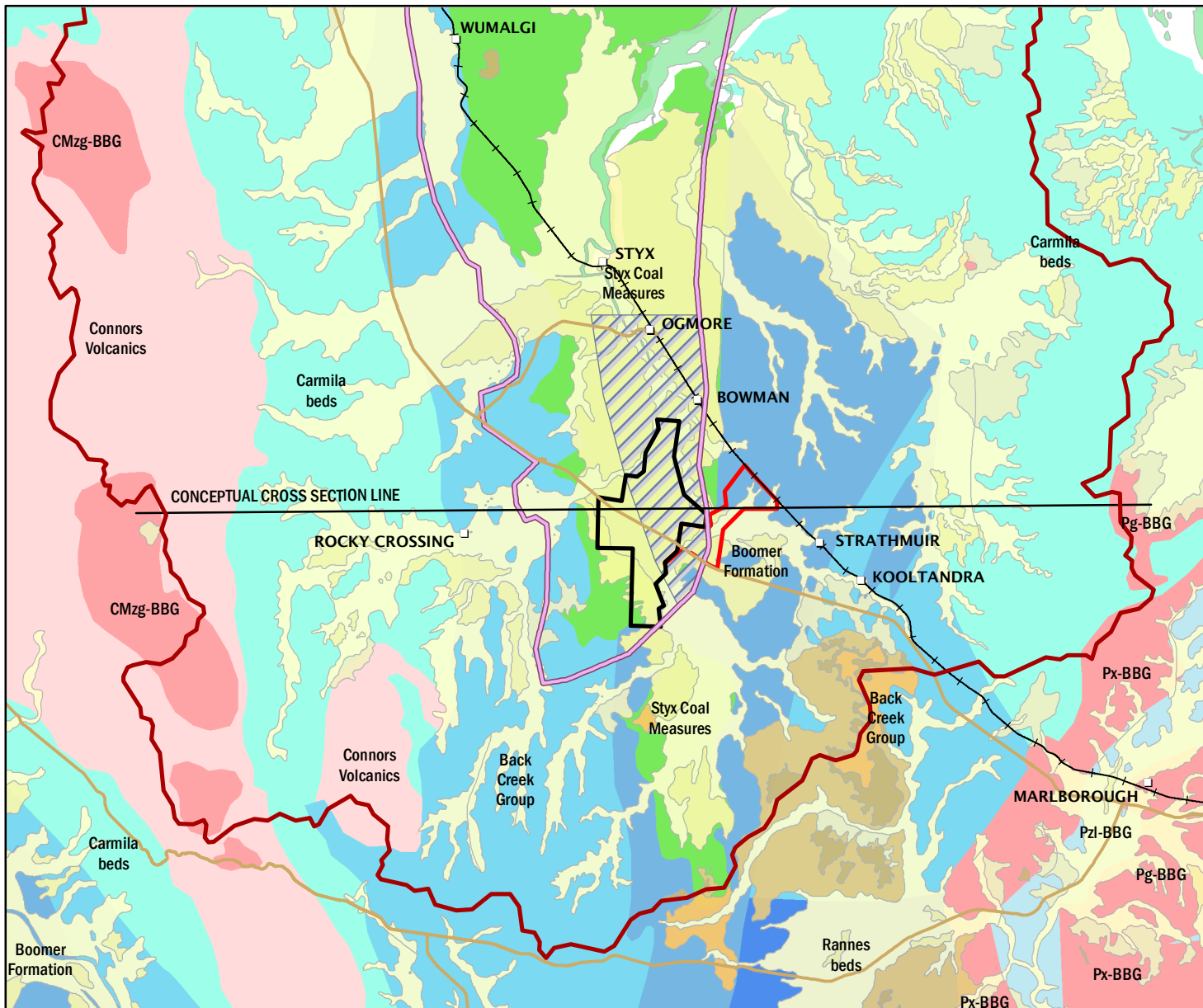
The Styx Basin is a small, elongate, Early-Cretaceous intracratonic sag basin containing less than 1,000 m of siliciclastic sediments and coal measures (Geoscience Australia<sup>1</sup>; Malone et al. 1969). Intracratonic sag basins are typically ‘saucer like’ in geometry and are developed by depositional infill of a sag in the Earth’s crust, which generally forms by gradual subsidence. The infill sediments of Styx Basin are known collectively as the Styx Coal Measures. The stratigraphic relationship between Styx Basin and the underlying Permian-Age (older) rocks is summarised in Table 2-1. The regional geology of Styx River Basin is shown on the geological map and cross section in Figure 2 and Figure 3.

**Table 2-1 Stratigraphy of Styx Basin**

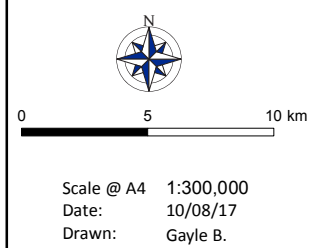
Age (Ma)	Group	Formation	Description <sup>1</sup>
Cenozoic (0 to 66)	-	Cenozoic deposits	Alluvium, colluvium, soils, estuarine deposits, etc.
<i>Unconformity</i>			
Early Cretaceous (100 to 145)	-	Styx Coal Measures	Quartzose sandstone, mudstone, conglomerate and coal
<i>Unconformity</i>			
Late to Early Permian (251 to 268)	Back Creek Group	Boomer Formation	Lithic sandstone, siltstone, mudstone, rare conglomerate
			Quartzose to lithic sandstone, siltstone, mudstone, carbonaceous shale, calcareous sandstone and siltstone, conglomerate, coal, limestone and sandy coquinite
Early Permian (284 ± 7)	Lizzie Creek Volcanic Group	Carmila beds	Siltstone and mudstone, volcanolithic sandstone and conglomerate and minor altered basalt; local rhyolitic to dacitic ignimbrite and volcanoclastic rocks
<i>Unconformity</i>			
Early Permian to Late Carboniferous (300 to 306.5 ± 1.6)	Connors Volcanic Group		Felsic to mafic volcanic rocks; rhyolitic to andesitic flows, high-level intrusives, and volcanoclastic rocks including ignimbrite

<sup>1</sup> Australian Stratigraphic Units Database; <http://www.ga.gov.au/data-pubs/data-standards/reference-databases/stratigraphic-units>

<sup>1</sup> <http://www.ga.gov.au/provexplorer/provinceDetails.do?eno=22644>



- BOWEN ROCK UNIT SOLID**
- Rock Unit Name**
- Back Creek Group
  - Boomer Formation
  - CMzg-BBG
  - Carmila beds
  - Connors Volcanics
  - PMzg-BBG
  - Pg-BBG
  - Px-BBG
  - Pzl-BBG
  - Rannes beds
  - Styx Coal Measures
  - Water body (unspecified)
- CENOZOIC SURFACE GEOLOGY**
- QUATERNARY**
- Qa-QLD (Qa)
  - Qf-QLD (Qf)
  - Qr-QLD, Qf-QLD > Styx Coal Measures (Qr, Qf > Kx)
- PLEISTOCENE**
- Qpa-QLD (Qpa)
- HOLOCENE**
- Qhe/s-YARROL/SCAG (Qhe/s)
- LATE TERTIARY-QUATERNARY**
- TQr-QLD > Td-QLD (TQr > Td)
  - TQr-QLD (TQr)
- TERTIARY**
- Ta-YARROL/SCAG (Ta)
  - Td-QLD (Td)



- Legend**
- Styx Local Geological Model
  - Styx Catchment
  - Styx Basin
  - Conceptual Cross Section Line
  - ML 80187
  - ML 700022
  - North Coast Rail Line
  - Main road

**Figure 2**  
Regional surface geology



DATA SOURCE  
QLD Spatial Catalogue (QSpatial), 2017

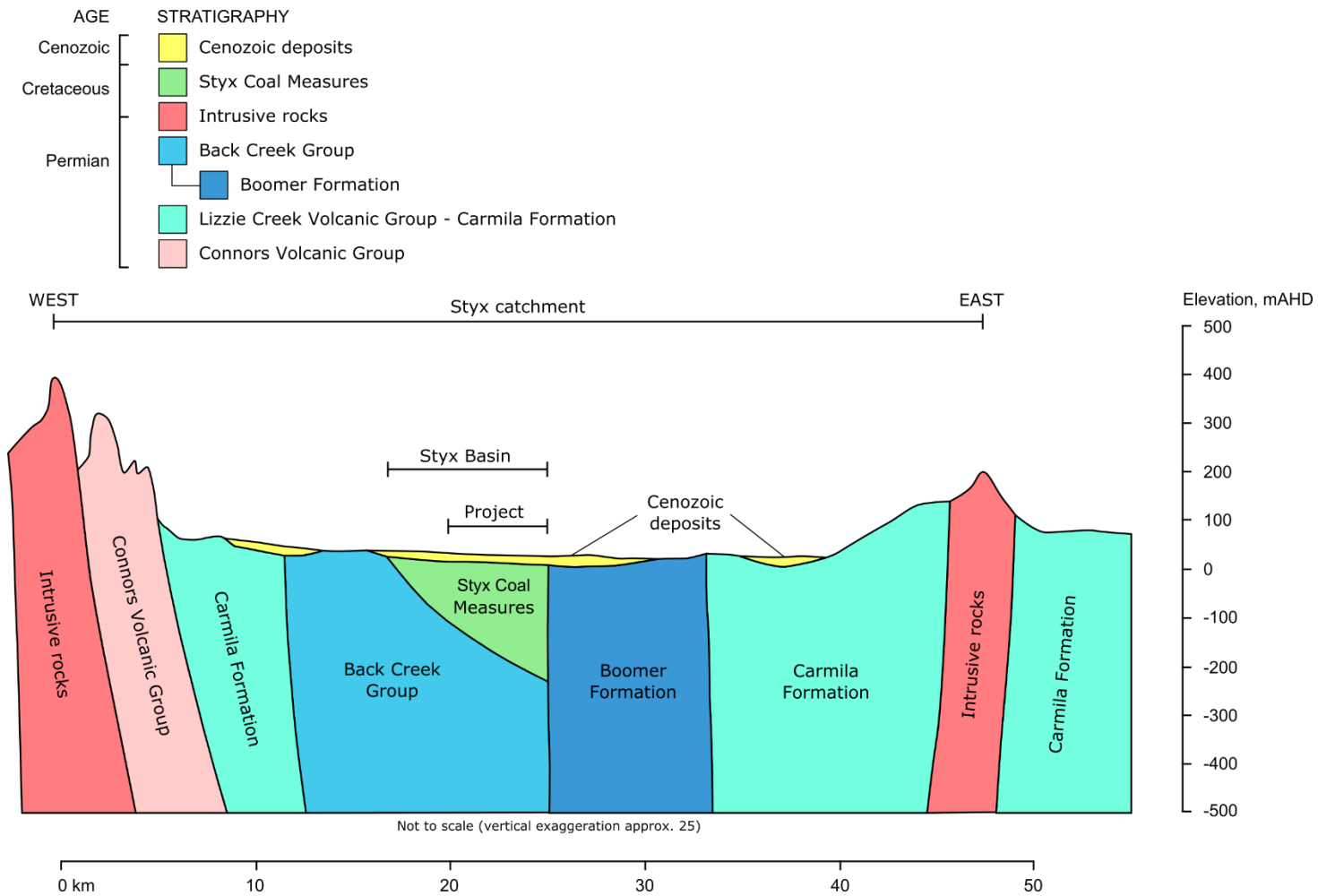


Figure 3 Geology cross section

The west-east geological cross section shown in Figure 3 is at the approximate latitude of the Project. An extended west-east geological cross section located to the south of the Project is shown on the Saint Lawrence 1:250,000 Geological Series map sheet (Bureau of Mineral Resources 1970). The relationship between geological units shown in Figure 3 is based on the geological interpretation and cross section from the Saint Lawrence map sheet.

In total, Styx Basin covers an area of approximately 2,000 km<sup>2</sup> and extends offshore to seawater depths of up to 100 m. The maximum known thickness of sedimentary rocks within the basin is reported as 387 m in an onshore coal exploration drillhole (Geoscience Australia). However, magnetic data suggest that the basin thickens offshore to the north. The basin is thought to have developed by subsidence of the Strathmuir Synclinorium, an older (deeper) feature containing Permian strata of the Bowen Basin. Styx Basin sediments unconformably lap onto Permian rocks of the Back Creek Group in the west and are faulted against them in the east. The basin plunges gently to the north under the waters of Broad Sound but the general dip of the Styx Coal Measures is to the east, with outcrop and sub-crop beneath surface Cenozoic deposits occurring along the west and central side of the basin.

The southern part of Styx Basin, where the Project is located, is bounded to the east by a post-depositional, high-angle reverse fault. Adjacent to the fault, the Cretaceous sedimentary rocks are folded and faulted. The sediments of the Styx Coal Measures are described in the Australian Stratigraphic Units Database<sup>2</sup> as quartzose sandstone, mudstone, conglomerate and coal. The environments of sediment deposition were freshwater, deltaic to paludal (marsh) with occasional marine incursions.

### 2.2.2 Back Creek Group and Boomer Formation

The Permian Back Creek Group unconformably underlies Styx Basin sediments, and overlies the Lizzie Creek Volcanic Group (Carmilla Beds) with apparent conformity (Malone et al. 1969). In the Project area, the Back Creek Group extends north-south approximately sub-parallel, beneath and to the west of Styx Basin. The sediments of Back Creek Group are described in the Australian Stratigraphic Units Database as quartzose to lithic sandstone, siltstone, mudstone, carbonaceous shale, calcareous sandstone and siltstone, conglomerate, coal, limestone and sandy coquinite.

To the east of Styx Basin, the Back Creek Group is represented by Boomer Formation, which comprises of sediments derived from a volcanic terrain. The Boomer Formation is described in the Australian Stratigraphic Units Database as lithic sandstone, siltstone, mudstone and rare conglomerate.

### 2.2.3 Lizzie Creek Volcanic Group - Carmila Beds

Permian sediments of the Carmila Beds underlie the Back Creek Group and unconformably overlie the Connors Volcanic Group. The Carmila Beds outcrop on and east of Connors Range, in a large area north of Marlborough, and on both sides and the southern end of Broadsound Range (Malone et al. 1969). Near Tooloombah homestead and farther south (near the Project area) the Carmila beds have been described by Malone et al. as mainly of volcanolithic sediments, with primary volcanics constituting only about 20 percent. The Australian Stratigraphic Units Database describes the Carmila Beds as siltstone and mudstone, volcanolithic sandstone and conglomerate and minor altered basalt; local rhyolitic to dacitic ignimbrite and volcanoclastic rocks.

<sup>2</sup> <http://www.ga.gov.au/data-pubs/data-standards/reference-databases/stratigraphic-units>

## 2.2.4 Connors Volcanic Group

The Connors Volcanic Group consists mainly of Carboniferous to Early Permian massive volcanics that unconformably underlie Lizzie Creek Volcanic Group. The rocks of Connors Volcanic Group outcrop in a linear zone, the Connors Arch, to the west of Styx Basin and in association with Broadsound Range. The Connors Volcanic Group are described in the Australian Stratigraphic Units Database as felsic to mafic volcanic rocks; rhyolitic to andesitic flows, high-level intrusives, and volcanoclastic rocks including ignimbrite.

## 2.3 Hydrogeology

### 2.3.1 Aquifer Tests

The Groundwater Database - Queensland<sup>3</sup> (GWDBQ) contains aquifer transmissivity values at the location of five bores screening the Cenozoic alluvial deposits at the locations shown in Figure 4. A summary of these data is presented in Table 2-2. The recorded values of transmissivity and hydraulic conductivity show moderate groundwater yields can be expected from relatively small aquifer intervals (0.7 to 4.6 m).

