APPENDIX N

Groundwater Technical Report

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT

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The Australian Government is delivering Inland Rail through the Australian Rail Track Corporation (ARTC), in partnership with the private sector.

Inland Rail Gowrie to Helidon EIS

Appendix N – Groundwater Technical Report

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Contents

1 Introduction 1

1.1 Project overview and objectives 1
1.2 Project location and key features 2
1.3 Objectives and scope of report 5

2 Legislative, policy standards and guidelines 8

2.1 Commonwealth legislation 8
2.1.1 Environment Protection and Biodiversity Conservation Act 1999 8
2.1.2 Water Act 2007 8
2.2 Queensland legislation 9
2.2.1 Environmental Protection Act 1994 9
2.2.2 Water Act 2000 9
2.2.3 Water Regulation 2016 10
2.3 Policies, plans, and guidelines 11
2.3.1 Environmental Protection Policy (Water and Wetland Biodiversity) 2019 11
2.3.2 Water Plans 11
2.3.3 EIS information guideline – Water 2016 14

3 Methodology 15

3.1 Groundwater study area 15
3.2 Approach 15
3.2.1 Stage 1 - Desktop study 15
3.2.2 Stage 2 – Geotechnical and hydrogeological investigations 17
3.2.3 Stage 3 – Groundwater impact identification 17
3.2.4 Stage 4 – Impact assessment 18
3.2.5 Stage 5 - Reporting 18
3.3 Impact assessment methodology 18
3.3.1 Magnitude of impacts 19
3.3.2 Sensitivity 19
3.3.3 Significance of impact 20
3.4 Cumulative impact assessment 21

4 Site setting 23

4.1 Location 23
4.2 Land use 24
4.3 Topography and drainage 24
4.3.1 Topography 24
4.3.2 Drainage 25
4.4 Climate and rainfall 27
4.4.1 Climate 27
4.4.2 Cumulative Rainfall Departure 28

5 Field investigations 30

5.1 Standpipe piezometer installation 32
5.2 Vibrating wire piezometer installation 32
5.3 Permeability testing 33

5.4 Groundwater level monitoring 33
5.5 Groundwater sampling 37

6 Geology 39

6.1 Regional geology 39
6.1.1 Clarence-Moreton Basin 39
6.1.2 Regional stratigraphy 40
6.1.3 Structural geology 42
6.2 Project geology 43
6.2.1 Surface geology 45
6.2.2 Alluvium/Colluvium (Quaternary/Tertiary) 45
6.2.3 Main Range Volcanics 48
6.2.4 Undifferentiated Tertiary Sediments 48
6.2.5 Walloon Coal Measures 49
6.2.6 Crater rim 49
6.2.7 Koukandowie Formation (Marburg Subgroup) 49
6.2.8 Gatton Sandstone (Marburg Subgroup) 50
6.3 Acid sulfate soils and acid rock drainage potential 50

7 Hydrogeology 52

7.1 Existing hydrogeological regime 52
7.1.1 Alluvium/Colluvium (Quaternary/Tertiary) 54
7.1.2 Main Range Volcanics 55
7.1.3 Koukandowie Formation 57
7.1.4 Gatton Sandstone 58
7.1.5 Walloon Coal Measures 59
7.2 Groundwater levels and flow 60
7.2.1 Alluvium/Colluvium (Quaternary) 61
7.2.2 Main Range Volcanics 63
7.2.3 Walloon Coal Measures 65
7.2.4 Koukandowie Formation 66
7.2.5 Gatton Sandstone 66
7.2.6 Groundwater flow summary 68
7.3 Groundwater quality 68
7.3.1 Alluvium/Colluvium (Quaternary/Tertiary) 71
7.3.2 Main Range Volcanics 72
7.3.3 Gatton Sandstone 73
7.3.4 Marburg Subgroup 74
7.3.5 Koukandowie Formation 75
7.3.6 Walloon Coal Measures 75
7.3.7 Salinity summary 76
7.3.8 Groundwater quality summary 77
7.4 Surface water – groundwater interaction 82
7.4.1 Regional surface water-groundwater interaction 82
7.4.2 Local surface water-groundwater interaction 82
7.5 Groundwater use 85
7.5.1 Registered bores 85
7.5.2 Groundwater entitlements 86
7.6 Groundwater dependent ecosystems 95
7.6.1 Potential aquatic groundwater dependent ecosystems 95
7.6.2 Potential terrestrial groundwater dependent ecosystems 97

7.6.3 Potential subterranean groundwater dependent ecosystems 97

8 Environmental values 107

8.1 Environmental values 107
8.2 Water quality objectives 112

9 Groundwater modelling 114

9.1 Construction methodology 114
9.2 Conceptual groundwater models 114
9.3 Predictive modelling of Toowoomba Range tunnel 117
9.3.1 Methodology and model construction summary 117
9.3.2 Boundary conditions 121
9.3.3 Model calibration 122
9.3.4 Hydrogeological design parameters 124
9.3.5 Model assumptions 125
9.3.6 Model results 126
9.3.7 Sensitivity analysis 136
9.3.8 Model limitations 137
9.3.9 Model reliability 137
9.4 Groundwater inflow to cuts along the alignment 138
9.4.1 Methodology 138
9.4.2 Model cuts 139
9.4.3 Modelled seepage rate results 140
9.4.4 Model limitations 141
9.5 Refinement of the predictive model 142

10 Potential impacts 143

10.1 Project elements relevant to potential groundwater impacts 143
10.1.1 Site clearing and grading 144
10.1.2 Embankments 145
10.1.3 Viaducts and bridges 146
10.1.4 Cut sections 147
10.1.5 Tunnelling 147
10.1.6 Construction water supply 148
10.1.7 Drainage infrastructure 150
10.2 Construction phase potential impacts 151
10.2.1 Water resources 151
10.2.2 Water quality 169
10.3 Operation phase potential impacts 170
10.3.1 Water resources 170
10.3.2 Water quality 176

11 Mitigation 178

11.1 Design considerations 178
11.2 Proposed mitigation measures 179
11.3 Groundwater management and monitoring program 185
11.3.1 Groundwater level monitoring 188
11.3.2 Groundwater quality monitoring 189
11.3.3 Data management and reporting 190
11.3.4 Summary 191

12 Impact assessment 192
12.1 Temporary impacts 192
12.2 Long-term impacts 192
12.3 Cumulative impacts 194
12.3.1 Surrounding projects and timeline relationships 194
12.3.2 Assessment of potential cumulative impacts 198

13 Conclusions 201
14 References 202

Appendices

Appendix A

Inland Rail Section 320 – Gowrie to Helidon Hydrogeological Interpretive Report.

Appendix B

Registered bore holes predicted to be impacted (outside of the groundwater study area)

Figures

Figure 1.1 Project location
Figure 4.1 Topography profile from Ch -1.76 to Ch 26.0 km
Figure 4.2 Topography and surface water features of the groundwater study area
Figure 4.3 Mean monthly pan evaporation and rainfall
Figure 4.4 Cumulative Rainfall Departure for Helidon Post Office BoM Station (040096)
Figure 5.1 Hydrograph of vibrating wire piezometers in 320-01-BH2102
Figure 5.2 320-01-BH2101 hydrograph
Figure 5.3 320-01-BH2103 hydrograph
Figure 5.4 320-01-BH2201 hydrograph
Figure 5.5 320-01-BH2216 hydrograph
Figure 5.6 320-01-BH2217 hydrograph
Figure 5.7 320-01-BH2218 hydrograph
Figure 5.8 320-01-BH2301 hydrograph
Figure 6.1 Clarence-Moreton Basin and key structural features
Figure 6.2 Identified faults in proximity to the groundwater study area (source: Hodgkinson et al. 2006)
Figure 6.3 Surface geology across the groundwater study area
Figure 7.1 Hydrograph of Lockyer Creek alluvium
Figure 7.2 Regional groundwater flow of Lockyer Creek alluvium
Figure 7.3 Regional groundwater flow of alluvium within and west of the Project area
Figure 7.4 Groundwater levels for MRV bores within 5 km of alignment (1980 to 2019)
Figure 7.5 Groundwater levels for MRV bores within 5 km of alignment (2010 to 2019)
Figure 7.6 Regional groundwater flow direction of the MRV
Figure 7.7 Regional groundwater flow direction of the WCM
Figure 7.8 Groundwater levels for Gatton Sandstone bore within 5 km of alignment
Figure 7.9 Groundwater flow direction of the Gatton Sandstone
Figure 7.10 Piper diagram of alluvium units within 5 km of the Project
Figure 7.11 Piper diagram of the MRV aquifer within 5 km of the Project
Figure 7.12 Piper diagram of the Gatton Sandstone aquifer within 5 km of the Project
Figure 7.13 Piper diagram of the Marburg Subgroup within 5 km of the Project
Figure 7.14 Surface water level (1432203A) with groundwater level (RN14320190)
Figure 7.15 Surface water level (1432203C) with groundwater level (RN14320190)
Figure 7.16 Groundwater level (RN14320190) with daily rainfall (BoM Station 040096)
Figure 7.17a-d Registered groundwater bores and project monitoring bores

Figure 7.18a-e Aquatic GDEs
Figure 7.19a-d Terrestrial GDEs
Figure 9.1 Conceptualisation of the Project
Figure 9.2 Conceptualisation of the Toowoomba Range tunnel
Figure 9.3 Model extent
Figure 9.4 Isometric view of groundwater model illustrating layering of the model
Figure 9.5 Long section of predictive model layers
Figure 9.6 Water supply bore distribution actual (red dots) vs simplified distribution (black crosses)
Figure 9.7 Observed and calibrated groundwater level elevation
Figure 9.8 Model calibration results
Figure 9.9 Predicted construction phase groundwater inflow for each unit
Figure 9.10 Predicted construction phase groundwater inflow for each tunnel feature
Figure 9.11 Western portal – Modelled groundwater level drawdown at 34 weeks (shallow MRV)
Figure 9.12 Intermediate ventilation shaft – Modelled groundwater level drawdown at 62 weeks (shallow MRV)
Figure 9.13 Intermediate ventilation shaft – Modelled groundwater level drawdown at 62 weeks (deep MRV)
Figure 9.14 Intermediate ventilation shaft – Modelled groundwater level drawdown at 62 weeks (Koukandowie Formation)
Figure 9.15 Modelled groundwater level drawdown at 107 weeks (shallow MRV)
Figure 9.16 Modelled groundwater level drawdown at 107 weeks (deep MRV)
Figure 9.17 Modelled groundwater level drawdown at 107 weeks (Koukandowie Formation)
Figure 9.18 Predicted operation phase (elapsed 20 years) groundwater level drawdown (green is shallow MRV; gray is Koukandowie Formation)
Figure 9.19 Seepage flow analytical model for cuts along the Project where h_0 is the undisturbed (ambient) piezometric water level and h is the piezometric head
Figure 10.1 Alignment profile schematic
Figure 10.2 Preliminary estimate of construction water requirements over time
Figure 10.3 Preliminary water demand along the alignment
Figure 10.4 Modelled groundwater level drawdown at 107 weeks (shallow MRV)
Figure 10.5 Modelled groundwater level drawdown at 107 weeks (deep MRV)
Figure 10.6 Modelled groundwater level drawdown at 107 weeks (Koukandowie Formation)
Figure 10.7 Modelled groundwater level drawdown at 62 weeks (shallow MRV)
Figure 10.8 Modelled groundwater level drawdown at 62 weeks (deep MRV)
Figure 10.9 Modelled groundwater level drawdown at 62 weeks (Koukandowie Formation)
Figure 10.10 Modelled groundwater level drawdown at 34 weeks (shallow MRV)
Figure 10.11 Modelled operation phase groundwater level drawdown (shallow MRV)
Figure 10.12 Modelled operation phase groundwater level drawdown (deep MRV)
Figure 10.13 Modelled operation phase groundwater level drawdown (Koukandowie Formation)
Figure 11.1 Development and implementation of the Groundwater Management and Monitoring Program over sequential Project phases
Figure 12.1 Projects surrounding the proposal - cumulative assessment

Tables

Table 1.1 Key features of the Project
Table 1.2 Groundwater Project objectives (ToR)
Table 3.1 Data sources for the Project
Table 3.2 Criteria for magnitude classification of potential impacts on groundwater
Table 3.3 Timeframes for duration terms
Table 3.4 Sensitivity criteria
Table 3.5 Significance assessment matrix
Table 3.6 Significance classifications
Table 4.1 Climate summary for Toowoomba Airport and Helidon Post Office BoM stations

Table 5.1 Project bore installation locations and results (feasibility design phase)
Table 6.1 Clarence-Moreton Basin Stratigraphy
Table 6.2 Summary of geological units traversed by the Project
Table 7.1 Hydrostratigraphic summary of the groundwater study area
Table 7.2 Project bore groundwater level data
Table 7.3 Groundwater elevation in alluvium units within 5 km of the alignment
Table 7.4 Groundwater elevation summary in the WCM within 5 km of the alignment
Table 7.5 Hydrochemical composition of water in four main aquifers
Table 7.6 Comparison of groundwater quality and Australian Drinking Water Guidelines
Table 7.7 Summary of groundwater salinity – Regional
Table 7.8 Summary of groundwater salinity across Project bores
Table 7.9 Comparison of groundwater quality data to guideline values in the groundwater study area
Table 7.10 Summary of registered bore usage types within the groundwater study area
Table 7.11 Summary of groundwater licences from aquifers within the groundwater study area
Table 7.12 Summary of town water supply bores within the groundwater study area
Table 7.13 Summary of groundwater entitlements and bores which intersect the groundwater study area
Table 7.14 Wetlands and springs
Table 8.1 Summary of EVs for groundwater relevant to the Project
Table 8.2 Summary of environmental values, water quality objectives and relevance to the Project
Table 8.3 Groundwater water quality objectives for the Project
Table 9.1 Summary of construction activities for the Project
Table 9.2 Summary of reference design aspects modelled
Table 9.3 Preliminary hydrogeological design parameters
Table 9.4 Hydrogeological parameters applied in the model based on model calibration
Table 9.5 Predicted maximum groundwater inflow - construction phase
Table 9.6 Total predicted inflow volumes – construction phase
Table 9.7 Total predicted inflow volumes – operation phase (20 years)
Table 9.8 Sensitivity analysis scenarios
Table 9.9 Construction phase sensitivity analysis of groundwater inflow (maximum results)
Table 9.10 Operation phase sensitivity analysis of groundwater inflow
Table 9.11 Project cuts modelled
Table 9.12 Design details of modelled cuts
Table 9.13 Estimated seepage rates for cuts likely to intersect groundwater
Table 10.1 Summary of key design elements with potential to impact on groundwater and assumptions
Table 10.2 Summary of embankment details
Table 10.3 Preliminary estimated of water requirements and potential water sources for construction activities
Table 10.4 Existing registered bores within the construction footprint
Table 10.5 Registered bores within the predicted groundwater drawdown extents (construction)
Table 10.6 Existing registered bores within the construction footprint near critical vibration areas
Table 10.7 Summary of groundwater dependent ecosystems within groundwater drawdown contours during construction
Table 10.8 Land parcels with water entitlements under the Water Act 2000 directly impacted by the Project
Table 10.9 Registered bores within the construction and permanent footprint
Table 11.1 Initial mitigation measures (design considerations)
Table 11.2 Groundwater mitigation measures
Table 11.3 Indicative minimum groundwater monitoring network
Table 11.4 Summary of Groundwater Monitoring and Management Program requirements for each Project delivery phase
Table 12.1 Significance assessment summary for groundwater
Table 12.2 Applicable projects and operations considered for the cumulative impact assessment
Table 12.3 Summary of potential cumulative impacts
Table 12.4 Summary of the cumulative impact assessment

Abbreviations

Abbreviation	Explanation
AHD	Australian Height Datum
ARD	Acid rock drainage
ARTC	Australian Rail Track Corporation Ltd
ASS	Acid sulfate soils
B2G	NSW/QLD Border to Gowrie Inland Rail project
BoM	Bureau of Meteorology
CEMP	Construction Environmental Management Plan
CIA	Cumulative Impact Assessment
DES	Department of Environment and Science
DNRME	Department of Natural Resources, Mines and Energy (former)
DRDMW	Department of Regional Development, Manufacturing and Water
DSITI	Department of Science, Information Technology and Innovation (former)
DTMR	Department of Transport and Main Roads
EC	Electrical Conductivity
EIS	Environmental Impact Statement
EP Act	*Environmental Protection Act 1994* (Qld)
EPBC Act	*Environmental Protection and Biodiversity Conservation Act 1999* (Cth)
EPP (Water and Wetland Biodiversity)	Environmental Protection Policy (Water and Wetland Biodiversity) 2019
EV	Environmental Value
FFJV	Future Freight Joint Venture
G2H	Gowrie to Helidon
GAB	Great Artesian Basin
GABORA	Great Artesian Basin and Other Regional Aquifers
GDE	Groundwater Dependent Ecosystems
GDR	Great Dividing Range
GMMP	Groundwater management and monitoring plan
H2C	Helidon to Calvert Inland Rail project
Inland Rail	Melbourne to Brisbane Inland Rail
km	kilometres
LGA	Local government area
m	metre
mbgl	metres below ground level
Mbgs	Metres below ground surface
ML	Megalitres
MRV	Main Range Volcanics
NHMRC	National Health and Medical Research Council
NR	Not reported
NSW	New South Wales
PASS	Potential acid sulfate soils

Abbreviation	Explanation
PVC	Polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
QC	Quality Control
QLD	Queensland
QR	Queensland Rail
SDPWO Act	*State Development and Public Works Organisation Act 1971* (Qld)
SEQ	South East Queensland
SWL	Standing Water Level
TBM	Tunnel boring machine
TDS	Total Dissolved Solids
The Basin	The Murray-Darling Basin
The Project	Gowrie to Helidon Inland Rail Project
the proponent	Australian Rail Track Corporation Ltd
UTS	Undifferentiated Tertiary Sediment
VWP	Vibrating wire piezometers
Water Act	*Water Act 2000* (Qld)
WCM	Walloon Coal Measures
WQOs	Water quality objectives

Glossary

Abbreviation	Explanation
Aggloemeratic	Agglomeratic material is a result of the coarse accumulation of large blocks of volcanic material.
Aquifer	An aquifer is an underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt). Groundwater can be extracted using a water bore. The study of water flow in aquifers and the characterization of aquifers is called hydrogeology.
Clarence-Moreton Basin	The Clarence Moreton Basin is a Mesozoic sedimentary basin on the easternmost part of the Australian continent. It is located in the far north east of the state of New South Wales around Lismore and Grafton and in the south east corner of Queensland.
Condamine River Basin	The Condamine River Basin is located on the northeast corner of the Murray Darling Basin. The major towns in the Basin are Toowoomba, Warwick, Cecil Plains, Dalby and Chinchilla. The dominant land use in the Basin is irrigated cropping, dryland cropping and open grazing. Coal Seam Gas and coal extractive industries are also prevalent throughout the Basin.
Darling Downs	The Darling Downs is a farming region on the western slopes of the Great Dividing Range in southern Queensland, Australia. The Downs are to the west of South East Queensland and are one of the major regions of Queensland.
Depression (hydrogeology)	A cone of depression occurs in an aquifer when groundwater is pumped from a bore. In an unconfined aquifer (water table), this is an actual depression of the water levels. In confined aquifers (artesian), the cone of depression is a reduction in the pressure head surrounding the pumped bore.
Drawdown (hydrogeology)	In subsurface hydrogeology, drawdown is the reduction in hydraulic head observed at a bore in an aquifer.
Ephemeral	A stream that flows only briefly during and following a period of rainfall in the immediate locality.
Fault (geology)	A fault is a crack in the Earth's crust. Typically, faults are associated with, or form, the boundaries between Earth's tectonic plates. In an active fault, the pieces of the Earth's crust along a fault move over time. The moving rocks can cause earthquakes.
Feeder dyke	The term feeder dyke is used for a dyke that acted as a conduit for magma. Magma flowed along, then out of the dyke, then formed another feature. In contrast to magmatic dykes, a sill is a magmatic sheet intrusion that forms within and parallel to the bedding of layered rock.
Fold (geology)	In structural geology, a fold occurs when one or a stack of originally flat and planar surfaces, such as sedimentary strata, are bent or curved as a result of permanent deformation. Synsedimentary folds are those due to slumping of sedimentary material before it is lithified.
Great Dividing Range	The Great Dividing Range, or the Eastern Highlands, is Australia's largest mountain range. It is the third longest land-based range in the world. The range is 3,500 km in length and runs along the whole east coast of Australia. Within the vicinity of the Project, the Great Dividing Range may be commonly referred to as the Toowoomba Range.
Great Escarpment	The Great Escarpment in eastern Australia is an escarpment that runs east of the Great Dividing Range along most of the east of the continent. It was created due to formation of a new continental margin in the Mesozoic, followed by tectonic uplifting of the divide and then scarp retreat. The escarpment is estimated to be approximately 3,600 km in length, from north to south.
Hydraulic conductivity	Hydraulic conductivity is a measure of the ease with which water flows through sediments, determining renewal rates of water, dissolved gases, and nutrients.
Lockyer Creek catchment	Lockyer Creek catchment includes the Lockyer Creek and all associated tributaries. The creek is a tributary of the Brisbane River and is the main drainage system in the Lockyer Valley. The catchment headwaters commence from the eastern slopes of the Great Dividing Range where watercourses flow in the north-easterly direction for more than 100 km before Lockyer Creek reaches its confluence with the Brisbane River north-northeast of Lowood, downstream from the Wivenhoe Dam.

Abbreviation	Explanation
Lockyer Valley	The Lockyer Valley Region is a local government area in the West Moreton region of South East Queensland, Australia, between the cities of Ipswich and Toowoomba
Mound (hydrogeology)	The surface representing the rise in water table or potentiometric surface caused by the injection of water.
Perennial	A perennial stream or perennial river is a stream or river (channel) that has continuous flow in parts of its stream bed all year-round during years of normal rainfall.
Quaternary	The Quaternary is a subdivision of geological time (the Quaternary Period) which covers the last 2.6 million years up to the present day. The Quaternary and the Tertiary Periods together form the Cenozoic Era.
Recharge (groundwater)	Groundwater recharge or deep drainage or deep percolation is a hydrologic process, where water moves downward from surface water to groundwater. Recharge is the primary method through which water enters an aquifer.
Salinity	Salinity refers to the movement and concentration of salt, in landscapes. Both soil and natural waters can become saline.
Southeast Queensland (SEQ)	Southeast Queensland is a bio-geographical, political and administrative region of Queensland which includes Brisbane, the Gold Coast and Sunshine Coast. The region extends from Noosa to the New South Wales border and west to Toowoomba.
Stratigraphy	Stratigraphy is a branch of geology concerned with the study of rock layers and layering. It is primarily used in the study of sedimentary and layered volcanic rocks. Stratigraphy has two related subfields: lithostratigraphy and biostratigraphy.
Toowoomba	The Toowoomba Region is a local government area located in the Darling Downs part of Queensland, Australia.
Tuffaceous	Tuffaceous material is a type of rock made of volcanic ash ejected from a vent during a volcanic eruption. Following ejection and deposition, the ash is compacted into a solid rock in a process called consolidation.
Viaduct	A viaduct is a bridge composed of several small spans for crossing a valley, dry or wetland, or forming an overpass or flyover. The term is conventional for a rail flyover as opposed to a flying junction or a rail bridge which crosses one feature.
Yield (hydrogeology)	Yield is a measure of how much and how quickly groundwater. It is stored in and can flow through layers known as aquifers and can be extracted from an aquifer.

Executive summary

The Project

The Gowrie to Helidon Project (the Project) consists of a single 28 kilometre (km) long dual gauge track, which involves the construction of embankments, bridges, viaducts, cuttings and a 6.24 km long undrained tunnel (the Toowoomba Range tunnel).

The Project generally follows the Gowrie to Grandchester future State transport corridor protected under the *Transport Planning and Coordination Act 1994*. This corridor was identified in the Gowrie to Grandchester Rail Corridor Study in 2003 and was subsequently protected as a 'future public passenger transport corridor' in September 2005 in the Public Passenger Transport Guideline made under the *Transport Planning and Coordination Act 1994*.

Purpose

This groundwater technical report has been prepared to address the relevant groundwater Terms of Reference (ToR) for the Project by assessing potential impacts of the Project on groundwater resources (groundwater levels, flow and quality) and users.

This report outlines the legislative framework and methodology for undertaking the groundwater assessment and potential impacts related to the Project. It describes the existing conditions (including climate, geology and hydrogeology), provides a summary of the environmental values (EVs), identifies potential impacts to groundwater from construction and operation of the Project, includes mitigation measures and presents a residual significance assessment of the identified potential impacts.

Existing environment

The alignment begins approximately 3.7 km west of Gowrie, at Charlton where it connects with the eastern end of New South Wales/Queensland Border to Gowrie (B2G) Inland Rail project. It then runs east, parallel to the existing QR West Moreton System rail corridor on the southern side (Western Line), for approximately 4.8 km before diverging from the West Moreton System rail corridor and passing into the proposed western tunnel portal within the vicinity of Boundary Street and the Toowoomba Bypass interchange at Gowrie.

The alignment then continues through the Toowoomba Range via an approximately 6.24 km long undrained tunnel with an intermediate ventilation shaft (and associated infrastructure) at Cranley. On the eastern side of the tunnel, the alignment exits the range through the eastern portal and continues down the Toowoomba Range via a series of viaducts, embankments and cuttings, past Postmans Ridge, after which it again runs parallel for 800 m to the existing West Moreton System rail corridor on the northern side (Main Line) to connect with the Helidon to Calvert (H2C) Inland Rail project, to the north-west of Helidon.

The South East Queensland (SEQ) Region has a hot and dry climate with warm to hot summers and mild to cool winters. Rainfall is seasonally distributed with a distinct wet season which occurs during the summer months of December through February, and an extended dry season from April through September.

The Great Dividing Range (GDR) is the highest point across the alignment, and creates a division in drainage basins between the east (coastal) and west (inland). West of the GDR, the main watercourse is Gowrie Creek, which flows west. East of the GDR, there are numerous watercourses and their ephemeral gullies which flow in the valleys between the ridges, with the main watercourses incised in the underlying Marburg Subgroup rocks (mainly the Koukandowie Formation). East of the GDR, the Project intercepts various ephemeral watercourses (Six Mile, Oaky, and Rocky creeks) and Lockyer Creek, which is the main drainage system in the Lockyer Valley.

The geology and hydrogeological regime of the Project are influenced by the GDR, where the GDR is a regional groundwater divide. The area west of the GDR is associated with the Main Range Volcanics (MRV) and area east of the GDR transitions to the Marburg Subgroup – comprised of the Koukandowie Formation (upper member) and Gatton Sandstone (lower member). The Woogaroo Subgroup, which outcrops to the north-east of the Project alignment underlies the Marburg Subgroup. The tunnel intersects the MRV from Project Chainage (Ch) 4.10 km to Ch 4.53 km and Ch 8.45 km to Ch 9.05 km and intersects the Koukandowie Formation from Ch 4.53 km to Ch 8.45 km and Ch 9.05 km to Ch 10.00 km. The tunnel intersects crater rim and colluvium units at the eastern portal.

Regional groundwater gradients generally decrease west of the divide and decrease steeply east of the GDR, down the escarpment, towards Helidon. The flow directions within the alluvial aquifers are generally represented by the surface water catchment boundaries, which correlates well with the groundwater divide.

Local groundwater flow in shallow alluvial aquifers is influenced by surface water-groundwater interaction, where there is a hydraulic connection. This is observed along Gowrie Creek, which flows west into the Condamine River Basin, and it is expected that groundwater in the shallow Gowrie Creek alluvium has a similar trend. East of the GDR, the Project crosses Rocky Creek, Oaky Creek, and Six Mile Creek which flow east, and feed Lockyer Creek, and it is expected that groundwater flow in the shallow alluvium follows the surface water pathways.

Groundwater quality data within the groundwater study area indicates generally fresh to brackish and slightly alkaline conditions. The acid sulfate soils maps, underlying geology and geochemistry suggest the Project has low likelihood of encountering inland Potential Acid Sulfate Soils (PASS) material. This suggests there is low likelihood of potential for acid rock drainage (ARD) during earthworks.

Existing registered groundwater bores identified within the groundwater study area total 202 registered bores including 23 water supply bores, zero petroleum or gas exploration, with the remaining 172 bores having an undefined use. Available water entitlements indicate the MRV is extensively relied upon for groundwater in the study area for Urban, Irrigation and Stock Intensive purposes.

There are numerous moderate and low potential aquatic groundwater dependent ecosystems (GDEs) (from regional studies) within the groundwater study area, including Gowrie, Oaky, Six Mile, and Lockyer creeks (and their tributaries). Available surface water and groundwater quality and level data indicate there is potential for surface water and groundwater connectivity within the groundwater study area (an approximately 1 km radius from the centre of the Project alignment).

While there are no registered/mapped groundwater springs within the study area, there are eight springs mapped within 10 km of the Project, which are typically located near existing watercourses. Lockyer Creek Spring is the closest spring to the Project and is located 3.2 km north of the Project in Lockyer Creek. The creek flows south, towards the Project.

There are numerous moderate potential terrestrial GDEs (from regional studies) in the groundwater study area. Ground-truthing of these environments was not undertaken due to land access constraints; it has been assumed for the purposes of the EIS, that the modelled extent of the GDEs are accepted as true presence, and thus form a potentially sensitive receptor.

The environmental values relevant to the groundwater study area include aquatic ecosystems, irrigation, farm supply/use, stock water, drinking water, and cultural and spiritual.

Potential impacts

The construction and operation of the Project has the potential to impact on groundwater and groundwater users through:

- Loss of, or damage to, registered bores and potentially unregistered bores
- Changes to groundwater level and flow paths from embankment loading
- Reduced groundwater levels due to seepage into cuttings and the Toowoomba Range tunnel
- Changes to groundwater quality from spills and uncontrolled releases, or from acid rock drainage.

Significant residual impact assessment

The potential impacts of the Project on groundwater levels, flow and quality were identified and a significance assessment was undertaken, with the key conclusion being:

- A moderate residual significance risk was identified for the potential of reduced groundwater levels to impact groundwater users (bores and potential GDEs) due to the Toowoomba Range tunnel and associated cuts and tunnel portals.
  - Ground-truthing of GDEs is required to confirm GDEs exist within predicted drawdown extents.
  - Continued baseline groundwater level monitoring will confirm groundwater levels at the tunnel and inform additional investigations and predictive modelling.
- A moderate residual significance risk during the construction phase was identified for potential contamination, or degradation of groundwater quality, including from spills and uncontrolled releases, water mixtures and emulsions from washdown areas, and wastewater from construction camps
- Low residual significance risks were identified as being low for all other potential impacts including loss of registered bores due to destruction or loss of access, changes to groundwater levels due to loading from embankments (i.e. upstream mounding and damming, and downstream groundwater level reductions), ARD from cuts and vegetation removal.

Recently completed and ongoing additional geotechnical works, including investigation and monitoring of groundwater levels at deep cuts, Toowoomba Range tunnel, and areas of foundation treatment in low lying floodplain areas will further inform detailed design.

Cumulative impact assessment

A cumulative impact assessment (CIA) was undertaken that considered the adjoining ARTC rail alignments and surrounding developments. The CIA identified a low significance due to adoption and implementation of mitigation measures.

1 Introduction

1.1 Project overview and objectives

Future Freight Joint Venture (FFJV) was engaged by Australian Rail Track Corporation (ARTC) to undertake a groundwater study in support of an Environment Impact Statement (EIS) for the Gowrie to Helidon (G2H) Project (the Project) – part of the Inland Rail Program, a national freight network approximately 1,700 kilometres (km) in length from Melbourne to Brisbane.

ARTC is seeking approval to construct and operate the Project which consists of a single 28 km long dual gauge track with three crossing loops. The Project will ultimately accommodate trains up to 3,600 metres (m) long based on business needs but is initially proposed to be constructed for 1,800 m long double stack container freight trains. The section connects with the eastern end of New South Wales/Queensland Border to Gowrie Inland Rail project (B2G project), adjacent to the Queensland Rail (QR) West Moreton System (Western Line) rail approximately 3.7 km east of Gowrie.

The Project runs east, parallel to the existing QR West Moreton System rail corridor on the southern side (Western Line), for approximately 4.8 km before diverging from the West Moreton System rail corridor east of Gowrie and passing into the proposed western tunnel portal within the vicinity of the Boundary Street/Toowoomba Bypass interchange at Gowrie.

The alignment then continues through the Great Dividing Range (GDR)/Toowoomba Range via an approximately 6.24 km long undrained tunnel with an intermediate ventilation shaft (and associated infrastructure) at Cranley. On the eastern side of the tunnel, the alignment exits the range through the eastern tunnel portal at Ballard and continues down the Toowoomba Range via a series of viaducts, embankments and cuttings, through Postmans Ridge, Lockyer and Helidon Spa. The alignments crosses Lockyer Creek, after which, it again runs parallels, for approximately 800 m, the existing West Moreton System rail corridor on the northern side (Main Line) to connect with the Helidon to Calvert Inland Rail project (H2C project), to the north-west of Helidon.

The Project is one of the “missing links” within the Inland Rail Program. As part of the broader Inland Rail Program, this Project provides a more direct route between Melbourne and metropolitan Brisbane when compared with the existing inland and coastal road and rail networks.

The Project design has responded to key environmental, social and economic factors and has been developed in line with engineering constraints to produce a feasible rail design. The rail design is based on minimising environmental, social and economic impacts, minimising disturbance to existing infrastructure and meeting engineering design criteria.

The objectives of the Project are to:

- Provide rail infrastructure between Gowrie and Helidon that meets the Inland Rail Program service offering
- Provide a more efficient route through the challenging terrain of the Toowoomba Range which will benefit all rail operators
- Minimise the potential for adverse environmental, social and economic impacts.

The objectives of Inland Rail as a whole are to:

- Provide a rail link between Melbourne and Brisbane that is interoperable with train operations to Perth, Adelaide and other locations on the standard gauge rail network. This will serve future rail freight demand and stimulate growth for inter-capital and bulk rail freight.
- Deliver an increase in productivity that will benefit consumers through lower freight transport costs
- Provide a step-change improvement in rail service quality in the Melbourne to Brisbane corridor and deliver a freight rail service that is competitive with road

- Improve safety, congestion and reduce environmental impacts by moving freight from road to rail
- Bypass bottlenecks within the existing metropolitan rail networks and free up train paths for other services along the coastal routes
- Act as an enabler for regional economic developments along the Inland Rail corridor.

1.2 Project location and key features

The Project is located in the Darling Downs region (west of Toowoomba and the South East Queensland (SEQ) region (east of Toowoomba) and is within the local government areas (LGAs) of Toowoomba and Lockyer Valley.

The Project location within regional context as well as the impact assessment corridor is shown in Figure 1.1.

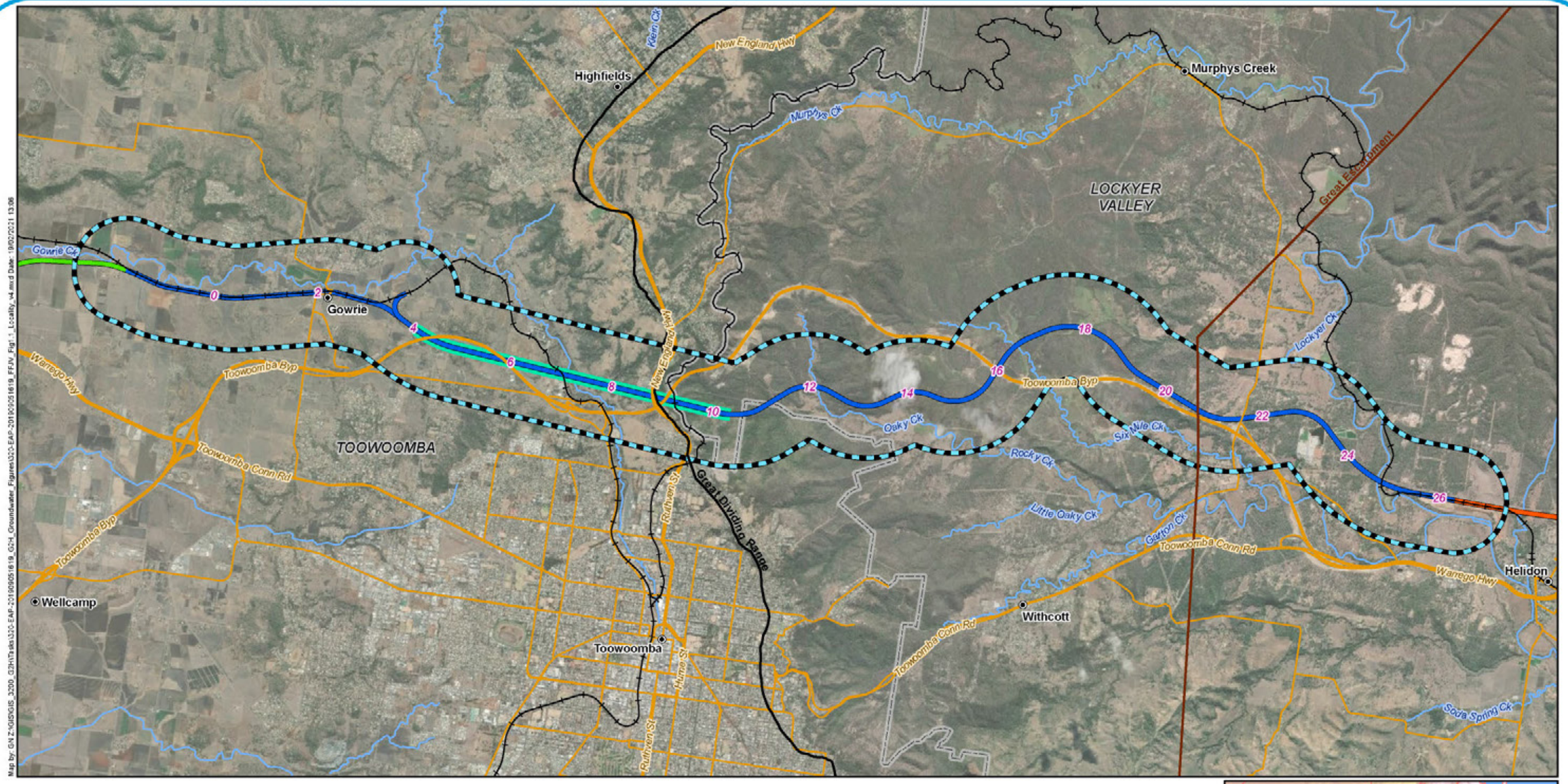
Key features of the Project are included in Table 1.1.

Table 1.1 Key features of the Project

Aspect	Description
Permanent features	
New track	▪ Approximately 28 km of new single-track dual gauge railway.
Rail corridor	▪ Establishment of approximately 22.4 km of new “greenfield” rail corridor ▪ Development of approximately 5.6 km of “brownfield” rail corridor ▪ The land required for the Project comprises a corridor with a minimum width of 62.5 m. A reduced corridor is required where the Project is collocated with the existing rail corridor or for the tunnel. ▪ The rail corridor will be of sufficient width to allow future crossing loop extensions to accommodate trains of up to 3,600 m in length ▪ The rail corridor will include land associated with the intermediate tunnel ventilation shaft and supporting infrastructure, access roads and other supporting infrastructure (e.g. water pipelines).
Tunnel	▪ Construction of an approximately 6.24 km long undrained tunnel through the Toowoomba Range including expanded corridor to accommodate tunnel portal infrastructure (e.g. tunnel operations facilities and tunnel material stockpile at the western tunnel portal) ▪ Intermediate ventilation shaft (which draws in air to ventilate the tunnel) and associated infrastructure to be established at Cranley ▪ Land acquisition (volumetric) for the tunnel will include a provisional area around the tunnel to protect the asset from future development.
Crossing loops and turnouts	▪ Crossing loops are places on a single-line track where trains in opposing directions can pass each other ▪ Three crossing loops, each a minimum of 2,200 m in length ▪ Turnouts allow the train to be guided from one section of track to another. Turnouts that tie-in to the existing West Moreton System rail corridor will be incorporated. There are 16 turnouts proposed along the alignment, including those associated with: – Crossing loops – Maintenance sidings – Cross overs between Inland Rail and the existing West Moreton System – Connection to the proposed InterLinkSQ facility – Connection at the western tunnel portal to the West Moreton System to allow for train movements between Brisbane and Toowoomba.
Bridges and viaducts	▪ Bridges and viaducts to accommodate topographical variation, crossings of waterways or other infrastructure such as roads ▪ There are 13 new bridge and viaduct structures, totalling approximately 6.7 km in length, proposed for the Project, comprising: – Two rail-over-waterway viaducts – Three rail-over-terrain-and-waterway viaducts – Four rail-over-terrain-road-and-waterway viaducts – One rail-over-road-rail-and-waterway viaduct

Aspect	Description
	– One rail-over-waterway bridge – One road-over-rail-and-waterway bridge – One road-over-rail bridge ■ Instream structures and scour protection measures associated with waterway crossings where relevant.
Drainage	■ Reinforced concrete pipe culverts and reinforced concrete box culverts. Scour protection measures will generally be installed around culverts and other drainage structures to minimise the potential for erosion.
Rail crossings	■ Rail crossings including grade separations/rail or road overbridges, occupational/private crossings and fauna crossing structures.
Embankments and cuttings	■ Embankments and cuttings will be required along the length of the alignment, this includes road and rail infrastructure within the alignment such as crossing loops and road of rail bridges ■ The total length of embankments required for the Project will be in the order of 15.4 km with a maximum embankment height of 33.3 m ■ The total length of cut for the Project will be in the order of 6.65 km with a maximum cut depth of 45.7 m.
Ancillary works	■ Associated rail infrastructure including maintenance sidings, Safeworking systems and signalling infrastructure ■ Ancillary works include signalling and communications, signage and fencing, drainage works, establishment and/or reinstatement of access roads, and installation or modification of services and utilities ■ Road closures and realignments; including closure of an existing level crossing on the QR West Moreton System rail line at Gowrie.
Environmental treatments	■ Potential noise barriers, fauna crossing structures, instream structures and fish passage design, fauna exclusion fencing, and rehabilitation and landscape treatments.
Temporary features	
Land	■ The corridor required for the Project is expected to comprise a width of 40 m to 62.5 m, extending wider where earthworks, structures and other associated infrastructure are required. For the existing rail corridor, the existing width has been generally maintained (where possible), and locally widened to accommodate the Project works. ■ The rail corridor will be of sufficient width to accommodate all proposed railway infrastructure, including the crossing loops, as well as future expansion to accommodate the potential for 3,600 m long trains ■ Temporary access tracks will be used to access construction sites. Where required, they will be retained to serve as rail maintenance access roads (RMAR) during the operation of the Project ■ Land requirements for construction will include temporary workspace, site offices and laydown facilities ■ Laydown areas will be located approximately every 5 to 10 km (avoiding 1% annual exceedance probability (AEP) floodplains where possible). Laydown areas will be required for activities such as tunnel construction, flash butt welding, concrete batching, water treatment facilities and rail assembly. ■ Approximately 2,500 square metres (m^2) of laydown areas to support bridge construction (where practicable, smaller near sensitive habitats).
Material sourcing	■ Identification, and lawful use of established quarries for sourcing construction materials.
Utilities	■ Clashes with utilities flagged and treatments identified for refinement during detailed design with utility relocations will be subject to separate assessments, with all necessary approvals obtained prior to any relocation being undertaken ■ Major utility impacts and treatments have been confirmed with utility owners.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Map by: GM Z:\GIS\GIS_3200_G2H\Trials\320-EAF-20190905\619_G2H_Groundwater_Figures\320-EAF-20190905619_FFJV_Fig1.1_Locality_v4.mxd Date: 19/02/2021 13:06

Legend

- 5 Chainage (km)
- Localities
- B2G project alignment
- G2H project alignment
- H2C project alignment
- Existing rail
- Major roads
- Minor roads
- Tunnel
- Major watercourses
- Great Dividing Range
- Great Escarpment
- Groundwater study area
- Local Government Areas



A3 scale: 1:80,000

0 1 2 3 4 5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/02/2021 Version: 4
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 1.1: Project location

Construction activities for the Project will likely include temporary roads, upgrades and/or alterations to existing roads. The construction of the Project may also require relocation of some services, depending on their proximity to the construction zone. These aspects have been considered in this groundwater study and will be confirmed during the detailed design stage of the Project.

The construction of the Toowoomba Range tunnel and associated viaducts, bridges, embankments, and cuts are considered most relevant to the groundwater impact assessment. These aspects, along the proposed 28 km length of new dual-gauge rail line, have the potential to impact on groundwater levels due to seepage into cuttings and tunnels and disturbance of shallow groundwater levels, flow and quality from placement of embankments, viaducts, pilings, bridges. The construction and operation elements relevant to groundwater have been considered as part of this technical report.

1.3 Objectives and scope of report

The objective of this report is to support the EIS submission by addressing all groundwater-related requirements of the *Terms of Reference for an environmental impact statement: Inland Rail – Gowrie to Helidon Project August 2017* (ToR). This groundwater impact assessment includes a description of the groundwater resources, an assessment of environmental values (EVs), conceptualisation of the groundwater resources, predictive modelling of the Project on groundwater resources, and the assessment of potential impacts of the Project within the EIS investigation corridor by application of a significance assessment approach for design elements and proposed Project activities considered relevant to groundwater (including cuts, tunnel, and embankments).

Table 1.2 presents the relevant groundwater ToR and the location within report where discussed.

In order to satisfy the ToR, this groundwater technical report includes:

- A description of relevant Project details
- An overview of existing environmental, geological, and hydrogeological conditions
- An assessment of environmental values (EVs) and water quality objectives (WQOs)
- Identification of potential impacts of the Project on groundwater resources
- A description of proposed measures to mitigate these impacts
- An assessment of potential impacts of the Project by application of a significance assessment approach.

Potential short- and long-term impacts have been assessed for construction and operation phases of the Project. Cumulative groundwater impacts related to existing or planned surrounding activities have also been assessed.

This technical report has been prepared to provide additional technical details to EIS Chapter 14 which summarises the study objectives to address the requirements of the ToR.

Table 1.2 Groundwater Project objectives (ToR)

ToR ID	Objective	Relevant EIS section
11.36	Identify the water related environmental values and describe the existing surface water and groundwater regime within the study area and the adjoining watercourses in terms of water levels, discharges and freshwater flows.	Section 8, 7.1 and 7.4 EIS Chapter 14: Groundwater, Sections 14.6.2, 14.6.3, 14.6.6 and 14.6.10
11.37	With reference to the EPP (Water and Wetland Biodiversity)[a] and section 9 of the *Environmental Protection Act 1994* (EP Act), identify the environmental values of surface water within the Project area and immediately downstream that may be affected by the Project, including any human uses of the water and any cultural values.	Section 8 EIS Chapter 14: Groundwater, Section 14.6.10

ToR ID	Objective	Relevant EIS section
11.38	At an appropriate scale, detail the chemical, physical and biological characteristics of groundwater within the area that may be affected by the Project. Include a description of the natural water quality variability within the groundwater study area associated with climatic and seasonal factors, and flows.	Section 7.3 EIS Chapter 14: Groundwater, Sections 14.6.3 to 14.6.4
11.39	Describe any existing and/or constructed waterbodies adjacent to the preferred alignment.	Section 4.3.2 EIS Chapter 14: Groundwater, Section 14.6.2
11.40	Identify the location and source aquifer of licensed groundwater extraction in those areas potentially impacted by the Project (e.g. near tunnels).	Section 7.5, Table 7.10 and Table 7.11 EIS Chapter 14: Groundwater, Section 14.6.6 and Table 14.11
11.41	The assessment of impacts on water will be in accordance with the Department of Environment and Heritage Protection information guideline for an environmental impact statement – ToR Guideline – Water, where relevant, located on the Department of Environment and Heritage Protection website (refer appendix 1).	Section 12 EIS Chapter 14: Groundwater, Sections 14.4 and 14.9
11.44	Where significant cuttings or tunnelling is proposed, identify the presence of any sulfide minerals in rocks with potential to create acidic, metalliferous and saline drainage. Should they be present, describe the practicality of avoiding their disturbance. If avoidance is not practicable, characterise the potential of the minerals to generate contaminated drainage and describe abatement measures that will be applied to avoid adverse impacts to surface and groundwater quality.	Sections 6.3, 10.2.2.3, 10.2.2.4, 10.3.2.1 and 10.3.2.2 EIS Chapter 14: Groundwater, Sections 14.6.4, 14.6.4.3 and 14.8.2
11.47	Describe how the water quality objectives identified above would be achieved, monitored and audited, and how environmental impacts would be avoided or minimised and corrective actions would be managed.	Section 11.2 EIS Chapter 14: Groundwater, Section 14.8.2 and Table 14.29
11.48	Describe appropriate management and mitigation strategies and provide contingency plans for: A - potential accidental discharges of contaminants and sediments during construction and operation D - management of acid sulfate soils and acid producing rock and associated leachate from excavations and disturbed areas.	Section 11.2 EIS Chapter 14: Groundwater, Section 14.8.2 and Table 14.29
11.52	Provide details of any proposed impoundment, extraction (i.e. volume and rate), discharge, use or loss of surface water or groundwater. Identify any approval or allocation that would be needed under the Water Act.	Sections 10.1.6, 10.2.1.7 and 10.3.1.6 EIS Chapter 14: Groundwater, Sections 14.7.3.1 (Construction water supple) and 14.7.4.1 (Operation water supply)
11.54	Develop hydrological models as necessary to describe the inputs, movements, exchanges and outputs of all significant quantities and resources of surface water and groundwater that may be affected by the Project. The models should address the range of climatic conditions that may be experienced at the site, and adequately assess the potential impacts of the Project on water resources. This should enable a description of the Project's impacts at the local scale and in a regional context including proposed: (a) changes in flow regimes from structures and water take (c) direct and indirect impacts arising from the Project. (d) impacts to aquatic ecosystems, including groundwater-dependent ecosystems and environmental flows.	Section 9 EIS Chapter 14: Groundwater, Sections 14.7.1, 14.7.3, 14.7.4 and 14.7.4.1 (Loss or damage to existing landholder bored and GDEs and springs)

ToR ID	Objective	Relevant EIS section
11.55	Provide information on the proposed water usage by the Project, including: (a) the estimated supply required to meet the demand for construction and full operation of the Project, including timing of demands (b) the quality and quantity of all water supplied to the site during the construction and operational phases based on minimum yield scenarios for water re-use, rainwater re-use and any bore water volumes (c) a plan outlining actions to be taken in the event of failure of the main water supply (d) sufficient hydrogeological information to support the assessment of any temporary water permit applications.	Sections 10.1.6, 10.2.1.7 and 10.3.1.6 EIS Chapter 14: Groundwater, Sections 14.7.3.1 (construction water supply) and 14.7.4.1 (Operation water supply)
11.56	Describe proposed sources of water supply given the implication of any approvals required under the Water Act. Estimated rates of supply from each source (average and maximum rates) must be given and proposed water conservation and management measures must be described.	Sections 10.1.6, 10.2.1.7 and 10.3.1.6 EIS Chapter 14: Groundwater, Sections 14.7.3.1 (construction water supply) and 14.7.4.1 (Operation water supply)
11.57	Determination of potable water demand must be made for the Project, including the temporary demands during the construction period. Include details of any existing town water supply to meet such requirements. Detail should also be provided to describe any proposed on-site water storage and treatment for use by the site workforce.	Section 10.2.1.7 EIS Chapter 14: Groundwater, Section 14.7.3.1 (Construction water supply)
11.58	Identify relevant Water Plans and Resources Operations Plans under the Water Act. Describe how the Project will impact or alter these plans. The assessment should consider, in consultation with Department of Natural Resources and Mines (DNRM), any need for: a) a resource operations licence b) an operations manual c) a distribution operations licence d) a water licence e) a water management protocol.	Sections 2.3.2, 10.1.6 and 10.3.1.6 EIS Chapter 14: Groundwater, Sections 14.4, 14.6.6, 14.7.4, Table 14.2 and Table 14.11 (Operation water supply)
11.59	Identify other water users that may be affected by the proposal and assess the Project's potential impacts on other water users.	Sections 7.5, 10.2.1.2 and 10.3.1.2 EIS Chapter 14: Groundwater, Section 14.7.4.1 (Loss or damage to existing landholder bores, Table 14.23, Table 14.24, Table 14.25 and Table 14.27
11.62	Describe measures to minimise impacts on surface water and ground water resources.	Section 11 EIS Chapter 14: Groundwater, Section 14.8.2 and Table 14.29
11.63	Provide a policy outline of compensation, mitigation and management measures where impacts are identified.	Section 11 EIS Chapter 14: Groundwater, Section 14.8.2 and Table 14.29

Table notes:

a The EPP (Water and Wetland Biodiversity) replaced the Environmental Protection (Water) Policy 2009 on 1 September 2019. This has occurred as a result of a review of the 2009 guidelines which confirmed a need for continued regulatory actions. The 2019 guidelines are substantially similar to the 2009 legislation, with only minor amendments. There have been a number of amendments to the drafting style to ensure the legislation reflects current drafting practice. Some provisions have been renumbered as a result. Other amendments have been made to clarify the intent of provisions and align the policy to best available knowledge and contemporary practice.

2 Legislative, policy standards and guidelines

This groundwater technical report has been prepared with consideration to key policies and legislation from the Commonwealth of Australia and the State of Queensland. The subsections below provide an overview of the legislation and policies relevant to the Project.

2.1 Commonwealth legislation

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) provides that any action (i.e. a Project, development, undertaking, activity or series or activities) that has, will have or is likely to have a significant impact on matters of national environmental significance, or other matters protected under the EPBC Act such as the environment of Commonwealth land, requires approval from the Commonwealth Minister for the Environment.

On the 10 February 2017, the Project was referred under the EPBC Act to Commonwealth Minister for the Environment and Energy (reference number EPBC 2017/7882). On 17 March 2017, the delegate of the Commonwealth Minister for the Environment determined the Inland Rail – G2H Project to be a 'controlled action' under the EPBC Act, with the Project requiring approval under the EPBC Act before it can proceed. The controlling provision for the determination was listed threatened species and communities, with the Project to be assessed in accordance with the bilateral agreement between the Queensland and Australian governments.

2.1.2 Water Act 2007

The *Water Act 2007* (Cth) provides the legislative framework for ensuring that Australia's largest water resource—the Murray-Darling Basin (the Basin)—is managed in the national interest. In doing so the *Water Act 2007* recognises that Australian states in the Basin continue to manage Basin water resources within their jurisdictions. The *Water Act 2007*:

- Established the Murray-Darling Basin Authority (MDBA) with the functions and powers, including enforcement powers, needed to ensure that Basin water resources are managed in an integrated and sustainable way
- Requires the Murray-Darling Basin Authority to prepare the Basin Plan - a strategic plan for the integrated and sustainable management of water resources in the Basin
- Establishes a Commonwealth Environmental Water Holder to manage the Commonwealth's environmental water to protect and restore the environmental assets of the Basin, and outside the Basin where the Commonwealth owns water.

The Queensland government has prepared the Water Plan (Condamine and Balonne) 2019, along with supporting documentation such as a healthy water management plan under the *Water Act 2000* (Qld) (Water Act). The plan was accredited by the Australian Government minister as being consistent with the Basin Plan and commenced on 21 September 2019.to meet accreditation under the Water Act 2007.

Compliance with the Water Act 2007 - Basin Plan 2012, will be achieved by complying with the Water Plan (Condamine and Balonne) 2019. The plan is the prevailing management plan for the surface water and groundwater resources (excluding water from the Great Artesian Basin) in the Condamine–Balonne water resource plan area which includes Gowrie Creek catchment.

The Project will also be required to adhere to EVs and corresponding WQOs (under the Queensland (EPP) (Water and Wetland Biodiversity) which is accredited under the Water Act (and the legislative instrument – Basin Plan) (e.g. Healthy Waters Management Plan: Condamine River Basin. (Environmental values and water quality objectives: Queensland Murray-Darling Basin, May 2018 (DES 2019a)).

2.2 Queensland legislation

2.2.1 Environmental Protection Act 1994

The *Environmental Protection Act 1994* (Qld) (EP Act) is Queensland's overarching environmental legislative framework for the protection and management of EVs. The objective of the EP Act is to protect Queensland's natural environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains ecological processes on which life depends i.e. ecologically sustainable development. The EP Act regulates activities that will or may have the potential to cause environmental harm and prescribes several mechanisms to ensure the objectives of the Act are met.

The EP Act identifies the EVs of Queensland watercourses, including groundwater located within the groundwater study area, which are protected under the Act and subordinate legislation. Environmental values, as defined by the Act, include:

- A quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety
- Another quality of the environment identified and declared to be an EV under an environmental protection policy or regulation.

The Project has the potential to adversely impact groundwater and therefore protected EVs are to be considered. Further information about EVs is presented in Section 2.3.

2.2.2 Water Act 2000

The *Water Act 2000* (Qld) (Water Act) provides a framework for the sustainable management of water and the management of impacts on underground water and for other purposes. The main purpose of the Water Act is to provide:

- Sustainable management of Queensland's water resources by establishing a system for the planning, allocation and use of water, including the preparation and implementation of water plans and water resource plans and the allocation of quarry material and riverine protection
- Sustainable and secure water supply and demand management for the southeast Queensland region and other designated regions
- Management of impacts on underground water caused by the exercise of underground water rights by the resource sector (inclusive of make good measures)
- Effective operation of water authorities.

Under the Water Act, water plans may set limitations on the taking or interfering of water in the plan area and prescribe the requirements for water entitlements or other authorisations. The Water Act also regulates the taking or interfering with the flow of water on, under or adjoining land (including surface water, artesian water, and in some instances overland flow where regulated through a water plan) and may require a water licence under the Water Act as evidence of entitlement to the resource and a development permit for operational work under the Planning Act where constructing or installing certain types of works. Further, the Water Act also requires a Riverine Protection Permit to authorise works involving the excavation, or placing of fill in a watercourse, lake or spring, unless an exemption applies.

The Project is likely to involve:

- Taking or interfering with the flow of water
  - During construction of the Project, water will be required for dust control, site compaction and reinstatement. A number of potential water sources have been investigated, including extraction of groundwater or surface water, private bores and watercourses

  - Overland flow diversions are proposed at the western portal of the Toowoomba Range tunnel, the intermediate tunnel ventilation infrastructure drain diversion at Cranley and drainage infrastructure at Postmans Ridge
- Taking or interfering with groundwater as part of the Toowoomba Range tunnelling activities
- Excavation or placing fill in a watercourse, lake or spring.

ARTC is an approved entity for the purposes of the riverine protection permit exemption requirements.

ARTC has consulted with Department of Regional Development, Manufacturing and Water (DRDMW) (formerly DNRME) regarding the water authorisation required under the various water plans because of the Project activities (e.g. construction water and inference with groundwater, short-term and long-term, due to the tunnel's construction and operation). DRDMW has noted the complexities of the groundwater resources in the area and the overarching legislation. Further consultation is required to confirm the approval process and to ensure that the Project complies with the legislative requirements under the Water Act and associated water plans, without adversely impacting existing water users and groundwater resources. The latter also includes measures to rectify any impairments to existing bores due to the Project. The outcomes of these discussions have informed the preparation of this study.

Further consultation with DRDMW is recommended to resolve some of the complexities associated with the Water Act and supporting water plans relevant to the Project. Noting that most of the issues relate to groundwater allocations.

It is also recognised that requirements for make good agreements are well described under Part 3 of the Water Act for the mining and coal seam gas industry but are unclear for a Project of this nature; however, ARTC are proposing to adopt some of the make-good obligations under the Act to ensure that the bore holder is properly compensated for any impacts from the Project and that any impairment caused by the Project is 'made good'. Further and ongoing consultation with DRDMW will be undertaken regarding this matter noting that ARTC's preference will be for monetary compensation and for the works to be undertaken by the bore owners where applicable. It is also acknowledged that resolution of this matter will assist in securing the relevant water authorisations for the construction and operation of the Project.

2.2.3 Water Regulation 2016

The Water Regulation 2016 is subordinate legislation made under the Water Act and prescribes administrative and operational matters for the Act. Such matters governed by the Water Regulation 2016 with relevance to the proposal include, but not limited to:

- Provide matters for the Minister's report on water plans
- Prescribe the purpose and conditions for which a constructing authority may take water
- Prescribes activities for which the taking of, or interfering with, water is authorised without an entitlement
- Provide for matters relating to water licences
- Provide matters for water supply and demand management
- Allow for seasonal water assignments and prescribe associated rules
- Provide criteria for establishing water allocations and prescribe water allocation dealing rules
- Prescribe requirements for decommissioning water bores
- Provide for works that are self-assessable and assessable development for the *Planning Act 2016* and prescribe the associated codes
- Make declarations about underground water taken to be water in a watercourse
- Provide rules for managing underground water not managed through a water plan.

The Project will require water for construction activities (potentially including groundwater and surface water) and works have potential to interfere with groundwater resources (flow and/or take of water), and as such provisions of the Water Regulation 2016 apply. Specifically, the Toowoomba City Basalts (TCB) groundwater management area, as prescribed in section 39 of the Water Regulation 2016. The Toowoomba City Basalts groundwater management area comprises the former Toowoomba City LGA and includes part of the Project disturbance footprint including the Toowoomba Range tunnel.

2.3 Policies, plans, and guidelines

2.3.1 Environmental Protection Policy (Water and Wetland Biodiversity) 2019

Under the EP Act, the Environmental Protection Policy (Water and Wetland Biodiversity) 2019 (EPP (Water and Wetland Biodiversity)) was established as subordinate legislation to achieve the objective of the EP Act in relation to Queensland waters. The objective of the EPP (Water and Wetland Biodiversity) is achieved by the:

- Identification of EVs and management goals for Queensland waters
- Stating water quality guidelines and WQOs to enhance or protect the identified EVs
- Provision of a framework for making consistent, equitable and informed decisions about Queensland waters
- Monitoring and reporting on the condition of Queensland waters.

EVs relevant to the Project are presented in detail in Section 8.

2.3.2 Water Plans

Water plans have been developed under the Water Act to sustainably manage and allocate water resources in Queensland. The Water Plan (Moreton) 2007, Water Plan (Condamine and Balonne) 2019 and Water Plan (Great Artesian Basin and Other Regional Aquifers) (GABORA) 2017 are relevant to the Project.

The purposes of the Water Plans are:

- To define the availability of water in the plan area
- To provide a framework for sustainably managing water and the taking of water
- To identify priorities and mechanisms for dealing with future water requirements
- To provide a framework for reversing, where practicable, degradation that has occurred in the natural ecosystems
- To provide a framework for-
  - Establishing water allocations to take surface water; and
  - Granting and amending water entitlements for groundwater; and
  - Granting water entitlements for overland flow water.

2.3.2.1 Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017

The Project is wholly located within the Water Plan (GABORA) area. The plan is divided into groundwater units, comprised of geological formation and geography; the relevant groundwater units for the Project include: Hutton, Precipice, and Springbok Walloon groundwater units. The purposes of this plan are to:

- Define the availability of water in the plan area
- Provide a framework for sustainably managing water and the taking of water in the plan area

- Identify priorities and mechanisms for dealing with future water requirements
- Provide a framework for reversing, if practicable, the degradation of groundwater-dependent ecosystems.

Within each groundwater unit are specified geological (hydrogeological) formations managed under the Water Plan (GABORA). The geological formations of relevance for each groundwater unit include:

- Hutton groundwater unit:
  - Marburg Subgroup including Gatton Sandstone and Koukandowie Formation
- Precipice groundwater unit:
  - Woogaroo Subgroup. While underlying the Marburg Subgroup (refer Section 6.2) within the groundwater study area (refer Section 3.1), the Woogaroo Subgroup it is not considered relevant for this assessment due to its depth below the Project (deepest unit in the CMB [Raiber et al 2016 & 2017]), understood hydraulic connectivity of the Subgroup that outcrops northeast of the G2H Project, as well as the entire project (including the Toowoomba tunnel) to be constructed wholly within and above the upper member of the Marburg Subgroup – the Koukandowie Formation.
- Springbok Walloon groundwater unit:
  - Walloon Coal Measures (WCM).

These groundwater units are further broken down into subareas for water management purposes (water license, permit, etc.). The relevant subareas of the Hutton groundwater unit include the Eastern Downs Marburg and Murphys Creek Marburg; Precipice groundwater unit subareas include the Eastern Downs Precipice and Murphys Creek Woogaroo; and the Springbok Walloon groundwater unit includes the Eastern Downs Springbok Walloon subarea.

Within these sub-areas, landholders are permitted to take water for stock and domestic purposes without the need for a water licence. The exception being the area within 5 km of the Lockyer Creek Spring where a licence is required for any new stock or domestic bore. All other uses require a water licence, water permit, or seasonal water assignment notice.

The plan also identifies several groundwater-dependent ecosystems, where the decisions on a water licence are dependent on the distance between and/or cumulative drawdown on the groundwater-dependent ecosystems. There are two groundwater-dependent ecosystems under the plan within the general vicinity of the Project.

It is noted that there is unallocated water under the water plans, which may be granted to a coordinated project under the State Development and Public Works Organisation Act 1971 (Qld) (SDPWO Act) (i.e., state or strategic reserve). Based on advice from DRDMW, there is State reserve water under the Water Plan (GABORA) 2017, with water potentially available in the Eastern Downs in the Springbok Walloons, Marburg and Precipice aquifers (approximately 990 ML).

2.3.2.2 Water Plan (Moreton) 2007

The Water Plan (Moreton) provides a framework for water entitlements/allocations to be managed under resource operations license for the Lockyer Valley water supply scheme, which states the process for granting or amending interim resource operation licenses, and interim water allocations for the construction of infrastructure to which the interim resource operation licences related.

The aquifers relevant to the Water Plan (Moreton) in the groundwater study area are:

- Oaky Creek alluvium
- Rocky Creek alluvium
- Six Mile Creek alluvium
- Lockyer Creek alluvium.

The section between Toowoomba and Helidon (distance of approximately 17.5 km between Ch 8.8 km and Ch 26.2 km) is located within the Lockyer Valley Groundwater Management Area (GMA) Implementation Area 2B. This is applicable to alluvial (Oaky, Rocky, Six Mile, and Lockyer creeks) and hard rock aquifers not covered by Water Plan (GABORA) to ensure management of groundwater in this area. It is noted that there are other stratigraphic units not specified in the plan because they are not recognised groundwater units but are located within the plan area (e.g. colluvial sediments).

Groundwater may not be taken in this GMA, unless it is for stock or domestic purposes, under a water entitlement or water permit, to allow monitoring for salinity control, or under an authorisation under section 72 of the plan (e.g., at the commencement of the plan, the owner of the land using an existing water bore on the land to take groundwater may continue to take groundwater using the bore).
The Water Plan (Moreton) 2007 includes performance indicators and objectives such as:

- Environmental flow objectives: assessing periods of low flow and medium- to- high flow
- Water allocation security objectives.

DRDMW have advised that there is no unallocated water, including State reserves, within the above-mentioned units available to the Project.

2.3.2.3 Water Plan (Condamine and Balonne) 2019

The Water Plan (Condamine and Balonne Basin) 2019, is the prevailing management plan for the surface water, overland flow (other than Great Artesian Basin (GAB) springs connected to underground water) and groundwater resources (excluding GAB resources) within Gowrie Creek catchment.

This Water Plan is applicable to groundwater in the western portion of the Project, west of the Great Dividing Range (GDR) and above the GAB sediments, and provides a framework for sustainably managing water (entitlements/allocations, ecosystems) under resource operations license for the Condamine-Balonne Water Resources Plan. The process for granting or amending interim resource operation licenses, and interim water allocations for the construction of infrastructure to which the interim resource operation licences related are governed under this plan.

This Water Plan is part of the Murray–Darling Basin Authority, which is working closely with State governments within the Basin to ensure water plans meet the requirements of the Basin and applies to the following aquifers in the groundwater study area:

- MRV
- Gowrie Creek alluvium.

The Project is within the Condamine and Balonne Underground Water Management Area and the Upper Condamine Basalts Underground Water Management Unit, which is part of the Main Range Volcanics (MRV) aquifer system composed of basaltic fractured rock aquifers

The plan defines the Upper Condamine Basalts as a part of the MRV, the main aquifer of relevance to the Project under this plan. The Project is associated with the Toowoomba City Basalts groundwater sub-area; the tunnel is primarily located within this sub-area except the eastern portion of the tunnel, located in the Water Plan (Moreton) 2007 area.

Under s29 of the *Water Act 2000,* the Toowoomba City Basalts groundwater sub-area comprises limitation areas of relevance to the Project, per below, where limitations on groundwater use can be applied:

- Toowoomba North Basalts – Gowrie Creek is the southern boundary of this limitation area and Project works to the north of the creek will intersect this area
- Toowoomba South Basalts – the western extent of the Project is located within this limitation area, including the western tunnel portal and the start of the tunnel (i.e. underlying the Toowoomba Bypass).

In July 2018 the status of the Upper Condamine Basalts (inclusive of the MRV) was updated to the following:

> *Groundwater authorisations are currently required for all, but stock or domestic take. It is anticipated that stock and domestic use will grow in the future, particularly in peri-urban areas, and will require continued monitoring. Overall, major groundwater issues include the following:*
>
> - *limited supplies, some scope for further development*
> - *water level declines*
> - *minor salinity issues emerging.*
>
> *Demand for new water for industrial use is high in Toowoomba and the surrounding areas. The impact on town water supply bores of nearby extractions is also an issue of concern.*

New water plans were drafted and published on 22 February 2019.The following restrictions have been made to all licenses in the MRV within the groundwater study area:

- Pumping is restricted to Monday, Tuesday, Wednesday, and Friday from 7.00 pm to 3.00 am
- Allocations have been restricted to 60 per cent of the licensed entitlement.

DRDMW have advised that there is no unallocated water, including State reserves, in the above- mentioned units available to the Project

The Condamine River Basin Healthy Waters Management Plan prepared in accordance with the EP Act and EPP (Water and Biodiversity) identifies the environmental values relevant to the area and recommends water quality objectives to protect these values. The Condamine and Balonne Water Management Protocol 2019 applies to surface water and groundwater in the plan area.

2.3.3 EIS information guideline – Water 2016

The Queensland Government's Department of Environment and Science (DES) have developed an informational guideline to assist in the development and assessment of water resources for EISs. This guideline was incorporated into the methodology, approach, and data sources for the groundwater impact assessment. The guideline is complimentary to the Project-defined ToR by the Coordinator-General.

3 Methodology

3.1 Groundwater study area

In this groundwater report, the EIS investigation corridor (herein referred to as the groundwater study area) is defined as the area within an approximately 1 km radius of the centre line of the proposed rail alignment. The groundwater study area is illustrated on Figure 1.1. Where the EIS investigation corridor extends further than 1 km either side of the alignment, this is generally to allow for any design optioneering and refinement of the alignment and construction access. In some areas, the maximum width of the EIS investigation corridor from the Project alignment is 3.4 km. Groundwater data outside of the define groundwater study area for the Project has been used to understand groundwater and identify impacts within the groundwater study area.

The groundwater study area includes the Project disturbance footprint including all permanent and temporary activities that have the potential to directly or indirectly affect the groundwater environment and was used to identify groundwater users (including registered bores) and potential groundwater dependent ecosystems (GDEs).

The extent of groundwater drawdown was not limited by the groundwater study area (i.e. the drawdown extents outside of the groundwater study area are identified and discussed).

3.2 Approach

To achieve the study scope and objectives outlined in the ToR, the groundwater impact assessment comprises two components: a description of the existing hydrogeological environment, and an assessment of the potential impacts of the Project on that environment.

A staged approach was adopted to allow for compilation and assessment of sufficient data to both:

- Address the groundwater requirements of the ToR
- Provide impact assessment-related recommendations for the detailed design.

The following stages were undertaken to prepare these assessments:

- Stage 1 – Desktop study
- Stage 2 – Geotechnical and hydrogeological investigations
- Stage 3 – Groundwater impact assessment
- Stage 4 – Significance assessment
- Stage 5 – Reporting.

Each of the stages are discussed further below.

3.2.1 Stage 1 - Desktop study

Available geological and hydrogeological literature and data were reviewed to inform a detailed description of the existing hydrogeological regime and identify groundwater EVs. Interrogation of publicly available databases, inclusive of registered groundwater bores and use, was undertaken and review of relevant studies and reports was performed.

The primary data sources utilised in the preparation of this report are presented in Table 3.1.

Table 3.1 Data sources for the Project

Data	Source
Hydrology/climate	Historical Climate Database - Bureau of Meteorology (BoM) (http://www.bom.gov.au/climate/data/) Inland Rail Section 320 – Gowrie to Helidon Hydrogeological Interpretive Report (Golder 2020a), refer Appendix A Inland Rail: Phase 2 – Gowrie to Helidon Geotechnical Factual Report (Golder 2020b) (refer EIS Appendix W: Geotechnical Factual Report) Geotechnical Factual Report G2K Geotechnical Data Collection project Gowrie to Helidon (Golder 2020c) Queensland Globe datasets (https://qldglobe.information.qld.gov.au/)
Soil types	Inland Rail Section 320 – Gowrie to Helidon Hydrogeological Interpretive Report (Golder 2020a) Geotechnical Factual Report G2K Geotechnical Data Collection project Gowrie to Helidon (Golder 2020c) Queensland Globe datasets (https://qldglobe.information.qld.gov.au/)
Geology/ Hydrostratigraphy	Inland Rail Section 320 – Gowrie to Helidon Hydrogeological Interpretive Report (Golder 2020a) Inland Rail: Phase 2 – Gowrie to Helidon Geotechnical Factual Report (Golder 2020b) (refer EIS Appendix W: Geotechnical Factual Report) Geotechnical Factual Report G2K Geotechnical Data Collection project Gowrie to Helidon (Golder 2020c) Summary Factual Report of Hydraulic Tests Toowoomba Tunnel Alignment (Golder 2020d) Department of Regional Development, Manufacturing and Water (DRDMW) (formerly the Department of Natural Resources, Mines and Energy (DNRME)) groundwater database accessed 1 May 2020 Queensland Globe datasets (https://qldglobe.information.qld.gov.au/)
Groundwater levels and quality	Inland Rail Section 320 – Gowrie to Helidon Hydrogeological Interpretive Report (Golder 2020a) Inland Rail: Phase 2 – Gowrie to Helidon Geotechnical Factual Report (Golder 2020b) (refer EIS Appendix W: Geotechnical Factual Report) Geotechnical Factual Report G2K Geotechnical Data Collection project Gowrie to Helidon (Golder 2020c) Summary Factual Report of Hydraulic Tests Toowoomba Tunnel Alignment (Golder 2020d) DRDMW groundwater database accessed 1 May 2020 Clarence-Moreton Bioregional Assessment [Australian Government Department of Environment] (Rassam et al 2014 & Raiber et al 2016 & 2017) (https://www.bioregionalassessments.gov.au/assessments/clarence-moreton-bioregion) Queensland Globe datasets (https://qldglobe.information.qld.gov.au/)
Groundwater Dependent Ecosystems	Bureau of Meteorology: GDE Groundwater Dependent Ecosystem Atlas: http://www.bom.gov.au/water/groundwater/gde/map.shtml Clarence-Moreton Bioregional Assessment (Rassam et al 2014) (https://www.bioregionalassessments.gov.au/assessments/clarence-moreton-bioregion) Queensland Globe datasets (https://qldglobe.information.qld.gov.au/)
Groundwater use and management	Queensland Globe database accessed 1 May 2020 DRDMW water entitlements database accessed 1 October 2020 https://data.qld.gov.au/dataset/water-entitlements Bureau of Meteorology National Groundwater Information System http://www.bom.gov.au/water/groundwater/ngis/ Clarence-Moreton Bioregional Assessment (Rassam et al 2014) Water Plan (Condamine and Balonne) 2019 Water Plan (GABORA) 2017 Water Plan (Moreton) 2007.

3.2.2 Stage 2 – Geotechnical and hydrogeological investigations

Geotechnical and hydrogeological site investigations along the Project alignment were undertaken to inform the feasibility design for the EIS between May and 10 November 2018. The field investigations included:

- Standpipe piezometer installation
- Hydraulic aquifer testing in standpipe piezometers
- Groundwater level monitoring
- Groundwater quality sampling of Project groundwater monitoring bores (Project bores)
- Laboratory analysis of groundwater samples.

The 2018 feasibility design stage investigations are discussed in Section 5 and outcomes were utilised to compliment the desktop geological and hydrogeological reviews (including groundwater level and quality) presented in Section 6 and Section 7, respectively.

The feasibility design stage investigations, and subsequently produced predictive groundwater model (refer Section 9), identified gaps in the understanding of the hydrogeological conditions the Project is expected to encounter. Since the feasibility design stage investigations in 2018, further geotechnical and hydrogeological investigations (Golder, 2020c/d) targeting the tunnel, portals, and shaft, have been undertaken. Specifically, these investigations were undertaken from December 2018 through June 2020 and aimed to further characterise the key aquifers of relevance to the Project and their relationships with each other. The works included advancement of geotechnical boreholes and testing, geophysical surveys, conversion of a select set of geotechnical boreholes into groundwater monitoring bores (14) including one deep bore (230 mbgl) at Mt Kynoch, construction of seven (7) vibrating wire piezometers (VWPs) to automatically record groundwater pressures for conversion to water levels, groundwater quality sampling at eight (8) completed new bores plus quality samples from aquifer characterisation testing at the western portal, deployment of automated pressure transducers in new bores, and hydrogeological tests inclusive of variable head tests, pumping tests, and packer tests.

The results from these recently completed geotechnical and hydrogeological investigations (Golder, 2020c/d) were considered and are presented, at a high level, to complement the desktop geological and hydrogeological reviews, where applicable (refer Sections 6 and7).

Further, these data were utilised to refine the mitigation measures and commitments to address identified data gaps as a result of the EIS process in Section 11.2, be utilised to refine the predictive groundwater model prior to commencement of construction for the Project, and inform the indicative GMMP (refer Section 11.3).

3.2.3 Stage 3 – Groundwater impact identification

Potential short-term (construction) and long-term (operational) impacts on the existing groundwater regime, at local and regional scales, were assessed (as described in Section 10) based on review of construction and rail operations with respect to the current geological and hydrogeological setting.

Groundwater predictive modelling was undertaken and utilised to inform the assessment of potential impacts on groundwater resources as a result of the construction and operation of the Toowoomba Range tunnel. Preliminary analysis of potential groundwater inflows to cuts along the Project has been carried out and reported as part of the preliminary hydrogeological interpretative assessment.

It is noted that ARTC have committed to refinement of the model and predictions from what is included in this report. The updated simulations will be completed and included in the Final EIS to better understand the impacts on groundwater and their significance, see Section 9.5.

3.2.4 Stage 4 – Impact assessment

The construction and rail operation details were assessed to consider potential short- and long-term groundwater impacts (both local and regional), using analytical assessments and numerical predictive groundwater modelling to inform of initial impacts on groundwater resources and users as a result of the Project.

A qualitative significance assessment was undertaken which considers the sensitivity (or vulnerability) of an EV and the magnitude of the potential impact to identify a significance rating.

The predictive modelling undertaken, as a component of the geotechnical works for the Project, allowed for assessment of the identified potential impacts on groundwater resources in terms of the sensitivity and magnitude criteria. The modular finite difference flow model (MODFLOW) modelling software was selected as it allows for assessing variable saturation conditions, flow and mass transport simulations, and for integrated groundwater and surface water modelling. The model was constructed to include sufficient layers to simulate the geological (and corresponding groundwater resources) units that will potentially be impacted during construction, including alluvium, colluvium, MRV (olivine basalt and deeper rhyolite), and Marburg Subgroup sediments (including Koukandowie Formation and Gatton Sandstone). The model includes optimum grid spacing, with a factor of 3, to openings, which is recognised to have the least numerical discrepancies when calculating inflow into tunnels; therefore, the minimum grid spacing of 35 metres (m) was deemed appropriate as the grid spacing is roughly three times the tunnel diameter (11 m). Appropriate model boundaries were selected sufficiently far from the tunnel so as not to influence model predictions.

The model calibration target selected included groundwater-level data with constraints of reasonable ranges of hydraulic conductivity (provided form the geotechnical study and desktop review) and recharge and evapotranspiration data. Steady-state calibration, followed by transient calibration (water level data to be compiled from loggers installed during the geotechnical study), were performed. Model parametrisation was determined using both the simple (homogeneous) and complex (heterogeneous) approach. Model parameter values were determined using PEST (parameter estimation and uncertainty analysis software).

The calibrated model was used to assess potential impacts on current groundwater resources, short- and long-term groundwater drawdown (construction and operation). Uncertainty and sensitivity assessments were undertaken to allow for consideration of data gaps and model assumptions.

Evaluation of significance classifications, with and without mitigation measures, was then performed (refer Section 10).

The results are considered to inform a Groundwater Management and Monitoring Plan that will be required for ongoing assessment of potential impacts on groundwater post-EIS (refer Section 12).

3.2.5 Stage 5 - Reporting

This groundwater technical report was prepared with factual, site-specific and publicly available data, predictive numerical modelling, and interpretation to perform an assessment of the potential impacts as a result the Project on groundwater resources.

3.3 Impact assessment methodology

The groundwater impact assessment for the Project uses a significance-based impact assessment framework to identify and assess Project-related impacts in relation to environmental receptors.

For this assessment, an ‘impact significance’ is dependent upon the sensitivity of the groundwater EV, the quality of the environment to be impacted, and the intensity, duration, magnitude, and potential spatial extent of the identified potential impact. The sensitivity/vulnerability of the groundwater EVs and the magnitude of the potential impact were determined, allowing the significance of potential groundwater impact(s) to be assessed. The following sections discuss and define impact magnitudes, receptor sensitivity, and impact significance.

3.3.1 Magnitude of impacts

The magnitude of a potential impact is essential to the determination of its level of significance on EVs/receptors.

The impact magnitude is divided into four categories, as included in Table 3.2. The magnitude of a potential impact is determined with techniques and tools that facilitate an estimation of the **extent**, **duration,** and **frequency** of the potential impacts.

Table 3.3 presents the timeframes for impact duration terms utilised to inform the magnitude of a potential impact.

Potential impacts identified for the Project are presented in Section 10; the impact assessment performed for the Project on groundwater resources is presented in Section 12.

Table 3.2 Criteria for magnitude classification of potential impacts on groundwater

Magnitude	Description
Major	An impact that is widespread, **permanent** and results in substantial irreversible change to the environmental value. Avoidance through appropriate design responses or the implementation of environmental management controls are required to address the impact.
High	An impact that is widespread, **long lasting** and results in substantial and possibly irreversible change to the environmental value. Avoidance through appropriate design responses or the implementation of site-specific environmental management controls are required to address the impact.
Moderate	An impact that extends beyond the area of disturbance to the surrounding area but is contained within the region where the Project is being developed. The impacts are **short term** and result in changes that can be ameliorated with specific environmental management controls.
Low	A localised impact that is **temporary** or **short term** and either unlikely to be detectable or could be effectively mitigated through standard environmental management controls.
Negligible	An extremely localised impact that is barely discernible and is effectively mitigated through standard environmental management controls.

Table 3.3 Timeframes for duration terms

Duration term	Timeframe – to be defined for each receptor type if required
Temporary	Months (e.g. 1 to 2 seasons; up to 12 months)
Short term	Up to 2 years (i.e. 12 to 24 months)
Medium term	From 2 to 10 years[a]
Long term/long lasting	From 10 to 20 years[b]
Permanent or irreversible	More than 20 years[c]

Table notes:

a. Derived from the term 'moderate' EAM Risk Management Framework 2009 (Great Barrier Reef Marine Park Authority 2009)
b. Derived from the term 'major' EAM Risk Management Framework 2009 (Great Barrier Reef Marine Park Authority 2009)
c. Derived from the term 'catastrophic' EAM Risk Management Framework 2009 (Great Barrier Reef Marine Park Authority 2009)

3.3.2 Sensitivity

To assess the significance of potential impacts on groundwater resources, sensitivity categories are applied and are split into four discrete groups as described in Table 3.4. These groupings are based on qualitative assessments utilising information related to the sensitivity or vulnerability of the EVs and the magnitude of the potential impact (refer Table 3.2).

Through the determination of sensitivity categories, the potential impacts are then able to be assessed through a matrix against the magnitude of the potential Project impacts to indicate the level of significance for each of the impact types.

Table 3.4 Sensitivity criteria

Sensitivity	Description
Major	▪ The environmental value is listed on a recognised or statutory state, national or international register as being of conservation significance and/or ▪ The environmental value is entirely intact and wholly retains its intrinsic value and/or ▪ The environmental value is unique to the environment in which it occurs. It is isolated to the affected system/area, which is poorly represented in the region, state, country or the world and/or ▪ It has not been exposed to threatening processes, or they have not had a noticeable impact on the integrity of the environmental value. ▪ Project activities would have an adverse effect on the value.
High	▪ The environmental value is listed on a recognised or statutory state, national or international register as being of conservation significance and/or ▪ The environmental value is intact and retains its intrinsic value and/or ▪ The environmental value is unique to the environment in which it occurs. It is isolated to the affected system/area, which is poorly represented in the region and/or ▪ The environmental value has not been exposed to threatening processes, or they have not had a noticeable impact on the integrity of the sensitive value. ▪ Project activities would have an adverse effect on the value.
Moderate	▪ The environmental value is recorded as being important at a regional level, and may have been nominated for listing on recognised or statutory registers and/or ▪ The environmental value is in a moderate to good condition despite it being exposed to threatening processes. It retains many of its intrinsic characteristics and structural elements and/or ▪ It is relatively well represented in the systems/areas in which it occurs but its abundance and distribution are exposed to threatening processes and/or ▪ Threatening processes have reduced its resilience to change. Consequently, changes resulting from Project activities may lead to degradation of the prescribed value and/or ▪ Replacement of unavoidable losses is possible due to its abundance and distribution.
Low	▪ The environmental value is not listed on any recognised or statutory register. It might be recognised locally by relevant suitably qualified experts or organisations e.g. historical societies and/or ▪ The environmental value is in a poor to moderate condition as a result of threatening processes, which have degraded its intrinsic value and/or ▪ It is not unique or rare and numerous representative examples exist throughout the system/area and/or ▪ It is abundant and widely distributed throughout the host systems/areas and/or ▪ There is no detectable response to change or change does not result in further degradation of the environmental value and/or ▪ The abundance and wide distribution of the environmental value ensures replacement of unavoidable losses is achievable.
Negligible	▪ The environmental value is not listed on any recognised or statutory register and is not recognised locally by relevant suitably qualified experts or organisations and/or ▪ It is not unique or rare and numerous representative examples exist throughout the system/area and/or ▪ There is no detectable response to change or change does not result in further degradation of the environmental value.

3.3.3 Significance of impact

The significance of a potential impact is a function of the **significance** of the EV, the **sensitivity** of the EV, and the **magnitude** of the potential impact. Although the sensitivity of the EV will not change (i.e. is generally determined qualitatively by the interaction of the receptor's condition, adaptive capacity, and resilience), the **magnitude** of the potential impact is variable and may be categorised qualitatively to facilitate the prediction of the significance of the potential impact.