**Table 2-2 Results from aquifer pumping tests recorded in the GWDBQ**

GWDBQ RN	HSU	Method	Duration, h	Interval, m	T, m <sup>2</sup> /d	K, m/d
57794	Alluvium	Pumping test	24	3.4	412	121
84983	Alluvium	Pumping test	4.5	0.7	107	153
88144	Alluvium	Pumping test	2	1.8	59	33
88145	Alluvium	Pumping test	120	4.6	60	13
88146	Alluvium	Pumping test	2.6	1.9	6	3

GWDBQ – Groundwater Database - Queensland (<https://data.qld.gov.au/dataset/groundwater-database-queensland>);  
T – Aquifer transmissivity; K – Hydraulic conductivity

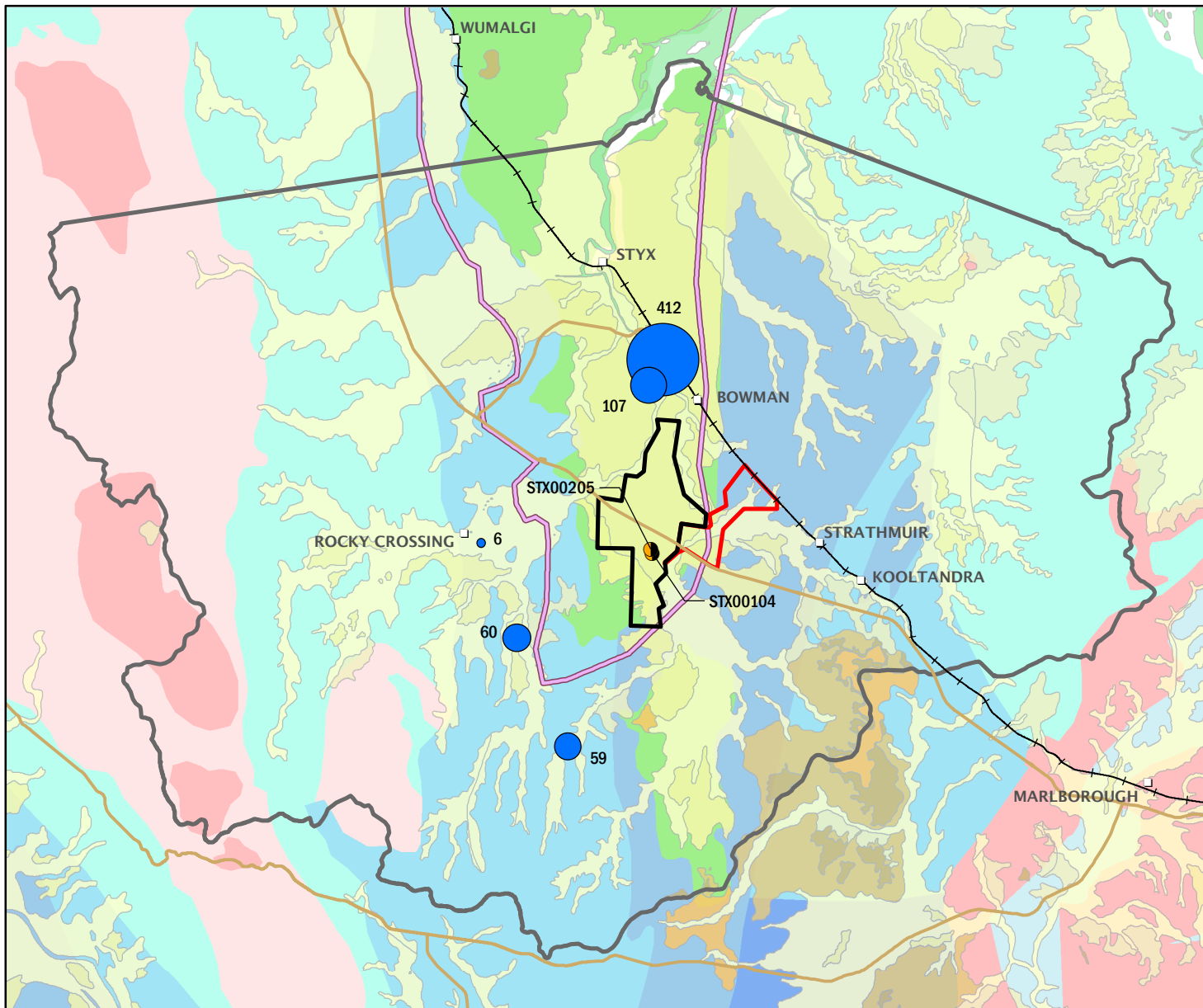
Groundwater investigations conducted for the Styx Trial Pit (AMEC 2014) included two aquifer air lift pumping tests undertaken at drillholes STX00104 and STX00205 but the results are inconclusive, likely due to the testing method, and a fault occurred during pumping of STX00205 that caused the test to be abandoned). The drillhole locations are shown in Figure 4 and a summary of the test results is presented in Table 2-3. In general, very low airlift yields were achieved during pumping, 0.03 L/s (approximately 2.6 kL/d) from STX00104 and 0.15 L/s (approximately 13 kL/d) from STX00205. The larger airlift rate from STX00205 was attributed to the presence of a gravel bed at the base of the “weathering” (located above the coal resource) and the presence of a 4-m thick coal seam.

**Table 2-3 Results from aquifer pumping tests for the Styx Trial Pit (AMEC 2014)**

Bore ID	Method	Hole depth, m	Interval, m	Average airlift rate, L/s	T, m <sup>2</sup> /d	S
STX00104	Air lift pump out	81.5	NR	0.03	9.5 (drawdown STX170) 2.1 (drawdown STX00103) 5.2 (drawdown STX00204) 0.013 (recovery)	- 4.4E-6 8.0E-7 2.0E-7
STX00205	Air lift pump out	88.3	NR	0.15	0.042 (recovery)	-

NR – Not reported; T – Aquifer transmissivity; S – Aquifer storativity (dimensionless)

<sup>3</sup> <https://data.qld.gov.au/dataset/groundwater-database-queensland>



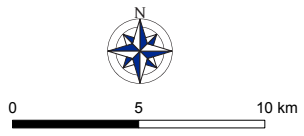
- BOWEN ROCK UNIT SOLID**
- Rock Unit Name**
- Back Creek Group
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  - CMzg-BBG
  - Carmila beds
  - Connors Volcanics
  - PMzg-BBG
  - Pg-BBG
  - Px-BBG
  - Pzl-BBG
  - Rannes beds
  - Styx Coal Measures
  - Water body (unspecified)
- CENOZOIC SURFACE GEOLOGY**
- QUATERNARY**
- Qa-QLD (Qa)
  - Qf-QLD (Qf)
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- Qhe/s-YARROL/SCAG (Qhe/s)
- LATE TERTIARY-QUATERNARY**
- TQr-QLD > Td-QLD (TQr > Td)
  - TQr-QLD (TQr)
- TERTIARY**
- Ta-YARROL/SCAG (Ta)
  - Td-QLD (Td)

**Legend**

**Aquifer Transmissivity m<sup>2</sup>/d**

- 10
- 25
- 50
- 75
- 100

- Styx drillholes
- Styx Basin
- Groundwater Model Boundary
- ML 700022
- North Coast Rail Line
- Main road
- ML 80187



Scale @ A4 1:300,000  
 Date: 10/08/17  
 Drawn: Gayle B.

**Figure 4**  
 Aquifer transmissivity from GWDBQ



DATA SOURCE  
 QLD Spatial Catalogue (QSpatial), 2017

Estimated values of aquifer storativity from the pumping test of STX00205 are close to, and below, the lower limit of practical values that are expected from the compressibility of water and rock— noting that values of specific storativity less than approximately  $1.0E-6 \text{ m}^{-1}$  are generally not anticipated on physical grounds. The small values of storativity indicate the observed responses at the observation bores were most likely caused by depressurisation of confined strata within the sequence intersected by the drillholes rather than drawdown of the water table.

### 2.3.2 Hydrogeological Properties from Literature Review

Review of information on the hydrogeological properties of geological units found within Styx River Basin is presented in Table 2-4. Not much of this information is derived from investigations or studies conducted within the basin. Where no relevant information has been found the values in the table are sourced from the literature, with values being consistent with sediment types for those units (e.g. Boomer Formation, Carmila Beds and Connors Volcanic Group).

Estimates of hydrogeological properties for Cretaceous coal measures in Queensland are hard to find. Some information was reported for the Maryborough Basin, which has a similar setting to Styx Basin, being located to the southeast (north of Brisbane) and straddling the coast with onshore and offshore parts. There is much more public information available about the hydrogeological properties of older and deeper Permian coal measures within Bowen Basin but the relevance to Cretaceous coal measures in the Styx Basin has not been established. In general, based on experience of Permian coal measures, there is an expectation that coal measures are more permeable than the overburden and underburden sediments that do not contain coal seams (i.e. the coal seams typically have the larger permeability). There is also an expectation the permeability of coal measures diminishes with burial depth due to compaction.

Information about the hydrogeological properties of the Back Creek Group is derived entirely from studies in the Bowen Basin. No examples from Styx Basin have been found. There is almost no information about the hydrogeological properties of the Lizzie Creek Volcanic Group and Connors Volcanic Group. Part of the reason for this lack of information is that none of these stratigraphic units are recognised as aquifers. In general, they contain sediments and rocks that are expected to exhibit hydrogeological properties consistent with very poor aquifers and aquitards.

The largest estimates of hydraulic conductivity are obtained for alluvial deposits and the fractured and weathered profile of surface exposures of rocks. These zones correspond to the shallow water-table aquifer targeted by farm and pastoral bores.

The available information for estimates of specific yield and storativity suggests that primary porosity of stratigraphic units is relatively small, with specific yield less than 0.05 (5%) and typically around 0.01 (1%).

**Table 2-4 Review of hydrogeological properties**

Stratigraphic unit	Kh, m/d	Kv, m/d	Sy	Ss, 1/m	Location	Method	Source
Alluvium and / or fractured and weathered rock profile	3 - 121	-	-	-	Styx River Basin	Pumping tests	1
	0.001 - 10	-	-	-	N/A	Literature review	7
	0.25	0.025	0.05	1e-4	Maryborough Basin	Groundwater modelling	2
Cretaceous coal measures - overburden	0.0075	0.00075	0.01	1e-5	Maryborough Basin	Groundwater modelling	2
Cretaceous coal measures - coal	0.001 - 0.22	0.0001 - 0.022	0.01	1e-5	Maryborough Basin	Groundwater modelling	2
Cretaceous coal measures - underburden	0.005	0.0005	0.01	1e-5	Maryborough Basin	Groundwater modelling	2
Cretaceous coal measures	0.004 - 45.7	-	-	-	Maryborough Basin	Falling head tests (eleven)	2
	0.65 - 1	-	-	-	Maryborough Basin	Single pumping test	
Boomer Formation - siltstone, mudstone, sandstone	0.00001 - 0.1	-	-	-	N/A	Literature review	7
Back Creek Group	0.002 - 0.1	-	-	-	Bowen Basin	Literature review	3
	0.0001 - 0.01	0.00001 - 0.001	0.03 - 0.18	5e-6 - 5e-4	Bowen Basin	Literature review	3
	0.025	0.0025	-	-	Bowen Basin	Groundwater modelling	3
	0.0108	0.00108	-	-	Bowen Basin	Groundwater modelling	3
	0.005	0.0005	0.05	1e-5	Bowen Basin	Groundwater modelling	3
	0.000108	0.0000108	0.03	1e-5	Bowen Basin	Groundwater modelling	4
0.000358	0.00000952	0.0005	6.07e-6	Bowen Basin	Groundwater modelling	5	
Carmila beds - siltstone, mudstone, sandstone	0.00001 - 0.1	-	-	-	N/A	Literature review	7
Lizzie Creek Volcanic Group	0.0000009	0.000001	0.0001	1e-6	Bowen Basin	Groundwater modelling	6
Connors Volcanic Group	0 - 0.00001	-	-	-	N/A	Literature review	7

Symbols: Kh – Horizontal hydraulic conductivity; Kv – Vertical hydraulic conductivity; Sy – Specific yield; Ss – Specific storativity

Sources: 1. Groundwater Database - Queensland (GWDBQ); 2. AGE (2010); 3. URS (2012); 4. URS (2013); 5. AGE (2014); 6. Drake Coal (2014); 7. Literature values (Bear 1972, Bouwer 1978, Freeze and Cherry 1979)



### 2.3.3 Water Table and Hydraulic Head

Observations of groundwater pressures / levels within Styx River Basin are mainly restricted to one (or several) measurements of depth to water table in individual groundwater bores. Historical time-series observations of water table elevation and hydraulic head are not identified within the river basin.

Figure 5 shows measurements of water table elevation in 48 bores that vary from approximately 1 mAHD near to the estuarine reach of Styx River (north of the Project) to approximately 100 mAHD near to the river basin boundary (south of the Project). In general, the elevation of the water table is a subdued reflection of regional topography, being higher in upland areas and lower in lowland areas. Multi-depth measurements of hydraulic head (e.g. nested monitoring bores) that could assist in defining vertical head gradients are have not been identified.

Values of water-table elevation in Figure 5 are calculated by subtracting measurements of depth to water table from ground surface elevations at the bore locations, which have been extracted from 1 second (30 metre) SRTM digital elevation data (Gallant et al. 2011). Some of the variation in water table elevation seen in these derived data may be the result of inaccuracies in the bore locations, inaccuracies in the STRM data, differences between ground surface elevation and the reference elevations that was used for measuring depth at the bores, or a combination of these factors.

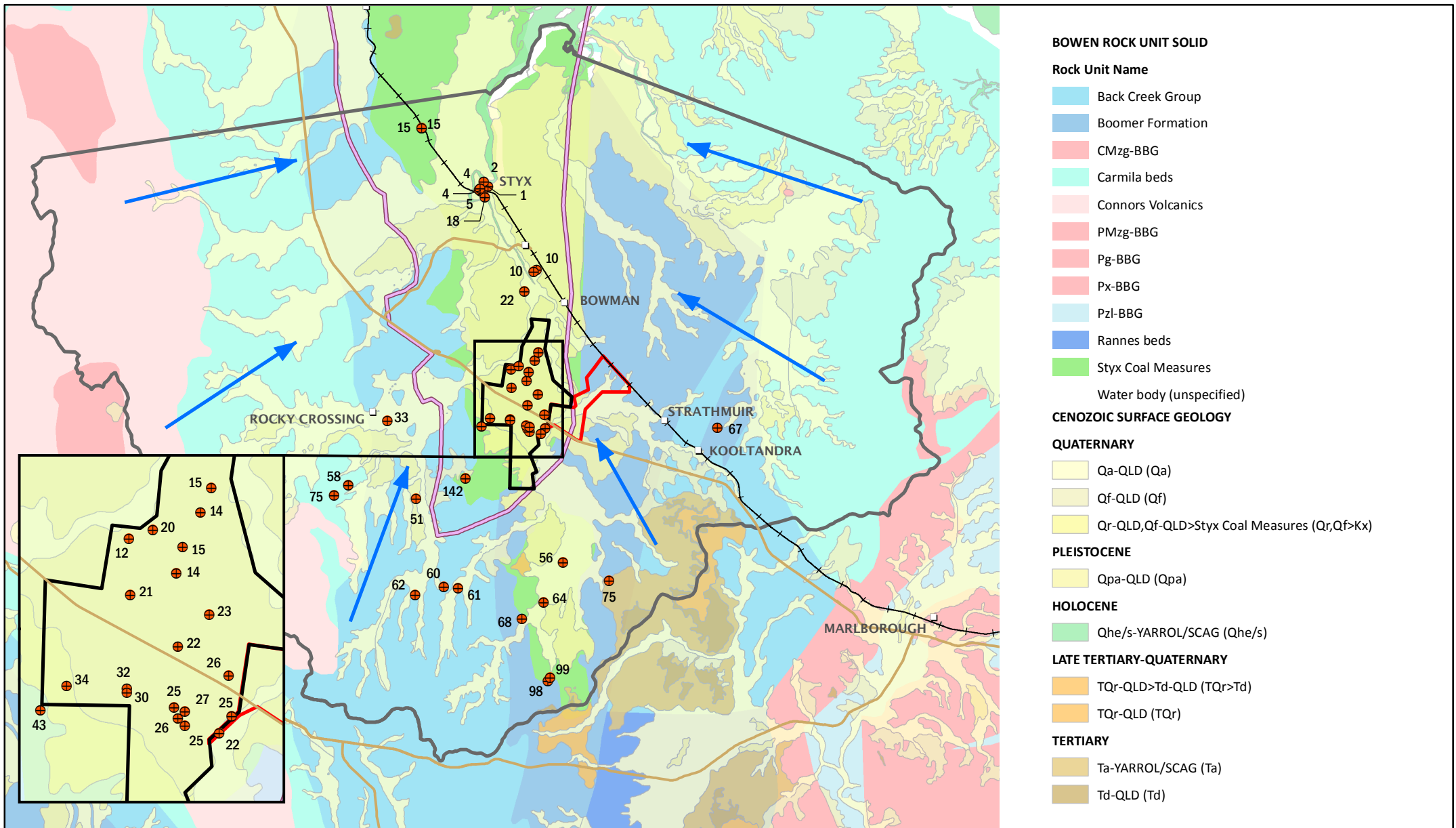
### 2.3.4 Groundwater Recharge

Measurements of groundwater recharge rates specific to Styx River Basin have not been not identified in this assessment. The review of Australian groundwater recharge studies by Crosbie et al. (2010) found there have been comparatively few published recharge studies in Queensland in the region of the Project. Based on the Method of Last Resort (MOLR) developed for data poor areas, the national map of groundwater recharge produced by Leaney et al. (2011) shows that the MOLR groundwater recharge rate within Styx River Basin is in the range 1 to 5 mm/y, which is equivalent to 0.1% to 0.7% of the long-term, mean annual rainfall of 755 mm/y at Strathmuir (BoM Station 33189)—located approximately 8 km from the Project site.

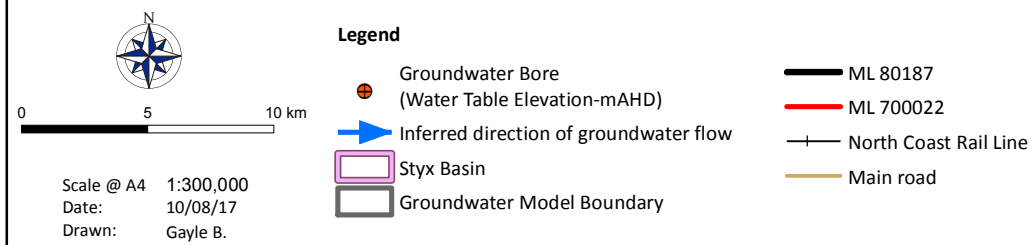
One approach to estimating recharge within Styx River Basin is to apply the chloride mass balance method (e.g., Crosbie et al. 2010) using the groundwater chloride concentrations recorded in the GWDBQ. Applying the chloride deposition rate for Rockhampton of 22.16 kg/ha/y measured by Crosbie et al. (2012) and the range of groundwater chloride concentrations 64 to 1,762 mg/L reported in the GWDBQ, the chloride mass balance method gives estimates of groundwater recharge rates in the range 1.3 to 35 mm/y, which is equivalent to 0.2% to 4.6% of the long-term mean annual rainfall of 755 mm/y at Strathmuir. These estimates are considered order-of-magnitude and can be affected by geochemical interactions of groundwater with subsurface minerals and evaporative concentration of salts in groundwater in areas of groundwater evapotranspiration.

For groundwater modelling of a coal mine within the Cretaceous Maryborough Basin, located to southeast of Styx Basin, an average groundwater recharge rate of 2 mm/y was used based on calibration of the groundwater model developed for that assessment (AGE 2010).

Together, these estimates suggest that groundwater recharge rates across Styx River Basin are likely to be a few percent, or less, of the annual rainfall rates across the basin.



**Figure 5**  
Water table elevation data points



DATA SOURCE  
QLD Spatial Catalogue (QSpatial), 2017



### 2.3.5 Evapotranspiration

Point potential evapotranspiration<sup>4</sup> (PPET) data available from the BoM are described as the evapotranspiration (ET) that would take place under the condition of unlimited water supply from an area so small that the local ET effects do not alter local air mass properties. The PPET data can be taken as a preliminary conservative estimate of evaporation from small water bodies such as farm dams and shallow water storages. The BoM has provided PPET data gridded at 0.1 degrees (approximately 10 km). The model area is intersected by 24 grid cells (6 × 4) with PPET values in the range 2,184 to 2,310 mm/y. These data are used to specify the land surface ET boundary condition in the groundwater modelling.

### 2.3.6 Groundwater Flow System

The regional groundwater flow system is driven by diffuse groundwater recharge from rainfall across Styx River Basin, slow subsurface drainage of groundwater toward the ocean, and discharge of groundwater by seepage and evapotranspiration along topographic depressions associated with watercourses and riparian vegetation, and at the coast and estuarine reaches of tidal rivers and creeks.

From the available observations of water-table elevation, the regional direction of groundwater flow generally follows topography, with movement from the direction of the river-basin boundary down slope toward the ocean and water courses (refer to Figure 5). A saltwater interface is expected within shallow groundwater at the coast. However, there are no known measurements of deep groundwater pressure at the coast that would indicate there is flow of terrestrial groundwater offshore within Styx Basin (e.g., artesian groundwater pressure at the coast).

Local directions of shallow groundwater flow within alluvium are likely to vary in response to local topography with flow toward areas of groundwater discharge along watercourses and associated riparian vegetation. There are insufficient data to provide an interpreted contour map of the water table or to construct a meaningful groundwater flownet over the river basin. However, the calibrated groundwater model provides an impression of regional- and local-scale groundwater flow within the area of the model domain (refer to Section 3).

### 2.3.7 Groundwater Extraction

No records of groundwater extraction within Styx River Basin have been identified in this assessment. However, the GWDBQ contains bore yield values from 41 bores that range from around 0.02 L/s (less than 2 kL/d) up to 6 L/s (approximately 0.5 ML/d). A frequency distribution of bore yield is shown in Table 2-5. Approximately half of the bores have yield values less than 1 L/s, and roughly three quarters have yield values less than 2 L/s. Of the remaining bores, approximately one quarter, have yields greater than 2 L/s. The GWDBQ also records design yields for five bores, which are estimates of their expected operational yields based on the results of aquifer pumping tests. The design yields vary from around 0.15 L/s to 6 L/s.

While the available data on bore yields provide a general context for assessing potential extraction rates from bores within Styx River Basin, they are not sufficient for deriving estimates of annual groundwater extraction.

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<sup>4</sup> [http://www.bom.gov.au/jsp/ncc/climate\\_averages/evapotranspiration/](http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/)

**Table 2-5 Frequency distribution of bore yields from the GWDBQ**

Bore yield (L/s)	Number of bores	Percent of bores (%)
< 1	20	48.8
1 to 2	10	24.4
2 to 3	4	9.8
3 to 4	2	4.9
4 to 5	2	4.9
5 to 6	3	7.3
Total	41	100.0

**Table 2-6 Bore design yields from the GWDBQ**

GWDB RN	Design yield (L/s)
57794	5.9
84983	0.88
88144	0.45
88145	1.47
88146	0.16

### 2.3.8 Interaction with Surface Water and Connected Systems

Information about the potential for interaction between groundwater and surface water within Styx River Basin is available from the National Atlas of Groundwater Dependent Ecosystems<sup>5</sup> (GDE Atlas) and the Queensland Government WetlandInfo<sup>6</sup>.

A map of GDE classification from the GDE Atlas is presented as Figure 6, and shows:

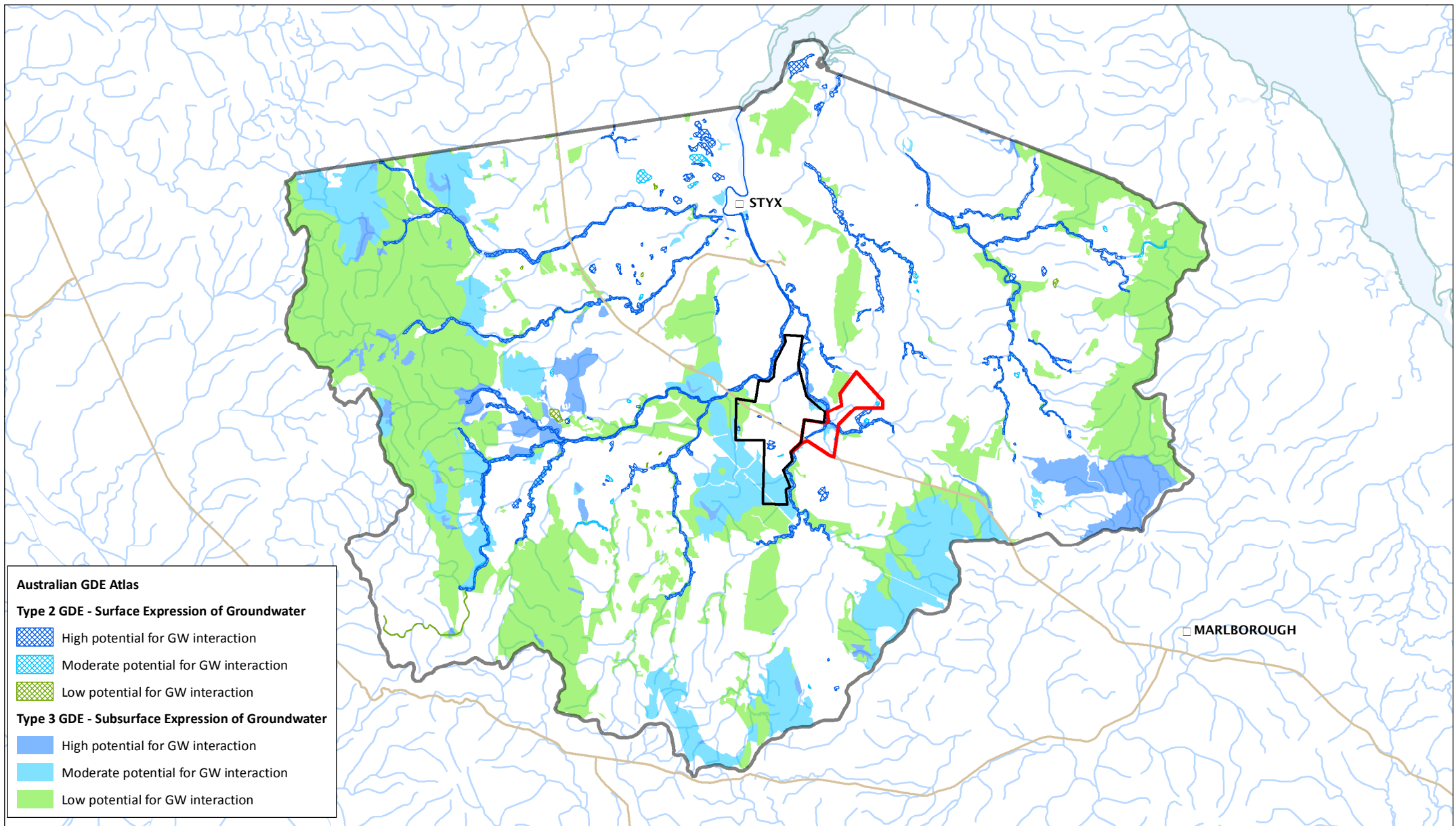
- Potential GDEs that are reliant on the surface expression of groundwater (Type 2 GDEs) are present along extensive reaches of water courses, including Styx River, Tooloomah Creek and Deep Creek adjacent to the Project area; most of these potential Type 2 GDEs are classified as having high potential for interaction with groundwater.
- Potential GDEs that are reliant on sub-surface expression of groundwater (Type 3 GDEs) are present within the basin, and are mostly classified as having low to moderate potential for interaction with groundwater. These potential Type 3 GDEs are mainly associated with upland slopes within the Connors Range geomorphology zone, and alluvial plains within the Broadsound Plain geomorphology zone.

Queensland Government WetlandInfo also shows small areas of riverine, fresh water bodies along Styx River and Tooloomah Creek but the extents of these areas are much smaller than the extent of potential Type 2 GDEs classified by the GDE Atlas.

More generally, occurrence of groundwater discharge to rivers and creeks within Styx River Basin is consistent with the elevation of the water table being topographically controlled. Because the water table cannot rise above land surface without groundwater discharge occurring, groundwater discharge is expected to occur where the surface drainage system is most deeply incised. In this situation, the water table is constrained where the topography is lowest but can rise to higher elevation under topographic highs.

<sup>5</sup> <http://www.bom.gov.au/water/groundwater/gde/>

<sup>6</sup> <https://wetlandinfo.ehp.qld.gov.au/wetlands/facts-maps/sub-basin-styx-river/>



**Australian GDE Atlas**

**Type 2 GDE - Surface Expression of Groundwater**

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction

**Type 3 GDE - Subsurface Expression of Groundwater**

- High potential for GW interaction
- Moderate potential for GW interaction
- Low potential for GW interaction

0 5 10 km

**Legend**

- Groundwater Model Boundary
- ML 80187
- ML 700022
- Main road
- Watercourse

**Figure 6**  
Groundwater dependent ecosystems

DATA SOURCE  
QLD Spatial Catalogue (QSpatial), 2017  
Geofabric v2.x, Bureau of  
Meteorology (BoM), 2017