Once the EV has been identified, and the **sensitivity** of the value and the **magnitude** of the potential impact have been determined, a significance assessment of the potential impact can be facilitated via application of a five by five matrix as detailed in Table 3.5.

Table 3.5 Significance assessment matrix

Magnitude of impact	Sensitivity				
	Major	**High**	**Moderate**	**Low**	**Negligible**
Major	Major	Major	High	Moderate	Low
High	Major	Major	High	Moderate	Low
Moderate	High	High	Moderate	Low	Low
Low	Moderate	Moderate	Low	Negligible	Negligible
Negligible	Moderate	Low	Low	Negligible	Negligible

Table 3.6 Significance classifications

Significance rating	Description
Major	Arises when an impact will potentially cause irreversible or widespread harm to an environmental value that is irreplaceable because of its uniqueness or rarity. Avoidance through appropriate design responses is the only effective mitigation.
High	Occurs when the proposed activities are likely to exacerbate threatening processes affecting the intrinsic characteristics and structural elements of the environmental value. While replacement of unavoidable losses is possible, avoidance through appropriate design responses is preferred to preserve its intactness or conservation status.
Moderate	Results in degradation of the environmental value due to the scale of the impact or its susceptibility to further change even though it may be reasonably resilient to change. The abundance of the environmental value ensures it is adequately represented in the region, and that replacement, if required, is achievable.
Low	Occurs where an environmental value is of local importance and temporary or transient changes will not adversely affect its viability provided standard environmental management controls are implemented.
Negligible	Does not result in any noticeable change and hence the proposed activities will have negligible effect on environmental values. This typically occurs where the activities are located in already disturbed areas.

Upon identification of the level of significance of a potential impact, mitigation measures are then applied to the potential (unmitigated) impact to identify the residual (mitigated) impact.

The identified potential impacts on groundwater resources, as a result of the Project, are presented in Section 10. Section 11 includes mitigation measures for the identified potential impacts and Section 12 presents the significance impact assessment (refer Table 12.1).

3.4 Cumulative impact assessment

A cumulative impact assessment (CIA) was undertaken to identify developments in proximity to the Project in space and time with potential to impose an additional/incremental impact on groundwater resources within the groundwater study area. That is, an assessment of developments from other existing, planned, or reasonably defined developments which may incrementally impact on the groundwater regime in addition to the Project.

The CIA undertaken for groundwater was undertaken per the methodology presented below.

Projects considered for the CIA for groundwater had to meet one or more of the selection criteria below:

- Have been declared a ‘coordinated project’ by the Coordinator-General under the SDPWO Act and an EIS is currently being prepared or is complete, or an Initial Advice Statement is available on the Queensland Department of State Development, Manufacturing, Infrastructure and Planning website
- Are currently being assessed under Part 1 of the Chapter 3 of the EP Act
- May use resources located within the region (including materials, groundwater, road networks or workforces) that are the same as those to be used by the ARTC Inland Rail Program

- Could potentially compound residual impacts that the ARTC Inland Rail Program may have on environmental or social values.

Projects excluded from the CIA include:

- Existing projects within the groundwater study area. Such projects are considered part of the 'existing environment'. These are accounted for in the impact assessment of the Project.
- Proposed projects not yet developed to the point their environmental assessment process has been made public.

The CIA process applied for groundwater included:

- A review of the potential impacts identified within the impact assessment (the existing environment at the time of the ToR is the baseline, prior impacts from past land use have not be considered)
- A register of assessable projects has been collated with timelines to demonstrate the temporal relationship between projects, inclusive of:
  - Identification of projects outside of the Inland Rail Program
    - Only 'state significant' or 'strategic' projects that are in the public domain as being planned, constructed or operated at the time of the ToR have been considered
    - Where additional projects worthy of consideration have arisen after the finalisation of the ToR, the Coordinator-General has been consulted to determine if assessment is required
  - The Inland Rail projects immediately adjacent to the Project within the assessment:
    - H2C project
    - B2G project
- Identification and mapping of the assessable projects and the Areas of Influence of the aspect (e.g. groundwater) to be considered:
  - Current operational projects and commercial or agricultural operations that are within the Areas of Influence in proximity to the Project are accounted for.
- Where there is a potential overlap in impacts (spatially or temporally), a CIA has been undertaken to determine the nature of the cumulative impact. This includes where the impacts are expressed qualitatively, the probability, duration, and magnitude/intensity of the impacts were considered as well as the sensitivity and value of the receiving environment.
- An assessment matrix method has been used to determine the significance of cumulative impacts with respect to beneficial or detrimental effects (refer Section 12.3)
- Where cumulative impacts are deemed to be of 'medium' or 'high' significance, additional mitigation measures are proposed beyond those already proposed by the groundwater technical impact assessment.

Where cumulative impacts could only be expressed qualitatively, professional judgement regarding the probability, duration, and magnitude/intensity of the impact, as well as the sensitivity and value of the receiving environment, was used to assess the relevance and significance of potential cumulative impact(s).

4 Site setting

4.1 Location

The Project is in the western segment of the Queensland projects of the Inland Rail Program between the B2G and H2C Inland Rail projects. The location of the Project and its regional context is shown on Figure 1.1.

The Project generally aligns with the Gowrie to Grandchester future State transport corridor. This transport corridor was initially identified in the Gowrie to Grandchester Rail Corridor Study in 2003. The primary purpose of the corridor was for a 200 km/hour passenger service, with the corridor subsequently identified as a 'future public passenger transport corridor' in September 2005 in the Public Passenger Transport Guideline made under the *Transport Planning and Coordination Act 1994*.

The Project commences approximately 3.7 km west of Gowrie (Ch 1.76 km) at Charlton where it connects with the eastern end of B2G project. It then follows the existing West Moreton System rail corridor for approximately 4.8 km. The Project deviates from the existing rail corridor to the south-east, before passing into the proposed western tunnel portal within the vicinity of the Boundary Street and the Toowoomba Bypass interchange at Gowrie. The alignment then continues with a 6.24 km tunnel under the Toowoomba Range, passing under the localities of Cranley, Mount Kynoch and Ballard (including under the Toowoomba Bypass) and emerging on the eastern side of the Great Dividing Range at the eastern tunnel portal, within the vicinity of Mt Kynoch. An intermediate ventilation shaft is also proposed at Cranley (Ch 6.83 km).

The Project then crosses through the northern edge of an area of Commonwealth land, previously utilised by the Department of Defence. Continuing east, the alignment passes on the northern side of Withcott and traverses areas of native vegetation and grazing properties, with proposed crossings over the valleys of Rocky Creek, Six Mile Creek and over the Toowoomba Bypass. The alignment continues to the north of the Toowoomba Bypass through Postmans Ridge, Lockyer and Helidon Spa, crossing Lockyer Creek, before tying into the existing West Moreton System rail corridor north-west of Helidon. The alignment runs parallel to the West Moreton System rail corridor for approximately 0.8 km before joining the proposed H2C project alignment.

The Toowoomba Range tunnel is located on the northern outskirts of Toowoomba with total length of 6.24 km. The tunnel is oriented west-north-west to east-south-east at a grade of about 1 in 64.4.

The western tunnel portal (Ch 4.10 km) is located near the Boundary Street/Toowoomba Bypass interchange where the surface level is 510.1 m AHD and the rail level is 490.0 m AHD. The approximate 600 m long western approach box cut will be up to 26 m in height at the western tunnel portal face, gradually reducing in height towards the west.

The eastern tunnel portal is on the lower slopes of the Great Escarpment in the vicinity of Mt Kynoch (Ch 10.34 km), where the surface level is 406.0 m AHD and the rail level is 394.4 m AHD. The eastern tunnel portal is located east and downslope from the existing New England Highway and the Main Line railway line. The approximately 100 m long cut at the eastern tunnel portal approach has a portal face that is about 13 m in height.

The tunnel invert is more than 200 m below the surface level between approximate Ch 8.45 km and Ch 9.05 km.

4.2 Land use

Land use within the groundwater study area is predominantly rural residential interspersed between the townships of Helidon, Toowoomba, and Gowrie, and includes significant transport infrastructure of the New England Highway, Toowoomba Bypass and West Moreton System rail corridor (Department of Science, Information Technology and Innovation (DSITI) 2016). Approximately 5.6 km of the proposed rail corridor is co-located with the existing QR West Moreton System rail corridor. The land use within 5 km of the Project has been divided into the following aspects:

- Grazing and native vegetation (45 per cent)
- Residential use (22 per cent)
- Irrigated cropping and modified pastures (11 per cent)
- Manufacturing and industrial (2 per cent)
- Transport and communication (1 per cent)
- Other including resource protection, services and conservation (20 per cent).

Land uses have been sourced from the DSITI (2016). Groundwater is used a key water supply source in the region.

The intended land use for the Project is rail and associated infrastructure, including viaducts, bridges, grade separations, the Toowoomba Range tunnel through the GDR, ventilation buildings and associated infrastructure at the western and eastern tunnel portals and the intermediate ventilation shaft at Cranley along with other ancillary infrastructure. In addition, land will be acquired for the purposes of road infrastructure though most changes to the road network will occur within existing road reserves.

4.3 Topography and drainage

4.3.1 Topography

The Project traverses through the GDR and Great Escarpment and crosses several hills, valleys, creeks and alluvial floodplains (shown in Figure 4.1). The Project traverses Gowrie Creek and Lockyer Creek catchments and various tributaries of these creeks (including Oaky, Rocky and Six Mile creeks).

The valleys in the Great Escarpment feed various creeks including Oaky, Rocky and Six Mile creeks. These creeks are supported by local catchments within the escarpment and feed into Lockyer Creek west of Helidon. The Project crosses Oaky, Rocky and Six Mile creeks and continues east to Helidon, where it crosses Lockyer Creek and then runs parallel with the existing West Moreton System rail corridor along Airforce Road.

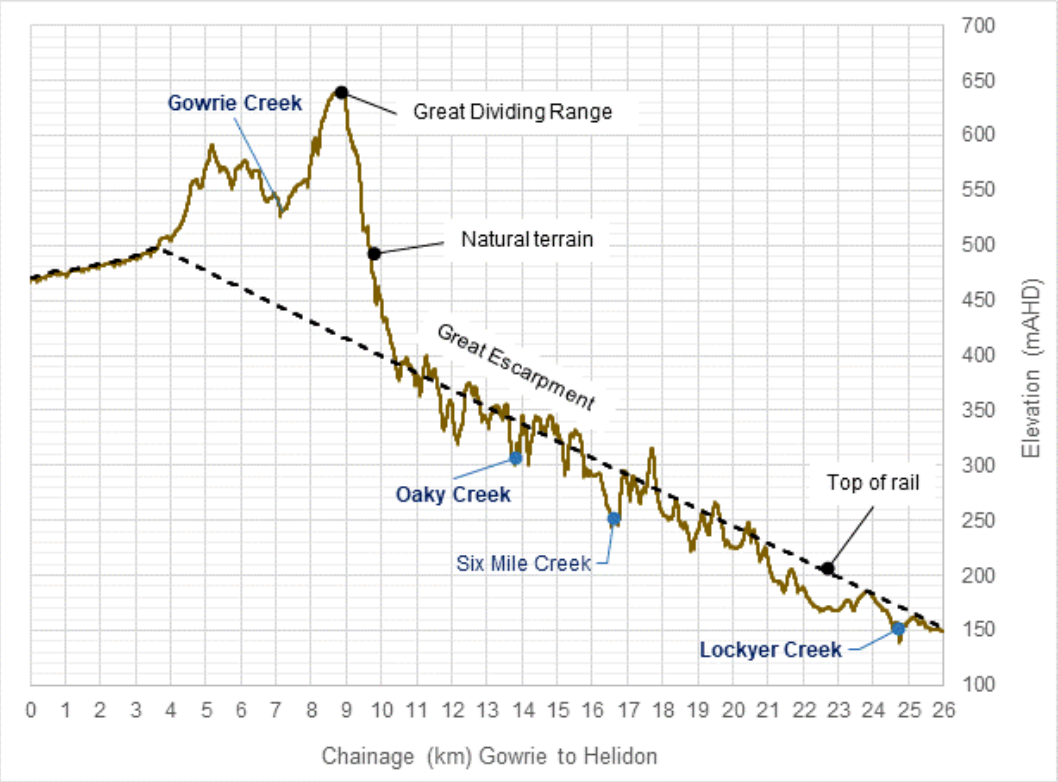


Figure 4.1 **Topography profile from Ch -1.76 to Ch 26.0 km**

4.3.2 Drainage

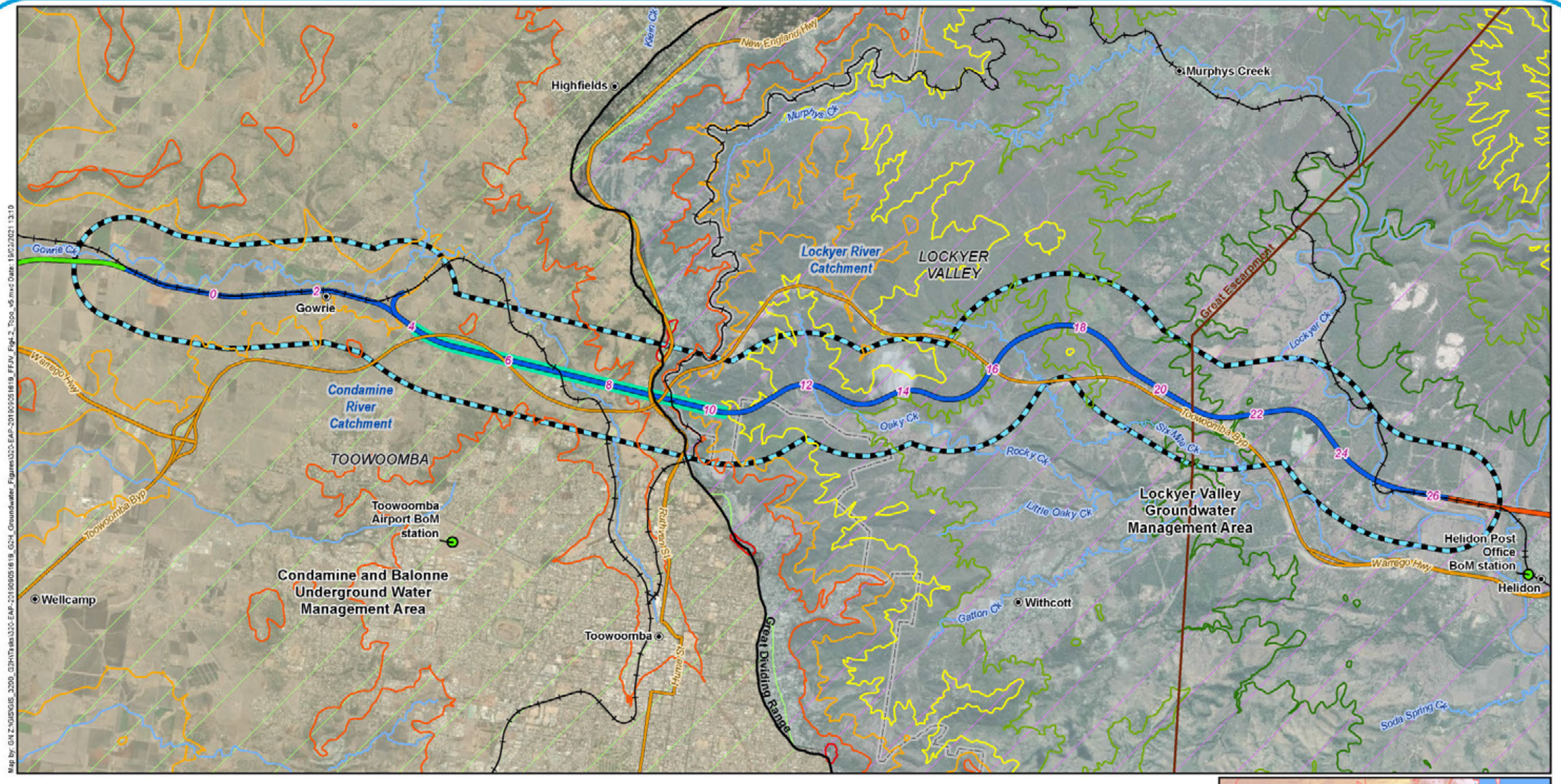
The GDR is the highest point across the Project alignment, is a recharge area, and divides the east (coastal) and west (inland) flow of watercourses. West of the GDR, the main watercourse is Gowrie Creek, which flows in the westerly direction. The Toowoomba Range tunnel underlies Gowrie Creek at Cranley (Ch 7.2 km) at approximate depth of 90 m and parallels the alignment north of the West Moreton System rail corridor from Ganzer Road west to the start of the Project. A new road bridge required for the Project intersects Gowrie Creek at Gowrie, approximately 100 m downstream of the existing bridge (Gowrie Junction Road).

East of the GDR there are numerous watercourses and their ephemeral gullies which flow in the valleys between the ridges, with the main watercourses incised in the underlying Marburg Subgroup rocks (mainly the Koukandowie Formation). Notable watercourses east of the GDR (as defined in the Queensland Globe database) are:

- Oaky Creek (ephemeral) – runs perpendicular and to the north of the alignment and intersects at Ch 13.8 km, where it becomes Rocky Creek (perennial)
- Six Mile Creek (ephemeral) – crosses the alignment at Ch 16.6 km and then runs south of the alignment from Ch 19.6 to 20.0 km (varying in proximity between 600 and 900 m from the alignment)
- Rocky Creek (ephemeral) – runs sub-parallel and to the south of the alignment, from approximately Ch 13.8 km to Ch 15.0 km (varying in proximity between 130 and 700 m from the alignment)
- Lockyer Creek (ephemeral) – intersecting the alignment at Ch 24.7 km and then running south of the alignment, sub-parallel to the H2C connection near Ch 26.2 km.

Six Mile Creek and Oaky Creek are tributaries of Rocky Creek, which joins Lockyer Creek further downstream at the end of the alignment (Ch 26.2 km). Lockyer Creek is the main drainage system in the Lockyer Valley. Figure 4.2 presents the primary surface water features and topography of the Project. Further detail on watercourses within the study area is provided in EIS Appendix L: Surface water quality technical report.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Map by: GN Z:\GIS\GIS_3200_G2H\Tasks\320-EAP-20190905\619_G2H_Groundwater_Figures\320-EAP-20190905619_FFJV_Fig4-2_Topo_v5.mxd Date: 18/02/2021 13:10

Legend

- BoM station
- Chainage (km)
- Localities
- B2G project alignment
- G2H project alignment
- H2C project alignment
- Existing rail
- Major watercourses
- Major roads
- Great Dividing Range
- Great Escarpment
- Tunnel
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Catchment

- Condamine River Catchment
- Lockyer Creek Catchment

Elevation (m AHD)

- 200
- 300
- 400
- 500
- 600
- 700



A3 scale: 1:80,000

0 1 2 3 4 5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/02/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 4.2:

Topography and surface water features of the groundwater study area

4.4 Climate and rainfall

4.4.1 Climate

The groundwater study area has a hot and dry climate with warm to hot summers and mild to cool winters. Rainfall is seasonally distributed with a distinct wet season which occurs during the summer months of December through February, and an extended dry season from April through September. Mean maximum monthly temperatures typically range from 28°C in summer to 18°C in winter.

The Toowoomba Airport BoM station (041529) has rainfall and evaporation data from 1996 to present however the Helidon Post Office BoM station (040096) has rainfall data from 1871. As a result, evaporation data was sourced from the Toowoomba Airport BoM station and rainfall data was sourced from Helidon Post Office BoM station. The Toowoomba Airport BoM station is in the Toowoomba Township at Ch 7.8 km and the Helidon Post Office BoM station is in the Helidon at Ch 26.2 km, both stations are shown in Table 4.1.

Climate data is only available at the Toowoomba Airport BoM station (041529) and is summarised in Table 4.1, along with rainfall data from the Helidon Post Office BoM station (040096).

Table 4.1 Climate summary for Toowoomba Airport and Helidon Post Office BoM stations

Month	Toowoomba Airport BoM station (041529)				Helidon Post Office BoM station (040096)
	Mean maximum temperature[a] (ºC)	Mean minimum temperature[a] (ºC)	Mean monthly rainfall[a] (mm)	Mean monthly evaporation[a] (mm)	Mean monthly rainfall[b] (mm)
January	28.4	17.6	91	180	121
February	27.6	17.6	102	150	101
March	26.2	16.5	86	135	84
April	23.3	13.4	26	110	49
May	19.9	10	36	85	45
June	17	7.6	36	60	44
July	16.7	6.6	27	75	36
August	18.7	7.5	31	105	26
September	22.3	10.6	36	135	35
October	24.5	12.8	65	160	63
November	26.2	14.8	75	175	79
December	27.6	16.6	106	180	105
Annual mean total	**-**	**-**	**690**	**-**	**760**

Table notes:

a. Toowoomba Airport - BoM Station 041529: record from 1996 to 2018
b. Toowoomba Airport - BoM Station 041529: record from 1871 to 2019

Average monthly evaporation (estimated from mean daily values) at Toowoomba Airport BoM station (041529) is compared to mean monthly rainfall data from the Helidon Post Office BoM station (040096) in Figure 4.3. The figure shows that pan evaporation exceeds rainfall for each month of the year. An overall negative climate budget generally prevails in the region.

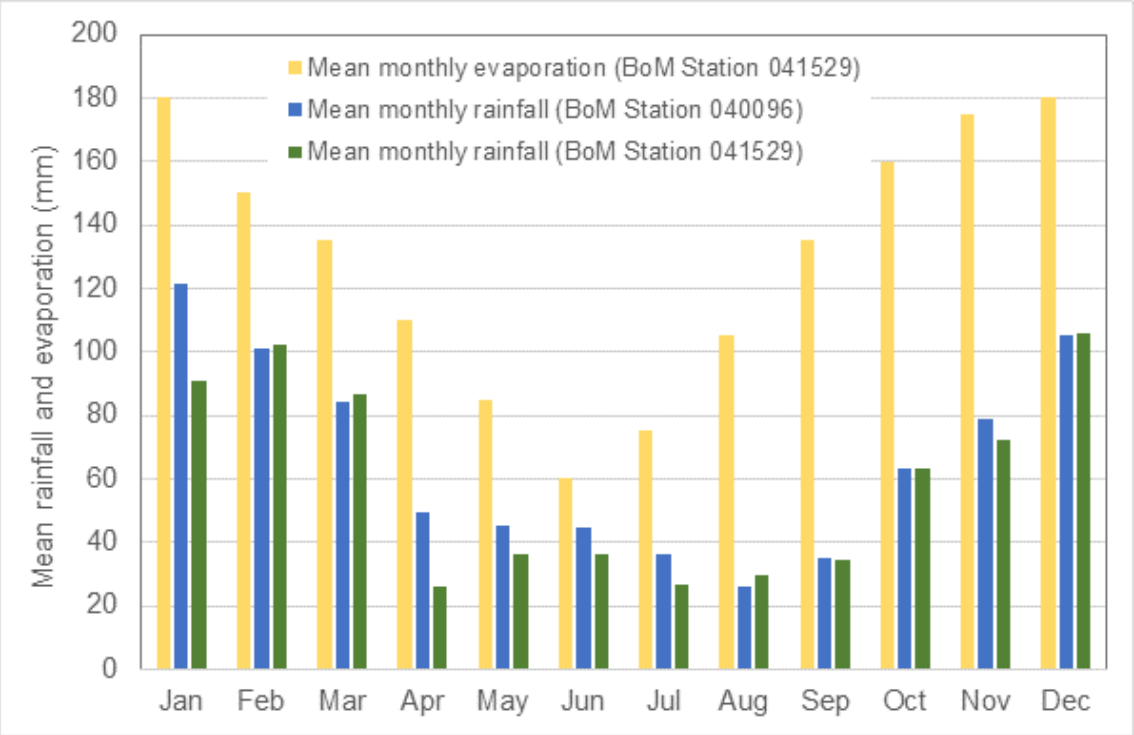


Figure 4.3 **Mean monthly pan evaporation and rainfall**

4.4.2 Cumulative Rainfall Departure

The Cumulative Rainfall Departure (CRD) (Weber and Stewart 2014) is a method used to evaluate short term/monthly rainfall trends compared to long-term average monthly rainfall records. A positive slope in the CRD is indicative of periods of above average rainfall and can be associated with increased groundwater recharge to unconfined aquifers. A negative slope indicates periods of below average rainfall. Groundwater levels in unconfined aquifers which receive direct rainfall recharge can be expected to reflect trends in the CRD.

Monthly rainfall records were used to calculate rainfall residuals and the Cumulative Rainfall Departure, for the Helidon Post Office BoM station (refer Table 4.1 and Figure 4.4).

Data shows there was a dry period which resulted in decreasing CRD between 1890 and 1920 however significant and consistent rainfall events during the 1950s and again in 2011 resulted in increasing CRD. It should be noted that in the past 24 months (through 2020) the region has received characteristically low rainfall, which is captured in the steep decline in the CRD. The region is currently drought declared, per The Long Paddock (last reviewed on 22 March 2021). The trend observed at Helidon Post Office BoM station (040096) at Ch 26.2 km is considered to be representative of the Project.

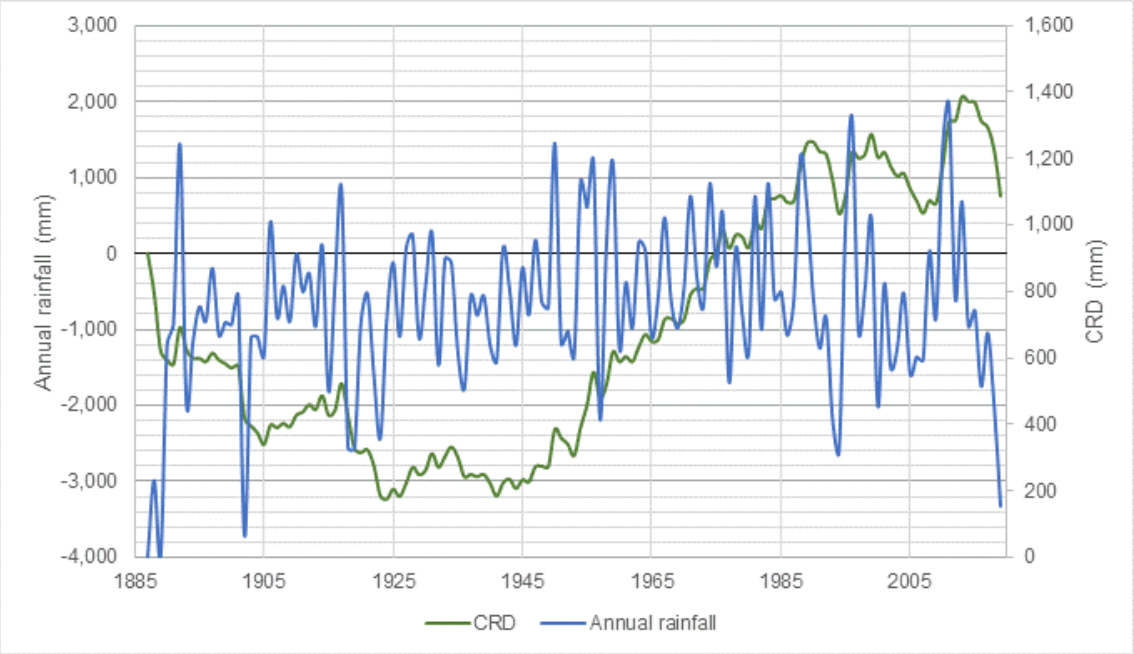


Figure 4.4 **Cumulative Rainfall Departure for Helidon Post Office BoM Station (040096)**

5 Field investigations

Between 4 July and 10 December 2018, geotechnical and hydrogeological feasibility design phase investigations were carried out by Golder within the Project disturbance footprint with the objective of obtaining geotechnical and hydrogeological data to inform the design and the EIS.

Hydrogeological investigations were conducted as part of the feasibility design phase investigation by qualified hydrogeologists or qualified field engineers with advice from a qualified hydrogeologist. Field investigations included:

- Standpipe piezometer installation (12 Project bores)
- Vibrating Wire Piezometer (VWP) installation (1 bore)
- Hydraulic aquifer testing (falling head test or rising head test) in standpipe piezometers
- Groundwater level monitoring
- Groundwater quality sampling of Project bores
- Laboratory analysis.

The feasibility design phase investigations are detailed and discussed in depth in the following document:

- Geotechnical Factual Report, Inland Rail Project - Gowrie to Helidon Section - Phase 2 dated 24 March 2020 (Golder 2020b) and is also provided as EIS Appendix W: Geotechnical factual report.

A summary of key hydrogeological results from the feasibility design phase investigations is provided in Table 5.1, including the screened interval depths, the screened lithology, water levels, and slug test results. The locations of Project bores installed during the feasibility design phase investigations are presented on Figure 7.17.

The feasibility design phase investigations, and subsequently produced predictive groundwater model (refer Section 9), identified gaps in the understanding of the hydrogeological conditions the Project is expected to encounter. Since the feasibility design phase investigations in 2018, further geotechnical and hydrogeological investigations (Golder, 2020c/d) targeting the tunnel, portals, and shaft, have been undertaken. Specifically, these investigations were undertaken from December 2018 through January 2020 and aimed to further characterise the key aquifers of relevance to the Project and their relationships with each other. The works included advancement of geotechnical boreholes and testing, geophysical surveys, conversion of a select set of geotechnical boreholes into groundwater monitoring bores, groundwater quality sampling of the new bores, and hydrogeological tests inclusive of variable head tests, pumping tests, and packer tests.

The results from these recently completed geotechnical and hydrogeological investigations (Golder, 2020c/d) were considered and are presented, at a high level, to complement the desktop geological and hydrogeological discussions (where applicable) in Sections 6 and 7.

The results of the post-feasibility design phase investigations (Golder 2020c/d) will be utilised to refine the predictive groundwater model and included in the Final EIS, as discussed in Section 9.5 and Section 11.2. Therefore, this section presents the feasibility design phase (2018) investigation only.

Table 5.1 Project bore installation locations and results (feasibility design phase)

Project chainage (approx.)	Bore ID	Screened interval (mbgl)	Screened Lithology	Aquifer	Surface elevation[a]	Median SWL (m AHD)	RL Range (m AHD)	Average Hydraulic Conductivity[b] (K) (m/day)
Ch 5.6 km	BH2101	105.0 – 117.0	Sandstone Siltstone	Koukandowie Formation	575.9	474.7	474.28 – 474.98	-
Ch 10.4 km	BH2103	17.0 – 26.0	Siltstone Sandstone	Koukandowie Formation	390.0	377.6	377.59-380.25	0.0010
Ch 11.8 km	BH2201	14.0 – 20.0	Sandstone Mudstone	Koukandowie Formation	326.9	320.5	314.94 – 323.93	0.0078
Ch 13.8 km	BH2203[c]	12.0 – 20.0	Sandstone	Koukandowie Formation	295.0	-	-	-
Ch 15.6 km	BH2301	12.0 – 20.0	Sandstone	Koukandowie Formation	319.9	309.3	309.29 – 311.84	-
Ch 16.6 km	BH2207	7.0 – 10.0	Sand and gravelly sand	Koukandowie Formation	253.0	Dry	Dry	0.1901[c]
Ch 19.8 km	BH2209	14.0 – 20.0	Sandstone	Gatton Sandstone	222.0	Dry	Dry	0.0488[c]
Ch 21.2 km	BH2212	11.4 – 20.9	Siltstone Sandstone	Gatton Sandstone	199.7	188.7[d]	-	0.0287
Ch 23.5 km	BH2215	11.0 – 20.0	Sandstone	Gatton Sandstone	178.0	Dry	Dry	3.9744[e]
Ch 22.6 km	BH2216	14.0 – 20.0	Sandstone	Gatton Sandstone	174.0	160.6	161.17 – 171.66	0.0009
Ch 24.6 km	BH2217	11.5 – 20.5	Sandstone	Gatton Sandstone	159.7	149.4	149.33 – 150.04	0.0302
Ch 24.8 km	BH2218	14.0 – 20.0	Sandstone	Gatton Sandstone	155.2	140.3	140.92 – 143.21	0.0023

Table notes:

SWL = Static water level; mbgl = metres below ground level

a. Surface elevation derived from Digital Elevation Model (DEM) spatial data

b. Mean hydraulic conductivity value derived from falling and rising head tests completed during feasibility design phase investigations

c. 320-01-BH2207, 320-01-BH2209 and 320-01-BH2215 bores are dry and estimated hydraulic parameters are indicative only.

d. 320-01-BH2212 data logger was installed above the groundwater level of the location. Therefore, hydrograph was not prepared for the bore. The data logger was lowered to below the groundwater level during the visit for the data download so the hydrograph data could be prepared later if required.

e. Hydrograph not available.

5.1 Standpipe piezometer installation

For the feasibility phase investigations, drilling and installation of 12 standpipe piezometers was conducted according to the *Minimum Construction Requirements for Water Bores in Australia: Edition Three* (National Water Commission, 2012)[1]. The design of the standpipe piezometer was provided by a qualified hydrogeologist, with installation conducted by the drilling contractor under the supervision of a qualified field engineer and licensed water bore driller.

All Project bores are equipped with 50 mm diameter class 18 PVC screw jointed pipes with 0.4 mm slotted screens and blank casing. A borehole diameter of 96 mm was drilled for the installation of the standpipe piezometers except for 320-01-BH2101, which was drilled at a diameter of 140 mm. A gravel pack (1 to 3 mm washed and graded gravel) was placed in the annulus of the borehole around the screen section which was then sealed with a bentonite plug. The annular space above the bentonite plug was grouted to the surface where a protective monument or gatic cover was installed.

The completed standpipe piezometers were developed at a later stage by purging via either manual bailing or purging with a 12-volt Twister groundwater pump. Purging was completed prior to sampling for groundwater quality analyses (discussed further in Section 5.5). Multiple groundwater bore volumes were removed from each standpipe piezometer to stimulate flow of ambient groundwater toward the standpipe to ensure suitable development of each well.

Field parameters for groundwater quality were monitored during development to quantify when drilling influences had been removed from the piezometer and groundwater representative of the aquifer was being purged. The standpipe piezometer was considered developed when purge water was free of sediment and field parameters had stabilised over subsequent readings.

5.2 Vibrating wire piezometer installation

Nested VWPs[2] were installed at bore 320-01-BH2102, which was drilled to 260 mbgl. VWP sensors were installed at depths of 184.4 mbgl (460.0 m AHD) and 204.7 mbgl (439.3 m AHD) within the inferred upper and lower MRV, respectively. The installation intervals were selected based on geotechnical logs, core photos and geophysical logs of the bore by a qualified hydrogeologist. The installation was conducted, under the supervision of qualified hydrogeologist and licenced water bore driller. The hydrograph of both VWPs is shown in Figure 5.1.

[1] At the time of the investigations, Edition three of *The Minimum Construction Requirements for Water Bores in Australia* (National Water Commission, 2012) was the most current reference document available.
[2] Slope Indicator from Durham Geo with a maximum pressure rating of 3,500 kilopascals

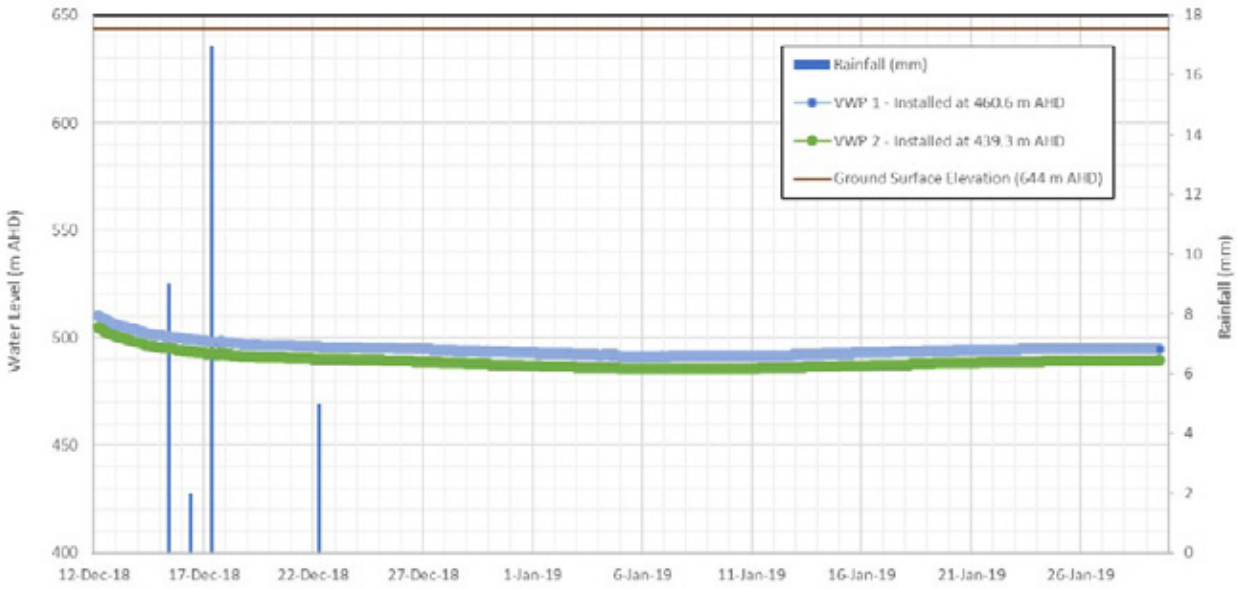


Figure 5.1 Hydrograph of vibrating wire piezometers in 320-01-BH2102

Source: Golder (2020a)

5.3 Permeability testing

In-situ hydraulic testing using the slug test method was conducted in eight of the completed Project bores. Bores 320-01-BH2207, 320-01-BH2209 and 320-01-BH2215 were dry at the time of monitoring. The slug tests involved inducing a change in groundwater level within the bore casing by inserting (falling head) and then removing (rising head) a solid slug or by sudden displacement of the water column in the casing using a gas slug and then measuring the water level response over time. Water level recovery was monitored until it returned to 90 per cent of the pre-test water level. The recorded data allows for an estimation of hydraulic conductivity of the screened soil or rock material.

The SWL was recorded before the slug was inserted in each bore. The hydraulic head (water level) was monitored until it returned (decreased) to within 90 per cent of the SWL, or when sufficient data was deemed to be collected at slow-recovering bores. The automated measurements were confirmed by comparing manual measurements collected using a water level meter. The objective of a hydraulic test is to estimate horizontal hydraulic conductivity (K) of a water saturated rock or soil formation intersected by the screen segment of the bore.

Slug test data were analysed using AQTESOLV™ Pro 4.0 which is an industry standard program widely used in the field of hydrogeology for hydraulic parameter estimation. The hydraulic test data was analysed by using the Hvorslev (1951) and Kansas Geological Survey (Hyder et al. 1994) solution methods. Hydraulic conductivity is reported in metres per day (m/s) and is a measurement of how easily water can move through pore spaces in a geological formation.

5.4 Groundwater level monitoring

A dedicated automatic pressure transducer was installed in 12 Project bores for continuous groundwater level monitoring over time. The transducers record total pressure on the sensor (water column above the sensor and atmospheric/barometric pressure) which is then converted to a groundwater level. Measurements are recorded at hourly intervals and calibrated by manual static water level measurements.

There were seven bores with available data from which hydrographs were developed, presented in Figure 5.2 through Figure 5.8; data was not available for all 12 bores (refer Table 5.1).