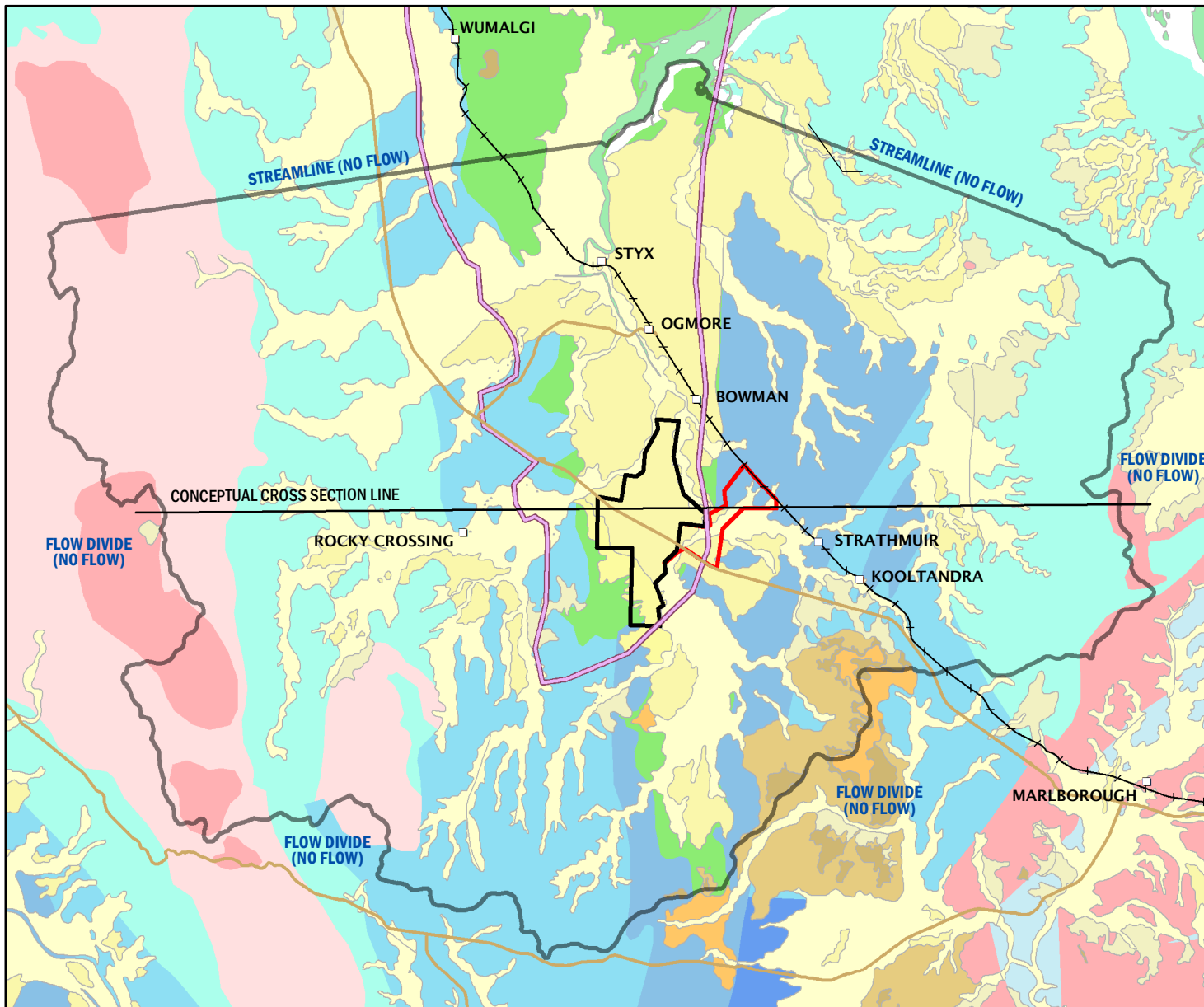
## 2.4 Conceptual Hydrogeological Model

An overview of the conceptual hydrogeological model for Styx River Basin is presented in Figure 7 and Figure 8. At the broadest level, the basin contains usable but relatively low capacity groundwater supplies in shallow water table aquifers that are hosted in the unconsolidated Cenozoic surface deposits, particularly within the alluvial infill sediments associated with surface drainage, and within fractured and weathered zones of outcropping Cretaceous rocks (Styx Basin) and older Permian rocks (Back Creek Group, Lizzie Creek Volcanics Group and Connors Volcanic Group). The deeper sediments underlying the Cenozoic surface deposits and below the zone of surface fracturing and weathering have much smaller permeability and are not known to yield useable groundwater supplies.

Figure 7 shows the hydrogeological boundary for the conceptual model, which has three main parts:

- Flow divide (no flow) – the western, eastern and southern parts of the boundary follow the ridge line of Styx River Basin –
  - because the elevation of the water table is topographically controlled, the ridge line of the Styx River Basin is also an approximate lateral flow divide for shallow groundwater;
  - groundwater flow in deeper sediments and rocks is less due to smaller permeability; however, in the absence of other hydrological controls, the distribution of groundwater pressure and direction of groundwater flow in deep rocks is expected to mimic the general patterns observed in the water-table aquifers;
- Streamline (no flow) – the straight parts of the northern boundary are approximate regional groundwater streamlines that are based on the regional slope of the water table from the boundary of Styx River Basin towards the ocean and estuarine portion of Styx River; and
- Constant head (0 mAHD) – the central part of the northern boundary follows the shoreline of Styx River Basin where the mean elevation of the water table is approximately equal to mean sea level (0 mAHD).

In this conceptualisation, shallow unconfined groundwater flow in Cenozoic sediments and fractured and weathered rocks within Styx River Basin is driven by diffuse groundwater recharge from rainfall within the basin. The water table slopes generally toward the ocean but locally follows topographic relief, with depth to water table from ground surface typically in the range 2 to 15 m in existing groundwater bores dependent on location. Most groundwater discharge is thought to occur by evapotranspiration from topographic lows, particularly along valleys of the surface drainage network, including evaporation of surface pools and bank seepage, and transpiration by riparian vegetation communities that access groundwater within their root zones. The main processes for interaction between groundwater and surface water are episodic groundwater recharge along flowing watercourses during wet conditions, and groundwater discharge to watercourses that intersect the water table during dry conditions.



**BOWEN ROCK UNIT SOLID**

**Rock Unit Name**

- Back Creek Group
- Boomer Formation
- CMzg-BBG
- Carmila beds
- Connors Volcanics
- PMzg-BBG
- Pg-BBG
- Px-BBG
- Pzl-BBG
- Rannes beds
- Styx Coal Measures
- Water body (unspecified)

**CENOZOIC SURFACE GEOLOGY**

**QUATERNARY**

- Qa-QLD (Qa)
- Qf-QLD (Qf)
- Qr-QLD, Qf-QLD > Styx Coal Measures (Qr, Qf > Kx)

**PLEISTOCENE**

- Qpa-QLD (Qpa)

**HOLOCENE**

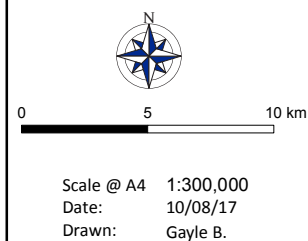
- Qhe/s-YARROL/SCAG (Qhe/s)

**LATE TERTIARY-QUATERNARY**

- TQr-QLD > Td-QLD (TQr > Td)
- TQr-QLD (TQr)

**TERTIARY**

- Ta-YARROL/SCAG (Ta)
- Td-QLD (Td)



**Legend**

- Groundwater Model Boundary
- Styx Basin
- Conceptual Cross Section Line
- ML 80187
- ML 700022
- North Coast Rail Line
- Main road

**Figure 7**  
Hydrogeological domain and boundary

DATA SOURCE  
QLD Spatial Catalogue (QSpatial), 2016



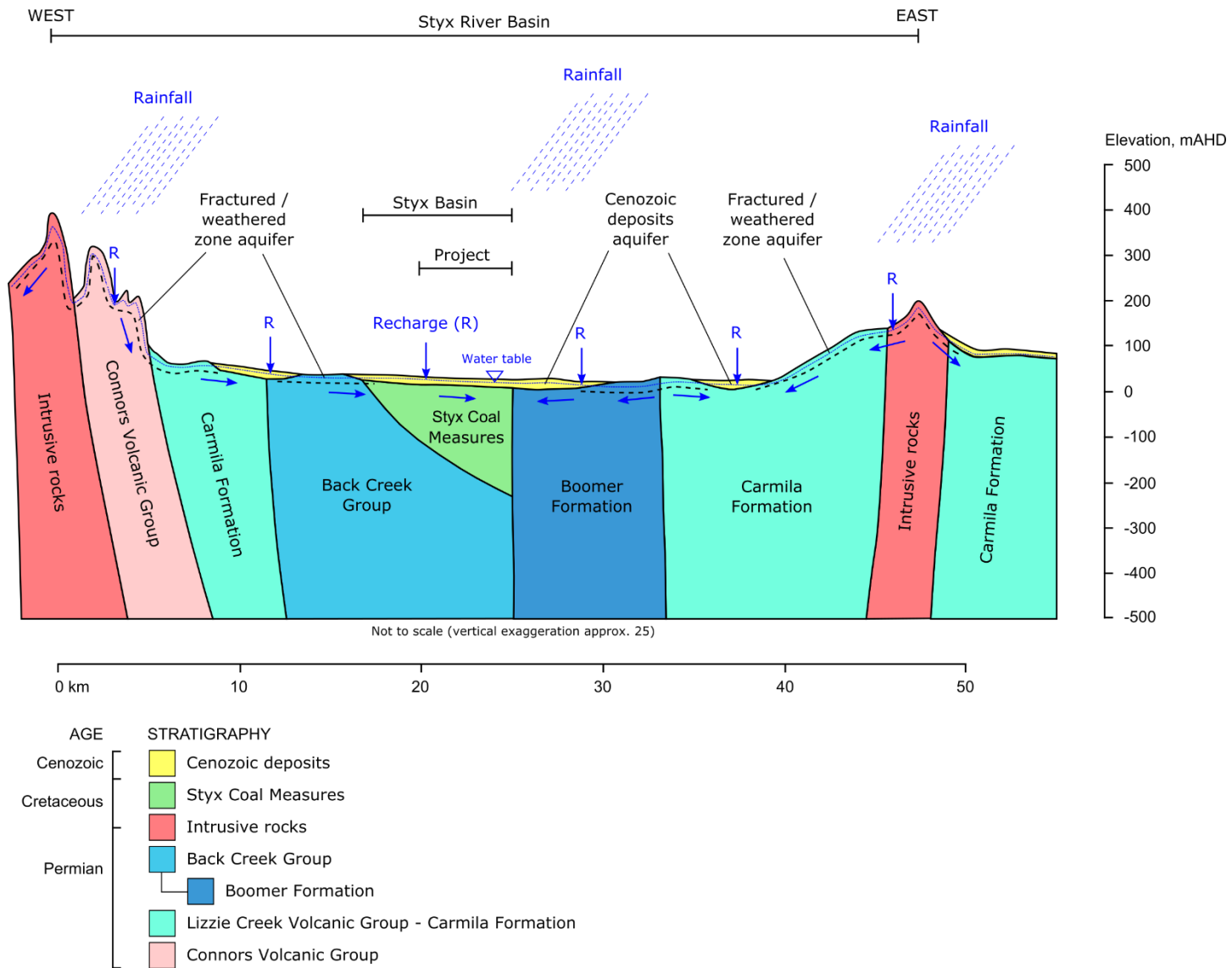


Figure 8 Conceptual hydrogeological cross section



## 3 Model Construction and Calibration

### 3.1 Overview

This section of the report describes how the numerical groundwater flow model is constructed, such that it is an appropriate representation of the conceptual hydrogeological model, and describes how the numerical model is calibrated to simulate the existing groundwater conditions as an indication of its suitability for conducting predictive simulations. The geometry of the groundwater model is constructed from the regional-scale geological model developed for the project, which is described first. The Proponent has also developed a local-scale geological model within Styx Basin for the purpose of resource assessment and development, but the scale of that geological model is much smaller than the groundwater model.

### 3.2 Regional-Scale Geological Model

A regional-scale geological model has been constructed using Leapfrog Hydro (v2.5) to support the groundwater modelling. The primary sources of information used for the geological model include the geological information in Section 2.2 (including the surface and solid geological maps), lithology logs recorded in the GWDBQ, and the upper and lower surfaces of coal seams from the Proponent's local-scale geological model.

The regional-scale model consists of four main geological units shown in Figure 9:

- Cenozoic surface deposits occurring mainly in association with alluvial infill deposits and colluvial slope deposits of the surface drainage network.
- Styx Basin – consisting of Cretaceous Styx Coal Measures, which are sub-divided into
  - overburden, consisting of the portion of the Styx Coal Measures above the upper-most coal seam delineated in the Proponent's local-scale geological model;
  - coal seams and interburden, consisting of the portion of the Styx Coal Measures between the upper- and lower-most coal seams delineated in the Proponent's local-scale geological model; and
  - underburden, consisting of the portion of the Styx Coal Measures below the lower-most coal seam delineated in the Proponent's local-scale geological model.
- Basement – consisting of all rocks of Permian Age and older that either underlie Styx Basin, or subcrop Cenozoic sediments or outcrop beyond the margin of Styx Basin, including Back Creek Group, Carmila beds (Lizzie Creek Volcanic Group) and Connors Volcanic Group.
- Intrusive rocks, various Permian-Age intrusions within the basement rocks and sediments.

Each geological unit in the Leapfrog Hydro model is represented by a three-dimensional volume that can be continuous or discontinuous within the geological model domain. The unit thicknesses and the contact surfaces between units are modelled by the software based on interpolation and extrapolation of the input data, which include manually drawn lines and intersections, and the specified stratigraphic relationships between the units.

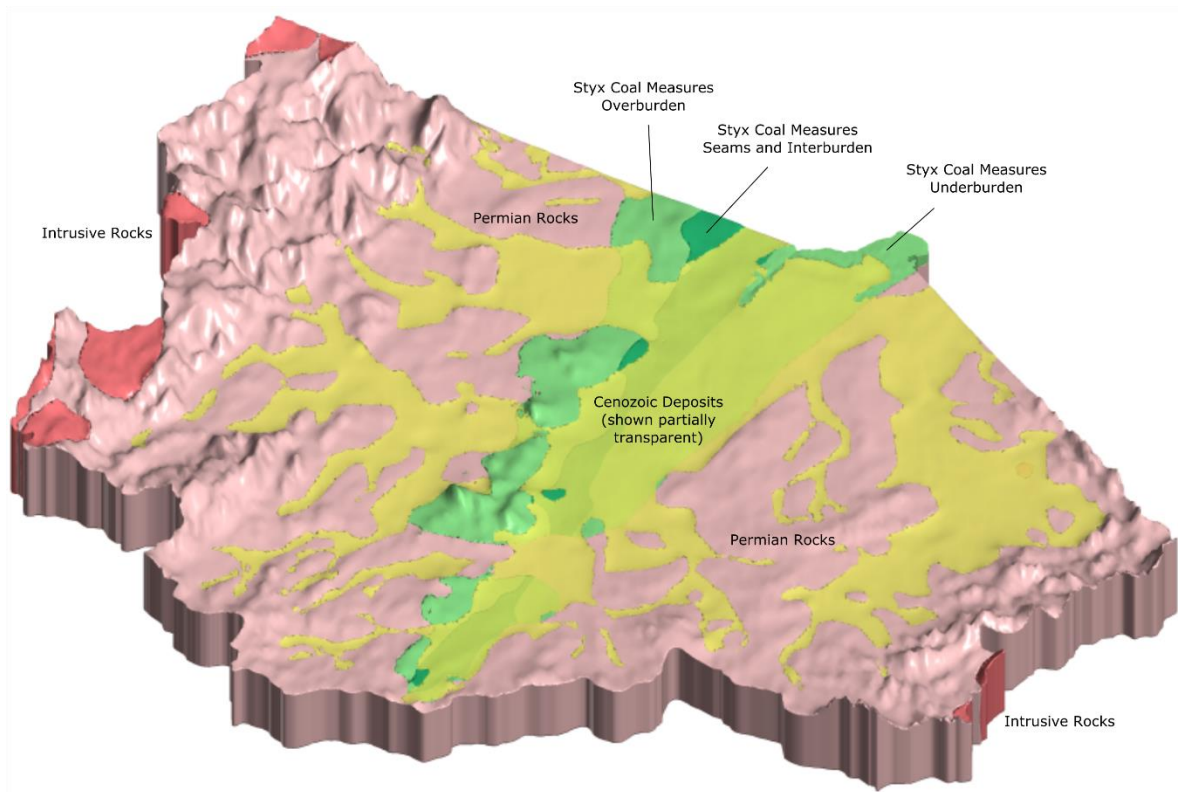


Figure 9 Regional-scale geological model (×5 vertical exaggeration)

## 3.3 Numerical Groundwater Flow Model

### 3.3.1 Modelling Platform

Several industry standard modelling codes are available for simulation of regional-scale groundwater flow. They roughly fall into two categories: finite element (FE) and finite difference (FD) codes. A finite difference code was selected for this modelling project. The most commonly used groundwater FD code is MODFLOW, developed by the United States Geological Survey (McDonald and Harbaugh 1988). The latest version was released in 2005, but commercially developed variations on the public-domain MODFLOW may also be available, which may have capabilities lacking in MODFLOW itself.