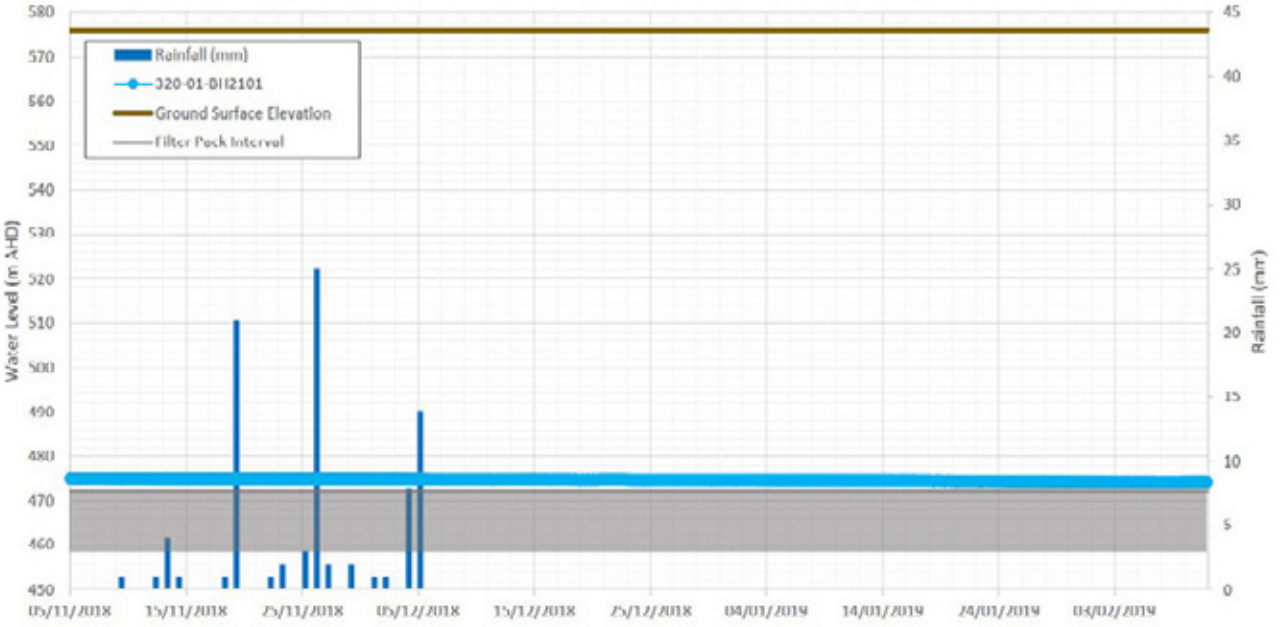


Figure 5.2 320-01-BH2101 hydrograph

Source: Golder 2020a

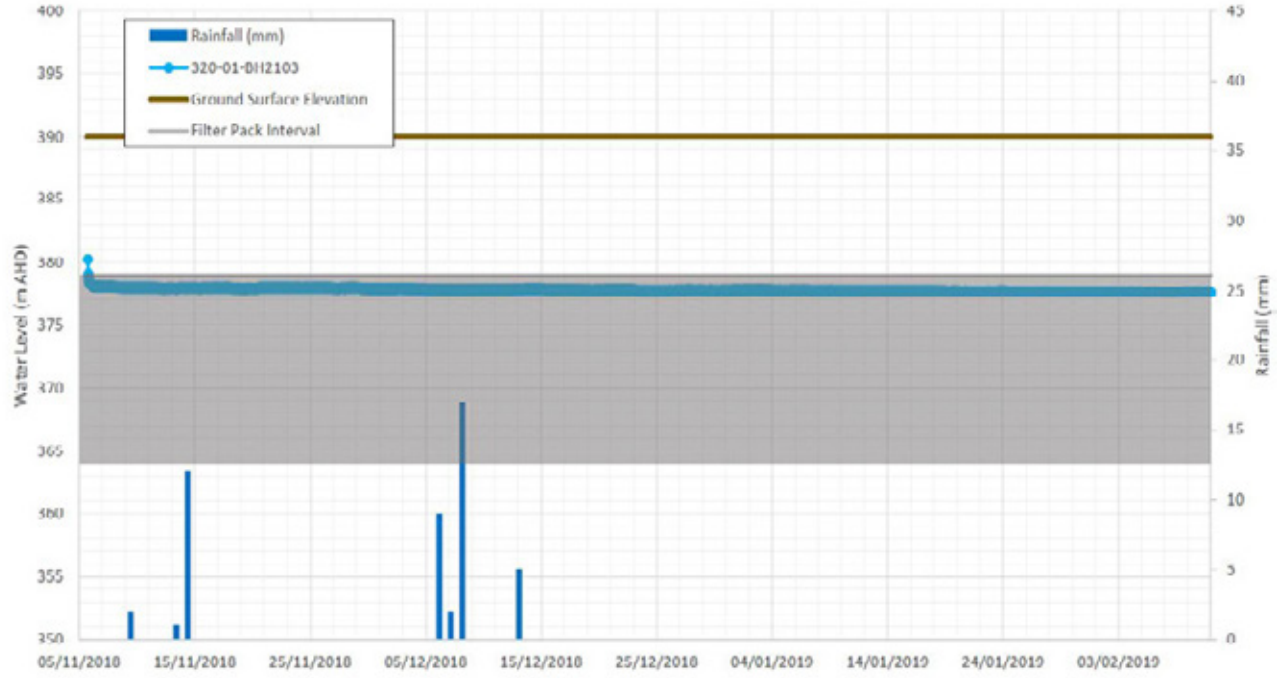


Figure 5.3 320-01-BH2103 hydrograph

Source: Golder 2020a

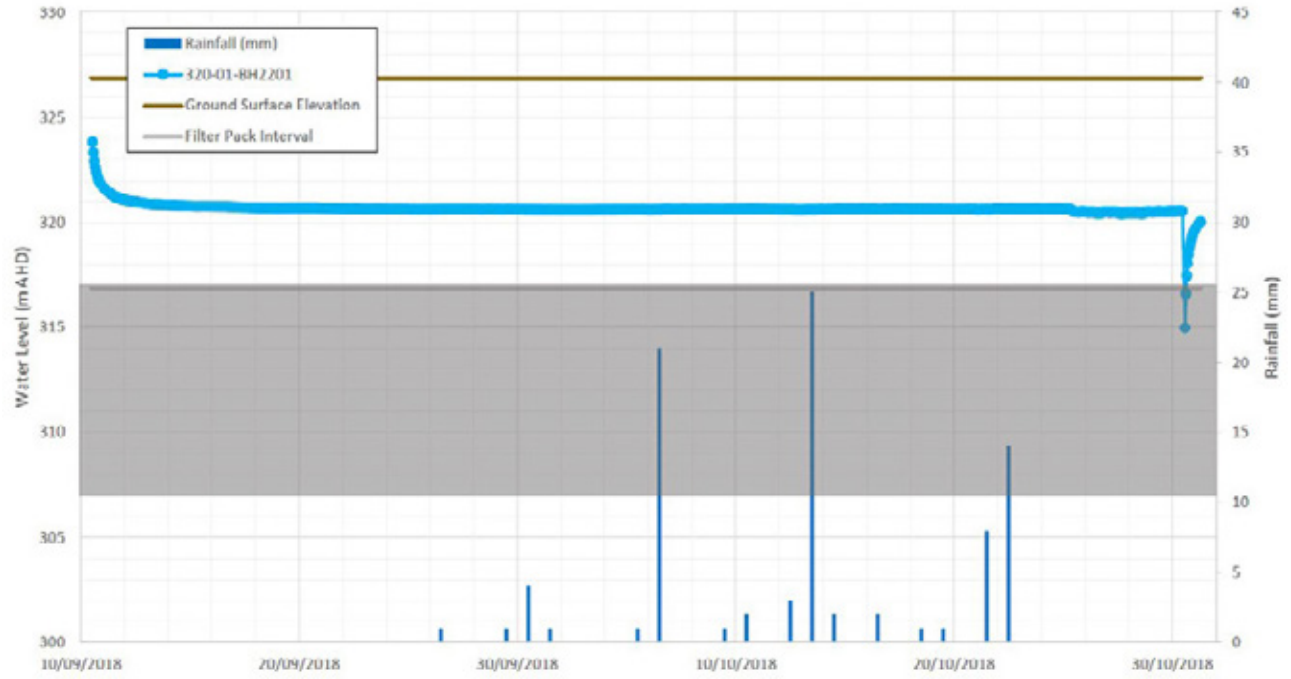


Figure 5.4 320-01-BH2201 hydrograph

Source: Golder 2020a

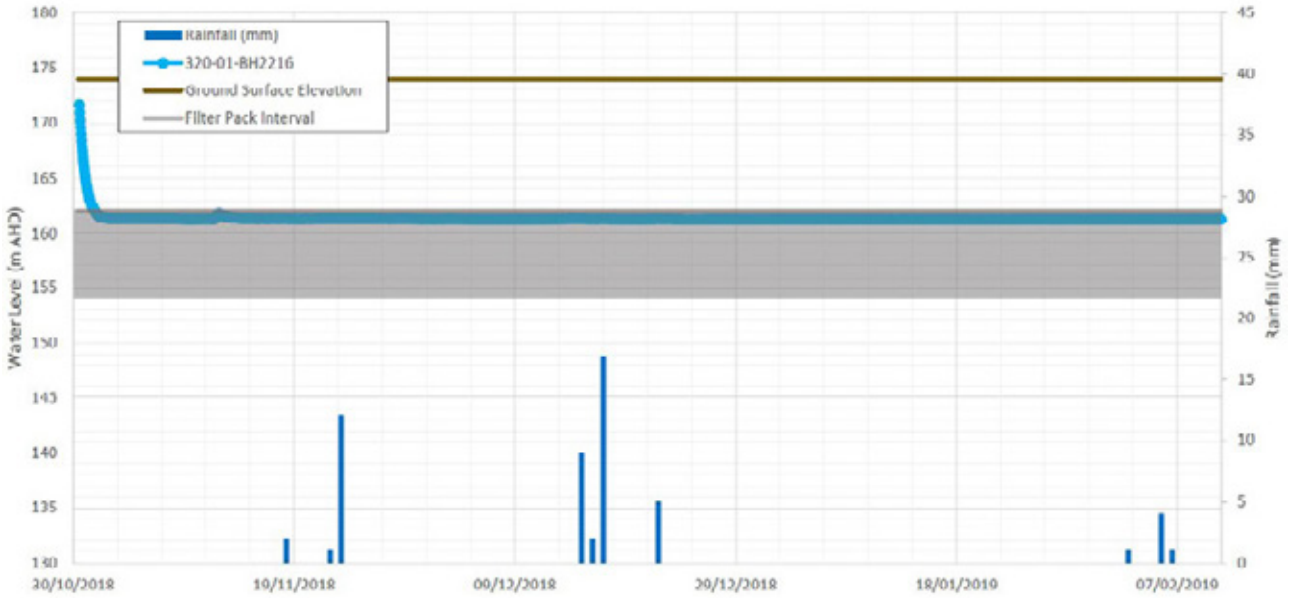


Figure 5.5 320-01-BH2216 hydrograph

Source: Golder 2020a

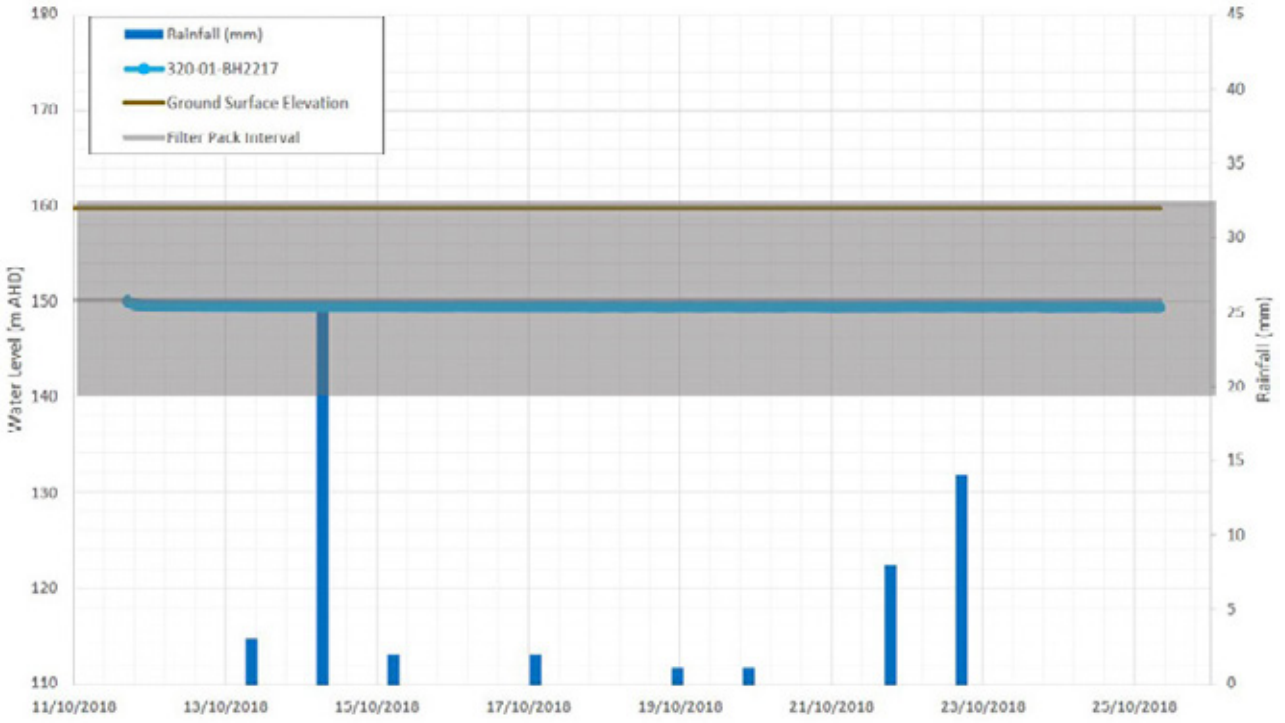


Figure 5.6 320-01-BH2217 hydrograph

Source: Golder 2020a

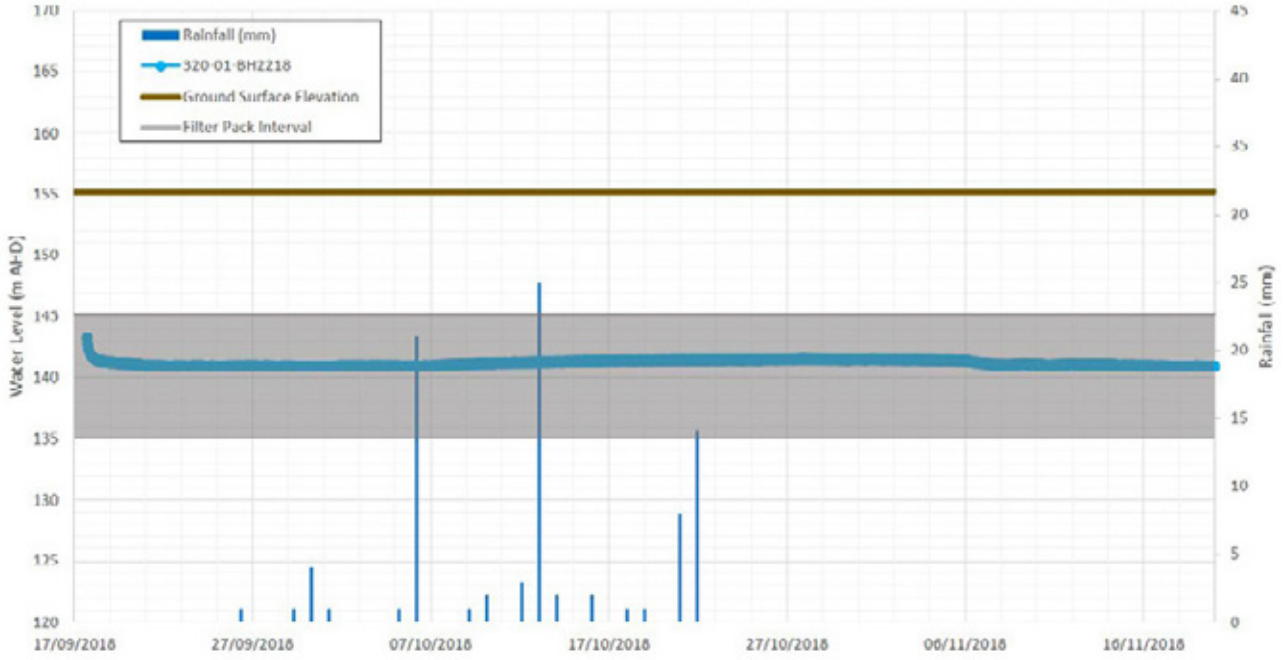


Figure 5.7 320-01-BH2218 hydrograph

Source: Golder 2020a

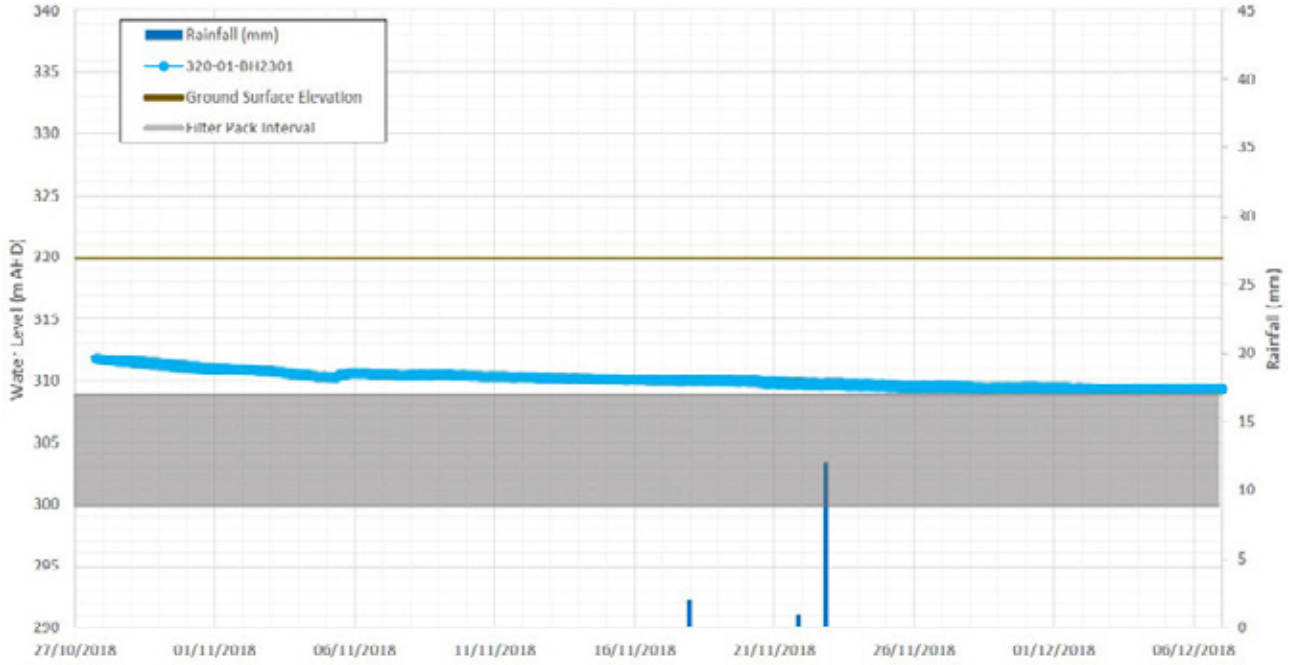


Figure 5.8 **320-01-BH2301 hydrograph**

Source: Golder 2020a

5.5 Groundwater sampling

One round of groundwater sampling was conducted for laboratory analyses, in 2018 for the feasibility design stage investigations, in accordance with AS/NZ 5667.1:1998 (Australian standards 1998a) and AS/NZ 5667.11:1998 (Australian standards 1998b) and Monitoring and Sampling Manual (DES 2018c) after completion of all Project bores. The sampling was conducted after completion of bore development; bore purging was conducted using super twister pump, manual bailing, or both methods. Groundwater samples were collected in laboratory provided containers and shipped in a cooler box chilled with ice under Chain of Custody to Australian Laboratory Services (ALS) in Brisbane, a National Association of Testing Authorities (NATA) accredited laboratory.

Samples were collected to provide quantitative data on groundwater chemistry, durability and/or salinity parameters. A total of eight samples were collected, with bores 320-01-BH2207, 320-01-BH2209 and 320-01-BH2215 being dry at the time of monitoring. Field quality control (QC) samples were collected during sampling along with field physiochemical measurements at the time of sampling. QC samples were collected to check that the samples were of acceptable quality on which to make decisions regarding water quality at the site. QC samples provide information that clarifies potential data errors attributable to cross contamination, inconsistencies in sampling and analytical issues.

The following parameters were analysed for each groundwater sample:

- Major anions and cations (calcium, magnesium, sodium, potassium, chloride, fluoride, sulfate, carbonate and bicarbonate alkalinity, hardness)
- pH
- Electrical conductivity
- Total dissolved solids (TDS)
- Total and dissolved metals (arsenic, boron, barium, beryllium, cadmium, chromium, cobalt, copper, manganese, iron, nickel, lead, selenium, vanadium, zinc and mercury)
- Nutrients (nitrate, nitrite, ammonia, reactive phosphorus, total nitrogen, total Kjeldahl nitrogen, total phosphorus)
- Sodium adsorption ratio (SAR).

Groundwater quality data for Project bores is presented in Table 5.1 and is compared with the Australian Drinking Water Guidelines (ADWG) by the National Health and Medical Research Council (NHMRC) (2011) and livestock drinking water guidelines (Australian and New Zealand Governments (AZNG) 2018) to identify the existing quality of the groundwater. The results indicate:

- TDS and sodium are outside the NHMRC guidelines across most bores
- Iron is outside the NHMRC guidelines at BH2217 and BH2201
- Chloride is outside the NHMRC guidelines at BH2201, BH2103 and BH2216
- Sulfate is outside the NHMRC guidelines at BH2103
- Arsenic and fluoride are outside the NHMRC guidelines at BH2217
- Project bores do not exceed the livestock drinking water guidelines.

Location of each of the Project bores are depicted on Figure 7.17.

6 Geology

6.1 Regional geology

6.1.1 Clarence-Moreton Basin

The Project is within the northern section of the regional Clarence-Moreton Basin (CMB), a sedimentary depositional basin. Understanding of the tectonic setting and structural elements in the CMB is still evolving (Rassam et al 2014). It is suggested that a strike-slip fault regime was initiated during major tectonic activity in the Late Carboniferous period. Strike-slip movement occurred along several major faults, controlling the magnitude of extension during evolution of the Basin. Structural features that had a major influence on the development of depositional centres are shown in Figure 6.1 and include:

- West Ipswich Fault: forms part of the Great Moreton Fault System and forms the eastern limit of the Laidley sub-basin in SEQ
- Gatton Arch: a broad basement ridge, over which sedimentary rocks of the CMB are folded over and become relatively thin, separating the Cecil Plains and Laidley sub-basins
- South Moreton Anticline: a broad structural high over which the Basin strata are folded and thin. This structure is bounded to the west by West Ipswich Fault and to the east by the East Richmond Fault.

The CMB covers approximately 43,000 km^2 and comprises Middle and Upper Triassic to Lower Cretaceous age sedimentary sequences of a combined thickness of 3,500 to 4,000 m (Rassam et al 2014). Paleogene and Neogene age cover are present across some parts of the CMB, as well as Quaternary age alluvial deposits associated with the various watercourses that flow through the groundwater study area.

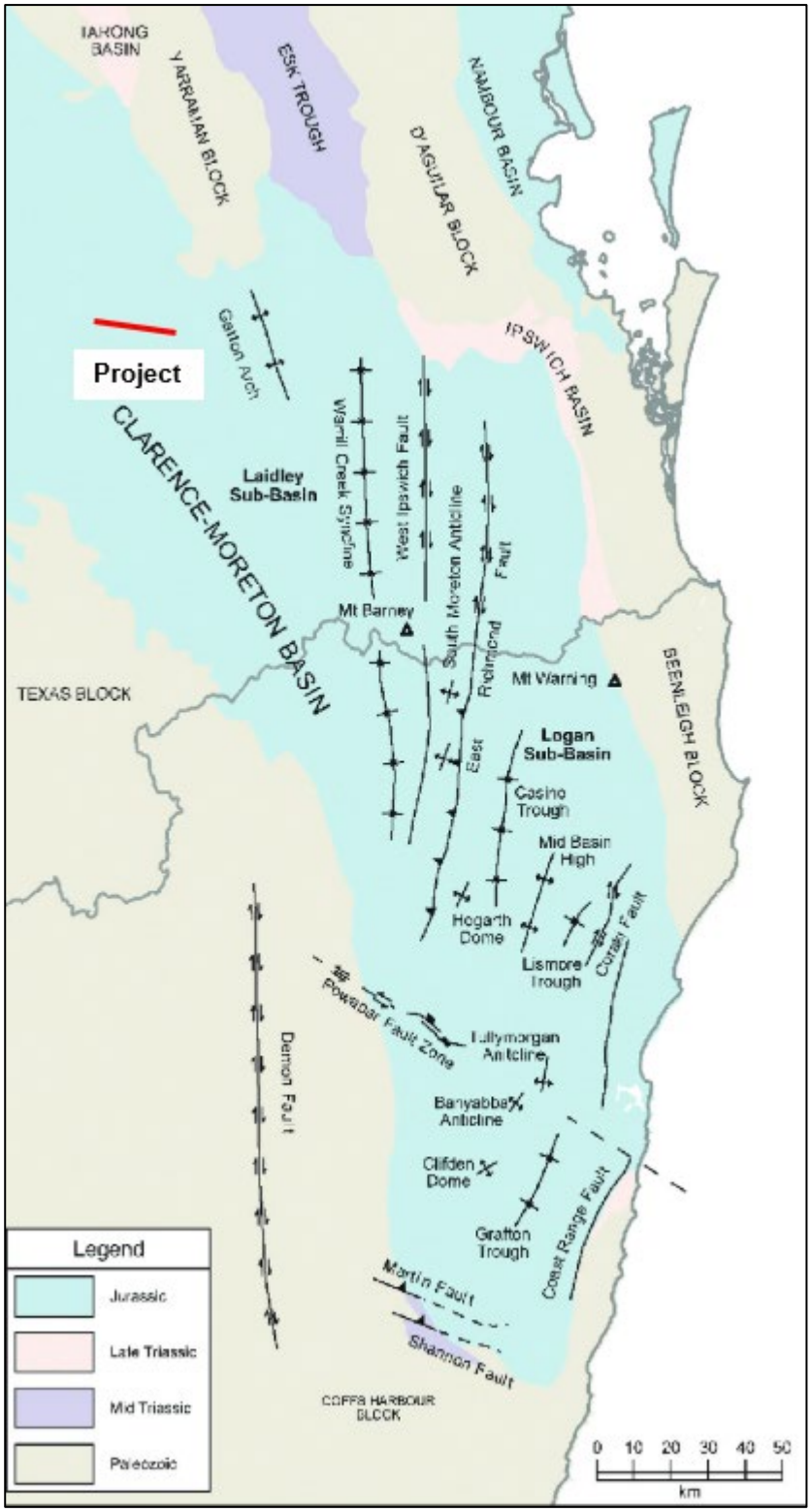


Figure 6.1 Clarence-Moreton Basin and key structural features

Source: Doig A and Stanmore P (2012)

6.1.2 Regional stratigraphy

A summary of the CMB stratigraphy (and overlying cover) is provided in Table 6.1 from youngest to oldest, with units relevant to the groundwater study area highlighted. Units highlighted in blue are traversed by Project; major coal-bearing units are in red. The Marburg Subgroup is comprised of the Koukandowie Formation and Gatton Sandstone.

Table 6.1 Clarence-Moreton Basin Stratigraphy

Age		Major Stratigraphic unit	Stratigraphic subdivision	Depositional environment	Generalised hydraulic characteristics
Quaternary		Undifferentiated	Alluvium/Colluvium/Coastal	Alluvium/ Colluvium/ Coastal	Aquifer (unconfined)
Paleogene and Neogene		Tertiary Volcanics	MRV/Lamington Volcanics/ Toowoomba Volcanics		Aquifer (unconfined)
Jurassic	Early Cretaceous	Grafton Formation	Rapville Member		Aquitard
			Piora Member		Aquifer/Aquitard
	Late Jurassic	Orara Formation (Kangaroo Creek Sandstone)	Bungawalbin Member	Fluvial to low-energy overbank	Aquitard
			Kangaroo Creek Sst Member	Fluvial channel	Aquifer/Aquitard
	Middle Jurassic	WCM	Maclean Sandstone Member	Sinuous meandering streams and backswamps	Aquifer/Aquitard
		Koukandowie Formation	Heifer Creek Sandstone Member	Sandy bedload channels	Low permeability aquifer/aquitard
			Ma Ma Creek Sandstone Member	Lacustrine environment	
			Towllum Basalt		
	Early Jurassic	Gatton Sandstone		Stacked channel sands in low-sinuosity streams	Low permeability aquifer/aquitard
			Calamia Member	Low-energy fluvial system	
			Koreelah Conglomerate Member	Valley-fill sediments	
Triassic	Late Triassic	Woogaroo Subgroup	Ripley Road Sandstone	Point bars and channel fills	Good aquifer
			Raceview Formation	Mixed fluvial environment	
			Aberdare/Laytons Range conglomerates	Braided river and alluvial fan	
		Ipswich Coal Measures	Redcliffe Coal Measures Evans Head Coal Measures		Aquifer/Aquitard
	Early/Middle Triassic	Nymboida Coal Measures			Aquifer/Aquitard

Source: Rassam et al 2014

6.1.3 Structural geology

6.1.3.1 Structural geology

Review of publicly available data in the Queensland Globe datasets does not indicate regional structures are mapped along the proposed tunnel or its vicinity (State of Queensland 2020). However, generally north-northwest to east-southeast trending faults and fold axes have been previously mapped to affect the CMB strata, both to the east and west of the tunnel. Therefore, potential remains that some regional structures may exist along the tunnel alignment below, hidden by the Tertiary volcanic deposits.

Figure 6.2 depicts the major structural elements of the CMB in relation to the groundwater study area. There is a north-west trending anomaly, which may be related to fissure feeders, dykes or other similar linear structures crossing the Toowoomba Range tunnel (Ch 4.2 km to Ch 10.2 km) at Ch 8.0 km and Ch 9.0 km. The trend line indicated on available radiometric imagery is sub-parallel with the alignment of the Great Escarpment and with the New England Highway near its current crossing with the Toowoomba Bypass. The inferred crater rim sequence was encountered on the north-western edge of this anomaly.

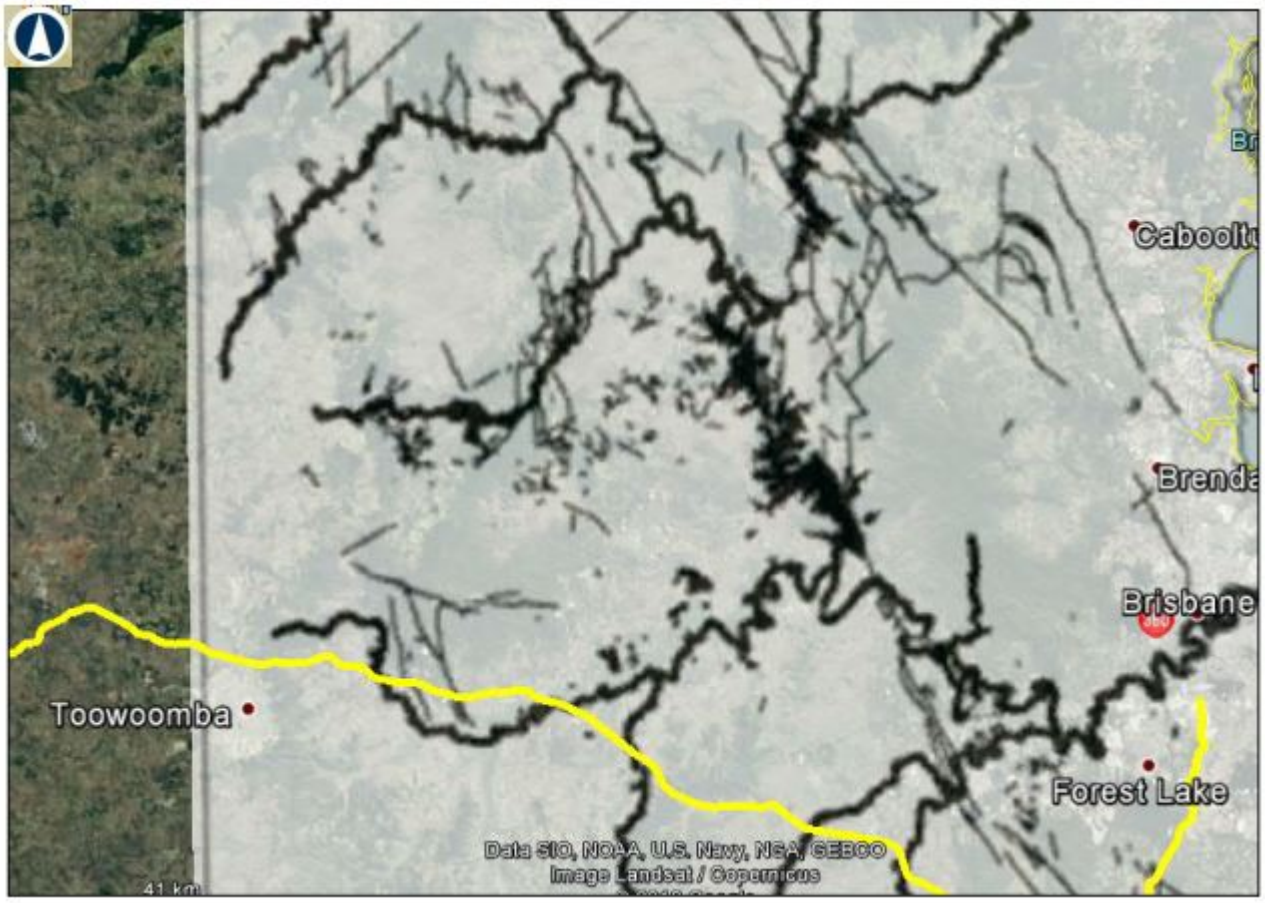


Figure 6.2 **Identified faults in proximity to the groundwater study area** (source: Hodgkinson et al. 2006)

Tuffaceous sediments consistent with the proximal area of an eruptive centre line, were encountered in Project bores between the existing New England Highway and Goombungee Road from Ch 8.0 to Ch 9.0 km. Agglomeratic and tuffaceous layers were also encountered in Project bore 320-01-BH2101 at Ch 5.5 km, which suggests an eruptive centre and feeder dyke system may also exist in this area. This indicates localised domains affected by potential feeder dykes. The dykes are anticipated to allow migration of the groundwater to the tunnel level and may be surrounded by tuffaceous and other extremely weathered material with anticipated soil properties. The exact location and distribution of the affected areas cannot be predicted using the data available at the time of the compilation of this document, but a feeder dyke system is postulated for the zone between approximate Ch 8.80 km and Ch 9.20 km. A similar, though smaller system may also exist around Ch 5.50 km and Ch 6.00 km.

No regional structures are mapped along the proposed tunnel or its vicinity however north-northwest to east-southeast trending faults and fold axes have been previously mapped to affect the CMB rocks (FFJV, 2019a). As a result, it is possible that some regional structures exist along the tunnel alignment, which are hidden by the basalt. No distinct regional faults or joint trends are reported for the basalts and they were not encountered during excavation of a pilot tunnel (discussed in Section 6.1.3). It was noted that the basaltic flows and the interbedded Undifferentiated Tertiary Sediment (UTS) layers tend to slope towards the west, which is likely to be indicative of eruptive centres located at or to the east of the Great Escarpment.

It is likely the tunnel will intersect one to two northwest trending regional structures and a smaller structure located in the western portion of the tunnel (Golder 2020b). This is based on the available radiometric data, increased proportion of tuffaceous material reported in the area and identified eruptive centres described in published literature.

6.1.3.2 Toowoomba Second Range Crossing pilot tunnel

A pilot tunnel was excavated to investigate the geology as part of the Toowoomba Second Range Crossing project. The pilot tunnel was constructed in the centre of the westbound tunnel with cross-sectional dimensions of 3 m by 2.4 m. Construction of the pilot tunnel commenced on 4 May 2007. The findings of the investigation were compiled by Bathurst and Heaton (2008).

Toowoomba was experiencing the worst drought on record at the time of construction and as a result the overall comment on groundwater during construction was that it was a dry tunnel. The investigation indicated that after rainfall in 2008 the groundwater drainage rate was approximately 10,000 litres per day (L/day).

As part of the pilot tunnel investigation, a total of 17 bores were drilled around the location of the tunnel. Investigation drilling indicated the tunnel associated with the Toowoomba Second Range Crossing intersect rock in the MRV. The pilot tunnel alignment crosses the Great Escarpment north of the New England Highway and south/southwest of Mount Kynoch, along a similar alignment to the Toowoomba Bypass. The Toowoomba Range tunnel traverses under the pilot tunnel at the New England Highway (approximate Ch 9.0 km). The pilot tunnel indicated that, at this location, there is a thick colluvial surface cover (between 2 m and 6 m thick) over weathered bedrock, which is subject to landslides.

Distinct faults or joint trends are not reported in the MRV and were not encountered during excavation of the pilot tunnel adjacent to the Toowoomba Range tunnel. It is noted that basaltic flows and interbedded UTS layers tend to slope towards the west, which is likely to be indicative of:

- Eruptive centres located at or to the east of the Great Escarpment
- Post-depositional tilting that has occurred as the Great Escarpment developed.

6.2 Project geology

Reference to the DRDMW *MinesOnlineMaps* (2019) indicates that the Project is underlain by the geological units listed in Table 6.2.

Table 6.2 Summary of geological units traversed by the Project

Geological unit	Location	Definition
Alluvium	Gowrie Creek: Ch -1.76 km to 7.2 km Oaky Creek: intercepted at Ch 13.8 km Rocky Creek: Ch 13.8 km to Ch 15.0 km Six Mile Creek: Ch 16.6 km and Ch 19.6 km to Ch 20.0 km Lockyer Creek: Ch 24.7 km to Ch 26.2 km At surface at 310-01-BH2201, 320-01-BH2207, 320-01-BH2209, 320-01-BH2212 and 320-01-BH2218.	Late Tertiary to Quaternary age alluvial deposits comprising clay, silt, sand and gravel. This occurs beneath watercourses including the creeks traversed by the Project (Gowrie, Oaky, Rocky, Six Mile and Lockyer creeks).

Geological unit	Location	Definition
Colluvium	Oaky Creek: intercepted at Ch 13.8 km Rocky Creek: 13.8 km to Ch 15.0 km Six Mile Creek: Ch 16.6 km and Ch 19.6 km to Ch 20.0 km Lockyer Creek: Ch 24.7 km to Ch 26.2 km At surface at Project bore 310-01-BH2103, 320-01-BH2203, 320-01-BH2215 and 320-01-BH2216. Underlying alluvium at Project 310-01-BH2201 and 320-01-BH2207.	Late Tertiary to Quaternary age colluvial deposits mainly derived from basalt and comprising soil, clay, cobbles and boulders. Surface geology maps indicate this is present near watercourses (co-located with alluvium) including Oaky, Rocky, Six Mile and Lockyer creeks within the groundwater study area. Project bores encountered colluvium at surface (Ch 10 km to 12 km and Ch 22 km to 24 km) and underlying alluvium (Ch 12 km and Ch 17 km).
MRV	West of Gowrie to the GDR (Ch -1.76 km to Ch 10.2 km)	Tertiary (Eocene to Miocene) age basaltic Volcanics comprising mainly olivine basalt with minor tuff and agglomerate
UTS	Ch 10.2 km to Ch 16.6 km	Sediments of apparent lacustrine origin and commonly tuffaceous occur as poorly consolidated or unconsolidated mudstone/siltstone/sandstone, sandy clay, tuff and coal
WCM	Ch 10.2 km to Ch 16.6 km	Middle Jurassic age sedimentary rock comprising shale, siltstone, sandstone and coal seams (coal not reported in groundwater study area).
Crater rim	Ch 8.6 km to Ch 8.85 km	Sequence of inter-mingled basaltic, pyroclastic and sedimentary rocks, likely to have originated from a sub-volcanic structure, such as a dyke, within an extrusive/crater complex.
Koukandowie Sandstone	GDR to the Great Escarpment (Ch 10.2 km to Ch 17.8 km)	Early Jurassic age unit comprises lithic labile and feldspathic labile sandstone. The Koreelah Conglomerate Member is only found in the western and central part of the CMB, but has not been identified near the alignment. However, the typically fine grained Calamia Member may be present as a basal unit of the Gatton Sandstone, well east of the Toowoomba Range tunnel.
Gatton Sandstone	Great Escarpment to Helidon (Ch 17.8 km to Ch 26.2 km)	Early to Middle Jurassic age unit comprising lithofeldspathic labile and sublabile to quartzose sandstone, siltstone, shale, minor coal and a ferruginous oolite marker. The beds are typically sub-horizontal, dipping less than 15 degrees to the south-west, with very gentle folding on a regional scale.
Woogaroo Subgroup (Precipice Sandstone)	Underlies Gatton Sandstone and adjacent to the groundwater study area to the northeast	The Late Triassic to Jurassic age Woogaroo Subgroup comprises thinly to thickly bedded fine to medium grained quartz-lithic and quartz sandstone, quartz (predominantly) sand and fine-grained gravel clast size conglomerate, silty sandstone and laminated claystone. Due to the depth of occurrence (deepest unit in the CMB) and understood hydraulic connectivity of the Woogaroo Subgroup (outcrops north-east of the G2H Project) to the alignment, the unit is not considered to be relevant for the Project.

Table note:

Data sourced from *MinesOnlineMaps* (2019)

The available mapping indicates the Toowoomba Range tunnel is anticipated to be located mainly within the sedimentary rock of the Koukandowie Formation, excluding the first 400 m from the western portal which will be located in the MRV. The MRV may be encountered within the tunnel or within the roof at other locations where the base of the MRV is lower, such as around Ch 6.1 km and east of Ch 8.5 km. The ventilation shaft at Ch 6.83 km encounters the MRV and Koukandowie Formation.

Thin layers of UTS (between 2 and 3 m thickness), comprising tuff and claystone may be encountered either within the basalt or at the transition from the basalt to the underling Koukandowie Formation, initially appearing below the tunnel invert and gradually migrating through the tunnel and into the crown.

The WCM, comprising highly to moderately weathered, very low to medium strength interbedded shale and sandstone, is reported to be present west of approximately Ch 5.12 km, between the basalt (or UTS where present) and the Koukandowie Formation. The transition zone between the tunnel being fully in the basalt and then fully within the Koukandowie Formation is estimated to be located between Ch 4.74 km and Ch 5.15 km. The proposed tunnel alignment crosses an up to 55 m thick sequence of mixed tuffaceous, sedimentary and basaltic rocks near Ch 8.70 km (at Project bore 320-01-BH2102) that has been interpreted as crater rim sequence adjacent to a potential former lava pool.

An apparently isolated, approximately 10 to 12 m thick lens of WCM is also identified at about Ch 10.17 km (east of the eastern tunnel portal) however the WCM rock is not anticipated to be present at the eastern tunnel portal.

Project bore 320-01-BH2101 was drilled at approximately Ch 5.5 km and about 50 m to the south of the proposed centreline of the tunnel, at an elevation of 575.90 m AHD to a depth of 150.84 m. At Ch 5.5 km the design rail level is anticipated to be at 469.19 m AHD, at a depth of about 116.9 m, corresponding to approximate depths of between 108 and 119 m at the bore. The subsurface conditions encountered in Project bore 320-01-BH2101 correlate well with the geological model and indicates that at approximate Ch 5.5 km the tunnel is fully within rock consistent with the Koukandowie Formation.

6.2.1 Surface geology

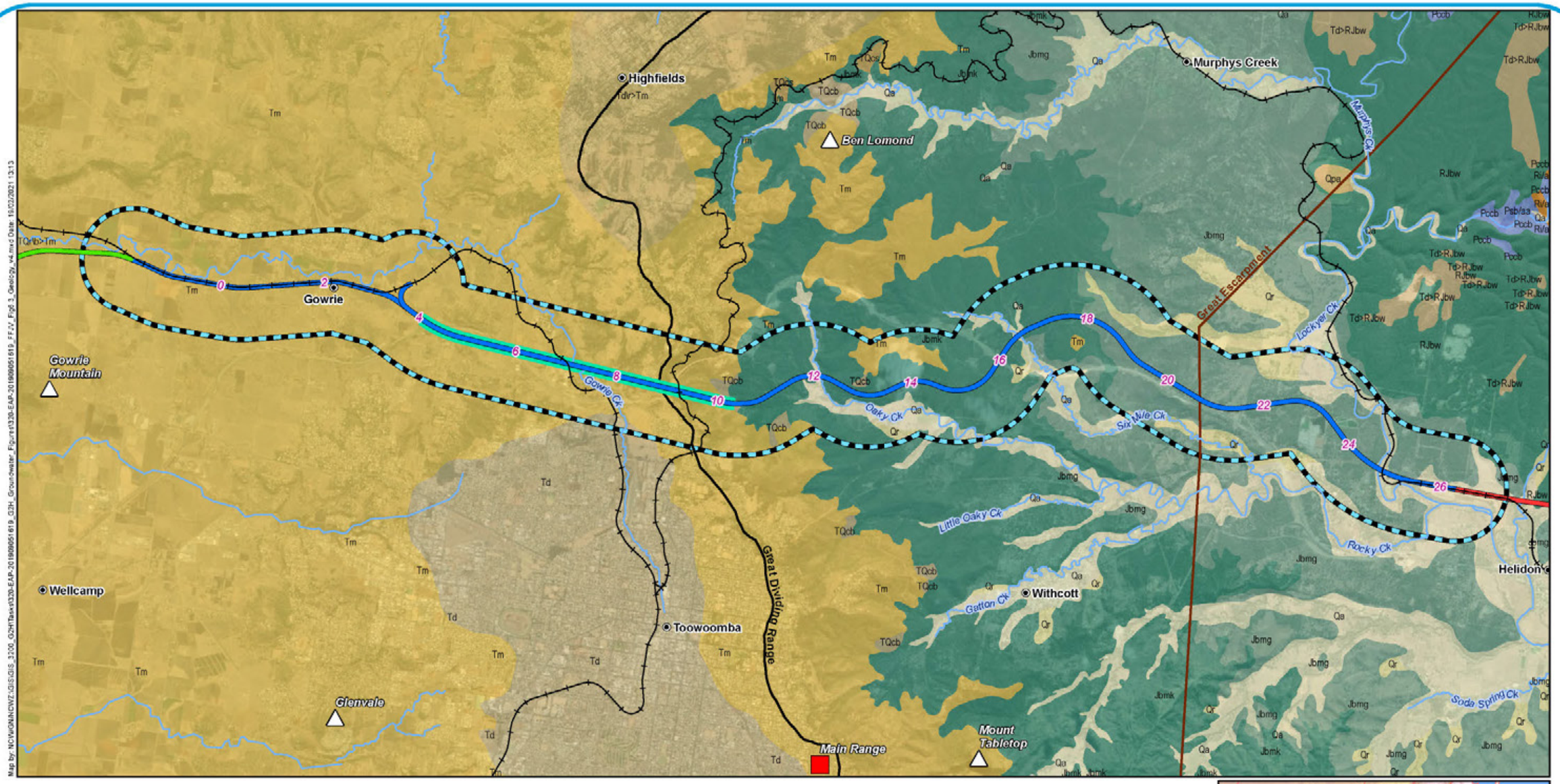
Surface geology traversed by the Project is shown in Figure 6.3 the surface geology west of the alignment is mapped as MRV and at the GDR (Ch 10.2 km) the geology changes to Koukandowie Formation and further east (Ch 17.0 km) the surface is outcropped by Gatton Sandstone. East of the GDR (known as the Great Escarpment) there are various creeks underlain by alluvium and the gullies adjacent to creeks are underlain by colluvium.