MODFLOW-SURFACT™ (SURFACT) was chosen as the most appropriate numerical package for this modelling project. SURFACT was developed by HydroGeoLogic Inc. (HydroGeoLogic 1998) specifically to handle issues associated with re-wetting of dry cells more effectively than MODFLOW 2005. Additional modifications available in SURFACT to address recognised limitations of MODFLOW 2005 include more accurate tracking of the water table, and additional robust solver packages (HydroGeoLogic 1998, Panday and Huyakorn 2008). The requirement of MODFLOW to retain laterally continuous model layers can result in numerous thin and mostly dry cells that can be problematic in areas where the water table extends across multiple layers, particularly in areas of large water-table drawdown (e.g. caused by mining below the water table) and in areas of steep topographic gradient. SURFACT is better able to simulate these conditions and provides better numerical stability than MODFLOW 2005.

Groundwater Vistas version 6 (ESI 2011) was selected as the graphical user interface for building the model and the associated pre- and post-processing of numerical modelling data. Additional

scripts have been written in Python and ArcGIS™ to perform customised pre- and post-processing tasks.

### 3.3.2 Model Extent and Boundary Conditions

The model boundary and boundary conditions are specified as described for the conceptual hydrogeological model in Section 2.4. The constant head (0 mAHD) boundary condition applied at ocean is specified in model layers 1, 2 and 3. Elsewhere, a no-flow condition is specified on the model boundary.

### 3.3.3 Model Grid

The model grid shown in Figure 10 was generated in Leapfrog Hydro and exported to Groundwater Vistas. The columns are aligned due north and are approximately parallel with the regional orientation of the Styx Basin and the bounding Permian rocks. The total number of active cells is 114,552 (19,092 per layer) consisting of 154 rows and 180 columns.

Local refinement is introduced within and surrounding the Project area. The 5 × 5 km area containing the mining lease application area has a uniform grid cell size 100 × 100 m. The surrounding area within a square 15 × 15 km surrounding the Project area has a maximum grid cell size 250 × 250 m, and beyond that area the maximum cell size is 500 × 500 m.

A cross-section through the model grid at the Project location is shown in Figure 11.

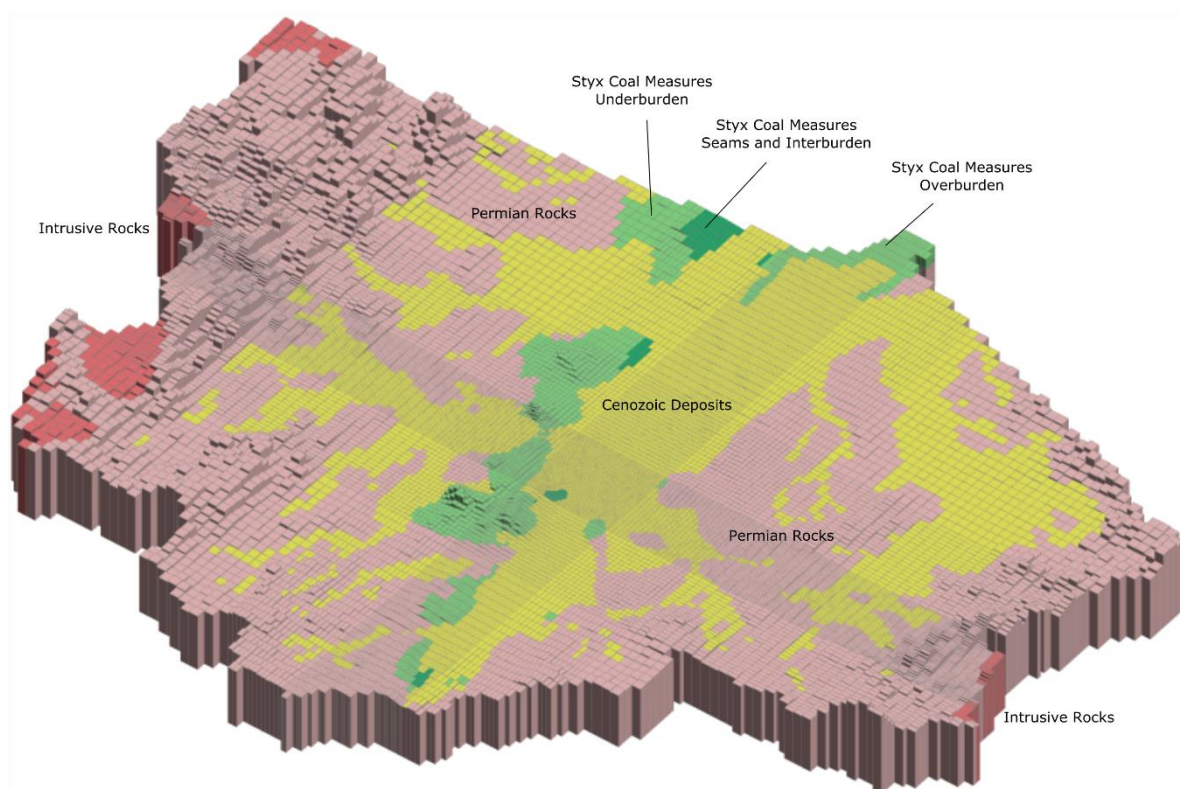


Figure 10 MODFLOW grid developed from the geological model (×5 vertical exaggeration)

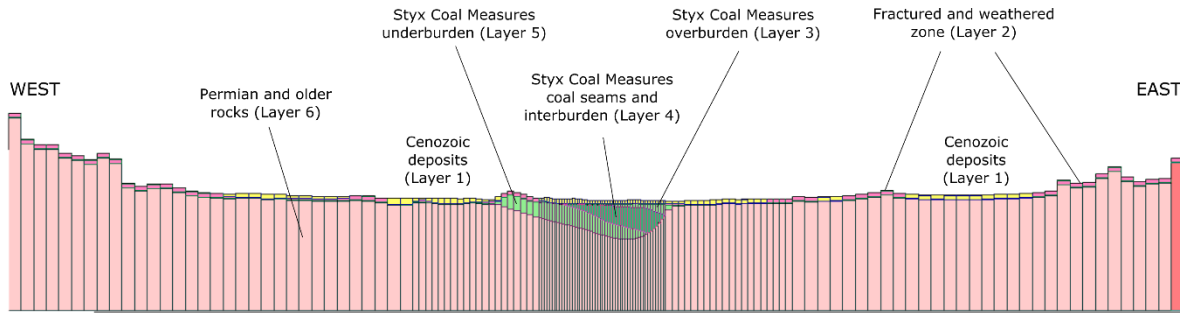


Figure 11 Model cross section, west to east through Project location

### 3.3.4 Model Layering

The model is designed with six layers as summarised in Table 3-1. The top surface of the model is set at topographic elevation and the bottom elevation of the model, located within Permian rocks, is set arbitrarily at -500 mAHD.

Table 3-1 Model layer design

Layer	Hydrostratigraphic Unit	Comment
1	Cenozoic deposits	0 to 50 m thick
2	Fractured and weathered zone	0 to 20 m thick, and extending beneath Cenozoic deposits where they are less than 20-m thick
3	Styx Coal Measures - overburden	0 to 160 m thick
4	Styx Coal Measures – coal seams and interburden	0 to 125 m thick
5	Styx Coal Measures - underburden	0 to 273 m thick
6	Permian rocks	Bottom elevation set arbitrarily at -500 mAHD

### 3.3.5 Groundwater Recharge and Evapotranspiration

Groundwater recharge is applied uniformly across the upper-most active layer of the model during simulations and represents an upper limit or maximum potential rate of recharge. Excess groundwater recharge, which would otherwise result in the water table rising above ground surface, is removed during simulations by evapotranspiration (ET). The net rate of groundwater recharge can vary between locations, and is equal to the difference between the applied rate of groundwater recharge and the ET rate. Evapotranspiration occurs if the water table rises above the ‘extinction depth’ for ET during a simulation, which is set equal to 3 m below ground surface.

The applied recharge rate represents the maximum rate of recharge that is possible at a location and its value is adjusted as part of the model calibration. The net recharge rate can vary spatially and is an output of the model, with the following possibilities:

- Net recharge is equal to applied recharge – this occurs when the elevation of the water table is below the extinction depth for ET (i.e., where it is more than 3-m below ground surface) and is the maximum possible rate.
- Net recharge is a positive value but less than applied recharge – this occurs when the water table elevation is just above the ET extinction depth and the rate of ET from the water table is less than the applied recharge rate.
- Net recharge is a negative value – this occurs when the water table elevation is well above the ET extinction depth and close to ground surface, and the rate of ET from the water table is greater than the applied recharge rate (i.e. there is net groundwater discharge).

The ET rate varies from zero at water-table depth below the extinction depth for ET up to the Point Potential evapotranspiration<sup>7</sup> (PPET) rate described in see Section 2.3.5.

## 3.4 Model Calibration

### 3.4.1 Overview

Model calibration generally involves changing values of model parameters within reasonable bounds until the model outputs fit historical measurements, such that the model can be accepted as a reasonable representation of the physical system of interest (Barnett et al. 2012). If this outcome cannot be achieved within the limits of the data and model design, then it is possible that the historical data are unreliable; the conceptualisation is flawed and needs to be reconsidered; the numerical model is flawed and does not properly represent the conceptual model; or some combination of these factors.

Once there is reasonable confidence in the reliability of the calibration targets, hydrogeological conceptualisation and model construction, the calibration procedure generally involves the following iterative steps:

- Identify historical measurements of quantities that can be predicted by the model (calibration targets), which usually consist of measurements of hydraulic head in groundwater bores, and sometimes groundwater flow information (e.g. groundwater seepage or discharge measurements).
- Identify the historical stresses on groundwater sources during the period when historical observations are available (e.g., groundwater pumping and extraction records).
- Run the groundwater model to simulate this historical period and compare the model predictions with the historical observation.
- Adjust the model parameters within realistic bounds and re-run the groundwater model until an acceptable statistical match is achieved between the simulated and observed values.

These steps can be performed manually or automatically using parameter estimation software such as PEST<sup>8</sup>, particularly when many calibration targets exist. The model calibration reported here is performed manually as the model design is relatively simple and the number of calibration targets is relatively small.

The model is calibrated in steady state due to lack of transient calibration targets.

### 3.4.2 Calibration Targets

Selected calibration targets consist of observed values of hydraulic head in 46 groundwater bores described in Section 2.3.3 and shown in Figure 12. They consist of single observations of hydraulic head at each bore location, with water table elevations values ranging from 1.7 to 118 mAHD.

<sup>7</sup> [http://www.bom.gov.au/jsp/ncc/climate\\_averages/evapotranspiration/](http://www.bom.gov.au/jsp/ncc/climate_averages/evapotranspiration/)

<sup>8</sup> <http://www.pesthomepage.org/>

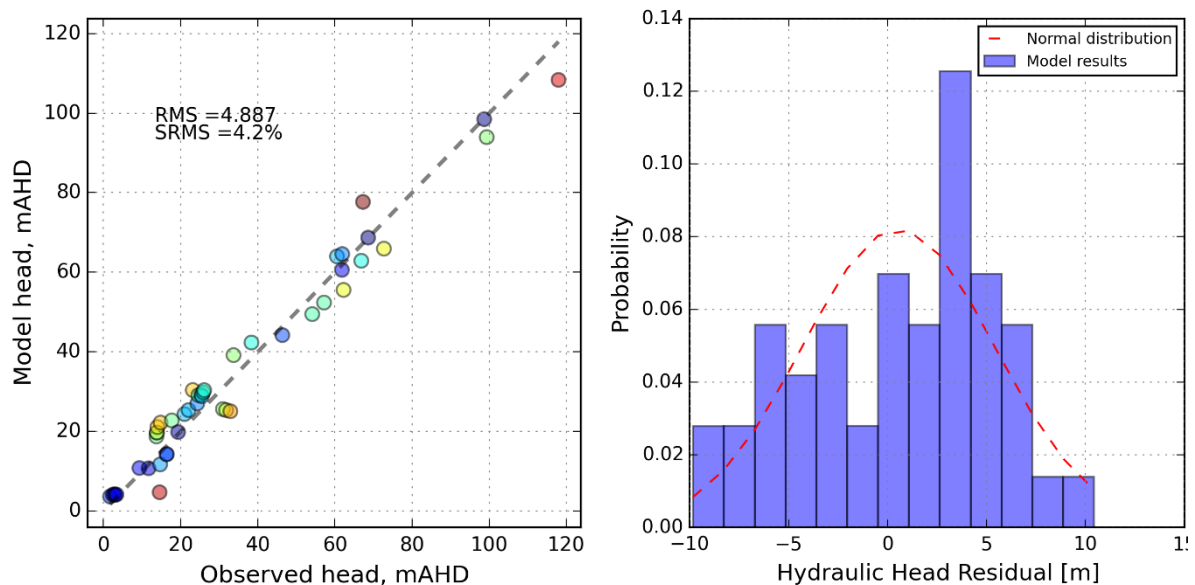
### 3.4.3 Calibration Results

Results from the steady state model calibration are summarised in Table 3-2 and Figure 12. Table 3-2 lists the adopted values of hydrogeological properties that are used later for the predictive simulations, and Figure 12 shows a scattergram of observed versus simulated values of hydraulic head at the locations of the calibration targets, as well as the probability distribution for the calibration residuals (the differences between the observed and simulated values). Much of the calibration fit reflects the relationship between water-table elevation and topography. The calibration fit is achieved as a balance between the applied rate of groundwater recharge and hydraulic conductivity of the Cenozoic deposits and the fractured and weather zone. In general, the adopted value of hydraulic conductivity in the Cenozoic deposits is larger based on evidence of significant (>5 L/s) bore yields and relatively flat water-table slopes. There is also evidence that bore yields from the fractured and weather zone rock can be significant (>5 L/s) within locally well-developed fracture systems; however, at larger scales, the fractured-weathered aquifer is expected to be less permeable and supports steeper water table slopes.

**Table 3-2 Adopted hydrogeological properties**

HSU	Kh, m/d	Kv, m/d	Ss	Sy
Cenozoic deposits	15	1.5	1.0E-4	0.05
Fractured and weathered zone	0.1	0.1	1.0E-5	0.01
Styx Coal Measures - overburden	5.0E-4	5.0E-5	1.0E-5	0.01
Styx Coal Measures – coal seams and interburden	5.0E-3	5.0E-4	1.0E-5	0.01
Styx Coal Measures - underburden	5.0E-4	5.0E-5	1.0E-5	0.01
Permian rocks – basement	1.0E-4	1.0E-5	1.0E-5	0.005
Permian rocks - intrusive	1.0E-6	1.0E-6	1.0E-5	0.001

Kh – horizontal hydraulic conductivity; Kv – vertical hydraulic conductivity; Ss – specific storativity (dimensionless); Sy – specific yield (dimensionless)



**Figure 12 Calibration scattergram and residuals**

While Table 3-2 includes the adopted values of specific storativity and specific yield, these values cannot be estimated from a steady state model calibration; noting that there is no concept of groundwater storage in a steady state model. Instead the values listed in Table 3-2 are based on the estimates compiled in Section 0.

Net recharge, the difference between applied recharge and the model-simulated ET, varies from the maximum positive rate of 2.9 mm/y at locations where the elevation of the water table is greater than 3 m below ground surface (the specified extinction depth for ET) to a maximum negative value of approximately -1405 mm/y at locations where ET is removing groundwater. The spatial distribution of net recharge for the calibrated steady-state model is shown in Figure 13.