Geotechnical investigations conducted for the Project are detailed in Section 5. Project bores are included alongside literature data to inform the local geology/hydrogeology of the study area and are referenced accordingly.

6.2.2 Alluvium/Colluvium (Quaternary/Tertiary)

6.2.2.1 Alluvium

Quaternary alluvium, including clays, silts, sands and gravels are associated with the primary surface water features along the Project, such as Gowrie, Oaky, Rocky, Six Mile and Lockyer creeks (refer Figure 6.3). The main source of alluvium deposits includes the weathered products of the MRV basalts (east and west of the escarpment) and the upper beds of the Marburg Subgroup (east of the escarpment. The alluvium sediments are considered limited in extent, both laterally and vertically, away from the watercourses.



Legend

- Mountain
- Range
- 5 Chainage (km)
- Localities
- Existing rail
- B2G project alignment
- G2H project alignment
- H2C project alignment
- Watercourses
- Great Dividing Range
- Great Escarpment
- Tunnel
- Groundwater study area

Geology

- Qa-QLD (Qa)
- Buaraba Mudstone (Pccb)
- Buaraba Mudstone/aa (Psb/aa)
- Ri/a-SEQ (Ri/a)
- Woogaroo Subgroup (RJbw)
- Gatton Sandstone (Jbmg)
- Koukandowie Formation (Jbmk)
- Main Range Volcanics (Tm)
- TQcb-SEQ Colluvium
- TQcs-SEQ (TQcs)
- TQr\b-SEQ>Main Range Volcanics (TQr\b>Tm)
- Td-QLD Duricrust
- Td-QLD>Woogaroo Subgroup (Td>RJbw)
- Td/r-QLD>Ferricrete on Main Range Volcanics
- Qpa-QLD (Qpa)
- Qr-QLD Colluvium



A3 scale: 1:80,000

0 1 2 3 4 5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/02/2021 Version: 4
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 6.3:
Surface geology across the groundwater study area

Map by: NCW\GNN\CWZ:\GIS\GIS_3200_G2H\Tasks\3320-EAP-20190905619_G2H_Groundwater_Figures\3320-EAP-20190905619_FFJV_Fig6.3_Geology_v4.mxd Date: 15/02/2021 13:13

6.2.2.2 Colluvium

Colluvium is unconsolidated material that has accumulated due to rapid or gradual erosion of a slope whereas alluvium sediments are deposited by watercourses as valleys filled in the late Quaternary period. The slopes and toe of the escarpment are frequently covered with colluvial deposits of various thicknesses. Depending on the source area and method of emplacement, the following five types of colluvium can be anticipated around the eastern tunnel portal area (Ch 10.2 km) (APB 2017):

- Soil colluvium – mainly comprising various mixtures of clay, silt, sand and gravel size particles of mixed origin
- Common colluvium – comprising approximately 20 to 50 per cent cobbles/boulders in a soil matrix. The cobble/boulder component is mainly of basaltic origin but locally, in lower topographic locations sandstone fragments also occur.
- Rocky colluvium – dominated by angular cobble and boulder size fragments of both basaltic and sedimentary origin, mainly sandstone
- Poorly cemented colluvium (often incorrectly referred to as “breccia”) – like common colluvium, however, with a cemented matrix. The poorly cemented colluvium mainly contains fragments of sedimentary rocks
- Rock scree - typically comprising fresh to slightly weathered, cobble and boulder size, angular basalt fragments that accumulate on the moderately inclined slopes beneath cliff forming basalt slopes.

All colluvium types are anticipated to have been accumulated by two distinct methods which affects the characteristics and diagnostic features: gradual accumulation of eroded material or from a landslide debris cone. Gradual accumulation of eroded material produces colluvium that drapes the slope beneath the source area and typically forms a wedge, which will be at the angle of repose until more material is added to re-establish the material’s angle of repose. The thickness of colluvium accumulated by this method is typically in the order of a few metres.

Conversely, colluvium that originated as a landslide debris cone, which was emplaced instantaneously, forms distinct sediment bodies and is frequently lobate in shape. A landslide debris cone is likely to have both basaltic and sedimentary material. This is due to landslides occurring in the weathered sedimentary rock, during the range retreat process, destabilising the overlying, often competent basalt. Colluvium accumulated as landslide debris may have a thickness of several tens of metres and extensive bodies may have been dissected subsequent to their emplacement by watercourses. There is a single Project bore (320-01-BH2103) near Oaky Creek which has colluvium thickness up to 10 m and potentially reflects this deposition type.

Surface geology maps indicate isolated areas of colluvium are present near the eastern tunnel portal, generally occurring at the bottom of steep slopes. The maps do not necessarily indicate the deposition type however several Project bores have encountered colluvium material and they are summarised below:

- 320-01-BH2103 – Ch 10.4 km – colluvium at surface to 10 mbgl
- 320-01-BH2201 – Ch 11.8 km – colluvium from 5 to 6 mbgl (underlying alluvium)
- 320-01-BH2203 – Ch 13.8 km – colluvium at surface to 2 mbgl
- 320-01-BH2207 – Ch 16.6 km – colluvium from 8 to 10 mbgl (underlying alluvium)
- 320-01-BH2216 – Ch 22.6 km – colluvium at surface to 2 mbgl
- 320-01-BH2215 – Ch 23.6 km – colluvium at surface to 2 mbgl.

Colluvium thickness across Project bores is typically around 2 m which indicates it is likely deposited by gradual accumulation of eroded material within the Great Escarpment.

6.2.3 Main Range Volcanics

The rocks of the Tertiary age MRV mainly comprise olivine basalt with variable content of associated pyroclastic rocks. The basalts of the proposed Toowoomba Range tunnel (Ch 4.10 km to 10.34 km) area belong to an informal subunit of the MRV, referred to as Toowoomba Volcanics, reported to be up to 330 m thick along the escarpment at Toowoomba (Willey 2012). Locally, the rock is massive near the base or in the middle of an individual flow, and vesicular and/or amygdaloidal towards the top. The term 'massive' is used with reference to the lack of abundant and visually identifiable vesicles/amygdales and not related to the presence or absence of discontinuities.

Columnar basalt is common where the flows were of considerable thickness, where lava pooling has occurred or in the feeder dyke system where the columns may be sub-horizontal. Quaquaversal orientation (sloping downward from the centre in all directions) of columns, inward dipping tuffs and thick fresh basalt are the main diagnostic features for the identification of extinct lava pools. The Toowoomba Volcanics are likely to have formed from fissure eruptions with individual lava pools along the feeder dyke system, rather than as a 'central volcano'. Lava pools have been identified at both the Harlaxton Quarry and Jubilee Park, south of the proposed eastern tunnel portal, with the identified potential lava pools along the escarpment appearing to be located on a north-westerly oriented trend line.

Petrographic analyses have been carried out on three different basalt types in the region in a study published by the DTMR (2003). The three basalt types were referred to as massive basalt, dark amygdaloidal basalt and white amygdaloidal basalt with 6 to 30 percent amygdales. The colour variation in amygdaloidal basalt is generally a reflection of the mineral composition where white is associated with barite and black is associated with chlorite minerals. The results of the study indicated that the primary constituents of the rock (i.e. feldspar, clinopyroxene and olivine) occur in a similar proportion in each of the three rock types. The proportion of green smectite clay for the three rock types was reported between 21 per cent and 82 per cent, indicating that all three rock types are likely to have originated as relatively thin, therefore glassy flows, which have subsequently undergone a de-vitrification and palagonisation process. The study also suggests the delineation of the three basalt types on petrographic basis is not warranted but can be used as a visual guide for predicting the engineering characteristics of the rock.

6.2.4 Undifferentiated Tertiary Sediments

The UTS are not recognised as a stratigraphic unit however it has been encountered and logged in the area during geotechnical investigations and excavations. Based on the few boreholes that have indicated the presence of this layer, the UTS occurs either directly underlying the MRV basalts or within the basalt. When beneath the basalt, the UTS appears highly to extremely weathered older sedimentary rocks of the WCM or Koukandowie Formation, except it is commonly represented by claystone rather than mudstone; with the plasticity of the resultant clays significantly higher and further includes the presence of tuff or tuffaceous layers.

The thickness of the UTS layers encountered varies greatly between 1 m and 12 m but appears to be typically between 1 m and 3 m. It is likely that the sediments were deposited in a relatively low lying or poorly drained swamp or lake environment before or between episodes of volcanic activity. Consequently, the UTS is likely to occur in isolated lenses, filling up the depressions in the landscape at the time of deposition.

Field identification of UTS and the soil, common and poorly cemented colluvium is difficult due to their variable composition and similar consistency characteristics. The UTS is likely to be very similar in appearance to the tuffaceous sediments surrounding the eruptive centres that formed the lava pools, as described by Willey (2012) and Willmott (1984), where most of the columnar basalt has formed.

6.2.5 Walloon Coal Measures

The WCM typically includes sandstone, siltstone, mudstone and coal in the upper half to two-thirds of the unit, with possible calcareous sandstone, impure limestone and ironstone (Wells and O'Brien 1994). The lower part of the unit represents stacked over bank deposits within highly sinuous fluviatile systems, with the upper part of this sub-unit deposited as coal swamps. The WCM rocks, where they outcrop at the surface, form gently undulating terrain due to their tendency to weather to clayey residual soil to a considerable depth.

The highly weathered sedimentary sequence rock underlying the basalts (Department of Mines 1985) and assigned to the WCM, is consistent with the general appearance of the WCM. This unit is expected to be present only in isolated patches along the alignment, while it is likely to be a continuous layer south of the alignment.

Geology maps do not indicate the WCM will be intercepted by the alignment however west of the GDR (Ch 10.2 km) there are 10 registered bores screened in the WCM within 5 km of the alignment and 1 bore within 1 km of the alignment. There are 2 bores at Ch 13.4 km reported to be screened in the WCM, where the nearby geology (within 400 m of the bores) is mapped as the Koukandowie Formation and MRV. There are two bores reportedly screened in the WCM at Ch 4.6 and 7.4 km and then 8 additional bores reportedly screened in the WCM between Ch -1.76 and 4.6 km, where the surface geology is the MRV.

6.2.6 Crater rim

The proposed tunnel alignment crosses an up to 55 m thick sequence of mixed tuffaceous, sedimentary and basaltic rocks near Ch 8.7 km at Project bore 320-01-BH2102. This was interpreted as crater rim sequence adjacent to a potential lava pool. Crater rim was encountered at the approximate level of the proposed tunnel. It comprises a series of interbedded mixed sedimentary, and volcanic rocks comprising tuff, sandstone, mudstone and basalt. The material comprises very low strength mudstones and weathered tuff to medium strength less weathered tuff and sandstone, while the basalt bands are of high and very high strength.

6.2.7 Koukandowie Formation (Marburg Subgroup)

The alignment between the GDR (Ch 10.2 km) and the Great Escarpment (Ch 17.8 km) is underlain by the Koukandowie Formation (also known as the upper member of the Marburg Subgroup). The Lower Jurassic Koukandowie Formation is a mixed-facies sequence deposited in sandy bedload channels or lacustrine environments with a thickness of 250 to 500 m. The Formation consists of sheets of interbedded sandstone, siltstone, claystone and minor coal. It is conformably overlain by the WCM and conformably rests on top of the Gatton Sandstone (lowest member of the Marburg Subgroup).

The Koukandowie Formation from the Marburg Subgroup is divided into:

- The Undifferentiated Koukandowie Formation, comprising interbedded sandstone and fine-grained sedimentary rocks
- The Heifer Creek Sandstone near the top of the unit, which comprises thickly bedded and massive quartzose sandstone with shale interbeds
- The basal Ma Ma Creek Member, comprising mainly fine-grained sedimentary rocks with lesser sandstone.

Department of Transport and Main Roads (DTMR) geotechnical investigations (2003 and 2006) indicate the sedimentary rock in the 'Marburg Formation' generally comprises 'greenish' grey, fine to occasionally medium and coarse-grained sandstone, finely laminated siltstone and mudstone, sub-horizontal bedding, sometimes clayey and friable. This appears to be consistent with the undivided part of the Koukandowie Formation.

A petrographic assessment of two sandstone samples from Project bores 320-01-BH2101 (366.3 to 366.0 m AHD) and 320-01-BH2102 (522.3 to 397.7 m AHD) indicated the rock comprises a fine-grained quartz feldspathic sandstone with clay matrix, consistent with the typical sandstones of the Koukandowie Formation. The reported quartz content of the two samples were 55 percent and 38 percent, respectively (Golder 2020a). While the analysed samples were taken from just below the proposed formation level of the tunnel (468 m AHD at BH2101 and 420 m AHD at BH2102), they are considered representative of the sandstones from the Koukandowie Formation.

The Koukandowie Formation is overlain by the Middle to Late Jurassic age WCM, comprising shale, siltstone, sandstone and coal seams. In contrast to the feldspatholitic and quartzose sandstones of the Marburg Subgroup, the sandstone in the WCM rocks tend to be thinly interbedded and volcanolithic in composition (Wells and O'Brien 1994).

6.2.8 Gatton Sandstone (Marburg Subgroup)

The Early Jurassic Gatton Sandstone is the lower member of the Marburg Subgroup. It underlies the Koukandowie Formation and rests conformably on the Triassic to Jurassic Woogaroo Subgroup (refer Table 6.1). The Gatton Sandstone is dominated by thick-bedded, relatively uniform, medium- to coarse-grained quartz-lithic and feldspathic sandstone, deposited as stacked channel sands in low sinuosity streams with high avulsion rates. Pebble beds, carbonised wood fragments and large-scale planar and cross-bedding are characteristic of this formation.

Between Ch 17.8 km (Great Escarpment) and Ch 26.2 km (Helidon) the Project is underlain by Gatton Sandstone which sub-crops beneath Quaternary alluvium for portions of the alignment near Oaky Creek, Six Mile Creek, Rocky Creek and Lockyer Creek. The Gatton Sandstone forms a low permeability fractured rock aquifer.

6.3 Acid sulfate soils and acid rock drainage potential

Acid sulfate soils (ASS) are typically associated with low lying coastal soils that were formed in a marine environment. The drainage of these soils can lead to their exposure and can reduce pH of the soil, associated watercourses and result in damage to ecosystems (Rassam et al 2014).

The probability of encountering potentially acid sulfate soils (PASS) was assessed via the Atlas of Australian ASS (Fitzpatrick et al 2011). The maps indicate the probability of encountering PASS is considered extremely low/very low for 80 per cent of the Project alignment and considered low/very low for the remaining alignment. Geotechnical investigations, which included site walkovers and geotechnical sampling, did not identify the presence of ASS or acid rock (which are generally igneous rocks containing greater than 65 per cent silica) within the Project. Furthermore, due to the underlying geology, geomorphic and climatic conditions relevant to the Project, the elevation (>20 m AHD lowest point) as well as existing ASS mapping indicating no to low risk, it is considered to be a low to no risk of inland ASS or potential inland ASS presence within the Project.

Soils were not directly tested to understand PASS however groundwater analysis can be used as an indicator of PASS and is described in the National acid sulfate soils Guidance by Water Quality Australia (2018). The ratio of soluble chloride to soluble sulfate can provide an indication of sulfidic material. Where the analysis indicates there is an elevated level of oxidised sulfate ions relative to chloride ions, these results provide an indication of PASS in the landscape.

Project bores were screened in the Koukandowie Formation and Gatton Sandstone, which are hard rock aquifers and do not necessarily reflect soil conditions in the groundwater study area. The chloride to sulfate ratio across Projects bores was less than 0.1. Chloride to sulfate ratio of less than two is an indication of an extra source of sulfate from previous oxidation however this comparison is not reliable in fresh to brackish water, which is the range of the Project bores. Further detail on groundwater chemistry is provided in Section 5.5 and 7.3.

Other parameters provided in DER's guidelines that indicate PASS require pH less than 4.0, soluble aluminium concentration greater than 1 mg/L and high alkalinity. The pH ranges between 7.0 and 8.0 (alkaline) and total alkalinity is high across Project bores. Aluminium was not analysed.

The acid sulfate soils maps, underlying geology and geochemistry suggest the Project has low likelihood of encountering inland PASS material. This suggests there is low likelihood of causing acid rock drainage (ARD) during earthworks.

7 Hydrogeology

7.1 Existing hydrogeological regime

There are three primary aquifers identified within the groundwater study area:

- Quaternary aquifer/s: shallow unconfined and/or perched aquifer(s) within colluvium or alluvium units
- MRV aquifer: a fractured basalt aquifer in the MRV which may be unconfined, semi-confined or confined
- Sedimentary aquifer/s: a confined/semi-unconfined aquifer in the sedimentary rock of the Gatton Sandstone, the Koukandowie Formation and the WCM.

The water-bearing strata associated with the primary aquifers and considered relevant in the groundwater study area are summarised in Table 7.1 based on surface geology, Project alignment and Raiber et al (2016).

Table 7.1 Hydrostratigraphic summary of the groundwater study area

Stratigraphic unit	Aquifer type	Main occurrences relevant to the Project	Approximate proportion of alignment crossing the aquifer	Typical thickness in groundwater study area	Lithology	Characteristics
Gowrie Creek alluvium	Quaternary	Underlying Gowrie Creek	1-2%	6 to 16 m[a]	Clay, silt, sand and gravel; in a generally fining upward sequence.	Unconfined porous aquifer
Oaky Creek alluvium		Underlying Oaky Creek	1-2%	12 to 13 m[a]		
Rocky Creek alluvium		Underlying Rocky Creek	1-2%	4 to 10 m[a]		
Six Mile Creek alluvium		Underlying Lockyer Creek	1-2%	13 to 18 m[a]		
Lockyer Creek alluvium		Underlying Six Mile Creek	1-2%	7 to 10 m[a]		
MRV	Volcanics	Present west of Gowrie to the GDR.	~40%	2 to 93 m[a] 330 m[b]	Olivine basalt	Pyroclastic rock
UTS	Sedimentary	Likely to occur in isolated lenses beneath or within MRV basalts.	<1%	1 to 12 m[b]	Clay, tuff, mudstone and fine-grained sandstone	High plasticity, hard consistency and very low strength
WCM	Sedimentary	Potentially present at subsurface.	<1%	67 to 154 m[a]	Lithic and silty sandstone with interbedded mudstone and siltstone	Fractured rock aquifer/aquitard
Koukandowie Formation	Sedimentary	Present between Gowrie and GDR.	~25%	10 to 17 m[a] 12 to 152 m[b]	Interbedded sandstone, siltstone, claystone and minor coal	Low permeability fractured rock aquifer/aquitard
Gatton Sandstone	Sedimentary	Present between the GDR and Helidon and is below alluvium at creeks in the Great Escarpment.	~25%	13 to 96 m[a]	Medium- to coarse-grained sandstone	Low permeability fractured rock aquifer/aquitard

Table notes:

a Local data sourced from the Queensland Globe database within 1 km of the Project
b Regional data sourced from Raiber et al (2016)

7.1.1 Alluvium/Colluvium (Quaternary/Tertiary)

The alluvial sediments in the eastern portion of the Project disturbance footprint are within the Lockyer Creek catchment and are associated with various watercourses in the groundwater study area (including Oaky, Rocky and Six Mile creeks), which overly Gatton Sandstone. These Quaternary sediments are significant to the Project in terms of groundwater because these sediments form a significant aquifer that is predominantly and readily recharged by rainfall and it is relied upon as an important water resource in the Lockyer Creek catchment.

Alluvial sediments in the western portion of the Project disturbance footprint are within the Gowrie Creek catchment of the Condamine River Basin; Gowrie Creek overlies the MRV. Groundwater in the Condamine River Basin is present in shallow alluvial and sandstone aquifers, and within the deeper confined strata of the Great Artesian Basin (GAB). Due to climate variability, groundwater recharge to the aquifers is strongly episodic and relies on periods of unusually high rainfall or wetter than average winter to increase deep drainage rates (DES 2019). The GAB is primarily recharged from infiltration occurring on the northwest slopes of the GDR.

The primary alluvial units of relevance in the groundwater study area are:

- Gowrie Creek alluvium
- Oaky Creek alluvium
- Rocky Creek alluvium
- Six Mile Creek alluvium
- Lockyer Creek alluvium.

7.1.1.1 Occurrence

Alluvium is likely to occur beneath creeks and above the MRV west of the GDR and above the Koukandowie Formation and Gatton Sandstone east of the divide. There are instances of colluvium occurring east of the divide within the Great Escarpment, this is present at the foothills near Rocky Creek and Six Mile Creek.

Gowrie Creek alluvium is expected to be intercepted by the alignment between Ch -1.76 km and Ch 2.0 km (where the proximity to the creek varies between 200 and 600 m) and again at Ch 7.2 km (where the creek is intercepted by the alignment).

Alluvium is then expected to be intercepted east of the GDR where the alignment intercepts Six Mile Creek, Oaky Creek, Rocky Creek and Lockyer Creek. The location of each watercourse is summarised below:

- Six Mile Creek (semi-ephemeral) – crosses the alignment at Ch 16.6 km and then runs south of the alignment from Ch 19.6 to 20.0 km (varying in proximity between 600 and 900 m from the alignment)
- Oaky Creek (semi-ephemeral) – runs perpendicular and to the north of the alignment and intersects at Ch 13.8 km, where it becomes Rocky Creek (perennial)
- Rocky Creek (semi-ephemeral) – runs sub-parallel and to the south of the alignment, from approximately Ch 13.8 km to Ch 15.0 km (varying in proximity between 130 and 700 m from the alignment)
- Lockyer Creek (perennial) – intersecting the alignment at Ch 24.7 km and then running south of the alignment, sub-parallel to the H2C connection near Ch 26.23 km.

7.1.1.2 Recharge and discharge mechanisms

Regional groundwater recharge values were estimated using the chloride mass balance by Raiber et al (2016). The number of groundwater samples in alluvium was 2,677 and the regional rainfall recharge estimates ranged between 3.9 and 32.5 millimetres per year (mm/year) with mean value of 10.6 mm/year.

Recharge to Quaternary aquifers is supplied by direct infiltration of rainfall and seepage, or episodic recharge, during large rainfall events and flooding. Underlying units also act as a source of recharge where upward vertical gradients and hydraulic connection occur. There is a net deficit of rainfall on average as annual average evaporation exceeds annual average rainfall. Direct infiltration of rainfall to groundwater is unlikely during dry periods because minor rainfall events would be absorbed by soil moisture and lost to evapotranspiration. Recharge primarily occurs in response to higher or continuous rainfall events and overall net recharge rates in the region are expected to be low.

Groundwater discharge primarily occurs via seepage to watercourses as baseflow during times of limited rainfall. Discharge via seepage into underlying units is considered to occur during the wet season and/or periods of elevated groundwater levels. Evapotranspiration from vegetation growing in the creek beds and along the banks are also a primary discharge mechanism from the alluvium units. Groundwater discharge in alluvium units is likely to occur via pumping bores as they are heavily utilised in the region, discussed in Section 7.5.

7.1.1.3 Hydraulic parameters/yields

A review of aquifer parameters and pumping test data in the Queensland Globe was carried out by Raiber et al (2016) to provide a range of hydraulic conductivities for hydrostratigraphic units in the CMB. A further review of hydrogeological parameters was provided by Golder (2020a). Data is only available for the alluvium unit in the groundwater study area; however, this is suitable to apply to colluvium as they are of similar composition and consistency (refer Section 6.2.2). The study by Raiber included 107 hydraulic conductivity values and ranged between 1 x 10^{-6} and 2 x 10^{-2} metres per second (m/s) and of these values approximately 40 per cent were greater than 1 x 10^{-3} m/s and 80 per cent greater than 1 x 10^{-4} m/s.

Site-specific hydraulic conductivity values are not available for the alluvium/colluvium aquifers as Project bores were not screened in alluvium/colluvium units. This is likely due to the focus on geotechnical investigations within the tunnel sediments.

Regional test records are considered strongly biased towards the high end of the hydraulic conductivity range due to most bores being drilled for irrigation purpose and therefore targeting the high yielding alluvial gravel and sand aquifers. The alluvium aquifer is likely transversely isotropic due to interbedding of sandy layers with beds of silt and clay. This unit has been used in the assessment of cuts, embankments and bridges and a typical value of 7 x 10^{-4} m/s has been adopted for the alluvium and colluvium units.

Available yield values were sourced from the Queensland Globe database for registered bores within 5 km of the Project. Yield values for bores screened in alluvium units varies between 2.5 to 6.2 litres per second (L/s) across the groundwater study area with mean value of 4.35 L/s. This high range of yield variability is attributed to the variable extent and nature of alluvial sediments that vary from coarse gravels to silty clays.

7.1.2 Main Range Volcanics

The MRV are comprised of primary permeability in the form of vesicular zones with secondary porosity in the form of cooling joints and fractures (Office of Groundwater Impact Assessment [OGIA] 2019). As a result, groundwater occurrence and hydraulic properties of the MRV are inherently variable due to the nature, location, and frequency of fractures and joints.

7.1.2.1 Occurrence

The alignment is underlain by the MRV from the western boundary of the alignment (Ch -1.76 km) to the GDR (Ch 10.2 km) and it is expected that alluvium beneath Gowrie Creek is underlain by MRV. The MRV is a type of basalt which is characterised by vesicular and weathered zones which can result in aquifer behaviour that ranges between unconfined, semi-confined or confined (OGIA, 2019). A fractured rock aquifer, the MRV is highly variable due to the nature of the fracture distribution. The MRV can have perched aquifers throughout due to the layering of basalt flows coupled with variable weathering. Along the alignment unconfined conditions are expected of this aquifer; however, it is considered that semi-confined and potentially limited confined conditions may also be present due to the complex heterogeneity of the non-massive basalts.

The MRV forms a significant productive aquifer and is mainly used for irrigation in the region (refer Section 7.5.1 and 7.5.2). Of the registered bores listed as accessing the MRV aquifer in Queensland Globe, approximately 40 per cent (46 out of 110 registered bores) are located within 1 km of the Project and approximately 60 per cent (399 out of 679 registered bores) are located within 5 km of the Project.

7.1.2.2 Recharge and discharge mechanisms

Primary recharge to the MRV is considered to be via direct rainfall infiltration and local vertical leakage from the underlying units along with adjacent flow through from Gowrie Creek alluvium after large rainfall events. Regional groundwater recharge values were estimated using the chloride mass balance by Raiber et al (2016). The number of groundwater samples in the MRV is 48 and the regional rainfall recharge estimates ranged between 11.3 and 41.4 mm/year with mean value of 25.5 mm/year. Springs are also a primary recharge mechanism for this unit (refer Section 7.6.1) in proximity to the groundwater study area.

Primary discharge mechanisms are considered to include bore extraction and local vertical leakage to under and overlying units.

7.1.2.3 Hydraulic parameters/yields

A review of aquifer parameters and pumping test data in the Queensland Globe database was carried out by Raiber et al (2016) to provide a range of hydraulic conductivities for hydrostratigraphic units in the CMB. A further review of hydrogeological parameters was provided by Golder (2020b). A total of 67 hydraulic conductivity values were available across the aquifer and results ranged between 1 x 10^{-9} and 3 x 10^{-2} m/s. Approximately 80 per cent of values were above 1 x 10^{-7} and 60 per cent were above 1 x 10^{-6} m/s. This indicates hydraulic conductivity is highly variable, which reflects the fractured nature of the aquifer.

Site-specific hydraulic conductivity values were estimated from slug tests conducted in October and November 2018. The MRV aquifer was tested at 320-01-BH2101 with four falling head tests undertaken. Hydraulic conductivity values ranged between 2.6 x 10^{-8} and 6.2 x 10^{-7} m/s, which reflects the lower end of the regional values observed in the MRV.

Available yield values were sourced from the Queensland Globe database for registered bores within 5 km of the Project. The MRV yield values from 116 registered bores ranged between 0.1 and 6.9 L/s with a mean yield of 1.3 L/s. This high range of yield variability is attributed to the fractured nature of the MRV aquifer.

Recently completed geotechnical and hydrogeological investigations (Golder, 2020c2020d) in the MRV in proximity to the Toowoomba Range tunnel support the highly variable nature of this unit with yield rates that range from inferred confined conditions with yield of 0.016 L/s and estimated hydraulic conductivity of 1.3 x 10^{-8} (Mt Kynoch, tunnel invert area) to yields that range from 0.8 L/s to 7 L/s in the MRV near the western portal.

7.1.3 Koukandowie Formation

7.1.3.1 Occurrence

The Project is underlain by the Koukandowie Formation from the GDR (Ch 10.2 km) to Ch 18 km. The alignment also crosses colluvium near Rocky Creek and Six Mile Creek in this segment of the alignment.

Between Ch 10.2 km and Ch 18 km, available data from the Queensland Globe database indicates there are less than 40 registered bores within 5 km of the alignment and six bores within 1 km of the alignment. Of the 40 registered bores, four are screened in the Koukandowie Formation, one in Gatton Sandstone and the remaining are in the Marburg Subgroup. The geology maps show this segment as Koukandowie Formation, which is part of the Marburg Subgroup. As such, these groundwater bores were assessed as part of the Koukandowie Formation.

In the groundwater study area, the Marburg Subgroup is not an extensively used water source and existing groundwater entitlements is generally used for irrigation, town water supply, stock and industrial (described in detail in Section 7.5). This is largely due to the extensive use of the MRV within the groundwater study area.

7.1.3.2 Recharge and discharge mechanisms

Regional groundwater recharge values were estimated using the chloride mass balance by Raiber et al (2016). A total of 21 groundwater samples were available for the Koukandowie Formation. The regional rainfall recharge estimates ranged between 1.6 and 5.9 mm/year with mean value of 2.7 mm/year. This is significantly lower than alluvium and the MRV (difference of 75 to 90 per cent), which reflects the limited recharge potential of this aquifer.

Recharge to the Koukandowie Formation is likely along ridgelines via direct infiltration of rainfall across the ridge where the aquifer is exposed at the surface and is covered in a thin layer of topsoil or through fracture networks. Perched groundwater may exist where more permeable weathered rock or soils are underlain by low permeable material.

Discharge from the bedrock formations occur via seepage into adjacent aquifers (including the overlying alluvial sediments when upward hydraulic gradients occur), and as throughflow to the north and northeast out of the groundwater study area.

7.1.3.3 Hydraulic parameters/yields

A review of aquifer parameters and pumping test data in the Queensland Globe database was carried out by Raiber et al (2016) to provide a range of hydraulic conductivities for hydrostratigraphic units in the CMB. A further review of hydrogeological parameters was provided by Golder (2020a). A total of 68 hydraulic conductivity values were available across the aquifer and results ranged between 3 x 10^{9} and 2 x 10^{-4} m/s. Approximately 40 per cent of values were above 1 x 10^{-7} and 20 per cent were above 1 x 10^{-6} m/s. This indicates the hydraulic conductivity of the Koukandowie Formation is highly variable, which reflects the fractured nature of the aquifer and the variability in hydraulic conductivity of the siliciclastic rocks with depth across the weathering profile (Golder 2020a).

Site-specific hydraulic conductivity values were estimated from slug tests conducted in October and November 2018. The falling head test was performed at the following Project bores screened in the Koukandowie Formation:

- 320-01-BH2101 – 4.0 x 10^{-8} m/s
- 320-01-BH2103 – 1.0 x 10^{-8} m/s
- 320-01-BH2201 – 9.0 x 10^{-8} m/s
- 320-01-BH2207 – 2.2 x 10^{-6} m/s
- 320-01-BH2301 – Not reported.

Hydraulic conductivity results are shown for Project bores that had data available at the time of reporting in August 2019 (Golder 2020a). Hydraulic conductivity values observed across Project bores reflect the lower end of the regional values observed in the Koukandowie Formation.

Regional studies have shown that the pre-Cenozoic aquifers within the CMB sequence are generally low yielding. Average yields ranging from 0.5 to 2.5 L/second in the sandstones, siltstones and conglomerates of the Bundamba Group – which includes the Marburg Subgroup, the Gatton Sandstone and the Koukandowie Formation (Rassam et al 2014).

Local yield values were sourced from the Queensland Globe database for registered bores within 5 km of the Project. There was a single yield value of 0.2 L/s in the Koukandowie Formation for this section of alignment. There were 10 yield values associated with the Marburg Subgroup in this segment of alignment with values ranging between 0.1 and 6.3 L/s and mean value of 1.0 L/s.

7.1.4 Gatton Sandstone

7.1.4.1 Occurrence

The section of Project underlain by the Gatton Sandstone extends from Ch 18.0 km to the end of the alignment (Ch 26.2 km), where it becomes alluvium associated with Lockyer Creek.

In the Queensland Globe database there are less than 168 registered bores within 5 km of the alignment in this section and 40 within 1 km of the alignment. Of the 40 registered bores, 22 are listed as accessing both the Gatton Sandstone and Marburg Subgroup. Since the Gatton Sandstone is part of the Marburg Subgroup, these groundwater bores were assessed as part of the Gatton Sandstone.

In the groundwater study area, the Marburg Subgroup is not an extensively used water source and existing groundwater entitlements are generally used for irrigation, town water supply, stock and industrial (described in detail in Section 7.5).

7.1.4.2 Recharge and discharge mechanisms

Regional groundwater recharge values were estimated using the chloride mass balance by Raiber et al (2016). The number of groundwater samples in the Gatton Sandstone is 242 and the regional rainfall recharge estimates ranged between 1.1 and 10.2 mm/year with mean value of 3.6 mm/year. This is similar to the Koukandowie Formation and reflects the limited recharge potential of this aquifer.

Similar to the Koukandowie Formation, recharge to the Gatton Sandstone is likely along ridgelines via direct infiltration of rainfall across the ridge where the aquifer is exposed at the surface and is covered in a thin layer of topsoil or through fracture networks. Perched groundwater may exist where more permeable weathered rock or soils are underlain by low permeable material.

Discharge from the bedrock rock formations occur via seepage into adjacent aquifers (including the overlying alluvial sediments when upward hydraulic gradients occur), and as throughflow to the north and northeast out of the groundwater study area.

7.1.4.3 Hydraulic parameters/yields

A review of aquifer parameters and pumping test data in the Queensland Globe database was carried out by Raiber et al (2016) to provide a range of hydraulic conductivities for hydrostratigraphic units in the CMB. A further review of hydrogeological parameters was provided by Golder (2020b). A total of 92 hydraulic conductivity values were available across the aquifer and results ranged between 5 x 10^{-10} and 2 x 10^{-5} m/s. Approximately 50 per cent of values were above 1 x 10^{-7} and 30 per cent were above 1 x 10^{-6} m/s.

Site-specific hydraulic conductivity values were estimated from slug tests conducted in October and November 2018. The falling head test was performed at the following Project bores screened in the Gatton Sandstone:

- 320-01-BH2209 – 5.7 x 10^{-7} m/s
- 320-01-BH2212 – 3.3 x 10^{-7} m/s
- 320-01-BH2215 – Not reported
- 320-01-BH2216 – Not reported
- 320-01-BH2217 – 3.5 x 10^{-7} m/s
- 320-01-BH2218 – 2.7 x 10^{-8} m/s.

Hydraulic conductivity results are shown for Project bores that had data available at the time of reporting in August 2019 (Golder 2020a). Hydraulic conductivity values observed across Project bores reflect the mid-range of the regional values observed in the Gatton Sandstone.

The argillaceous matrix and carbonate cementation of the Gatton Sandstone which is believed to have reduced the effective porosity and thus the capacity of the sandstone to store water has been considered in the reduced value range for specific yield (0.015 to 0.10 L/s and mean value of 0.05 L/s) of the Gatton Sandstone (Golder 2020a).

Regional studies have shown that the pre-Cenozoic aquifers within the CMB sequence are generally low yielding. Average yields ranging from 0.5 to 2.5 L/second in the sandstones, siltstones and conglomerates of the Bundamba Group – which includes the Marburg Subgroup, the Gatton Sandstone and the Koukandowie Formation (Rassam et al 2014).

Local yield values were sourced from the Queensland Globe database for registered bores within 5 km of the Project. Available yields for 15 registered bores screened in the Gatton Sandstone had values ranging between 0.3 and 6.0 L/s and median value of 2.5 L/s. There were 22 registered bores screened in the Marburg Subgroup with available yields, with values between 0.1 and 6.1 L/s with a mean yield of 2.1 L/s.

7.1.5 Walloon Coal Measures

7.1.5.1 Occurrence

There are 10 registered bores screened in the WCM within 5 km of the Project, including a single bore within 1 km. Registered bores are concentrated from Ch -1.76 to Ch 5.0 km and Project bores indicate WCM is present under the Toowoomba Range tunnel. Surface geology maps do not indicate the presence of WCM at the surface within the groundwater study area.

There is not extensive use of groundwater from the WCM aquifer in this region, particularly in comparison with the MRV. The water entitlements in the WCM are mainly for irrigation and stock (described in detail in Section 7.5).

7.1.5.2 Recharge and discharge mechanisms

Regional groundwater diffuse recharge values were estimated using the chloride mass balance by Raiber et al (2016). The number of groundwater samples in the WCM is 90 and the regional diffuse recharge estimates ranged between 1.3 and 9.7 mm/year with mean value of 3.5 mm/year. This is similar to diffuse recharge observed in the Marburg Subgroup (Gatton Sandstone and Koukandowie Formation) and reflects the limited recharge potential of the WCM.

Surface geology maps and registered bore information indicate the WCM is not present at surface within the groundwater study area. The Project bores indicate the WCM underlies the MRV and overlies the Koukandowie Formation under the Toowoomba Range tunnel. As a result, the main pathway for recharge to the WCM is limited to vertical migration via fractures in the MRV. The primary mechanism for discharge is vertical migration to underlying units or pumping (mainly for irrigation and stock).

7.1.5.3 Hydraulic parameters/yields

A review of aquifer parameters and pumping test data in the Queensland Globe database was carried out by Raiber et al (2016) to provide a range of hydraulic conductivities for hydrostratigraphic units in the CMB. A further review of hydrogeological parameters was provided by Golder (2020b). A total of 82 hydraulic conductivity values were available in the WCM and results ranged between 2 x 10^{-11} and 8 x 10^{-4} m/s. Approximately 50 per cent of values were above 1 x 10^{-7} m/s and 40 per cent were above 1 x 10^{-6} m/s. This indicates hydraulic conductivity is highly variable and reflects the fractures nature of the aquifer and the variability in hydraulic conductivity of the siliciclastic rocks with depth across the weathering profile (Golder 2020a).

Site-specific hydraulic conductivity values are not available for the WCM as Project bores were not screened in this aquifer.

Available yield values were sourced from the Queensland Globe database for registered bores within 5 km of the Project. There was a single yield value of 0.8 L/s in the WCM aquifer.

7.2 Groundwater levels and flow

The water table along the Project alignment is typically a subdued version of topography, with the depth to groundwater increasing beneath topographic highs (for example the GDR and Great Escarpment), and shallower groundwater levels in lower lying reaches (such as close to surface water drainage lines). This is particularly evident in the MRV and Gatton Sandstone.

Depths to shallow groundwater are affected by various processes and influences, including the interaction between local net recharge and the hydraulic conductivity of units, presence of shallow aquitards, surface water features and groundwater extraction. Irrigated areas may contribute to excess recharge along river systems or groundwater level drawdown when irrigation water is sourced from groundwater bores.

Groundwater levels were recorded in October and November 2018 at eight of the 12 Project bores installed along the Project disturbance footprint, as part of the feasibility design geotechnical investigation (Golder 2020b) and are summarised in Table 7.2 and bore locations are depicted on Figure 7.17. Groundwater level data indicates there is limited data available along the Toowoomba Range tunnel.

It is noted that the post-feasibility design stage geotechnical and hydrogeological investigations (Golder 2020c/d) installed VWPs and deployed automated pressure transducers in select new monitoring bores. These data will be utilised to refine the conceptual and predictive models and will be incorporated into the Final EIS.

Where discrepancies occur between the nominated aquifer in Golder's preliminary hydrogeological report (Golder 2020a) and factual geotechnical report (Golder 2020b), the interpretation in Golder (2020a) has been adopted.

Table 7.2 Project bore groundwater level data

Project bore ID	Aquifer[a]	Filter pack interval (mbgl)[b]	Depth to groundwater (mbgl)[b]	Approximate groundwater elevation (m AHD)[b]	Comment
320-01-BH2101	Koukandowie Formation	104 - 117	101.24	474.66	Ch 5.6 km - Toowoomba Range tunnel
320-01-BH2103	Koukandowie Formation	9 - 11	12.40	377.60	Ch 10.4 km - Eastern tunnel portal - Offices - Fuel storage
320-01-BH2201	Koukandowie Formation	9 - 10	6.36	320.52	Ch 11.8 km - Oaky Creek Viaduct Pier Access

Project bore ID	Aquifer[a]	Filter pack interval (mbgl)[b]	Depth to groundwater (mbgl)[b]	Approximate groundwater elevation (m AHD)[b]	Comment
320-01-BH2203	Koukandowie Formation	10 - 11	-	-	Ch 13.8 km - Withcott Viaduct 2 Pier Access
320-01-BH2207	Koukandowie Formation	5 - 6	-	-	Ch 16.6 km - Bridge laydown for Toowoomba Bypass - Toowoomba Bypass and Six Mile Creek Viaduct
320-01-BH2209	Gatton Sandstone	7 - 8	Dry	Dry	Ch 19.8 km
320-01-BH2212	Gatton Sandstone	8 - 10	10.93	188.74	Ch 21.2 km Murphys Creek Road Viaduct
320-01-BH2215	Gatton Sandstone	5 - 6	-	-	Ch 23.6 km - Bridge laydown for Withcott Seedlings Viaduct
320-01-BH2216	Gatton Sandstone	10 - 12	13.45	160.55	Ch 22.6 km
320-01-BH2217	Gatton Sandstone	7.5 - 9.5	10.34	149.35	Ch 24.6 km - Bridge laydown for Lockyer Creek bridge
320-01-BH2218	Gatton Sandstone	9 - 10	14.90	140.32	Ch 24.8 km - Bridge laydown for Lockyer Creek bridge
320-01-BH2301	Koukandowie Formation	10 - 11	10.59	309.31	Ch 15.6 km - Bridge laydown for McNamaras Road Bridge

Table notes:

a. From Golder (2020a)
b. From Golder (2020b)

7.2.1 Alluvium/Colluvium (Quaternary)

There is limited groundwater data related to Quaternary aquifers near the Project, with no registered bores screened in colluvium units within the groundwater study area. There are 18 registered bores listed in Queensland Globe as accessing alluvium units within 5 km of the alignment (Gowrie, Oaky, Rocky, Six Mile and Lockyer creeks), six of which are located within 1 km.

Out of the 18 registered bores, several are perforated across multiple units (composite bores) or constructed as open holes and are therefore not representative of groundwater levels in alluvium units. The remaining 10 bores, accessing Gowrie Creek, Oaky Creek, Rocky Creek and Lockyer alluvium units, are summarised in Table 7.3.