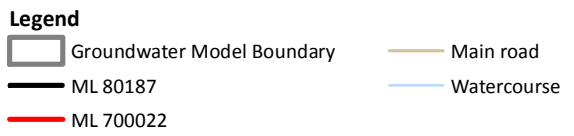
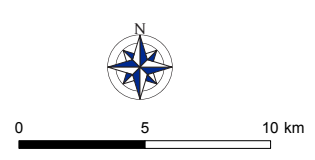
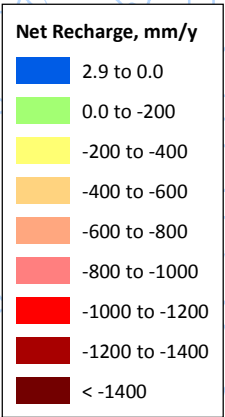
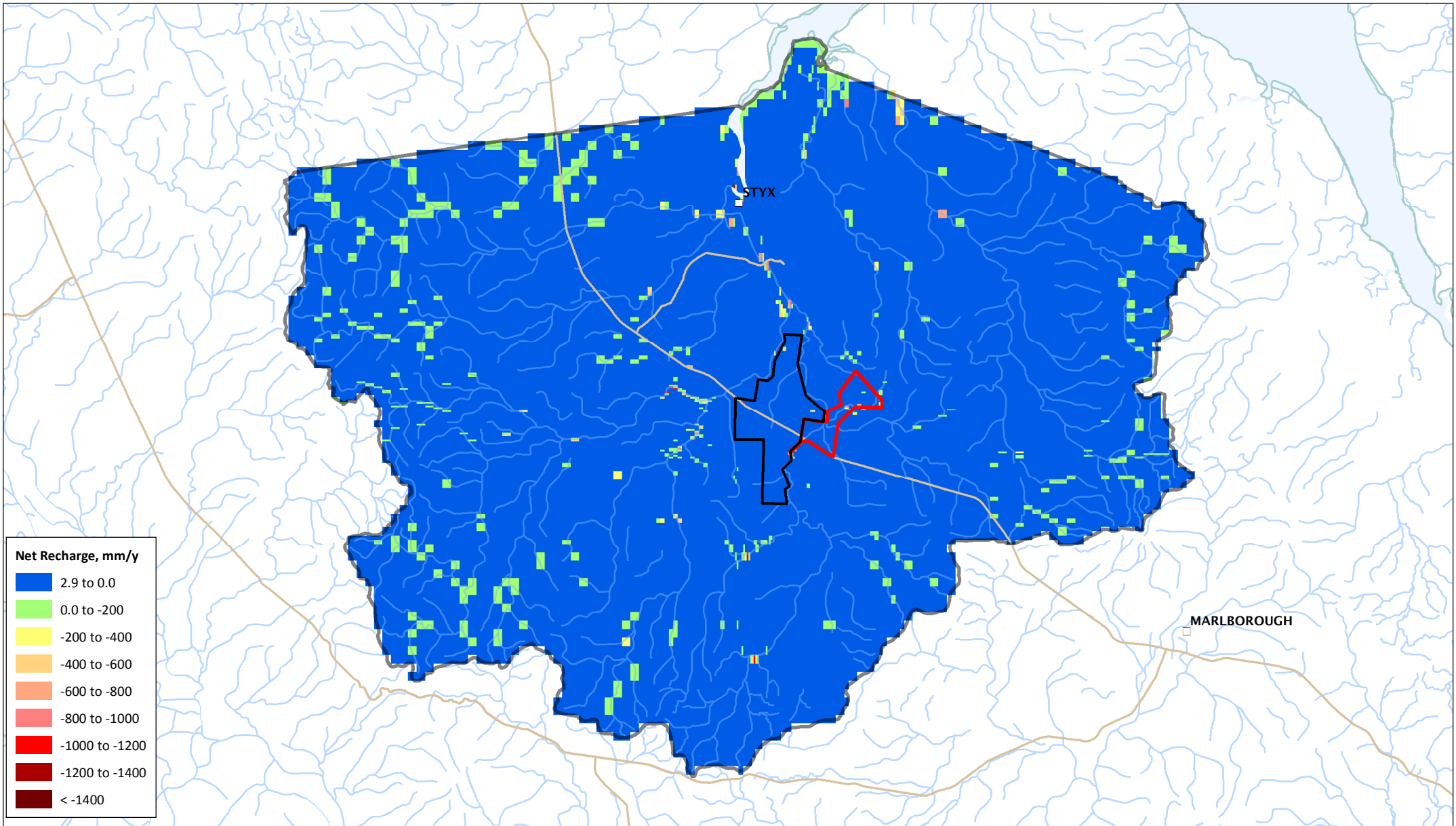
The adopted value of hydraulic conductivity in Cenozoic deposits is relatively large but provides necessary regional transmissivity to conduct groundwater from recharge areas to discharge areas without the water table filling to ground surface. Re-calibration of the model to smaller values of hydraulic conductivity in the Cenozoic deposits would be possible with smaller rates of groundwater recharge. The maximum groundwater recharge rate of 2.9 mm/y used for the model calibration is based on the review outcomes presented in Section 2.3.4.

### 3.4.4 Model Mass Balance

The model water balance reported in Table 3-3 is a check that the steady-state model is solving accurately and does not contain a mass-balance discrepancy. The percent error in the model mass balance is smaller than 0.002% and demonstrates that the results are numerically accurate.

**Table 3-3 Steady-state water balance**

Component	Rate (positive values are inflows), kL/d
Applied groundwater recharge	11,834
Evapotranspiration	-11,770
Flow at constant head boundaries	-64
Imbalance	0.0



Scale @ A4 1:300,000  
 Date: 10/08/17  
 Drawn: Gayle B.

**Figure 13**  
 Net recharge for the calibrated steady-state model

DATA SOURCE  
 QLD Spatial Catalogue (QSpatial), 2017  
 Geofabric v2.x, Bureau of  
 Meteorology (BoM), 2017





## 4 Predictive Simulations

### 4.1 Representation of Mining

#### 4.1.1 Overview

Mine development is represented in the groundwater model based on the sixteen-year mine plan and schedule shown in Figure 14. The mine schedule is used to develop a passive dewatering sequence that will be achieved by collecting groundwater reporting to the active pit areas in sumps and pumping out.

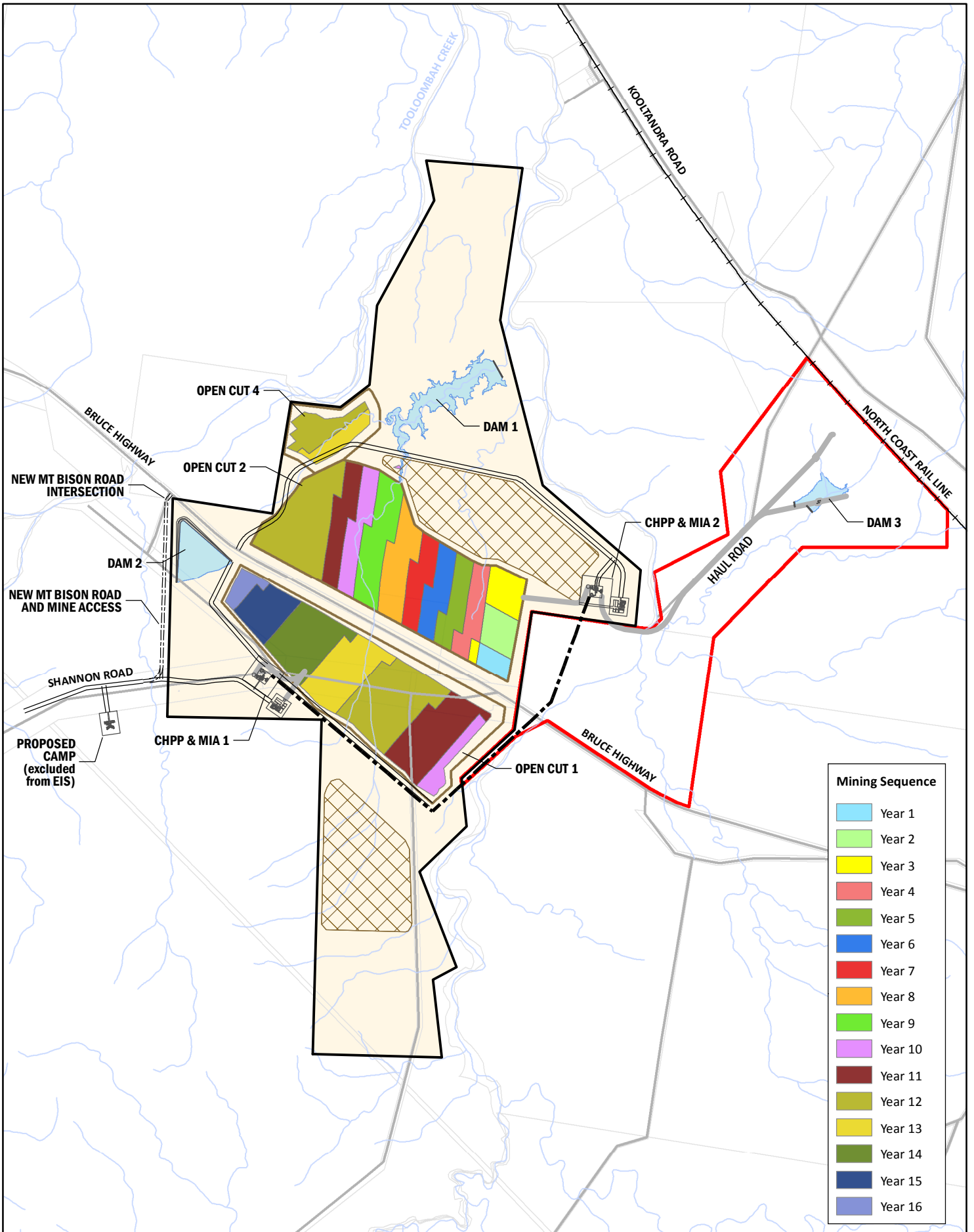
The dewatering schedule implemented in the groundwater modelling is summarised in Table 4-1 and is based on the following assumptions:

- The mine pits will be progressively backfilled during mining and the backfill material will have larger porosity than the in-situ rocks, requiring a greater volume of water to saturate the backfill during recovery of the water table compared to the surrounding (undisturbed) rocks.
- All groundwater inflow reporting to active areas of pits will be collected in sumps and pumped out.
- Since the mining schedule progresses from the deepest to shallowest areas of pits, the backfilled areas will not be dewatered, such that the water table within the backfilled areas will be free to recover without risk of inflow and drainage into active (higher) areas of the pits.
- Mined-out pits will be backfilled above the level of the pre-mining water table except for final voids within Pit 1 and 4, where lakes are likely to form following post-mining recovery of the water table.

**Table 4-1 Representation of the mining schedule in the groundwater modelling**


Mining year	Mining sequence (year) <sup>[1]</sup> <sup>[2]</sup>		
	Pit 2	Pit 1	Pit 4
1	1		
2	1, 2		
3	1, 2, 3		
4	1, 2, 3, 4		
5	1, 2, 3, 4, 5		
6	4, 5, 6		
7	5, 6, 7		
8	7, 8		
9	8, 9		
10	9, 10	10	
11	10, 11	11	
12	11, 12	12	12
13		13	12, 13
14		14	FV <sup>[3]</sup>
15		15	FV
16		16	FV
17		FV	FV

- Notes:
1. Refer Figure 15 for sequence
  2. Grey shaded cells represent 'no dewatering'
  3. FV – final void



Mining Sequence	
[Light Blue]	Year 1
[Light Green]	Year 2
[Yellow]	Year 3
[Red]	Year 4
[Green]	Year 5
[Blue]	Year 6
[Dark Red]	Year 7
[Orange]	Year 8
[Light Green]	Year 9
[Purple]	Year 10
[Dark Red]	Year 11
[Olive Green]	Year 12
[Yellow]	Year 13
[Dark Green]	Year 14
[Dark Blue]	Year 15
[Blue]	Year 16

**Figure 14**  
Mine plan and schedule

  
 Scale @ A4 1:55,000  
 Date: 10/08/17  
 Drawn: Gayle B.

Legend			
	ML 80187		North Coast Rail Line
	ML 700022		Haul roads
	Open-cut Mine Pit		Proposed mine infrastructure
	Dam Catchment		Watercourse
	Waste Dump Area		Main road
	Overland Conveyor		Cadastral boundary

DATA SOURCE  
QLD Open Source Data, 2017



Dewatering of mine pits and depressurisation at the pit faces is represented in the groundwater modelling using seepage face boundary conditions at which the maximum value of hydraulic head is constrained to the elevation of the seepage face. Seepage face boundary conditions are activated sequentially at the elevation of the pit floor with the timing shown in Table 4-1. A seepage face can discharge groundwater if the pressure at the seepage face would otherwise be greater than atmospheric pressure and by this means maintains the water table at the elevation of the pit floor. Model-calculated fluxes at seepage faces are summed for groups of model cells over time to calculate the predicted inflows rates and volumes to the mine pits.

#### 4.1.2 Water Storages

Three water storages are proposed at the mine site, including Dam 1 located east of Pit 4 and north of Pit 2, Dam 2 located west of Pits 1 and 2, and a small storage associated with the Train Loadout Facility located further to the east of the mine pits (Figure 1). The groundwater modelling considers two alternate possibilities - either the storages permanently contain water and connect and leak to groundwater, or the storages are sealed and do not interact with groundwater. A situation somewhere between these two extreme cases is likely.

For the case in which the storages permanently contain water and leak to groundwater, the storages are represented in the groundwater model using River boundary conditions, based on the following assumptions:

- Dam 1 has a water level of approximately 26 m AHD and contains water permanently from year 1 to 16 of mining, after which it is empty.
- Dam 2 has a water levels of approximately 38 m AHD and contains water permanently from year 1 to 16 of mining, after which it is empty.
- The loadout-facility storage has a water levels of approximately 36 m AHD and contains water permanently from year 1 to 16 of mining, after which it is empty.

In the absence of measured data, the parameters of the River boundary conditions use the surface-water stage heights (surface water levels) listed above, and cell conductance values of 100 m<sup>2</sup>/d based on cell length and width 100 m, saturated thickness 10 m below the bed of the storages, and vertical hydraulic conductivity 0.1 m/d. The modelling results are effected by the assumed value of conductance, which represents the degree of connection between surface water and groundwater, and controls the potential for surface water leaking from the storages to mitigate drawdown, and to contribute additional inflow to the dewatered pits.

For the case in which the storages are disconnected from groundwater, they are not represented in the groundwater modelling because they are assumed to have no effect on groundwater conditions.

#### 4.1.3 Pit Backfill

For the groundwater model, backfill material in the mine pits is assumed to have the following arbitrary properties:

- horizontal hydraulic conductivity 1 m/d;
- vertical hydraulic conductivity 0.1 m/d; and
- fillable porosity 0.2.

These choices of parameter values affect the rate at which the predicted water table will recover in the backfilled areas of the mine pits after dewatering ceases. However, they do not affect the predictions of mine inflows.