Table 7.3 Groundwater elevation in alluvium units within 5 km of the alignment

Alluvium unit	Bore ID	Project chainage (km)	Groundwater elevation (m AHD)	Depth to groundwater water (mbgl)	Screen interval (mbgl)
Gowrie Creek	RN19198	-1.76	512.6	14.0	13.8-15.2
	RN48468	1.2	464.8	6.0	10.9-11.6
Oaky Creek	RN48325	13.8	459.4	9.8	11.8-12.8; 12.20-17.60
Rocky Creek	RN48520	21.6	No data provided	5.4	5.5-7.9; 8.1-9.10

Alluvium unit	Bore ID	Project chainage (km)	Groundwater elevation (m AHD)	Depth to groundwater water (mbgl)	Screen interval (mbgl)
Lockyer Creek	RN14320196	28.1	124.6	3.2	No data provided
	RN14320850	30.3	121.0	11.9	No data provided
	RN14320851	30.2	118.2	14.0	No data provided
	RN14320852	27.1	116.1	17.4	No data provided
	RN14320853	29.9	117.0	15.8	No data provided
	RN14320854	30.3	117.6	16.1	No data provided

Table notes:
Sourced from the DRNME groundwater database where data was available, with indicative groundwater elevation data

Long-term groundwater level data was available for six bores which intersect the Lockyer Creek alluvium (located east of the GDR). Figure 7.1 presents a hydrograph for the Lockyer Creek alluvium, which is considered representative of the alluvium unit within the groundwater study area. There is no long-term groundwater level data available in the Gowrie, Oaky, Rocky and Six Mile Creek alluvium units.

Groundwater level data indicates groundwater in alluvium units is generally shallow and follows topography and the hydrograph indicates groundwater is responsive to rainfall recharge. Figure 7.2 depicts the regional groundwater flow patterns within the Lockyer Creek alluvium, which reflects groundwater flow east of the GDR. The Gowrie Creek alluvium is recognised to be recharged by the Wetalla water treatment plant (Toowoomba Regional Council) and acts as recharge for the downstream Oakey Creek alluvium (DNRME 2017). Figure 7.3 depicts the regional groundwater flow for alluvial units within the western portion and west of the Project; note Gowrie Creek alluvium recharges Oakey Creek alluvium that recharges Upper Condamine Alluvium.

Groundwater flows from the GDR to the east and west, which indicates the GDR is a groundwater divide in the region.

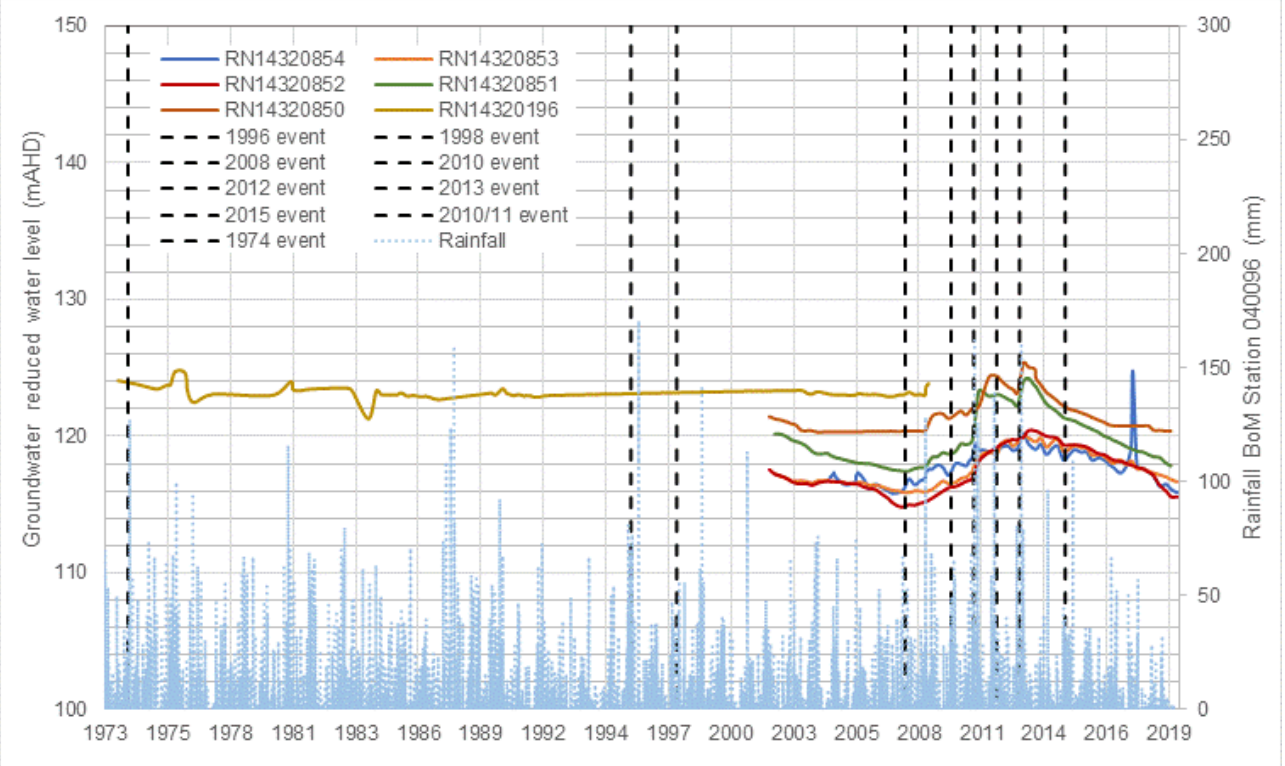


Figure 7.1 **Hydrograph of Lockyer Creek alluvium**

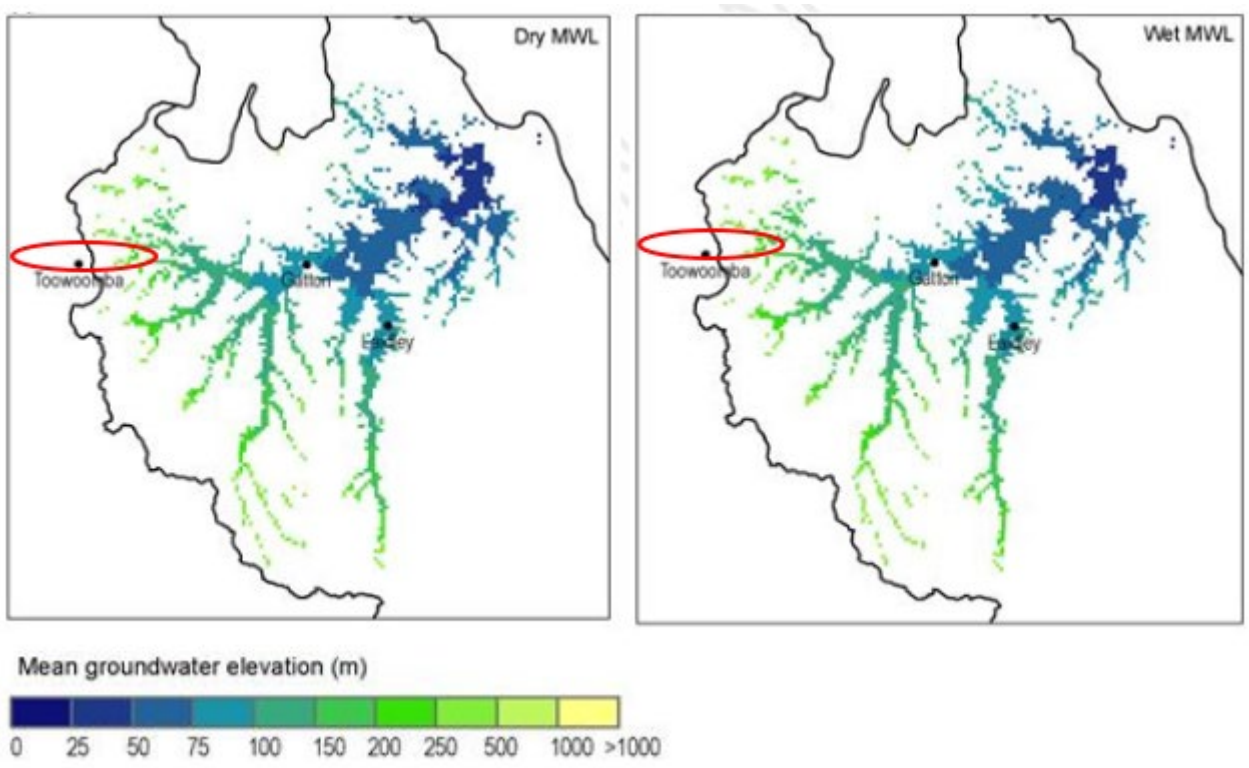


Figure 7.2 Regional groundwater flow of Lockyer Creek alluvium

Source: Raiber et al 2016

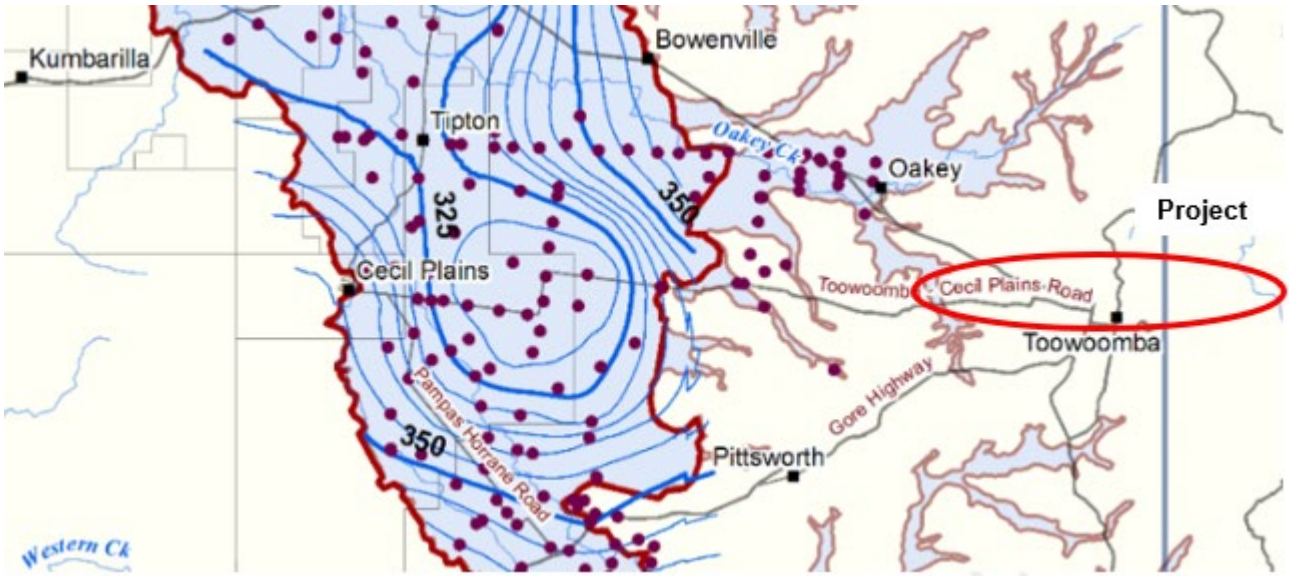


Figure 7.3 Regional groundwater flow of alluvium within and west of the Project area

Source: OGIA 2019

7.2.2 Main Range Volcanics

There is limited long-term groundwater level data within 1 km of the Project west of the GDR. As a result, the search was expanded to 5 km of the alignment and 11 registered bores with long-term data were identified. Figure 7.4 and Figure 7.5 reports the long-term bores in the MRV aquifer along with large climatic events reported since 2008 and historically since 1980.

In the groundwater study area, the MRV comprises complex spatial distribution of variable basalt types resultant from numerous lava flows. Each basalt flow can be different to the others and, as such, have different hydraulic conductivities within the same aquifer.

Groundwater levels in the MRV aquifer are difficult to correlate due to local groundwater abstractions, the nature of fractured rock aquifers, and multi-flow events that create variable connectivity throughout the aquifer. This is reflected in the large variations in hydraulic head distribution for MRV bores within the groundwater study area. The large variations in groundwater levels are considered to be resultant of the isolated fracture networks within the MRV, various confining attributes of the units within the MRV, and/or local influence from abstraction (refer Section 7.5).

The GDR forms a groundwater divide that separates regional groundwater flow patterns. Groundwater flow from this divide are towards the east and west; Figure 7.6 depicts the regional groundwater flow patterns for the MRV. Local groundwater flow systems are influenced by topography and surface water-groundwater interaction where there is a hydraulic connection from the MRV to overlying units and/or as baseflow to surface water features.

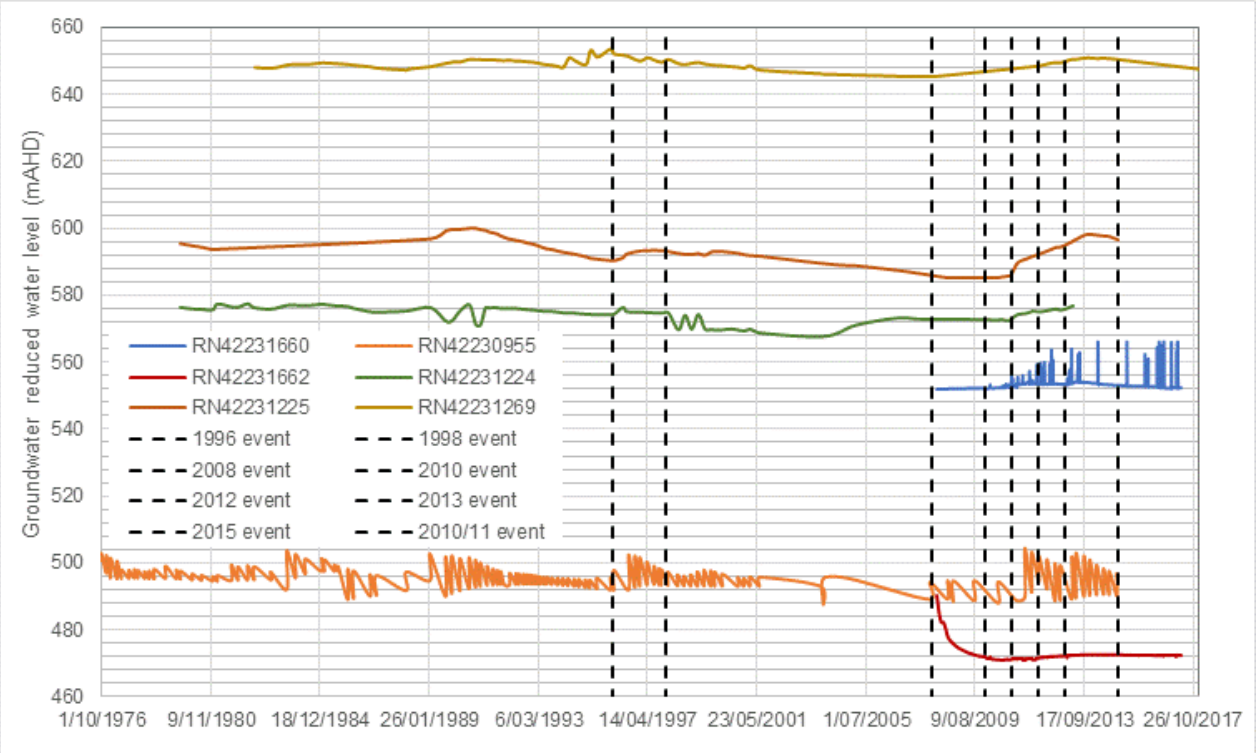


Figure 7.4 **Groundwater levels for MRV bores within 5 km of alignment (1980 to 2019)**

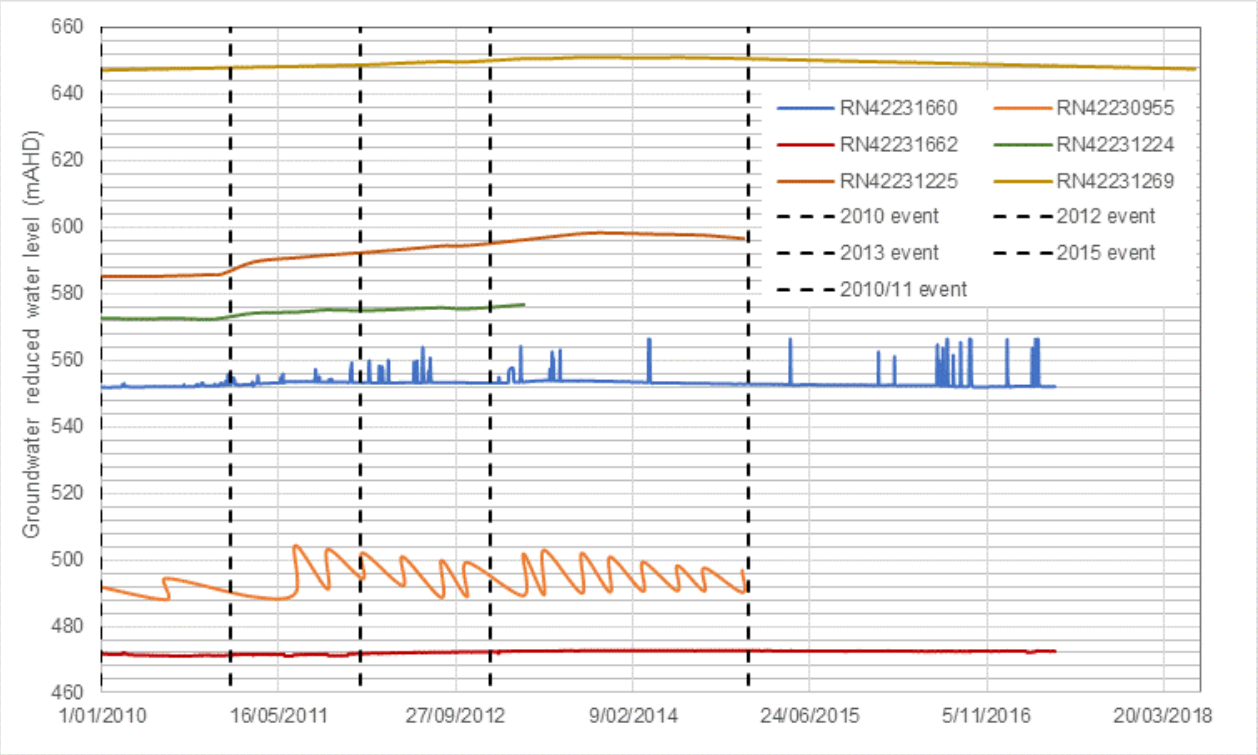


Figure 7.5 **Groundwater levels for MRV bores within 5 km of alignment (2010 to 2019)**

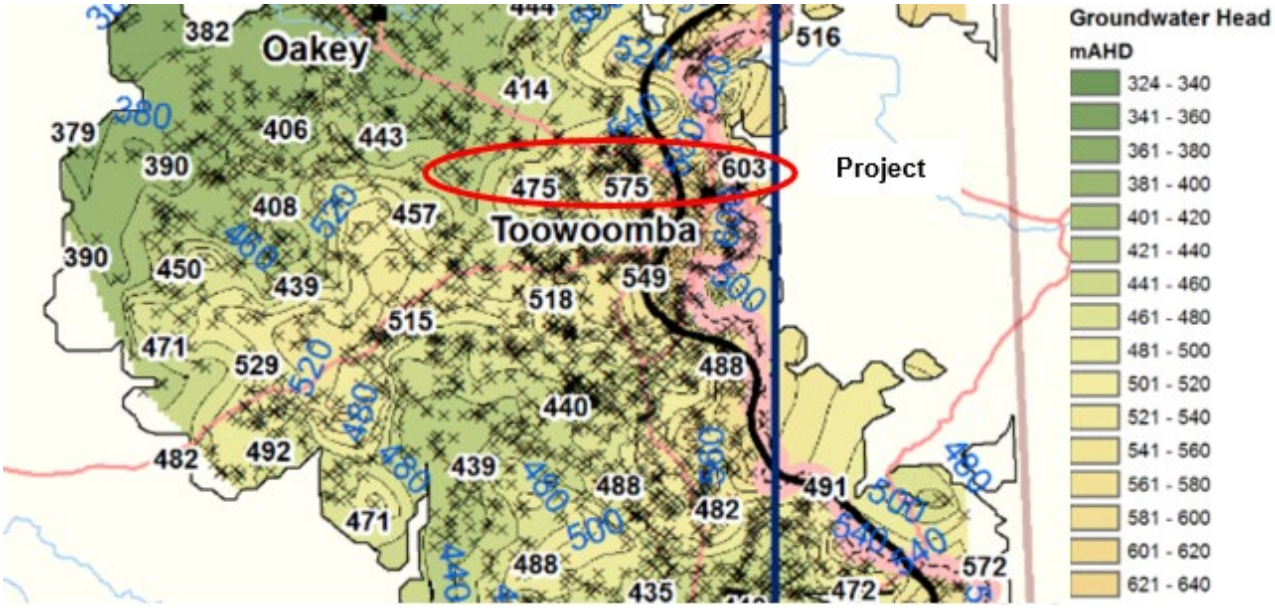


Figure 7.6 **Regional groundwater flow direction of the MRV**

Source: OGIA 2019

7.2.3 Walloon Coal Measures

There are three registered bores reported to be screened across the WCM within 5 km of the alignment where one of these bores is within the groundwater study area. There is no long-term groundwater level data available within 20 km of the project therefore a hydrograph was not developed for this unit. However, the registered bores with groundwater elevation data available for the WCM are summarised in Table 7.4.

Table 7.4 Groundwater elevation summary in the WCM within 5 km of the alignment

Bore	Project chainage (km)	Bore elevation (m AHD)	Date of measurement	Standing Water Level (mbgl)	Water elevation (m AHD)
RN36052	outside study area	467.46	23/03/1971	4.87	462.59
RN17290	outside study area	572.43	9/03/1967	54.9	517.53
RN55061	7.2	571.01	21/03/1979	134.1	436.91

Figure 7.7 depicts the regional groundwater flow direction, which shows groundwater flows from the GDR to the west.

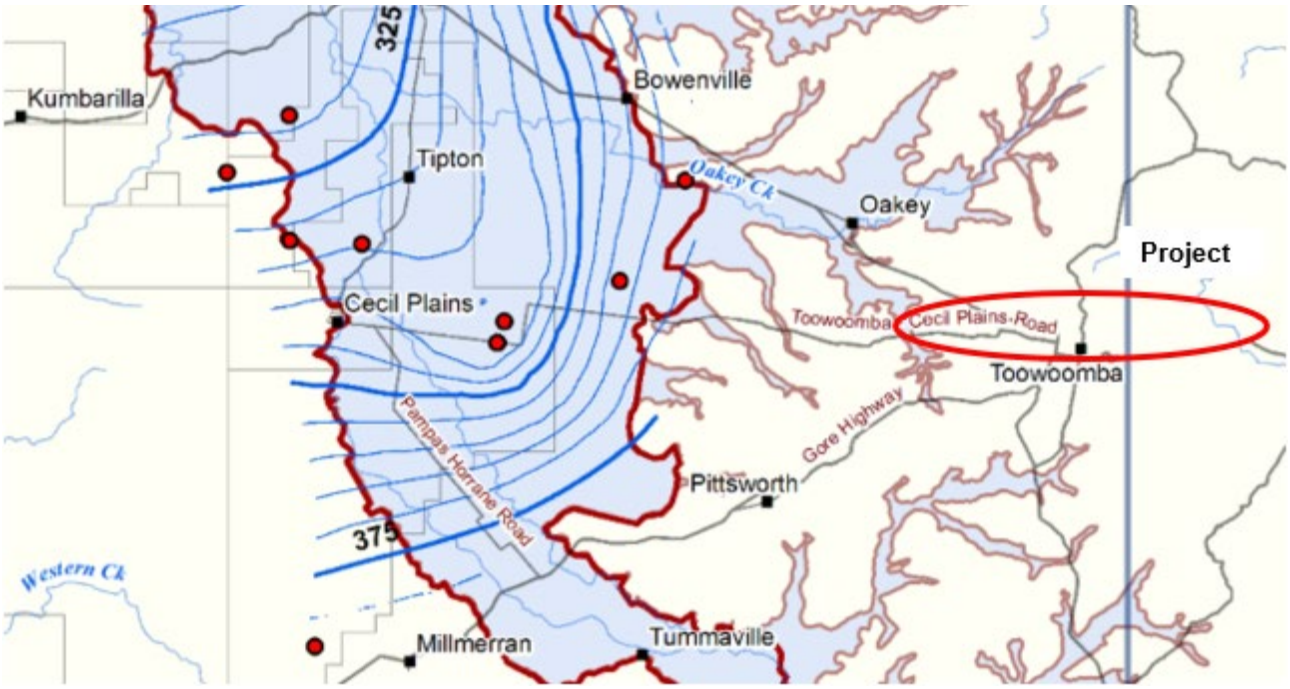


Figure 7.7 Regional groundwater flow direction of the WCM

Source: OGIA 2019

7.2.4 Koukandowie Formation

There are no registered bores screened in the Koukandowie Formation with single groundwater level observations or long-term data, within 5 km of the groundwater study area. As a result, groundwater level in this aquifer was assessed using site-specific data captured across the Project bores. Paucity of data in the Koukandowie Formation is largely due to the extensive use of the MRV in the groundwater study area.

A summary of the Project bores screened in the Koukandowie Formation is provided in Table 7.2. The site-specific data indicates the potentiometric head along the alignment decreases gradually from the GDR to the west and decreases more rapidly east of the GDR (shown in the conceptual site model in Figure 9.1 and Figure 9.2).

7.2.5 Gatton Sandstone

A total of three bores were identified with long-term groundwater level data available in the Gatton Sandstone aquifer, in addition to four geotechnical bores (located along the alignment) converted to monitoring bores during a geotechnical investigation in 2018 (refer Figure 7.8).

The long-term groundwater level in the Gatton Sandstone shows a delayed and limited response to climatic events, particularly in comparison to the MRV aquifer. Groundwater elevations (125.85 to 155.33 m AHD) decrease from Ch 21.2 km towards the eastern end of the alignment following the topography. The regional groundwater flow direction of the Gatton Sandstone is from the GDR to the east and is presented in Figure 7.9.

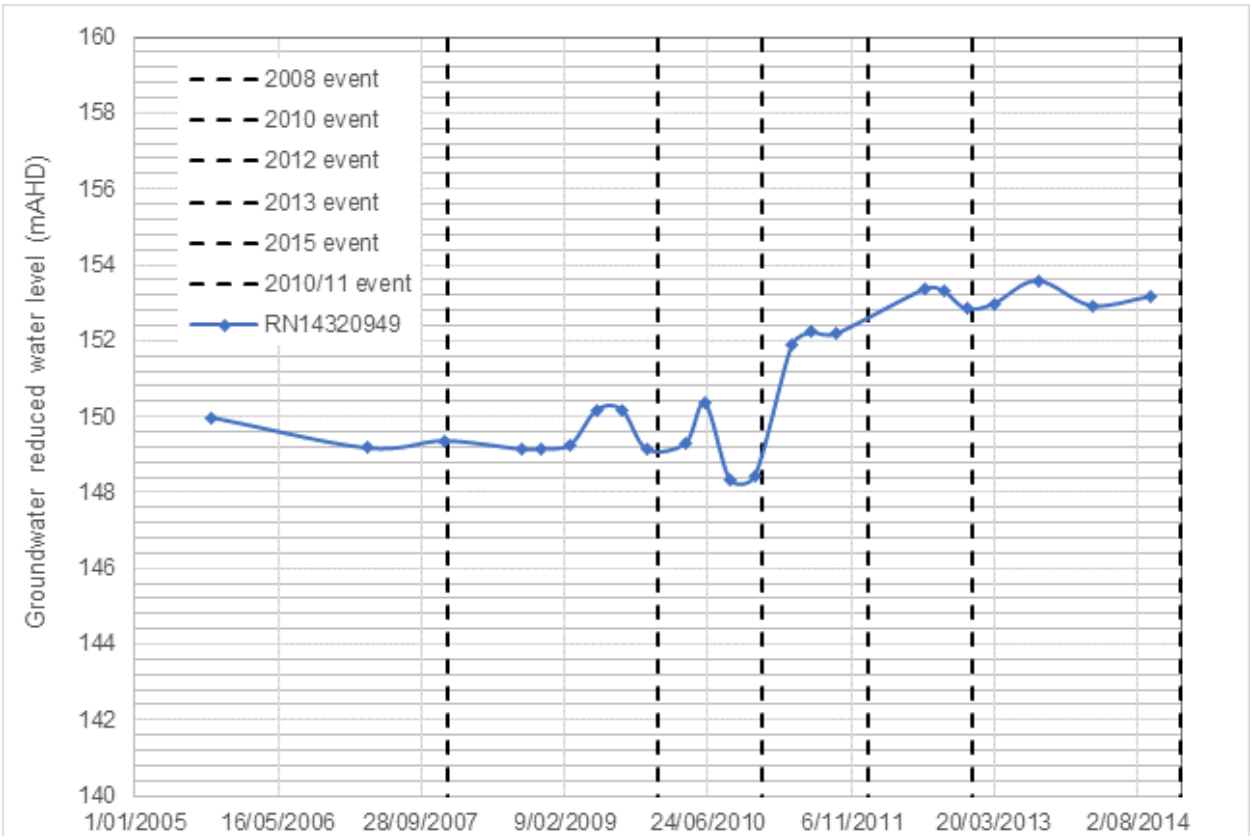


Figure 7.8 **Groundwater levels for Gatton Sandstone bore within 5 km of alignment**

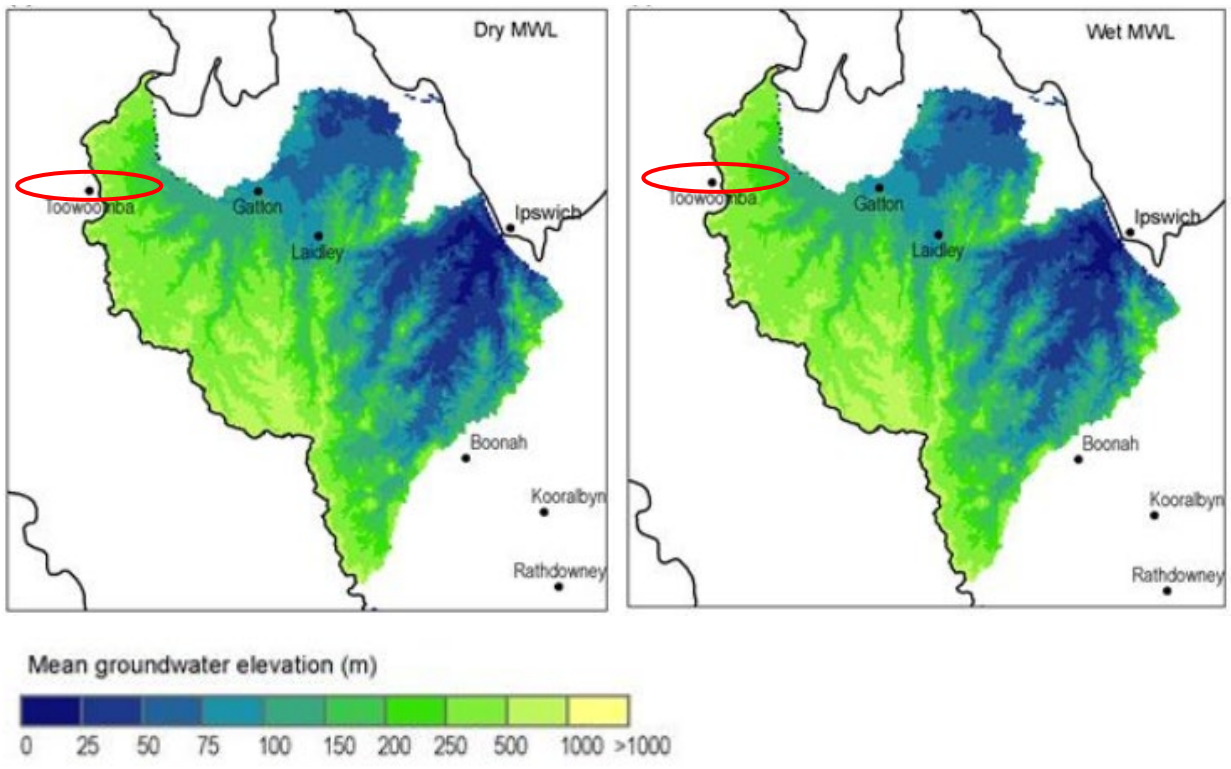


Figure 7.9 **Groundwater flow direction of the Gatton Sandstone**

Source: Raiber et al 2016

7.2.6 Groundwater flow summary

Regional groundwater levels and flow direction in the Toowoomba region is influenced by the GDR, where the GDR is a regional groundwater divide. This was observed in single point measurements taken at the site-specific Project bores along the alignment and is shown in Figure 9.1. Groundwater gently decreases to the west of the divide and decreases steeply east down the escarpment towards Helidon. The flow direction of the alluvium aquifer may be represented by the surface water catchment boundaries, which correlates well with the groundwater divide observed.

Local groundwater flow in the alluvial aquifers (Gowrie Creek, Oaky Creek, Rocky Creek, Six Mile Creek and Lockyer Creek alluvium) is generally influenced by surface water-groundwater interaction, where there is a hydraulic connection. This is observed along Gowrie Creek, which flows west into the Condamine River Basin and it is expected that groundwater in the shallow Gowrie Creek alluvium has a similar trend. East of the divide the Project crosses Rocky Creek, Oaky Creek and Six Mile Creek which flow east, and feed Lockyer Creek and it is expected that groundwater flow in the shallow alluvium follows the surface water pathways. Section 7.4 further discusses the hydraulic connectivity inferred between Gowrie Creek, associated alluvial sediments, and the underlying MRV.

The height of groundwater above the tunnel and the hydraulic gradient either side of the divide affects the rate of flow to the tunnel and portals. Since hydraulic heads increase during high rainfall episodes/seasons and decrease during extended periods of no/low rainfall, seasonality is also a factor controlling groundwater flow.

Climate change can cause groundwater reduction due to prolonged periods of drought. Currently the Project is in a fully drought declared area (The Long Paddock 2021). Drought reduces rainfall and surface water level, which acts as recharge to alluvial aquifers (refer Section 4.4. Alluvial waters will reduce in these areas which rely on surface water to recharge. Groundwater level will also reduce in areas where groundwater discharges to surface water. Recharge to aquifers which subcrop/outcrop (other than alluvium) are also considered to be impacted by prolonged drought conditions. Groundwater will also be impacted by prolonged drought where there are dams that act as artificial recharge (e.g. controlled releases).

As a result of the EIS process, the paucity of localised continuous groundwater level data (publicly available and from the feasibility design stage investigations) has promoted the construction of new monitoring bores and VWPs post-feasibility design stage investigations to inform this recognised data gap. The new monitoring bores were equipped with automated pressure transducers. The data recorded on the new VWPs and automated pressure transducers along with those installed in the feasibility design stage investigation bores (continuous datasets from 2018) will be assessed and incorporated into the predictive model refinement to enhance the existing predictions of Project impacts on water levels for the Final EIS.

In summary, from the highest point of the GDR and the apex of the groundwater divide, groundwater flow gently flows west of the GDR following topography. East of the GDR, shallow groundwater follows the escarpment, with steep relief, towards Helidon. The flow direction of the alluvium aquifer is typically represented by the surface water catchment boundaries, which reflects the groundwater divide.

7.3 Groundwater quality

Groundwater quality is discussed here in terms of salinity, total dissolved solids (TDS) as mg/L and/or electrical conductivity (EC) as microsiemens per centimetre (µS/cm)[3]. These parameters readily allow comparison of groundwater condition, hydrogeological mechanisms (i.e. recharge/discharge areas) and the potential uses that the groundwater is suitable for (i.e. the EV of the groundwater). Groundwater salinity is characterised as being freshwater (and potable) where TDS is 0 to 1,000 mg/L, brackish where TDS is 1,001 to 10,000 mg/L and saline where TDS is between 10,001 and 100,000 mg/L. For a TDS beyond 100,000 mg/L groundwater is considered brine (Fetter, 2014).

[3] Electrical conductivity is a measurement of how well an aqueous solution can- conduct an electrical current (in uS/cm). TDS can be approximated from EC using a conversion factor, which changes depending on the type of salts in the groundwater. TDS can also be measured directly by laboratory. Salinity is like TDS in that it is an estimate of salt in the water, derived from EC using a conversion factor (typically 0.5).

Regional groundwater chemistry in the Clarence-Moreton Bioregion varies considerably between aquifer systems due to spatial and temporal separation. Groundwater in Quaternary aquifers (alluvial units) is generally fresher than groundwater in sedimentary rock aquifers (including the WCM, Koukandowie Formation and Gatton Sandstone). The main control of spatial variability between aquifers systems is the nature of the connectivity between surface water systems and shallow aquifers with deep aquifer systems. For example, groundwater in the MRV near the headwaters of Lockyer Creek is commonly fresh due to increased recharge from Quaternary aquifers. A gradual decrease in groundwater quality has been observed downstream of the headwater where connectivity with Quaternary aquifers is conceptualised to decrease (Rassam et al. 2014)

Water quality of the confined aquifers range from fresh to saline and exhibits greater variability than overlying Quaternary aquifers. Water quality in the MRV aquifer is generally fresh due to thin soil coverage and rapid recharge from fractures whereas groundwater in the sedimentary rock aquifer of the WCM varies between 750 and 49,475 mg/L (Metagsco 2007).

Water quality data available within 5 km of the Project comprises samples from 258 groundwater monitoring bores. Samples were collected over 96 years from 1922 to 2019. Project bores were also sampled and analysed in 2018. Groundwater chemistry data has been obtained from the Queensland Globe database and the Geotechnical Factual Report (Golder 2020b). Groundwater chemistry data is summarised in Appendix A.

There are 179 sets of complete cation and anion analytical records and information about the screened formation, the number of bores is summarised as:

- Quaternary aquifer (alluvium) – four bores
- Sedimentary rock aquifer of Marburg Subgroup – 39 bores
- Sedimentary rock aquifer of Gatton Sandstone – seven bores
- MRV aquifer – 100 bores.

Groundwater samples were taken based on the location of each unit, with samples of the MRV and WCM taken west of the GDR and the Koukandowie Formation and Gatton Sandstone taken east of the GDR.

A summary table of geochemistry data collected for registered bores is provided in Table 7.5.

Table 7.5 Hydrochemical composition of water in four main aquifers

Aquifer	Hydrochemical type	Major ions	Median (mg/L)	Range (mg/L)	No. of observations
Gowrie Creek alluvium	Mg-Cl	Sodium (Na)	120	-	1
		Potassium (K)	0	-	
		Calcium (Ca)	112	-	
		Magnesium (Mg)	588	-	
		Bicarbonate (HCO_3)*	185	-	
		Chloride (Cl)	1,920	-	
		Sulfate (SO_4)	245	-	
Oaky Creek alluvium	Unclear	Sodium (Na)	72	-	1
		Potassium (K)	1	-	
		Calcium (Ca)	102	-	
		Magnesium (Mg)	101	-	
		Bicarbonate (HCO_3)*	520	-	
		Chloride (Cl)	277	-	
		Sulfate (SO_4)	16	-	
Rocky Creek alluvium	Na-HCO_3-Cl	Sodium (Na)	92	65-119	2
		Potassium (K)	0.75	0-1.5	
		Calcium (Ca)	70	60-79	

Aquifer	Hydrochemical type	Major ions	Median (mg/L)	Range (mg/L)	No. of observations
		Magnesium (Mg)	73	54-92	
		Bicarbonate (HCO_3)*	291	248-334	
		Chloride (Cl)	293	156-430	
		Sulfate (SO_4)	9.5	6-13	
Lockyer Creek alluvium	Na-HCO_3-Cl	Sodium (Na)	46	21-355	8
		Potassium (K)	1.5	0.6-7.7	
		Calcium (Ca)	11	0.5-62	
		Magnesium (Mg)	9.3	3.4-90	
		Bicarbonate (HCO_3)*	105	38-750	
		Chloride (Cl)	61	30-610	
		Sulfate (SO_4)	5.7	5-20.5	
Gatton Sandstone	Na-HCO3	Sodium (Na)	572	133-820	7
		Potassium (K)	0.4	0.1-0.9	
		Calcium (Ca)	1.8	0.4-9.4	
		Magnesium (Mg)	2.4	0.5-13.7	
		Bicarbonate (HCO_3)*	19.8	5.5-25.1	
		Chloride (Cl)	8.8	4.5-30.8	
		Sulfate (SO_4)	0.3	0.1-2.9	
MRV	Unclear	Sodium (Na)	119	2-1,340	100
		Potassium (K)	1.6	0-15	
		Calcium (Ca)	49	0-292	
		Magnesium (Mg)	34	0-487	
		Bicarbonate (HCO_3)*	268	0-870	
		Chloride (Cl)	220	40-2,520	
		Sulfate (SO_4)	8	0-273	
Marburg Subgroup	Unclear	Sodium (Na)	505	62-1,670	39
		Potassium (K)	9	0-64	
		Calcium (Ca)	35	4-122	
		Magnesium (Mg)	18	1-122	
		Bicarbonate (HCO_3)*	791	120-2,000	
		Chloride (Cl)	215	86-2,690	
		Sulfate (SO_4)	10	0-96	

Source: Queensland Globe 2019

Tables notes:

* HCO_3 as bicarbonate according to the Queensland Globe database

The Piper diagram is one of the most commonly used techniques to interpret water chemistry data. This method plots major cations and anions on adjacent tri-linear fields, with these points then being extrapolated to a central diamond field. Here the chemical character of water, in relation to its environment, can be observed and changes in the quality interpreted. The cation and anion plotting points are derived by computing the percentage equivalents per million for the main diagnostic cations of Ca, Mg, and Na+/K+, and anions Cl, SO_4, and CO_3/HCO_3.

Waters from different environments typically plot in diagnostic areas or “hydrochemical facies”. The upper half of the diamond normally contains water of static environments, while the middle area normally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates a dynamic groundwater environment. Sodium chloride brines (old water) normally plot in the right corner of the diamond shape while recently recharged water plots on the left corner of the diamond plot. The top corner normally indicates water contaminated with gypsum (sulfate impact).

7.3.1 Alluvium/Colluvium (Quaternary/Tertiary)

The alluvium aquifer is an extensive source of drinking water in the region. As a result, geochemistry across the alluvium units (Gowrie Creek, Oaky Creek, Rocky Creek, Six Mile Creek and Lockyer Creek alluvium) was compared with Drinking Water Guidelines by NHMRC (2011), which is summarised in Table 7.6.

Table 7.6 Comparison of groundwater quality and Australian Drinking Water Guidelines

Parameter (unit)	Drinking Water Guidelines (NHMRC)	Groundwater minimum value	Groundwater mean value	Groundwater maximum value
TDS mg/L	600 (aesthetic)	520	**720**	**870**
pH (pH units)	6.5-8.5 (aesthetic)	7.6	7.9	8.0
Chloride (mg/L)	250 (aesthetic)	160	**530**	**1,920**
Sodium (mg/L)	180 (aesthetic)	70	180	**710**
Fluoride (mg/L)	1.5 (health)	0.1	0.3	0.5
Sulfate (mg/L)	250 (aesthetic)	6	50	250

Source: NHMRC 2011

Table note:

Values in bold and underlined have exceeded the guideline value

Mean groundwater quality values are generally within guidelines values however salinity and chloride are outside aesthetic guidelines values. The salinity range across the alluvium units is indicative of freshwater (less than 1,000 mg/L) which reflects a regularly recharged aquifer with minimal residence time to facilitate water-sediment interaction i.e. this is a typical dynamic primary aquifer system.

The Piper diagram was used to determine the hydrochemical character of the alluvium units (refer Figure 7.10).

The geochemistry across the alluvium units east of the GDR (Lockyer Creek and Rocky Creek) is Na-HCO_3-Cl, which is consistent with areas of mixing. Gowrie Creek alluvium is Mg-Cl dominant, which is different to geochemistry observed east of the divide.

The alluvium aquifer is likely influenced by local factors such as agricultural activities as well as proximity to roads and topographic highs (particularly the GDR). The main water usage from the alluvium aquifer is irrigation. The water entitlements in the alluvium aquifers within the groundwater study area is low in comparison with the MRV. A total of 140 megalitres (ML) per year is sourced from alluvium compared to 61,000 ML/year sourced from the MRV (refer Section 7.5).

The geochemistry of alluvium aquifers is also impacted by connectivity with the MRV, which occurs west of the divide. The freshwater characteristics observed in the alluvium (mean salinity of 720 mg/L) is present in the MRV (mean salinity of 920 mg/L), this indicates there is recharge from alluvium units occurring.

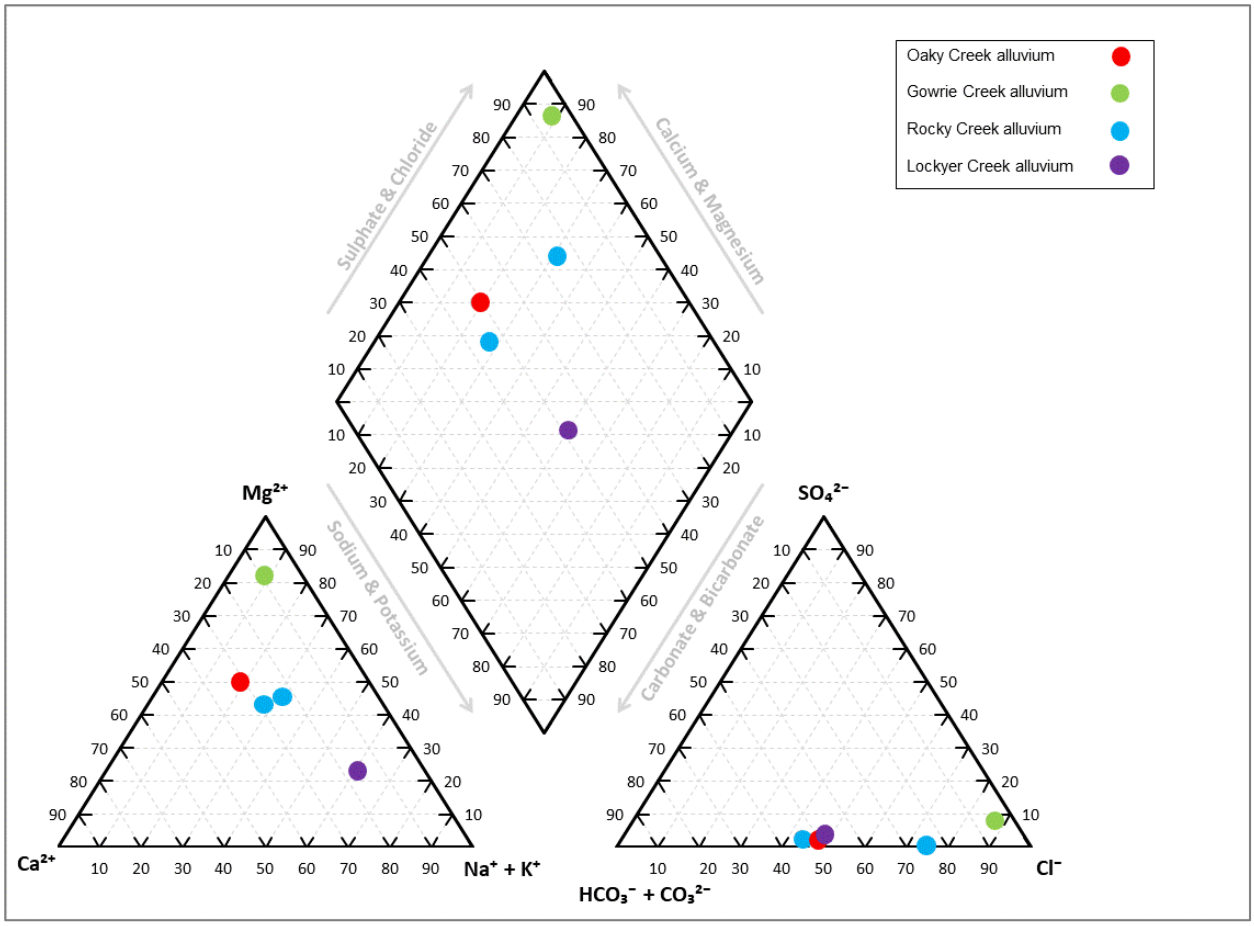


Figure 7.10 **Piper diagram of alluvium units within 5 km of the Project**

7.3.2 Main Range Volcanics

Groundwater from the MRV has been classified as Na-HCO_3-Cl dominant in literature (DNRME 2019) and this is confirmed in the geochemistry data; however, the Piper diagram (refer Figure 7.11) shows that groundwater within this aquifer is highly variable. The two main groups observed are magnesium (Mg) and sodium (Na) dominant where the magnesium dominant group possibly reflecting cation exchange between Na and Mg. The scattered nature of the samples indicates that there are multiple processes occurring in the aquifer and these range from recent recharge to mixing environments and cation exchange of magnesium and calcium for sodium.

Salinity of the MRV is associated with freshwater with mean salinity of 930 mg/L, which indicates there is recharge from Quaternary aquifers occurring west of the GDR, in addition to rainfall recharge received by outcrops/subcrops of this unit. This confirms the regional groundwater conceptualisation.

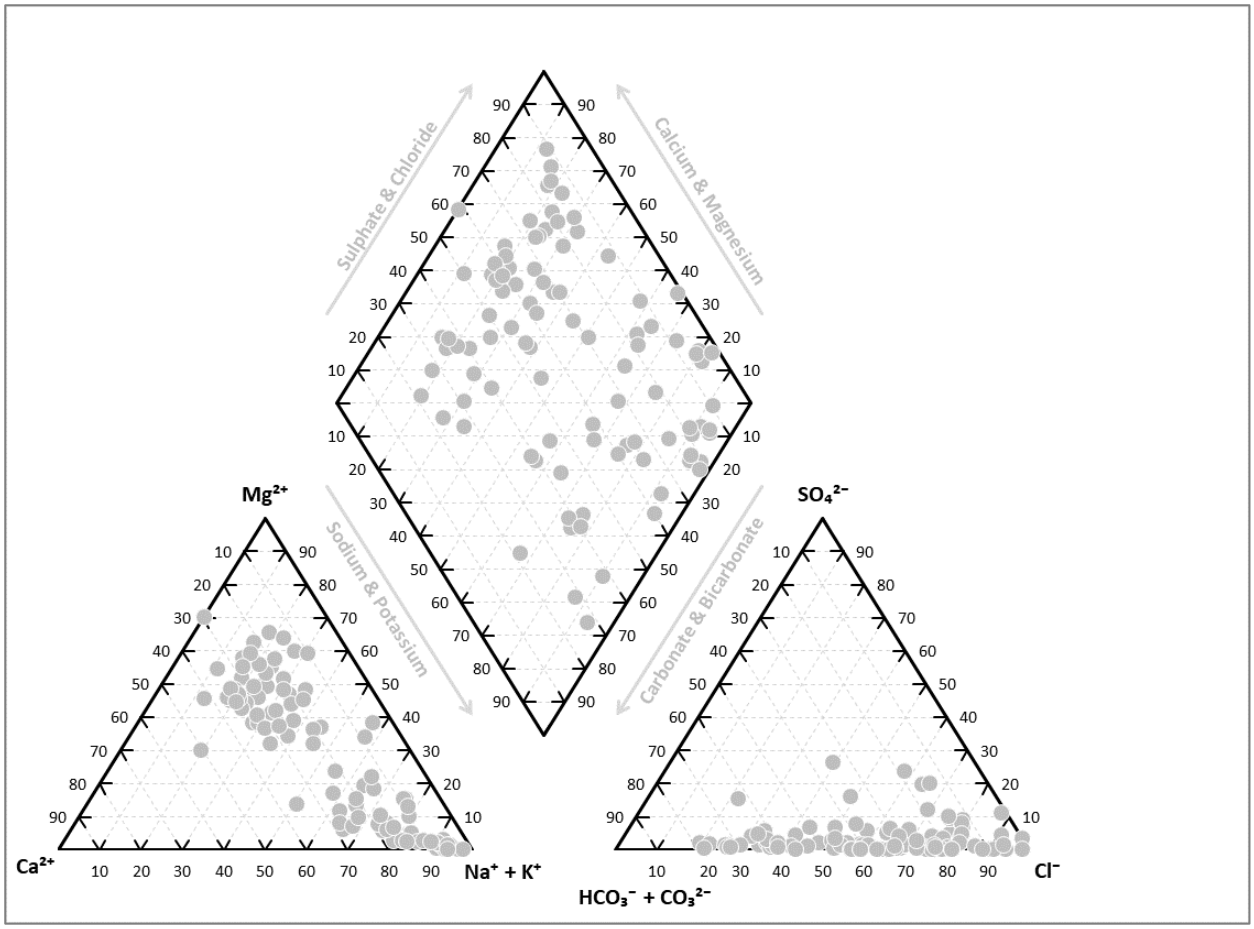


Figure 7.11 **Piper diagram of the MRV aquifer within 5 km of the Project**

7.3.3 Gatton Sandstone

The Piper diagram of Gatton Sandstone (refer Figure 7.12) does not appear to have a distinct trend or hydrochemical signature however groundwater is Na-HCO_3 dominant.

Project bores sampled included 320-01-BH2217 (Gatton Sandstone) and 320-01-BH2201 (Koukandowie Formation). The geochemistry observed at these bores indicate the water type is Na-HCO_3, with 320-01-BH2201 having a higher relative content in chloride.

Salinity of the Gatton Sandstone was associated with brackish quality with mean salinity of 1,500 mg/L. This is consistent with regional groundwater chemistry observations, where groundwater in Quaternary aquifers is fresher than in sedimentary rock aquifers due to the nature of connectivity between shallow aquifers and deep aquifer systems. The decrease in water quality confirms the regional hydrogeological conceptualisation, which suggests that groundwater quality decreases downstream of the headwater where connectivity with Quaternary aquifers is expected to decrease.

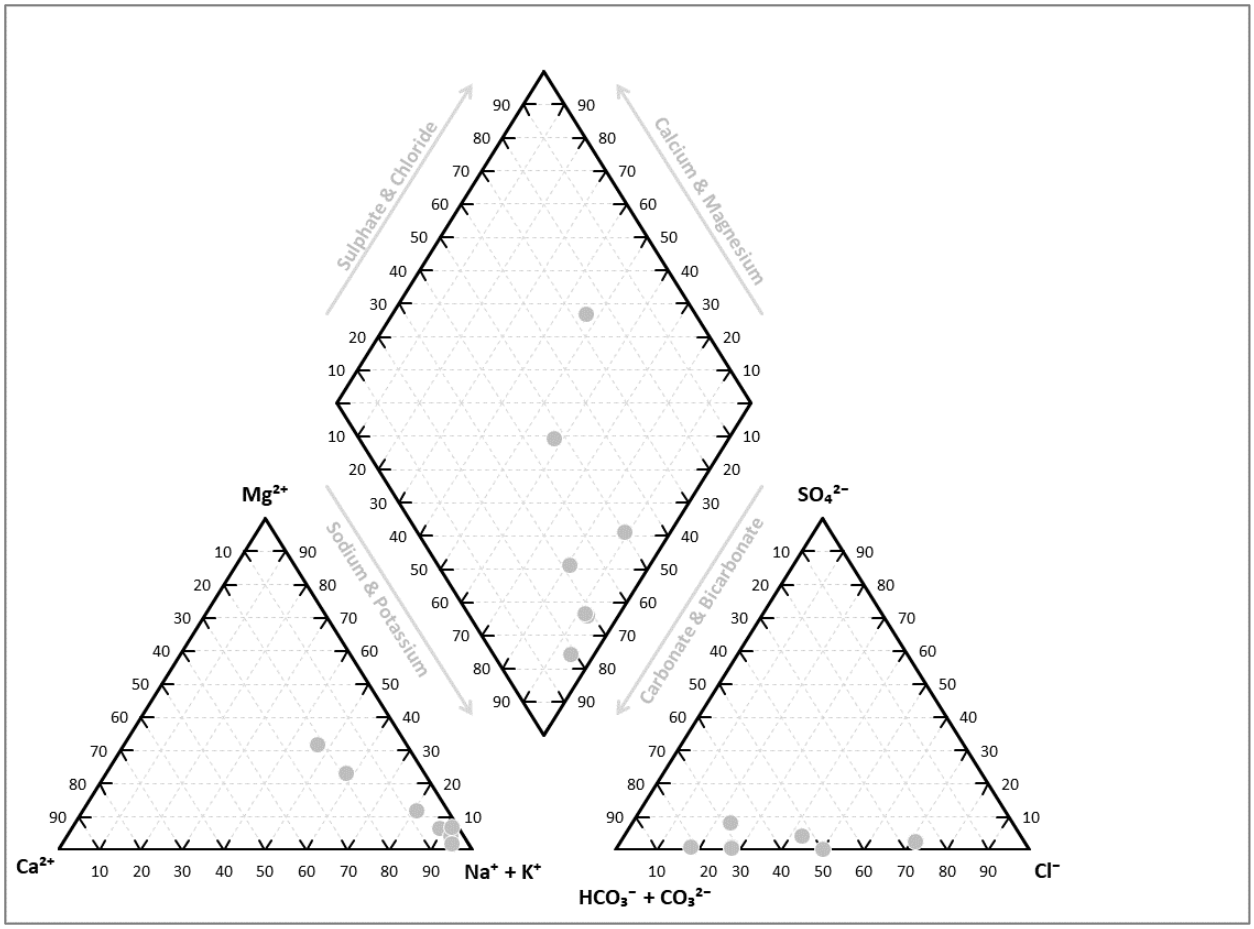


Figure 7.12 Piper diagram of the Gatton Sandstone aquifer within 5 km of the Project

7.3.4 Marburg Subgroup

The Piper diagram (refer Figure 7.13) shows sedimentary rock aquifers of the Marburg Subgroup varies between Na-Cl and Na-HCO_3 water types. Variation of water types may be attributed to water bores screened across formations, geological structures separating formations or general variability over time.

Salinity of the Marburg Subgroup was associated with brackish water with mean salinity of 1,400 mg/L. This is consistent with regional groundwater chemistry in the Clarence-Moreton Bioregion, where groundwater in Quaternary aquifers is fresher than in sedimentary rock aquifers due to the nature of connectivity between shallow aquifers and deep aquifer systems. The decrease in water quality confirms the regional hydrogeological conceptualisation, which suggests that groundwater quality decreases downstream of the headwater where connectivity with Quaternary aquifers is expected to decrease.

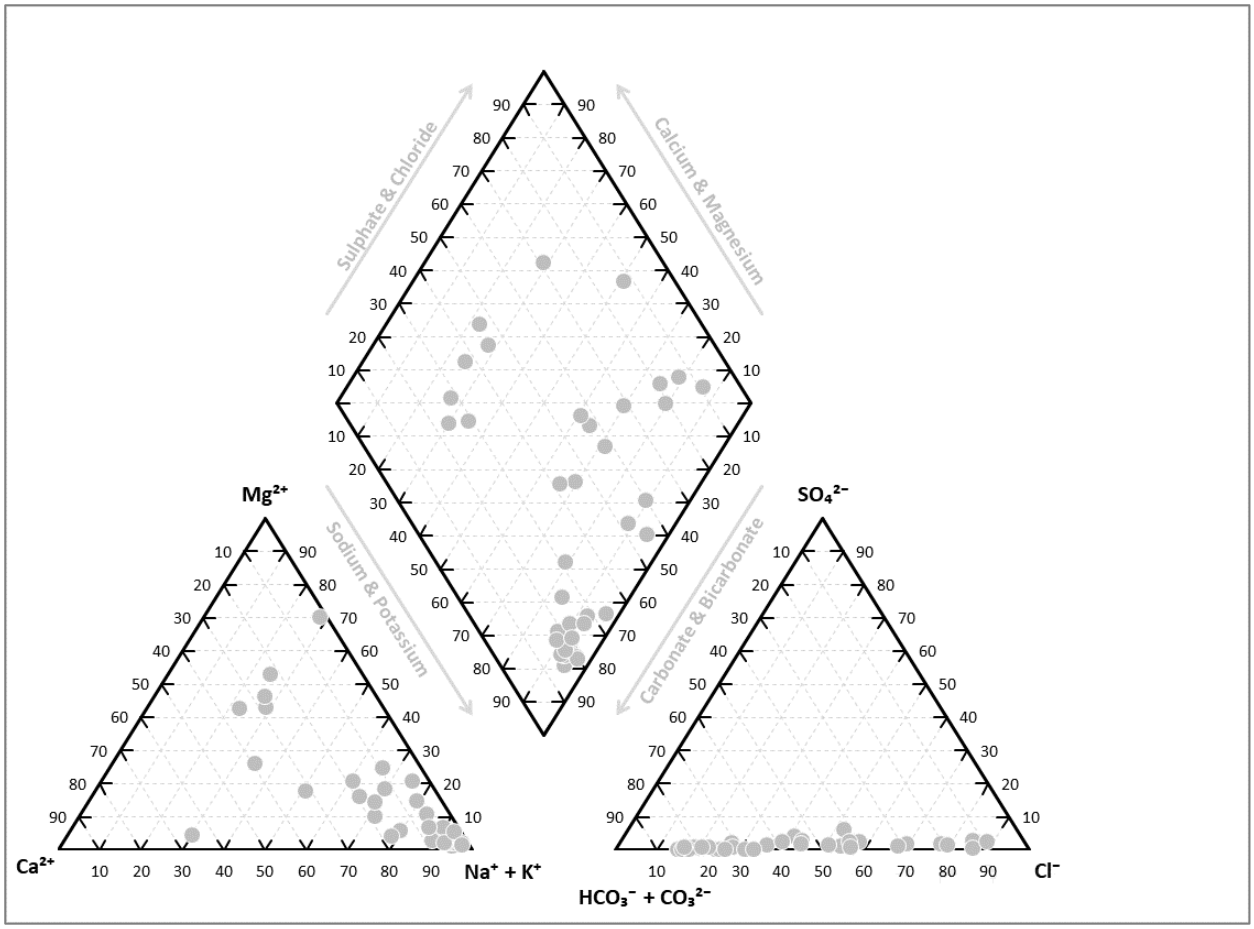


Figure 7.13 **Piper diagram of the Marburg Subgroup within 5 km of the Project**

7.3.5 Koukandowie Formation

There is no geochemistry data available for the Koukandowie Formation within 5 km of the Project according to the Queensland Globe database. The Marburg Subgroup data was sampled from bores located east of the GDR, where the geology is associated with the Koukandowie Formation. As a result, the Marburg Subgroup geochemistry can be interpreted as reflecting the characteristics of the Koukandowie Formation.

The Marburg Subgroup is associated with Na-Cl and Na-HCO_3 water types with high variability observed across the sampling bores. The Project bore screened in the Koukandowie Formation (320-01-BH2201) is classified as Na-HCO_3 water type with high chloride content, which confirms the geochemistry observed within the Marburg Subgroup in the groundwater study area.

7.3.6 Walloon Coal Measures

There are 10 registered bores screened in the WCM within 5 km of the alignment and one bore within 1 km of the alignment. Registered bores are concentrated from Ch -1.76 to 5.0 km and Project bores indicate WCM is present under the Toowoomba Range tunnel. Surface geology maps do not indicate the presence of WCM at the surface within the groundwater study area.

It is likely the geochemistry of the WCM aquifer is highly variable in the region due to the nature of the unit and the hydraulic connectivity (leakage) with overlying units (known fresher quality). There are two groundwater bores within the WCM with salinity values in the groundwater study area. The bores are located at Ch 1.0 km and Ch 2.0 km with salinity of 490 mg/L and 550 mg/L respectively. The fresh groundwater values suggest there is connectivity with the Gowrie Creek alluvium (freshwater unit), mostly likely via the MRV, at these locations.

7.3.7 Salinity summary

An assessment of salinity and EC in the CMB was provided by Rassam et al (2014) based on multiple references and data sets. A summary is provided in Table 7.7, together with data from bores within the groundwater study area where available.

Table 7.7 Summary of groundwater salinity – Regional

Aquifer unit	No. samples	Salinity[1] (mg/L)			EC (µS/cm)			Groundwater study area	
		Minimum	Mean	Maximum	Minimum	Mean	Maximum	Sample size	Median EC and salinity
Lockyer Valley alluvium[2]	307[a]	~91	1,904	18,000	-	-	-	8	380 µS/cm 233 mg/L
	NR[a]	-	-	-	-	3,327	-		
	100[c]	-	-	-	350	-	25,000		
Koukandowie Formation[4]	9[a]	359	4,248	14,496	-	6,607	-	39	2,150 µS/cm 1,333 mg/L
	21[a]	-	-	-	765	4,750	20,000		
MRV	NR[a]	500	-	1,500	-	-	-	100	1,290 µS/cm 673 mg/L
WCM[3]	92[a]	-	-	-	86	4,095	26,500	3	1,000 µS/cm 520 mg/L
Gatton Sandstone	42[a]	333	6,452	24,294	-	9,971	-	7	2,850 µS/cm 1,806 mg/L
	11[c]	-	-	-	-	7,643	-		
	7[d]	-	866	-	-	-	-		

Table notes:

Source as referenced by Raiber et al (2016): a – Pearce et al (2007a); b – DNRM (2013); c – Pearce et al (2007b); d – McKibbin (1995)

1 Salinity term used by Raiber et al (2016), rather than TDS.
2 No regional data available for Oaky Creek, Rocky Creek and Gowrie Creek.
3 Data only available for the Upper Condamine Catchment (west of Toowoomba)
4 Data not available for Koukandowie Formation in the Queensland Globe database therefore data for Marburg Subgroup is shown in table.

Samples were taken from eight Project bores in October 2018. Laboratory results for EC and salinity are summarised in Table 7.8. Field measurements of EC are provided where laboratory results were not available.

Table 7.8 Summary of groundwater salinity across Project bores

Project bore ID	Formation sampled	EC (µS/cm)	Salinity (mg/L)
320-01-BH2101	Koukandowie Formation	-	-
320-01-BH2103	Koukandowie Formation	1,460	921
320-01-BH2201	Koukandowie Formation	2,640	1,570
320-01-BH2203	Koukandowie Formation	-	-
320-01-BH2207	Koukandowie Formation	Dry	Dry
320-01-BH2209	Gatton Sandstone	Dry	Dry
320-01-BH2212	Gatton Sandstone	-	-
320-01-BH2215	Gatton Sandstone	Dry	Dry
320-01-BH2216	Gatton Sandstone	2,800	1,770
320-01-BH2217	Gatton Sandstone	2,080	1,300
320-01-BH2218	Gatton Sandstone	1,210	1,160
320-01-BH2301	Koukandowie Formation	5,690	3,420

Table notes:

"-" no data available

Salinity and EC ranges are generally consistent with the findings of Rassam et al (2014) for the wider CMB, with salinity values in groundwater from sedimentary bedrock formations in the groundwater study area typically brackish (i.e. between 1,001 and 100,000 mg/L).

The post-feasibility design stage geotechnical and hydrogeological investigations (Golder 2020c/d) indicate groundwater quality from new bores installed since 2018 are consistent with the data in Table 7.7 and Table 7.8 for key aquifers of the groundwater study area.

7.3.8 Groundwater quality summary

The publicly available groundwater quality data (Queensland Globe/DRDMW datasets, 5 km search radius from centreline) along with results from the feasibility design stage investigations was tabulated into Table 7.9 to compare the quality of the aquifers described above. This comparison allows for a cursory assessment of the ambient water quality conditions, prior to construction, to identify areas where degradation currently exists and to inform of the EVs to be maintained.

As a general overview of water quality in each aquifer zone, the following have been identified as exceeding guideline values:

- TDS is outside the NHMRC Drinking Water Guidelines in the Rocky Creek alluvium.
- TDS exceeds both the NHMRC Drinking Water and ANZG stock water guidelines in the MRV, Marburg Subgroup and Gatton Sandstone.
- Chloride exceeds the NHMRC Drinking Water Guidelines in all aquifers.
- Fluoride, sodium, and iron exceed the NHMRC Drinking Water Guidelines in the MRV, Marburg Subgroup and Gatton Sandstone.

Table 7.9 Comparison of groundwater quality data to guideline values in the groundwater study area

Parameter	Guidelines		Gowrie Creek Alluvium			Oaky Creek Alluvium			Rocky Creek Alluvium			Lockyer Creek alluvium		
			(n = 1)			(n = 1)			(n = 2)			(n = 8)		
	ANZG stock water (2018)	NHMRC Drinking Water (2011)	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
Physiochemical														
Electrical conductivity (µS/cm)	-	-	-	-	5,800	-	-	1,640	991	1,680	1,336	150	2,350	380
pH value (pH units)	-	6.5-8.5	-	-	7.8	-	-	7.6	7.9	8	7.95	5.9	8.3	6.9
Turbidity (NTU)	-	-	-	-	-	-	-	-	-	-	-	-		
Hardness as $CaCO_3$ (mg/L)	4,000	6,000	-	-	2,699	-	-	671	374	576	475	15	525	71
Alkalinity (mg/L)	-	-	-	-	152	-	-	429	205	274	240	31	634	86
Sodium adsorption ratio	-	-	-	-	1	-	-	1.2	1.5	2.2	1.9	1.6	9.1	2.7
Total Dissolved Solids (mg/L)	2,000[b]	600	-	-	-	-	-	-	524	867	696	119	1,433	233
Dissolved anions														
Bicarbonate (mg/L)	-	-	-	-	185	-	-	520	248	334	291	38	750	105
Carbonate (mg/L)	-	-	-	-	-	-	-	1.3	-	-	1.1[a]	0.2	11.5	2.95
Chloride (mg/L)	-	250	-	-	1,920	-	-	277	156	430	293	29.6	610	61
Fluoride (mg/L)	2	1.5	-	-	0.5	-	-	0.2	-	-	0.1[a]	0.1	0.8	0.3
Sulfate as SO_4 (mg/L)	1,000	250	-	-	245	-	-	16	6	13	10	5	20.5	5.7
Dissolved cations														
Sodium (mg/L)	-	180	-	-	120	-	-	72	66	119	92	21.1	355	46
Potassium (mg/L)	-	-	-	-	-	-	-	1	-	-	1.5[a]	0.6	7.7	1.5
Iron (mg/L)	-	0.3	-	-	-	-	-	-	-	-	-	0.01	1.4	0.02
Calcium (mg/L)	1,000	-	-	-	112	-	-	102	60	79	70	0.5	62	11
Magnesium (mg/L)	-	-	-	-	588	-	-	101	54.3	92	73.2	3.4	90	9.3
Nutrients														
Phosphate (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-	-	0.2
Nitrogen (mg/L)	-	-	-	-	-	-	-	-	4.2	10.9	7.6	-	-	-

Parameter	Guidelines		Gowrie Creek Alluvium			Oaky Creek Alluvium			Rocky Creek Alluvium			Lockyer Creek alluvium		
			(n = 1)			(n = 1)			(n = 2)			(n = 8)		
	ANZG stock water (2018)	NHMRC Drinking Water (2011)	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
Dissolved metals														
Zinc (mg/L)	20	3	-	-	-	-	-	-	-	-	-	-	-	-
Aluminum (mg/L)	5	0.2	-	-	-	-	-	-	-	-	-	-	-	-
Boron (mg/L)	5	4	-	-	-	-	-	-	-	-	-	-	-	-
Copper (mg/L)	0.5	2	-	-	-	-	-	-	-	-	-	-	-	-

Parameter	Guidelines		MRV (n = 100)			WCM (n = 3)			Marburg Subgroup (n = 39)			Gatton Sandstone (n = 7)		
	ANZG stock water (2018)	NHMRC Drinking Water (2018)	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
Physiochemical														
Electrical conductivity (µS/cm)	-	-	440	7,520	1,190	940	2,560	1,000	791	9,000	2,150	980	3,690	2,850
pH value (pH units)	-	6.5-8.5	6.8	8.9	7.8	6.8	8.3	8.0	7.1	8.9	8.0	7.4	8.7	7.7
Turbidity (NTU)	-	-	-	-	1,450[a]	-	-	-	-	-	-	-	-	-
Hardness as $CaCO_3$ (mg/L)	4,000	6,000	5	2,494	256	105	506	308	20	733	162	72	1,157	217
Alkalinity (mg/L)	-	-	15	717	223	84	374	220	100	1,647	654	280	1,257	1,024
Sodium adsorption ratio	-	-	0.7	21.4	3.2	1.7	7.3	7.0	1.4	41	14.9	3.9	29	23.7
Total Dissolved Solids (mg/L)	2,000[b]	600	254	4,338	673	489	550	520	448	4,954	1,333	567	2,311	1,806
Dissolved anions														
Bicarbonate (mg/L)	-	-	18.3	870	268	102	450	260	120	2,000	791	336	1,530	1,210
Carbonate (mg/L)	-	-	0.1	10	1.3	3.2	3.6	3.4	0.6	63	6.65	1.0	43	2.5
Chloride (mg/L)	-	250	40	2,520	223	79	812	185	85.7	2,690	215	160	1,092	2.04
Fluoride (mg/L)	2	1.5	0.01	103	0.2	0.1	0.2	0.15	0.1	1.6	0.5	0.2	2.04	0.89
Sulfate as SO_4 (mg/L)	1,000	250	1.1	273	17	4.5	100	8.5	1.2	96	10	3	140	14
Dissolved cations														
Sodium (mg/L)	-	180	2	1,340	124.5	67	378	165	62	1,670	505	133	820	572
Potassium (mg/L)	-	-	0.3	15	2.15	6.0	8.6	7.3	1.8	64	15	5	36	15
Iron (mg/L)	-	0.3	0.01	0.85	0.02	0.05	6.0	3.025	0.01	0.11	0.02	-	-	-
Calcium (mg/L)	1,000	-	2	292	50	32	171	41	4.1	122	35	7.8	188	36
Magnesium (mg/L)	-	-	0.1	487	35	6	50	19	0.9	122	18	5.7	167	29
Nutrients														
Phosphate (mg/L)	-	-	-	-	1.0[a]	-	-	-	-	-	-	-	-	-
Nitrogen (mg/L)	-	-	0.1	250	8.7	-	-	0.5[a]	0.2	21	1.2	1.0	3.5	1.0

Parameter	Guidelines		MRV (n = 100)			WCM (n = 3)			Marburg Subgroup (n = 39)			Gatton Sandstone (n = 7)		
	ANZG stock water (2018)	NHMRC Drinking Water (2018)	Min	Max	Median	Min	Max	Median	Min	Max	Median	Min	Max	Median
Dissolved metals														
Zinc (mg/L)	20	3	0.01	0.14	0.01	-	-	-	-	-	-	-	-	1.9[a]
Aluminum (mg/L)	5	0.2	0.01	0.05	0.035	-	-	-	-	-	-	-	-	0.05[a]
Boron (mg/L)	5	4	0.01	0.06	0.03	-	-	-	-	-	-	-	-	0.39[a]
Copper (mg/L)	0.5	2	0.02	0.03	0.03	-	-	-	-	-	-	-	-	0.03[a]

Table notes:

Section 9.3 Livestock drinking water guidelines (ANZG 2018); Table 10.6 Guideline values for physical and chemical characteristics (NHMRC 2018)

a Only single data value available
b Most conservative guideline value out of the range provided in Table 9.3.3

7.4 Surface water – groundwater interaction

7.4.1 Regional surface water-groundwater interaction

The majority of the groundwater study area falls within the Clarence-Moreton Bioregion assessment area where strong evidence of interaction between groundwater and surface water has been reported (Raiber et al 2016); based on several lines of evidence including: assessment of groundwater and surface water quality, streamflow time series data, groundwater hydrographs, and streambed elevation. The degree of hydraulic connectivity is variable both spatially and temporally. For example, increasing groundwater salinity during droughts in parts of the Lockyer Valley alluvial aquifers in the eastern portion of the groundwater study area linked to leakage from the underlying sedimentary bedrock (Gatton Sandstone), which contains more saline water (Raiber et al 2017). Subsequent to heavy rainfall/flood events, the hydraulically connected alluvial aquifers and adjacent surface water features experience a 'first flush' where rainfall recharges surface water which, in turn, recharges the alluvial aquifers and can result in decreased salinity of the alluvial aquifers. Groundwater quality collected from the alluvial units before and after a first flush event can be markedly different, based on the degree of hydraulic connectivity.

It is anticipated there is interaction between watercourses and shallow groundwater in the associated alluvial sediments, particularly where drainage channels are more deeply incised, and groundwater levels are shallow. This is considered to occur proximal to Gowrie, Oaky, Rocky and Six Mile creeks.

The degree of interconnection varies laterally due to local variations in alluvial sediment lithology, underlying bedrock geology and drainage channel morphology, as well as seasonally due to changes in groundwater elevations. At times watercourses may change from gaining systems (receiving baseflow from shallow groundwater) to losing systems (with surface water locally recharging the alluvial sediments).

7.4.2 Local surface water-groundwater interaction

Local surface water and groundwater interaction was assessed by identifying trends between water level and salinity (measured using electrical conductivity and/or total dissolved solids) in surface water and groundwater over time. There are two surface water monitoring gauges located within the groundwater study area with available data, one in Gowrie Creek (422326A, located 287 m upstream of the Project alignment) and one in Lockyer Creek (143203C, located 913 m downstream of the Project alignment).

Long-term groundwater level data downstream of the Lockyer Creek gauge has been reviewed from RN14320190, located approximately 300 m to the north-east which provides continuous data since 2002.

Daily surface water and groundwater elevation is shown in Figure 7.14 and Figure 7.15. Groundwater elevation with daily rainfall from the BoM Station 040096 is shown in Figure 7.16. Surface water gauge data and groundwater data are both responsive to rainfall over time and share similar trends, which indicates surface water-groundwater connectivity at Lockyer Creek. This is likely evident in the unconsolidated material across all alluvium aquifers identified within the groundwater study area.

Groundwater elevation in the Lockyer Creek alluvium is responsive to rainfall recharge over long periods, although the response and recovery are more gradual when compared to the rapid and short duration observed in the Lockyer Creek stream gauge. Rainfall recharge responsiveness is evident during the dry period between 1965 and 1969 which resulted in decreasing groundwater elevation between 1966 and 1970. There were then a series of rainfall events between 1970 and 1974 which resulted in increasing groundwater elevation in the same time frame.

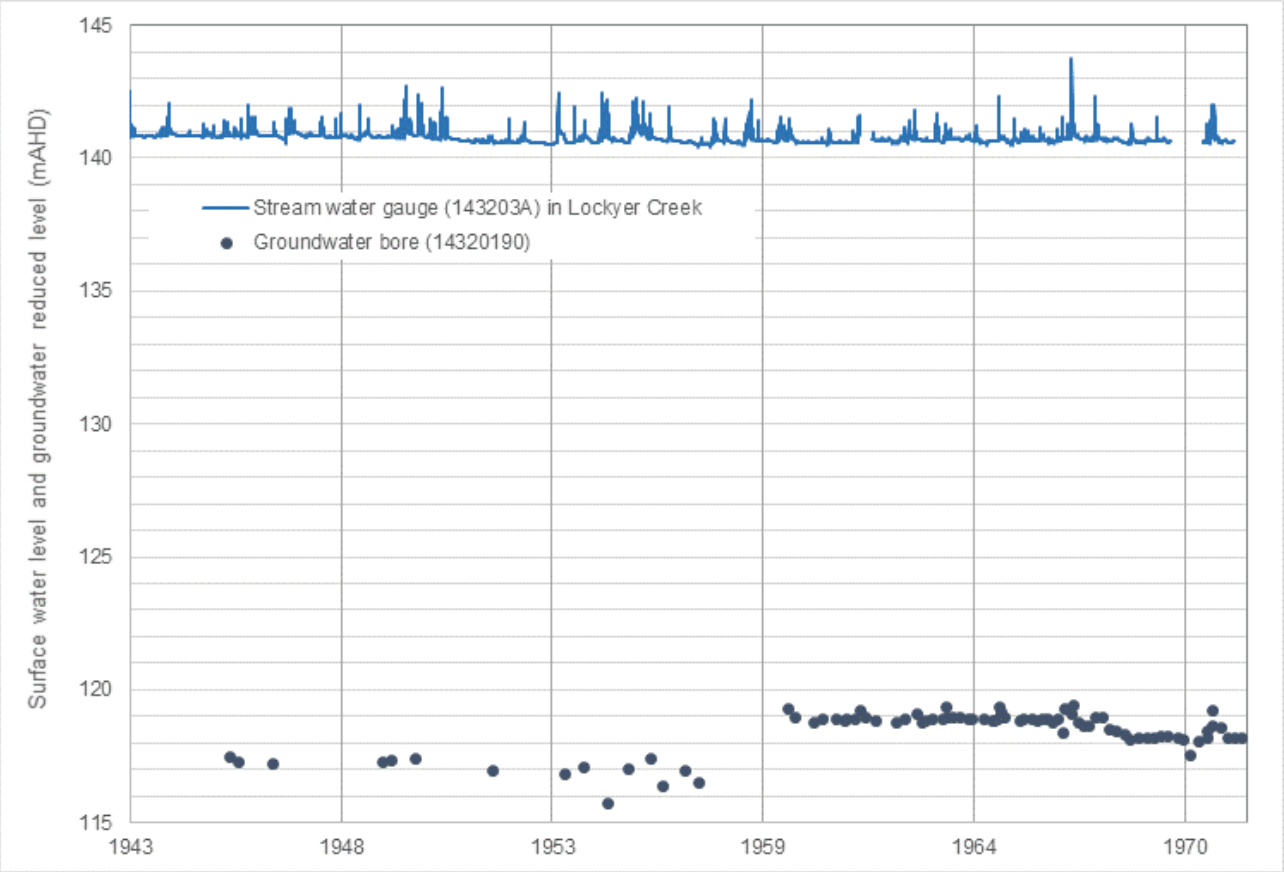


Figure 7.14 **Surface water level (1432203A) with groundwater level (RN14320190)**

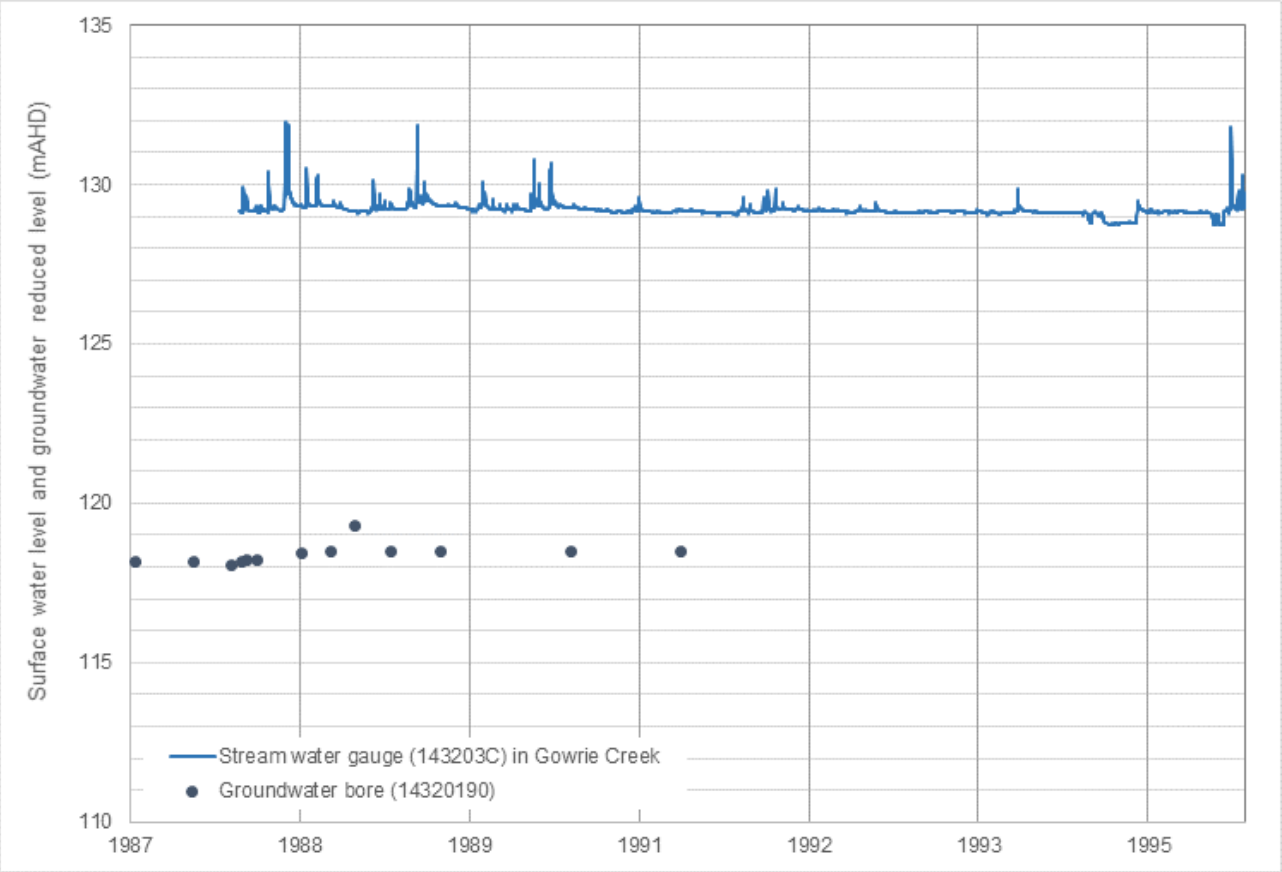


Figure 7.15 **Surface water level (1432203C) with groundwater level (RN14320190)**

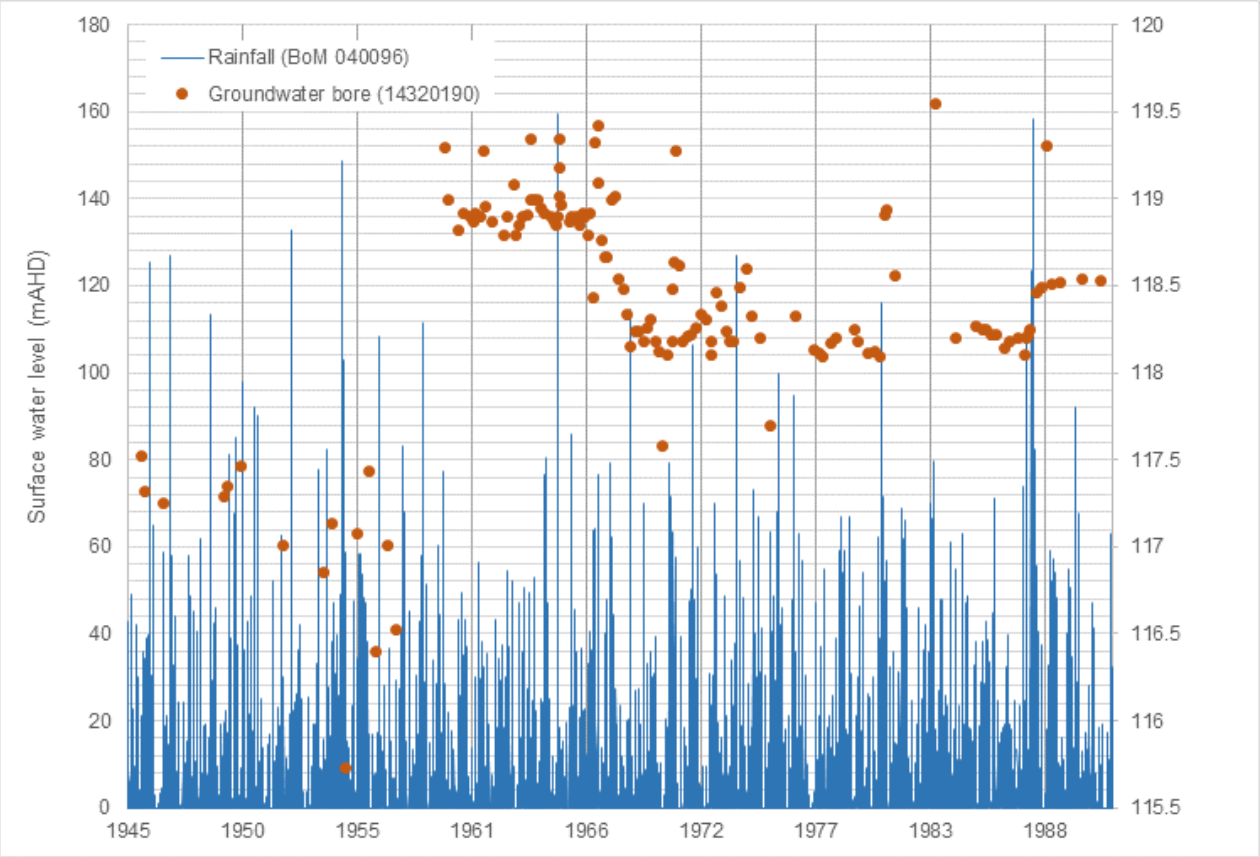


Figure 7.16 Groundwater level (RN14320190) with daily rainfall (BoM Station 040096)

Geochemistry is another indicator of surface water-groundwater interaction and the main indicator is salinity. Fresh groundwater indicates freshwater mixing from a surface water source, and this was evident in the MRV (mean salinity of 930 mg/L). Mean salinity reported at stream water gauge 143203C (Lockyer Creek at Helidon) is 600 mg/L and mean salinity at groundwater bore RN14320190 is 1,000 mg/L. Salinity is in the freshwater range which suggests there is interaction with the alluvium aquifer beneath Lockyer Creek.