#### 4.1.4 Final Mine-Pit Voids

A simple assessment of whether the water table is likely to recover above the base of the final voids is made based on the annual rainfall and evaporation potentials and the catchment areas of the final voids, which are assumed to be defined by areas enclosed by the void perimeters. For average annual rainfall 0.75 m/y and average annual evaporation potential 2.2 m/y, the following assessments are applied to the final voids (Figure 15):

- Pit 1 final void – the area required to evaporate a rainfall volume of  $0.75 \text{ m/y} \times 229,760 \text{ m}^2 = 172,320 \text{ m}^3/\text{y}$  at an evaporation rate of 2.2 m/y is approximately 78,327 m<sup>2</sup>, which equates to a wall elevation in the final void of approximately 15 m AHD; and similarly
- Pit 4 final void – the area required to evaporate a rainfall volume of  $0.75 \text{ m/y} \times 516,000 \text{ m}^2 = 387,000 \text{ m}^3/\text{y}$  at an evaporation rate of 2.2 m/y is approximately 175,909 m<sup>2</sup>, which equates to a wall elevation in the final void of approximately -55 m AHD.

Thus, excluding groundwater seepage into the final voids, it is roughly estimated that the surface water levels in the final voids in Pits 1 and 4 would recover to around 15 m AHD and -55 m AHD, respectively. In the groundwater modelling, these conditions are simulated using Seepage Face boundary conditions that are set to the above elevations from the end of mining (year 17) onwards. This choice means that in model simulations the water bodies in the final voids can recover up to these specified elevations but no higher, resulting in permanent drawdown of the water table relative to pre-mining conditions, caused by the final voids acting as groundwater discharge (evaporation) features.

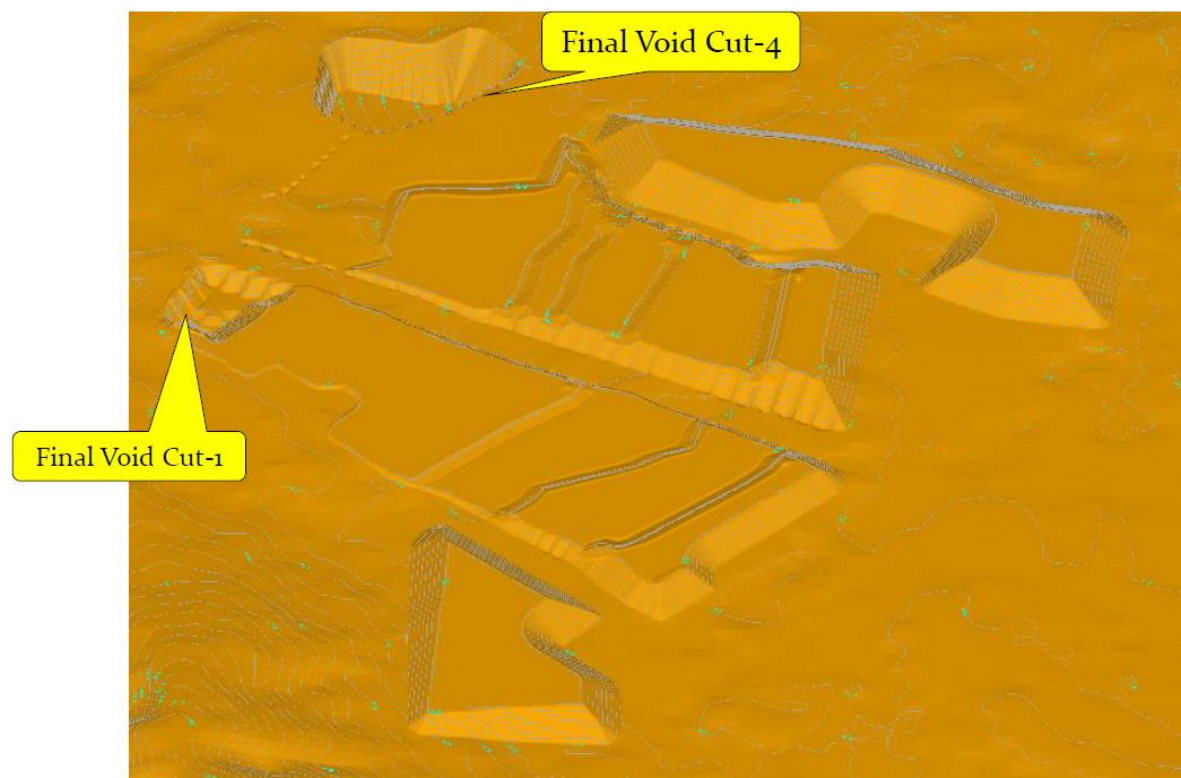


Figure 15 Final rehabilitation surface showing final voids (Source: Alpha-Mine Planning 4U)

### 4.1.5 Grid Refinement

Additional grid refinement has been added to the predictive model (developed from the calibration model) to accommodate a larger mine plan than existed when the calibration model was constructed. The grid refinement includes a slightly larger area with 100 × 100 m grid cells to encompass the expanded mine plan. The total number of active cells in the refined grid is 171,720 (28,620 per layer) consisting of 159 rows and 180 columns.

### 4.1.6 Stress Periods

Predictive model simulations are run for 117 years, consisting of a pre-mining stress period of 1 year, sixteen stress periods of 1 year each during mining, and a post-mining stress period of 100 years. The stress periods during mining are shown diagrammatically in Figure 16. Time stepping during stress periods uses the ATO (auto time stepping) package of MODFLOW-SURFACT.

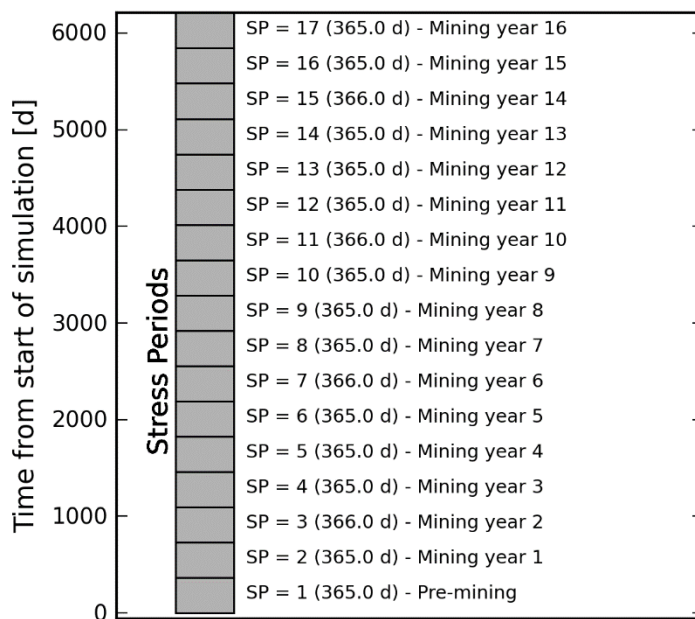


Figure 16 Model stress periods during mining (post-mining stress period not shown)

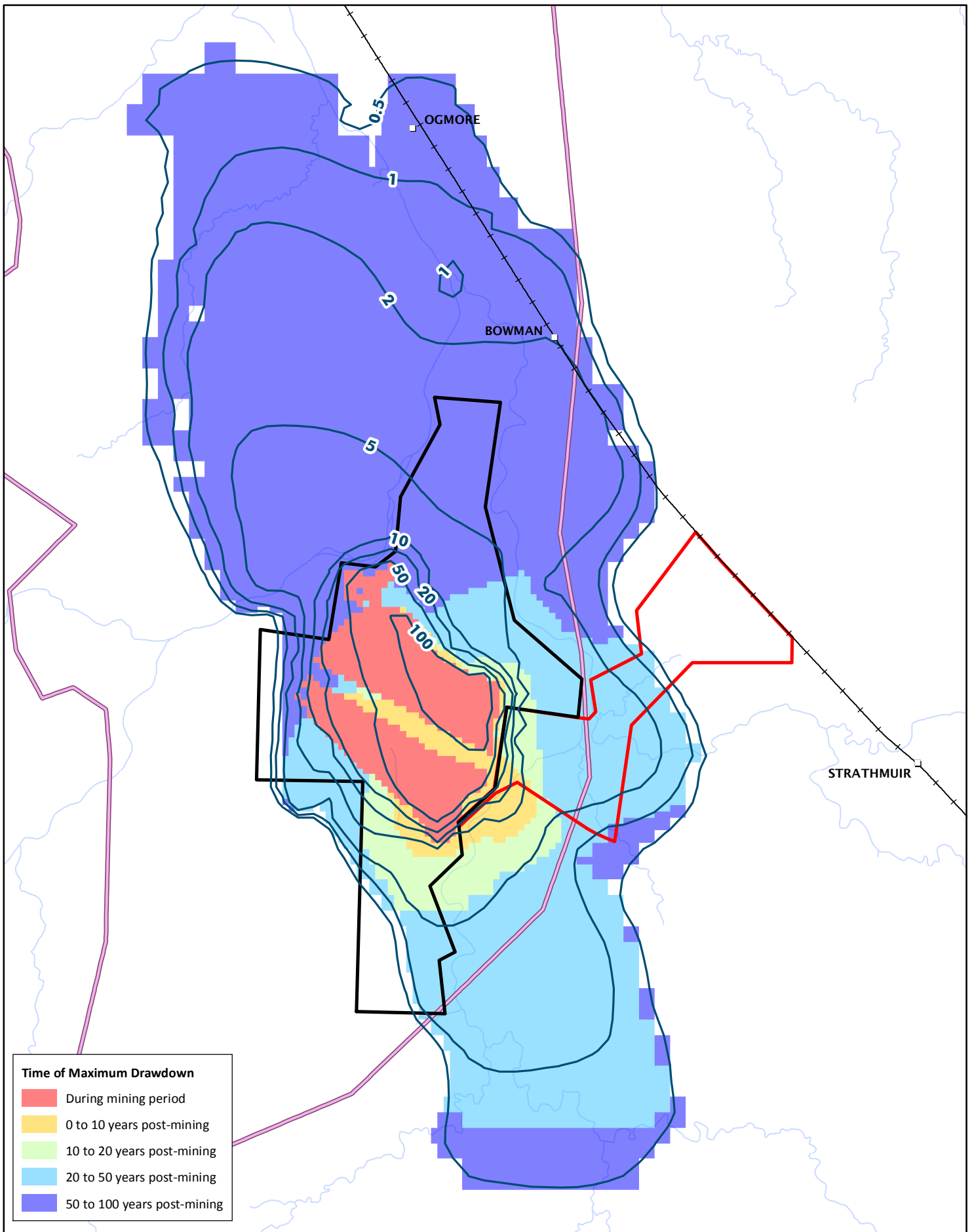
## 4.2 Modelling Results

### 4.2.1 Predicted Drawdown and Mounding

The numerical model has been used to predict the extent (vertically and laterally) of groundwater drawdown or mounding arising from the mine water affecting activities, specifically mine dewatering / depressurisation and water storages. As the mine area has been dewatered and depressurised during the period of mining, the period after mining will involve recovery of groundwater levels / pressures within the mine area and, as a result, areas surrounding the mine will continue to show declining levels / pressures as water is 'fed' into the recovery zones.

Figure 17 and Figure 18 presents the predicted evolution of drawdown extent (due to recovery of groundwater in response to mine pits) over time following cessation of mining, and Figure 19 presents the predicted evolution of mounding extent (due to potential leakage of groundwater from water storages) during mining. The following provides brief description of the figures:

- Figure 17 and Figure 18 present the predicted maximum extent of drawdown associated with mine water affecting activities, including permanent water storages, and time period when that maximum drawdown is predicted to occur. As shown
  - the effect of water storages (lined or unlined) has little effect on the evolution of drawdown extent during or following mining;
  - the drawdown ‘cone of depression’ is shown to be elongated north-south and largely restricted to the valley fill Cenozoic sediments and underlying rocks;
  - during mining  
(as expected) large water table drawdowns of more than around 50 m are predicted to occur beneath, and immediately surrounding, the mine pits during mining;
  - 0 to 20 years after mining finishes  
the extent of maximum drawdown (between around 2 and 10 m) expands slowly up-gradient (to the south of the mine);
  - 20 to 50 years after mining finishes  
the extent of maximum drawdown (between around 1 and 5 m) expands up-gradient (largely to the south and east of the mine), whilst the extent of maximum drawdown (of between 2 and 10 m) slowly expands to the north; and
  - 50 to 100 years after mining ceases  
the extent of maximum drawdown (between around 0.5 and 10 m) expands significantly toward the north.
- Figure 19 presents the predicted maximum extent of mounding associated with possible leakage of water from storages during mining. As shown, the extent of mounding is predicted to be largely restricted to the valley fill Cenozoic sediments, and mine dewatering / depressurisation is likely to restrict the timing of mounding to within the first 8 to 12 years of mining. The mounding extent is considered conservative (see Section 4.2.2 for explanation).



**Time of Maximum Drawdown**

- During mining period
- 0 to 10 years post-mining
- 10 to 20 years post-mining
- 20 to 50 years post-mining
- 50 to 100 years post-mining



0 0.5 1 km

**Legend**

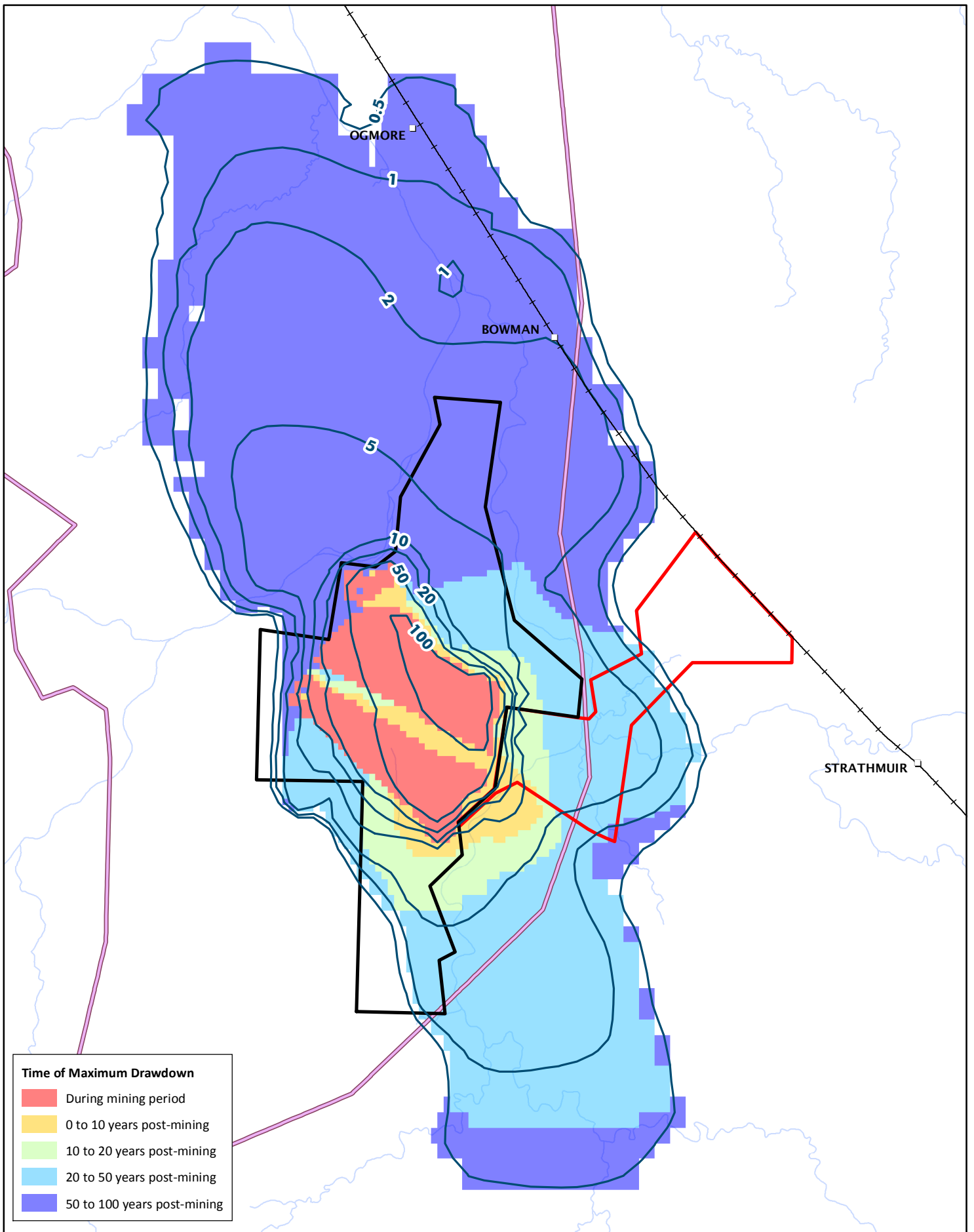
- Maximum Drawdown Contour, m
- ML 80187
- ML 700022
- Styx Basin
- North Coast Rail Line
- Watercourse

Scale @ A4 1:80,000  
 Date: 10/08/17  
 Drawn: Gayle B.

**Figure 17**  
 Predicted drawdown extent and  
 time period of maximum drawdown  
 with water storage interaction

DATA SOURCE  
 QLD Spatial Catalogue (QSpatial), 2017





**Time of Maximum Drawdown**

- During mining period
- 0 to 10 years post-mining
- 10 to 20 years post-mining
- 20 to 50 years post-mining
- 50 to 100 years post-mining



0 0.5 1 km

**Legend**

- Maximum Drawdown Contour, m
- ML 80187
- ML 700022
- Styx Basin
- North Coast Rail Line
- Watercourse

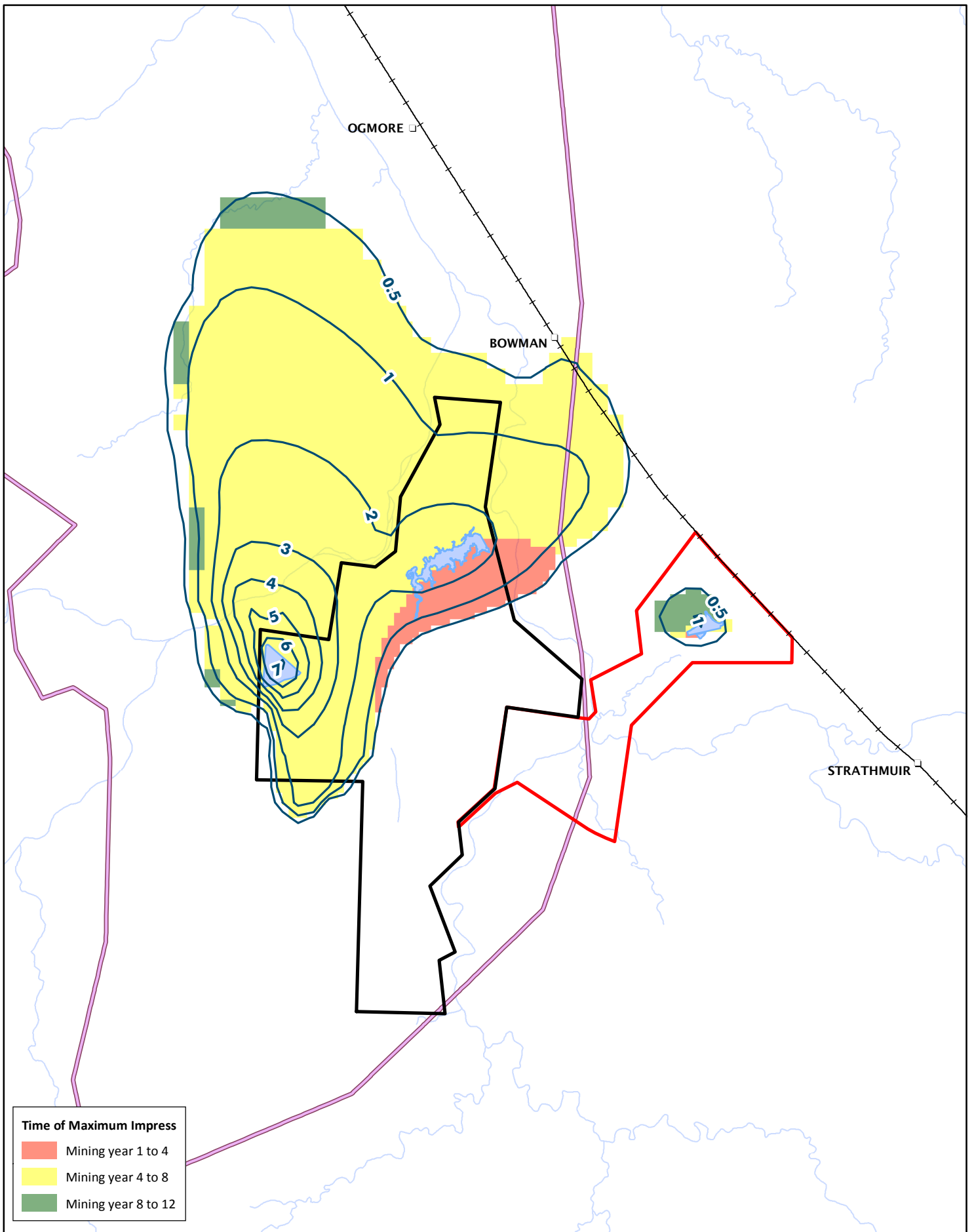
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 Date: 10/08/17  
 Drawn: Gayle B.

**Figure 18**  
 Predicted drawdown extent and time period of maximum drawdown with no water storage interaction

DATA SOURCE  
 QLD Spatial Catalogue (QSpatial), 2017







**Time of Maximum Impress**

- Mining year 1 to 4
- Mining year 4 to 8
- Mining year 8 to 12



0 0.5 1 km

Scale @ A4 1:80,000  
 Date: 10/08/17  
 Drawn: Gayle B.

**Legend**

- Maximum Impress Contour, m
- Water Storage Dam
- ML 80187
- ML 700022
- Styx Basin
- North Coast Rail Line
- Watercourse

**Figure 19**  
 Predicted mounding extent and time period with permanent storages

DATA SOURCE  
 QLD Spatial Catalogue (QSpatial), 2017



### 4.2.2 Predicted Inflow to Mine Pits

Average rates of predicted annual inflow of groundwater to the mine pits are summarised in Figure 20 and Figure 21. The timing of when groundwater inflows to the pits commence in the modelling is controlled by the dewatering schedule presented in Table 4-1.

Leakage of water from the storages has the effect of roughly doubling the predicted inflow rates to the mine pits from around year six of mining onwards. However, this result assumes the storages permanently contain water and continually leak. Within this context, it is likely that the simulated leakage rates from the storages are too high since they imply a water supply of several megalitres per day into the storages on a permanent basis.

Total inflows to the pits with no leakage from the storages are predicted to generally decrease over the first nine years of mining, from around 2.5 to 0.7 ML/d, then increase again to around 1.8 ML/d in year 10 of mining when Pit 1 starts, and then decrease over the remainder of the mining period to less than 0.5 ML/d at the end of mining.

The predicted inflow rates are necessarily sensitive to the adopted values of hydrogeological properties in the HSUs representing the Styx Coal Measures. As a rule-of-thumb, changing the hydraulic conductivity of HSUs to values that are double the adopted values would roughly double the predicted inflow rates, while halving them would roughly halve the predicted inflow rates.

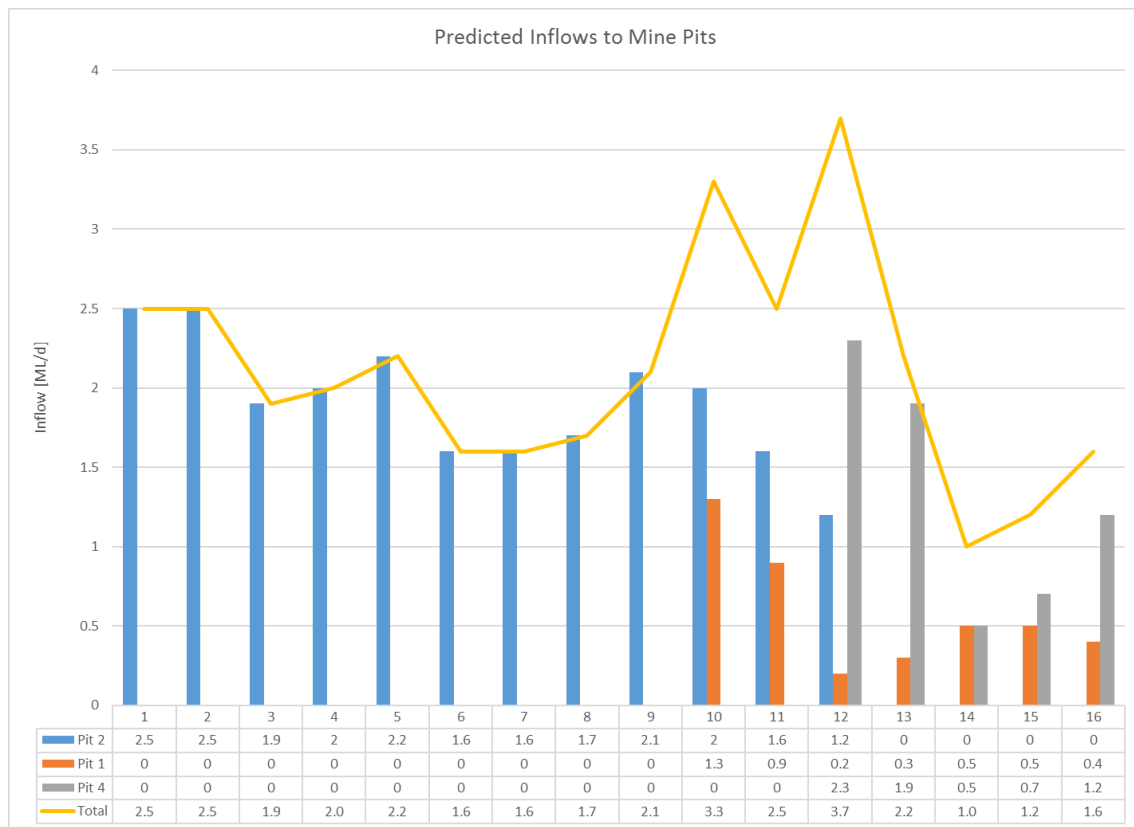


Figure 20 Predicted mine inflows with water storage interaction

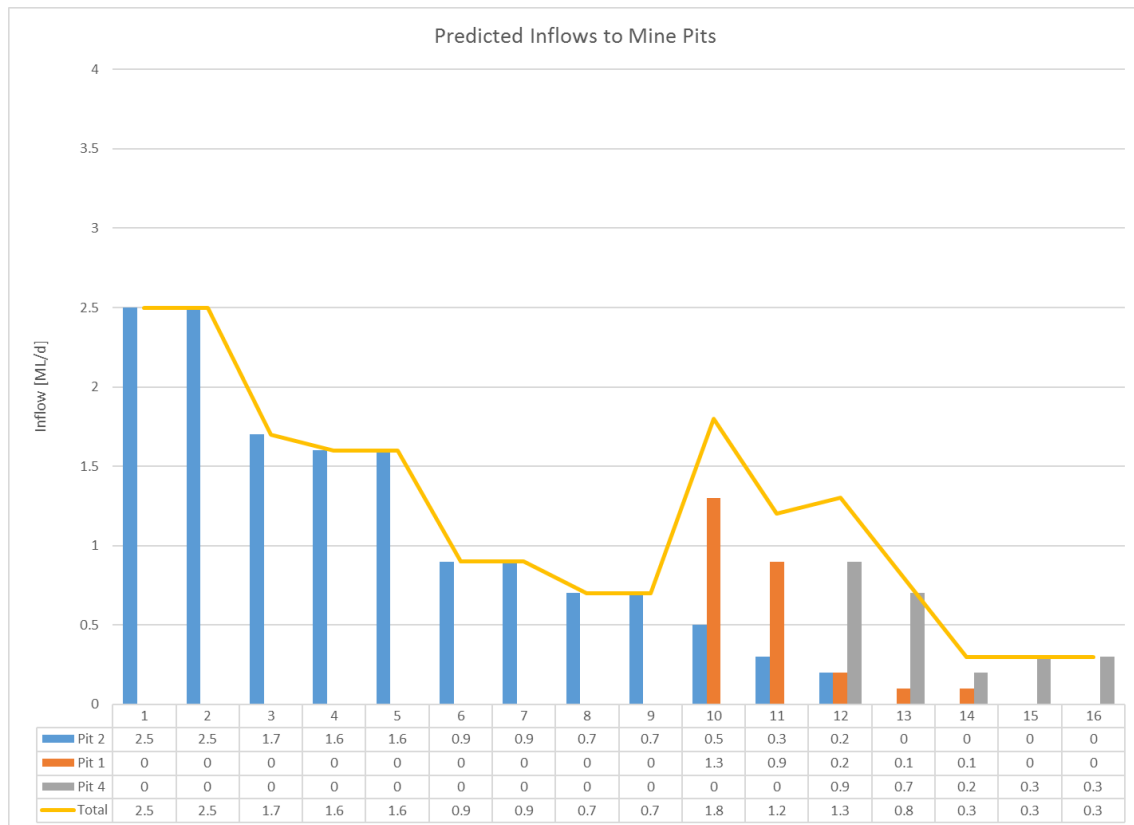


Figure 21 Predicted mine inflows with no water storage interaction

## 4.3 Model Confidence and Uncertainty

### 4.3.1 Model Confidence Level Classification

The Australian Groundwater Modelling Guidelines (Barnett et al. 2012) introduce the concept of confidence level classification. According to the Guidelines the level of confidence of a model typically depends on available data, whether or not a model can be calibrated using available data, and whether model predictions are required for periods with stresses that are similar to those in the past or for periods with very different stresses.

The groundwater model developed for the Project is considered to have the characteristics of Class 1 confidence level, i.e. a low to moderate confidence level (or a low to medium complexity model according to the MDBC guideline), typical for an impact assessment model. Mining causes changes to the hydrogeological system that are large compared to the pre-mining condition, over a timeframe that is greater than the period of the past hydrological observations. In other words, future stresses are many times more than those in the past and the predictive model timeframe is more than 10 times the period of hydrological observations. The challenge for modellers is to take advantage of all available information, adopting conservative assumptions where appropriate and undertaking sensitivity analysis (e.g. bounding analyses or testing different conceptual models) to explore the effects of parameter uncertainty that cannot be reduced by calibration.

As data become available, the Styx groundwater model can be updated, revised and recalibrated to achieve a higher confidence level. For example, pumping tests will be proposed along with a hydrogeochemical sampling and analysis program to provide additional information on groundwater and surface water interactions.

### 4.3.2 Model Limitations

The geometry and properties of natural environments can never be fully characterised and the past and potential future hydrogeological processes can only be inferred from a limited number of uncertain measurements. Therefore, simplifications are necessary and uncertainty is inherent in groundwater modelling.

The groundwater model for the Project has been constructed from all available geological data (borehole logs and geological maps) and calibrated in steady state to measured groundwater levels with parameter values that are consistent with those derived from hydraulic testing and the literature. The predicted groundwater inflow rates, albeit considered conservative, are also consistent with those observed and predicted at other mines in the Bowen Basin.

Where uncertainty cannot be reduced through model calibration, conservative assumptions have been made and effects of parameter uncertainty have been explored through sensitivity analysis.

## 5 References

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