The hydraulic relationship between Gowrie Creek and adjacent units, including the associated alluvial sediments and underlying MRV, are of interest to the Project. It is important to understand the local relationship between these units particularly temporal influences on recharge and discharge mechanisms between groundwater units so that an informed impact assessment can be undertaken for the Project.

Generally, it is recognised that these units (Gowrie Creek alluvium and MRV) are hydraulically connected at various locations where Gowrie Creek has incised into the MRV (direct relationship) and where alluvial sediments overlie the (weathered) MRV (indirect relationship) and influence each other, hydraulic gradient dependant. The degree of connectivity, particularly in the groundwater study area, is not well defined. Therefore, the hydraulic relationship between Gowrie Creek and the MRV can only be inferred in the groundwater study area due to a paucity of aquifer characterisation data for the MRV at Gowrie Creek.

The Upper Condamine Basalts (comprise the Toowoomba City Basalts sub-area of the Water Plan (Condamine and Balonne) 2019 area, a recognised groundwater unit of importance within the MRV in the groundwater study area, are considered to generally consist of an upper unconfined weathered and fractured zone with a lower, more limited in extent, semi-confined fracted zone (DNRME, 2018). The presence of numerous small, overlapping lava flows and columnar joints creates vertical and horizontal hydraulic discontinuities. The upper weathered basalt layers are important for groundwater recharge during heavy precipitation events, with a delay period of about a month between rainfall and recharge (DNRME, 2018). In some areas, the upper weathered basalt (the major recharge zone) feeds creek beds even during dry periods (Willey 2003). It is noted that the Gowrie Creek Management Strategy (WBM and Hassell 1998) indicate seepage/recharge from the MRV into surface units/features had primary occurrence in West and East creeks, tributaries to Gowrie Creek.

The Wetalla Wastewater Treatment Plant is recognised to provide artificial recharge to Gowrie Creek that supports the perennial nature of this creek north and upgradient of the Project. The perennial areas of the creek, where alluvial sediments are consistently saturated, the vertical hydraulic gradients in these sediments may act as recharge to the underlying MRV after significant rain events. However, in areas of the creek that are not perennial/saturated, it is considered that the underlying MRV act as recharge to the alluvial aquifers associated with Gowrie Creek within and proximal to the groundwater study area and vice versa when conditions allow for alluvial sediments to recharge the MRV.

7.5 Groundwater use

Under the Water Plan (GABORA) 2017, the groundwater study area is located within the Hutton Sandstone and Springbok Walloon groundwater units. These groundwater units include the Eastern Downs Marburg, Murphy's Creek Marburg and Eastern Downs Walloon sub-areas of the Water Plan (GABORA, 2017). Within these Sub-Areas, landholders are permitted to take water for stock and domestic purposes without the need for a water licence. All other uses require a water licence, water permit, or seasonal water assignment notice.

Under the Water Plan (Moreton) 2007, the groundwater study area is located within the Lockyer Valley GMA. Groundwater users who were taking groundwater for purposes, other than stock and domestic, at the time plan commenced, were authorised to continue to use the groundwater (stock and domestic uses do not require a license/entitlement). Those authorisations remain today as a licensing process has not yet been carried out in these areas.

The Water Plan (Condamine and Balonne) 2019 is applicable to the Gowrie Creek alluvium and MRV (Upper Condamine Basalts subarea). Within this unit the Project is associated with the following groundwater management areas (GMAs), noting stock and domestic uses do not require a license/entitlement:

- Toowoomba North Basalts – Gowrie Creek is the southern boundary of this GMA and works to the north of the creek will intersect this GMA
- Toowoomba South Basalts – the western extent of the Project is located within this GMA, including the western tunnel portal and the start of the tunnel (i.e. underlying the Toowoomba Bypass)
- Toowoomba City Basalts – the tunnel is primarily located within this GMA except the eastern portion of the tunnel, located in the Water Plan (Moreton) area.

The registered use of bores within the groundwater study area, as well as those with groundwater entitlements (licences) to extract groundwater per the relevant Water Plans are detailed in the following subsections.

7.5.1 Registered bores

Registered bores provide details of the location, water levels, construction details, stratigraphic logs, and water quality information for private registered bores and Queensland Government groundwater investigation and monitoring bores. Registered groundwater bore usage types have been sourced from the Queensland Globe database accessed online most recently on 1 December 2020. Where licensed groundwater extraction exists for registered bores these are identified, noting that no entitlement is required for domestic and stock watering use. Individual bore data from the Queensland Globe database correlates well with information available from Web-based Agriculture Land Information, which shows existing water licences in use within the groundwater study area. Web-based Agriculture Land Information is a Queensland government initiative that has a broad range of applications including local government planning and protection of important areas for agriculture and informing investors of an area's suitability for particular agricultural land uses (DNRME 2020).

Bores constructed prior to 2002 were not required to register with DNRME (now DRDMW) and as a result the Queensland Globe database is not a complete record of bores within the groundwater study area; however, it is the most accurate and recent information available publicly. Since 2002, all groundwater bores, regardless of type, are required to be registered/included (drillers must submit the bore's drill/lithologic and construction log to DRDMW) in the database.

A groundwater bore survey will be undertaken during the detailed design phase to accurately capture all groundwater bores (registered and unregistered) within the groundwater study area (refer Section 11.2).

Table 7.10 Summary of registered bore usage types within the groundwater study area

Aquifer	Water supply bores	Petroleum or Gas Exploration	Not defined	Total number of bores
Gowrie Creek alluvium	-	-	1	1
Oaky Creek alluvium	-	-	1	1
MRV	-	-	10	10
WCM	-	-	1	1
Helidon Sandstone	10	-	-	10
Marburg Subgroup	3	-	-	3
Woogaroo Subgroup	1	-	-	1
Aquifer not listed	16	-	159	175
Total	**30**	**0**	**172**	**202**

Table notes:

Queensland Globe database accessed on 1 December 2020 https://data.qld.gov.au/dataset/groundwater-database-queensland

7.5.2 Groundwater entitlements

A review of reported groundwater uses from relevant aquifers surrounding the alignment has been completed to assist with the evaluation of EVs (discussed in Section 8). This review is based on the Queensland water entitlements database (DNRME 2020) which details the licence type and source aquifer. Water entitlements (licences) allow landowners to take water for use on that land, including from a spring, watercourse, lake aquifer of flowing water across the land.

Groundwater entitlements within the groundwater study area are summarised in Table 7.11.

Table 7.11 Summary of groundwater licences from aquifers within the groundwater study area

QLD Water Plan	Water source	Licensed purpose	No. of entitlements[1]	Water made available (ML/yr)[2]	% of assigned water volume
Water Plan (Condamine and Balonne) 2019	Gowrie Creek Alluvium	Irrigation	2	35	100
	Toowoomba City Basalts (MRV)	Urban	1	3,800	97
		Irrigation	2	12.7	3
	Toowoomba North Basalts (MRV)	Irrigation	4	13	
	Toowoomba South Basalts (MRV)	Irrigation	5	95	
		Stock intensive	1	1	0.02
Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017	Eastern Downs Marburg (Marburg Subgroup – inferred Koukandowie Formation)	Irrigation	6	63	97
		Educational facility	1	2	3
	Murphys Creek Marburg (Helidon [Precipice] Sandstone)	Domestic supply	1	No data	0
	Murphys Creek Woogaroo (Precipice Sandstone)	Domestic supply/ stock	1	No data	0
	Helidon [Precipice] Sandstone (Clarence Moreton 3 Management Unit)	Construction	1	36.5	100

Table notes:

1 DRDMW water entitlements database accessed online on 1 October 2020 https://data.qld.gov.au/dataset/water-entitlements

2 The Toowoomba City Basalt sub-area is currently subject to a limitation notice under the *Water Act 2000*.

A total of 25 groundwater entitlements are licenced to extract groundwater from the study area. The largest groundwater entitlement (83456R) that intersects with the groundwater study area is for the authorised purpose of Urban supply (various uses). The entitlement includes 54 registered bores located across 15 Lot and Plans within the Toowoomba City Basalts sub-area, that are entitled to extract up to 3,800 megalitres per year (ML/yr) from the MRV. Of these 15 Lot and Plans, only one is located within the groundwater study area at Ch 9.0 km (Lot 924 on Plan SP154259). A single registered bore is located within this land parcel (RN172182) related to the entitlement, part of the Water Plan (Condamine and Balonne) 2019, details of which are summarised in Table 7.12.

It should be noted that there are four registered bores (RN64075, RN64989, RN64990 [not located within the groundwater study area] and RN87233) located approximately 500 m northeast of Ch 2.0 km, associated with groundwater entitlement 406584. These bores are licenced to take up to 300 ML/yr from the Marburg Subgroup[4] for purposes of town water supply. However, the entitlement is currently Under Amendment and has only been included in Table 7.12 for reference.

Table 7.12 Summary of town water supply bores within the groundwater study area

Bore	Lot and plan	Chainage (km)	Distance to alignment (m)	Aquifer	Total bore depth (m)
RN172182	924/SP154259	7.9	600	MRV	85.0
RN64075	1/RP844692	2.8	530	Marburg Subgroup	78.4
RN64989	46/SP106677	2.6	680	Unknown	49.4
RN87233	1/RP844692	2.8	620	Marburg Subgroup	123.4

The remaining groundwater licenses extract groundwater from the Gowrie Creek Alluvium (35 ML/yr), MRV (121 ML/yr; excludes 3,800 ML previously discussed), Eastern Downs Marburg (inferred Koukandowie Formation) (65 ML/yr), and the Helidon Sandstone of Clarence Moreton 3 Management unit (36.5 ML/yr). The licenced purposes include Urban, Irrigation, Stock Intensive, Domestic Supply, Construction, and Education Facility. The entitlements are part of the Water Plan (GABORA) 2017 and Water Plan (Condamine and Balonne) 2019. While there are water licences in the Murphys Creek Marburg (reported as Helidon/Precipice Sandstone in the database) and Murphys Creek Woogaroo, these are for stock and domestic purposes and do not impact/reduce the available overall volume of groundwater managed from these units. Bores associated with the licences are summarised in Table 7.13.

[4] The groundwater database bore cards refer to the Marburg Subgroup; however, inferred to be screened in the Koukandowie Formation as this is the primary water bearing unit of the Marburg Subgroup.

Table 7.13 Summary of groundwater entitlements and bores which intersect the groundwater study area

Authorisation	Chainage (km)	Lot/Plan	Registered bores within entitlement [a]	QLD Water Plan	Source aquifer	Entitlement purpose	Entitlement per year (ML)[d]
100837	0.0	2/RP40070	107601	Water Plan (GABORA) 2017	Marburg Subgroup	Irrigation	10
171251	0.0	2/RP76562	137159; 94161	Water Plan (GABORA) 2017	Marburg Subgroup	Irrigation	16
404530	0.0	26/RP24609	64092	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	35
607785	0.8	456/A34873	48325	Water Plan (Condamine and Balonne) 2019	Gowrie Creek Alluvium	Irrigation	17
607786	0.6	457/A34873	61200	Water Plan (Condamine and Balonne) 2019	Gowrie Creek Alluvium	Irrigation	18
19583R	0.0	22/SP285308	19583	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	20
48082R	1.8	35/AG4088	48082	Water Plan (Condamine and Balonne) 2019	MRV	Stock Intensive	1
48322G	22.4	153/CH31327	48322	Water Plan (GABORA) 2017	Marburg Subgroup[b]	Domestic Supply	Not provided in database
48594R	0.0	457/A34873	48594	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	5
52816R	2.2	421/AG4084	52816	Water Plan (GABORA) 2017	Marburg Subgroup	Educational Facility	2
56751R	0.8	459/A34873	56751	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	5
61504R	0.8	458/A34873	61504	Water Plan (GABORA) 2017	Marburg Subgroup	Irrigation	20
64092R	0.0	26/RP24609	83537	Water Plan (GABORA) 2017	Marburg Subgroup	Irrigation	5
64284R	-0.4	2/RP55460	64284	Water Plan (GABORA) 2017	Marburg Subgroup	Irrigation	8
64444R	-0.6	4/RP34896	64444; 71524	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	6
71287R	4.8	1/RP187723	71287	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	3.7
75566	22.0	1/RP901408	75566	Water Plan (GABORA) 2017	Precipice	Stock	Not provided in database

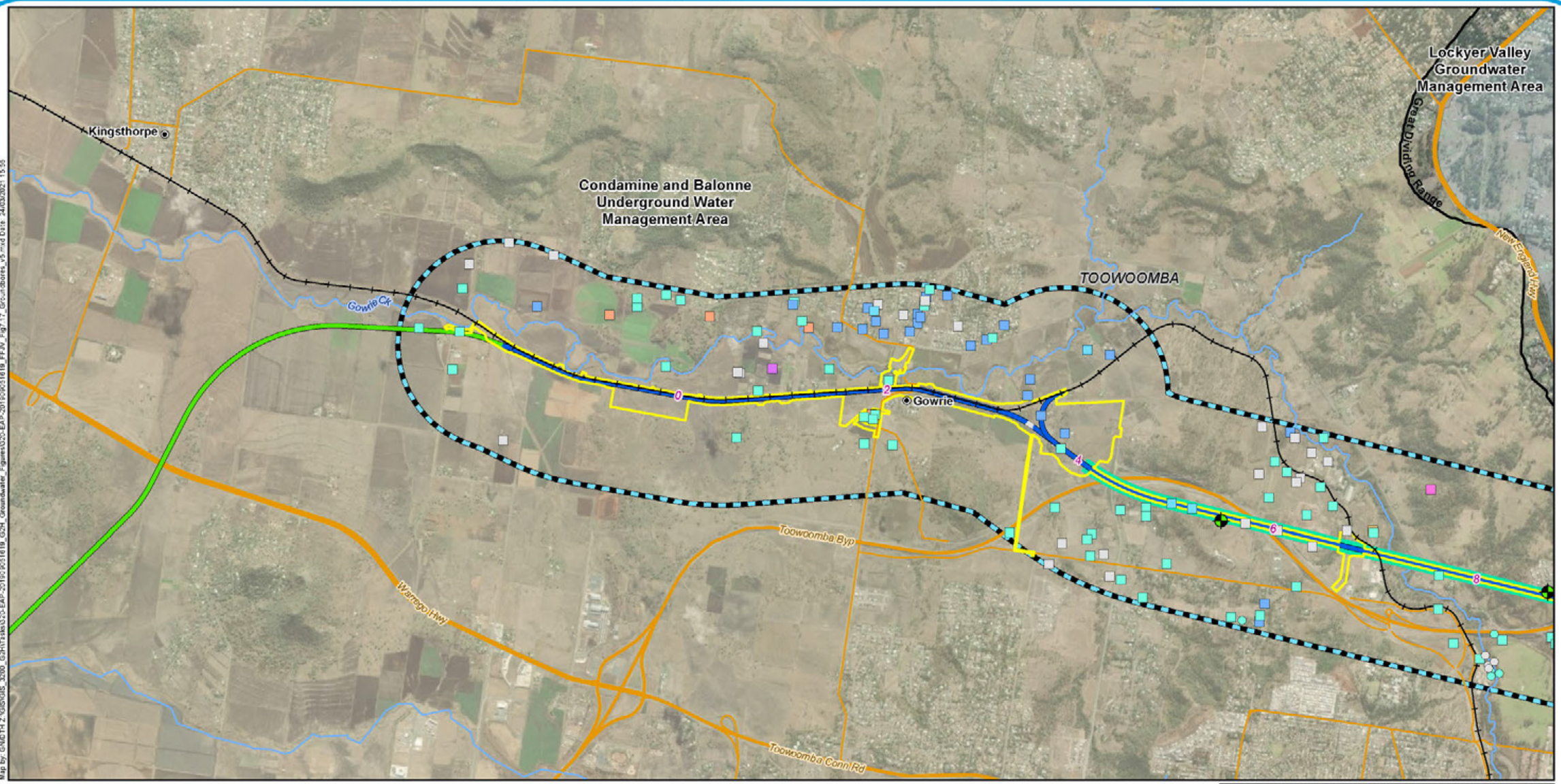
Authorisation	Chainage (km)	Lot/Plan	Registered bores within entitlement [a]	QLD Water Plan	Source aquifer	Entitlement purpose	Entitlement per year (ML)[d]
83456R[c]	9.0	1128/D1029; 1129/D10128; 153/SP170586; 179/D361160; 2/RP138176; 2/SP123785; 20/SP267311; 215/AG3332; 218/AG2714; 26/SP219889; 3/CP911919; 337/SP138139; 5/SP113678; 50/RP122995; 924/SP154259	119298; 119626; 119627; 119628; 119629; 119630; 119631; 119633; 119634; 119635; 119636; 119637; 119638; 119639; 119640; 119641; 119642; 119644; 119645; 119647; 119648; 119649; 119650; 119651; 119652; 119653; 119654; 119655; 137168; 137169; 137174; 172182; 26031; 26036; 26037; 48487; 52711; 61013; 61103; 66539; 66725; 83454; 83455; 83456; 86679; 87181; 87182; 87183; 87184; 87185; 94095; 94096; 94097; 94098	Water Plan (Condamine and Balonne) 2019	MRV	Urban	3,800
86679R[c]	9.0	152/A346	119298; 119626; 119627; 119628; 119629; 119630; 119631; 119633; 119634; 119635; 119636; 119637; 119638; 119639; 119640; 119641; 119642; 119644; 119645; 119647; 119648; 119649; 119650; 119651; 119652; 119653; 119654; 119655; 137168; 137169; 137174; 172182; 26031; 26036; 26037; 48487; 52711; 61013; 61103; 66539; 66725; 83454; 83455; 83456; 86679; 87181; 87182; 87183; 87184; 87185; 94095; 94096; 94097; 94098	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	9
87063R	1.8	438/A34873	87063	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	3
87219R	4.4	6/SP289028	87219	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	3
87663R	4.6	7/SP198121	87663	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	31

Authorisation	Chainage (km)	Lot/Plan	Registered bores within entitlement [a]	QLD Water Plan	Source aquifer	Entitlement purpose	Entitlement per year (ML)[d]
94171R	-0.8	2/RP138824	Not provided in database	Water Plan (Condamine and Balonne) 2019	MRV	Irrigation	0
94213R	1.8	439/A34873	94213	Water Plan (GABORA) 2017	Marburg Subgroup	Irrigation	4

Table notes:

a Data source: DRDMW water entitlements database accessed online on 1 October 2020 https://data.qld.gov.au/dataset/water-entitlements
b The source aquifer was listed as the Helidon Sandstone; however, based on the groundwater database bore card and aquifer attribution the source aquifer is inferred to be the Marburg Subgroup
c Only one bore is located within the groundwater study area (RN172182); however, the remainder of the bores attached to the licence have been included for completeness
d The Toowoomba City Basalts sub-area is currently subject to a limitation notice under the *Water Act 2000*.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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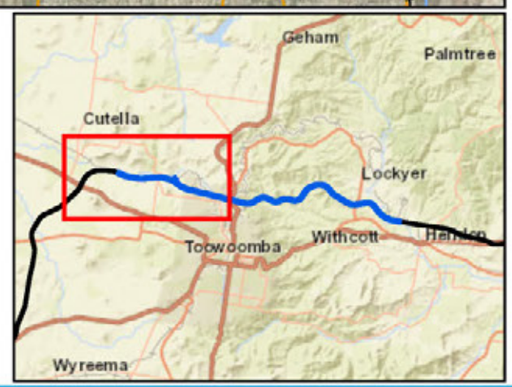
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- Localities
- Bridges
- B2G project alignment
- G2H project alignment
- Tunnel
- Existing rail
- Major roads
- Minor roads
- Major watercourses
- Great Dividing Range
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Bore status

- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer

- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup



A3 scale: 1:40,000

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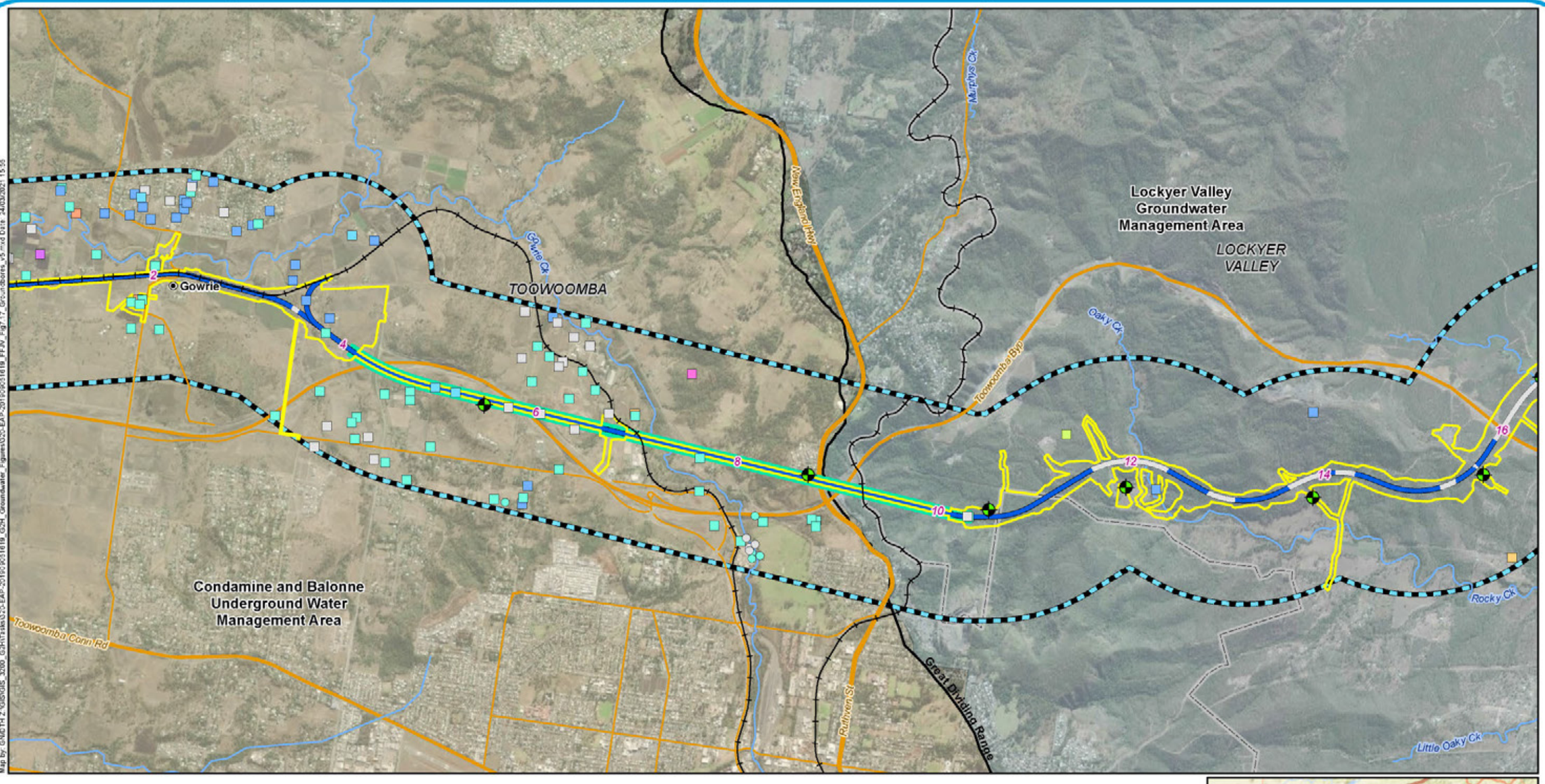
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Gowrie to Helidon

Figure 7.17a:
Registered groundwater bores and project monitoring bores

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Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



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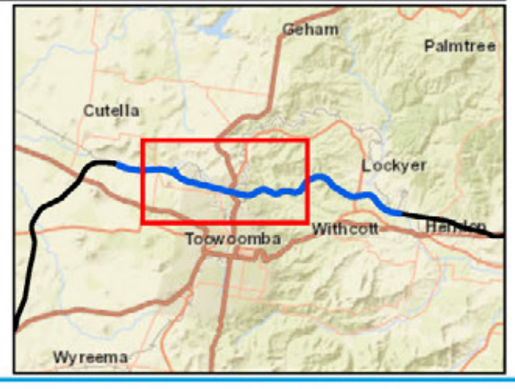
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- Localities
- Bridges
- G2H project alignment
- Tunnel
- Existing rail
- Major roads
- Minor roads
- Major watercourses
- Great Dividing Range
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Bore status

- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer

- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup



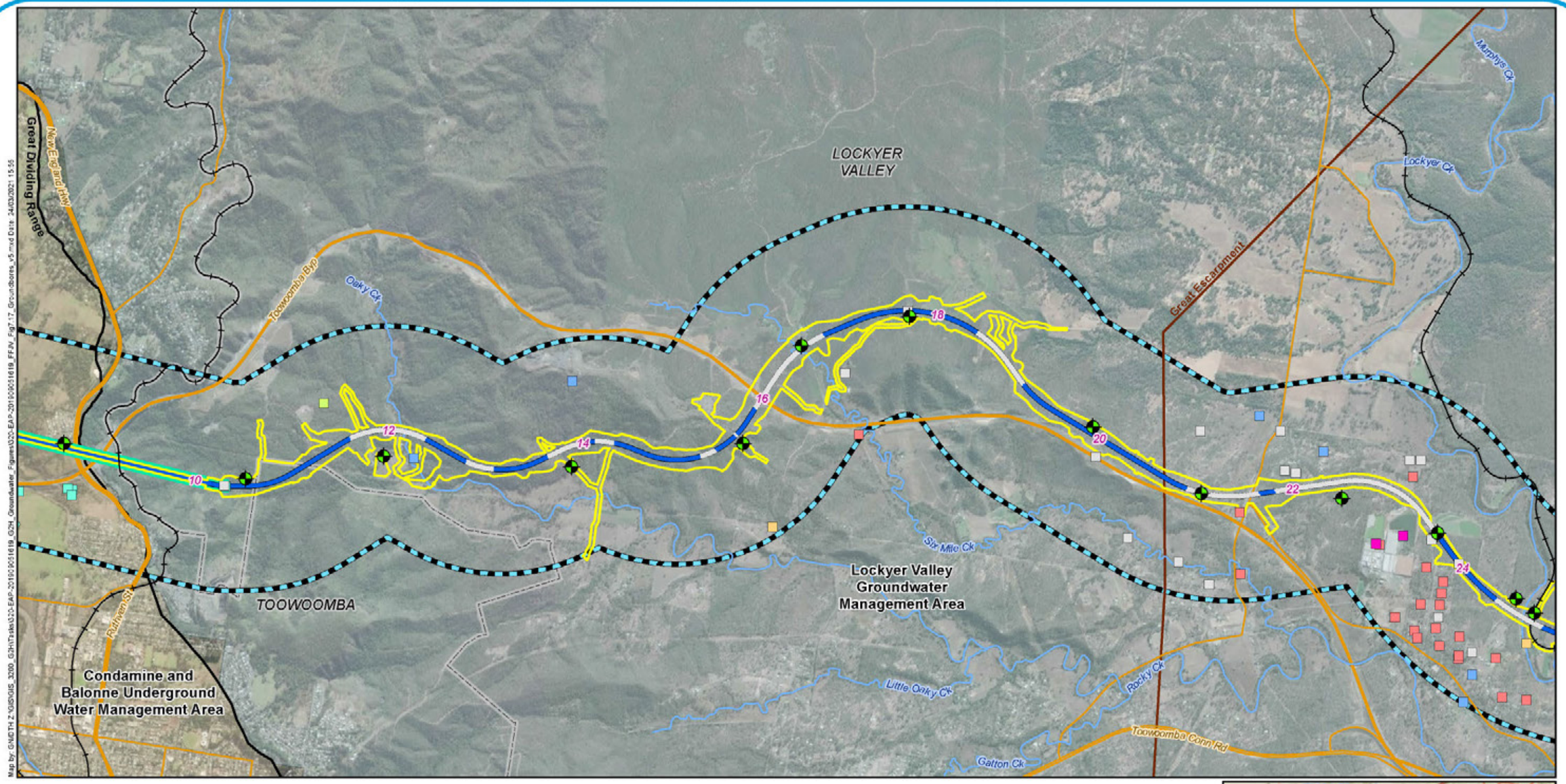
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.17b:
Registered groundwater bores and project monitoring bores

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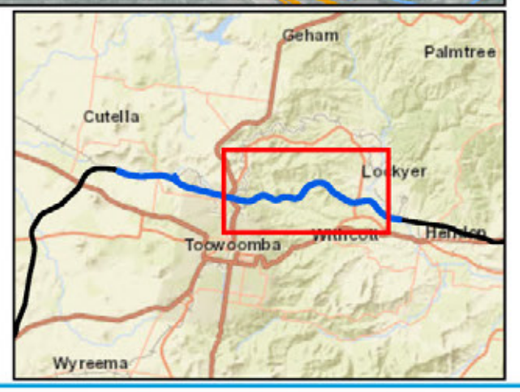
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- 5 Chainage (km)
- Localities
- Bridges
- G2H project alignment
- Tunnel
- Existing rail
- Major roads
- Minor roads
- Major watercourses
- Great Dividing Range
- Great Escarpment
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Bore status

- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer

- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup



A3 scale: 1:40,000
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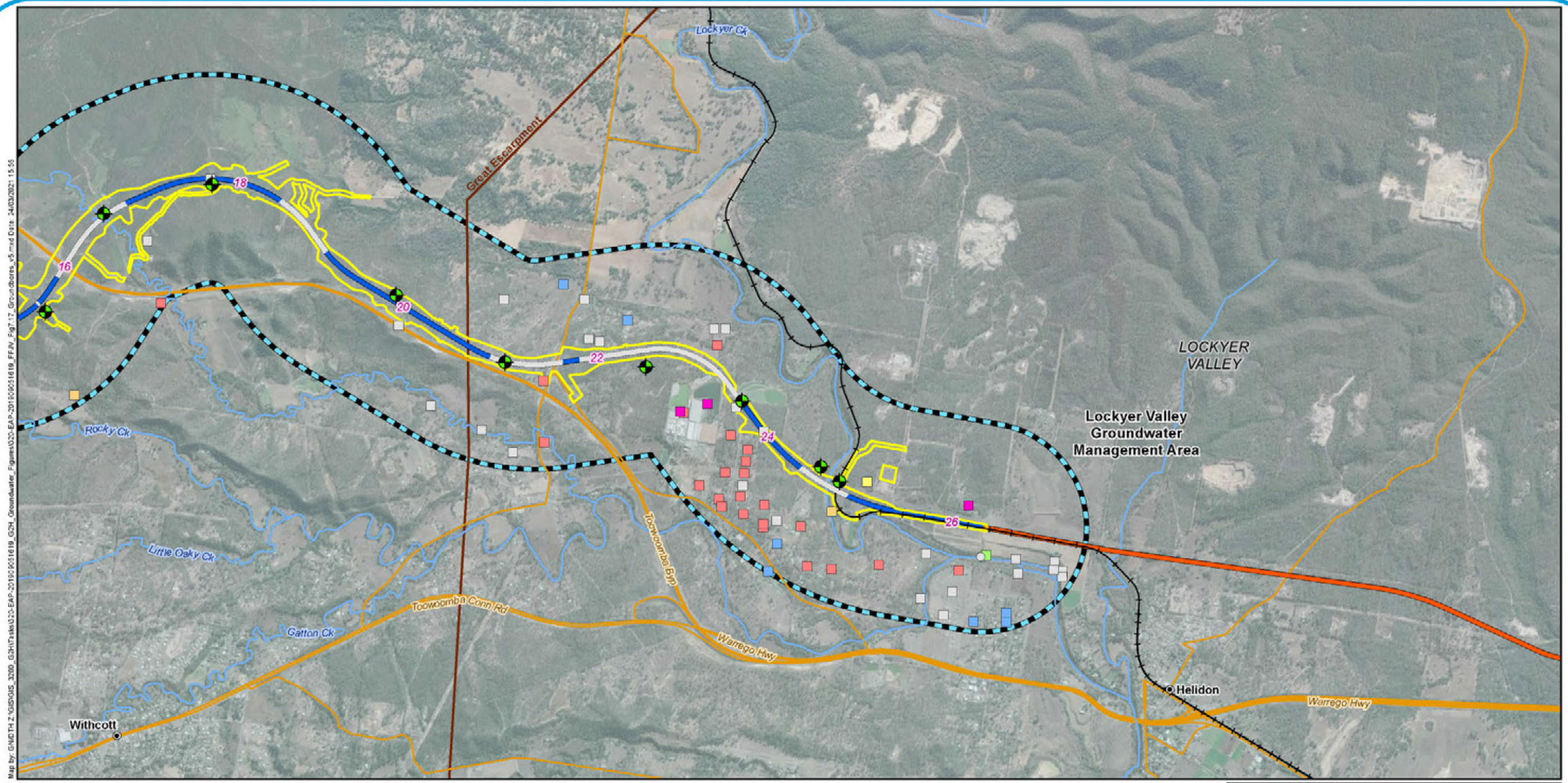
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 7.17c:
Registered groundwater bores and project monitoring bores

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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



Map by: GMDTH Z:\GIS\GIS_3200_G2H\Tasks\320-EAP-20190025161\9_G2H_Groundwater_Figures\320-EAP-20190025161\9_FFW_Fig7.17_Groundbores_v5.mxd Date: 24/03/2021 15:55

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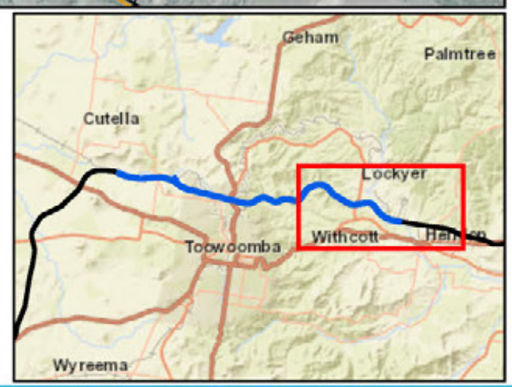
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- Localities
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- Tunnel
- Existing rail
- Major roads
- Minor roads
- Major watercourses
- Great Escarpment
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area

Bore status

- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer

- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup



A3 scale: 1:40,000
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.17d:
Registered groundwater bores and project monitoring bores

7.6 Groundwater dependent ecosystems

The Groundwater Dependent Ecosystems Atlas (GDE Atlas) was developed as a national dataset of Australian GDEs and potential GDEs (BoM 2019). The Atlas contains information about:

- **Aquatic** ecosystems: reliant on the surface expression of groundwater and includes surface water systems (freshwater only) which may have a groundwater component (i.e. rivers, springs and wetlands)
- **Terrestrial** ecosystems: reliant on the subsurface presence of groundwater, and includes all vegetation ecosystems
- **Subterranean** ecosystems: such as caves and aquifer ecosystems.

It is important to note that the Atlas GDE mapping is from two broad sources:

- National assessment – national scale assessment based on a set of rules that describe potential for groundwater/ecosystem interaction and available GIS data
- Regional studies – more detailed assessment by States and/or regional agencies using approaches included field work, analysis of satellite imagery and application of rules/conceptual models. The Queensland state GDE database has been developed by DES (last updated in May 2018) and is available in the DRDMW QSpatial Catalogue.

In 2012, the Australian Government funded the development of the national BoM GDE Atlas and co-funded, with the Queensland Government, the Queensland GDE Mapping Project (responsible for the regional/state GDE dataset) (DSITI 2015). Regional studies included in the Queensland Globe platform, managed by the Queensland DES, were included to compliment the BoM GDE Atlas with Queensland data. The primary datasets that comprise the regional studies include primarily regional ecosystem maps, wetlands maps, and a springs database (DSITI 2015).

Further it is noted that there are no GDEs listed under the water plans relevant to the Project, Lockyer Creek Spring, along with the section of Murphys Creek between Fifteen Mile Creek and Alice Creek and the section of Lockyer Creek downstream of the Murphys Creek and Alice Creek confluence to Lockyer Siding Road are recognised as GDEs under the Water Plan (GABORA) 2017. The latter is recognised under the Water Plan (GABORA) 2017 as Murphy's Creek approximately 5 km upstream of the proposed Lockyer Creek crossing.

The identification of potential GDEs in the Atlas does not confirm that the ecosystem is groundwater dependent, this is confirmed by undertaking an ecology investigation to identify the location, extent and source of the GDE. A field program was undertaken to inform the aquatic and terrestrial ecosystems which is detailed in EIS Appendix I: Terrestrial and aquatic ecology technical report.

Ground truthing of GDEs was limited due to the climatic conditions limiting the likelihood of confirming the presence of a GDE (e.g. the recharge area for any springs east of the divide is limited and seepage will be dependent on local rainfall) with no springs or seepages identified during ground-truthing activities (e.g. geotechnical investigations or ecological surveys). Land access conditions also impacted the extent of survey works in some areas; therefore, the modelled extent of the aquatic GDEs are accepted as true presence and, thus, forms a potentially sensitive receptor.

7.6.1 Potential aquatic groundwater dependent ecosystems

There are numerous moderate and low potential aquatic GDEs (from regional studies) within the groundwater study area, including Gowrie, Oaky, Six Mile and Lockyer creeks (and their tributaries). Gowrie and Lockyer creeks are designated as moderate potential for aquatic GDEs, described as wetlands 'supplied by alluvial aquifers with near-permanent flow'. This is supported by the available surface water and groundwater quality and level data which indicate potential for surface water and groundwater connectivity within the groundwater study area.

Near Gowrie Creek the ecosystems are intermittently connected to aquifers with brackish salinity in unconsolidated Quaternary alluvium, associated with catchment constrictions. Towards the GDR and in the upper reaches of Oaky Creek the ecosystems are intermittently connected to aquifers with fresh salinity in permeable rock (basalt) and in low rainfall areas. In Lockyer Creek and Six Mile Creek the GDEs are associated with alluvium along these ephemeral creeks.

The locations of potential aquatic GDEs are shown on Figure 7.18.

All of the aquatic habitats/watercourses assessed as a component of the aquatic and terrestrial ecology field works for the EIS were found to be of poor to fair condition. This included three locations associated with Gowrie Creek, four locations associated with Rocky Creek, three locations associated with Lockyer Creek, and one location associated with Six Mile Creek (refer EIS Appendix I: Terrestrial and aquatic ecology).

There are no registered groundwater springs within the groundwater study area based on a review of the Queensland Globe website (State of Queensland 2020). There are eight registered springs within 10 km of the Project, which are typically located near existing watercourses (shown in Figure 7.18 and Figure 7.19). Lockyer Creek Spring is the closest spring to the Project, which is located approximately 3.2 km upstream of the Project in Lockyer Creek. The reported source aquifer for the Lockyer Creek Spring is the Precipice Sandstone (Woogaroo Subgroup); this aquifer is not expected to be encountered by the Project.

Details of the wetlands and springs are summarised in Table 7.14.

Table 7.14 Wetlands and springs

Wetland/spring ID	Spring Type	Latitude	Longitude	Surface elevation (m AHD)	Distance from alignment (km)	Source aquifer (primary)[c]
Lockyer Creek Spring	Permanently Saturated	-27.49412	152.09059	176[a]	3.2	Precipice Sandstone (Woogaroo Subgroup)
Helidon Spring	Permanently Saturated	-27.57383	152.10626	149[a]	3.8	Unknown
Merigancan Creek	Permanently Saturated	-27.42661	151.90710	491[b]	7.9	Basalt[d]
Wellcamp Spring	Intermittently Saturated	-27.57014	151.84716	483[a]	8.2	Basalt[d]
Eustondale Spring	Intermittently Saturated	-27.58157	151.89009	531[a]	8.4	Basalt[d]
Lilligreen Spring	Intermittently Saturated	-27.43901	151.95607	598[b]	8.5	Basalt[d]
Kearneys Spring	Permanently Saturated	-27.60254	151.93932	667[b]	9.5	Basalt[d]
Westbrook Creek	Intermittently Saturated	-27.60388	151.91082	597[b]	10.3	Basalt[d]

Table notes:

a. Elevation sourced from FFJV Section 320 LiDAR
b. Elevation sourced from Google Earth (outside of available FFJV Section 320 LiDAR)
c. Data from the Queensland Springs Database (https://www.data.qld.gov.au/dataset/springs/resource)
d. It is assumed that basalt is referring to the MRV observed in the detailed surface geology maps

Anecdotal information suggests there are additional (unmapped) wetland springs within the groundwater study area that are not included on published maps. These wetlands are likely located near the eastern portion of the study area and near the eastern portal of the Toowoomba Range tunnel. Further field investigation will be undertaken post-EIS, during optimal conditions, to confirm locations, if any, of unmapped springs.

It is noted that several wetlands were identified as a component of the aquatic and terrestrial ecology field works; however, no wetland springs/spring-fed wetlands were identified. Generally, wetlands identified were dams, reservoirs, farm dams, and wetlands associated with floodplains (refer EIS Appendix I: Terrestrial and aquatic).

7.6.2 Potential terrestrial groundwater dependent ecosystems

There are numerous moderate potential terrestrial GDEs (from regional studies) in the groundwater study area. Near Gowrie Creek the ecosystems are intermittently connected to aquifers with brackish salinity in unconsolidated Quaternary alluvium associated with catchment constrictions. Towards the GDR and in the upper tributaries of Oaky Creek the GDEs are in low rainfall and low capacity permeable rock, associated with basalt. Near Lockyer Creek and Six Mile Creek the mapped terrestrial GDEs are associated with alluvial aquifers along these ephemeral creeks.

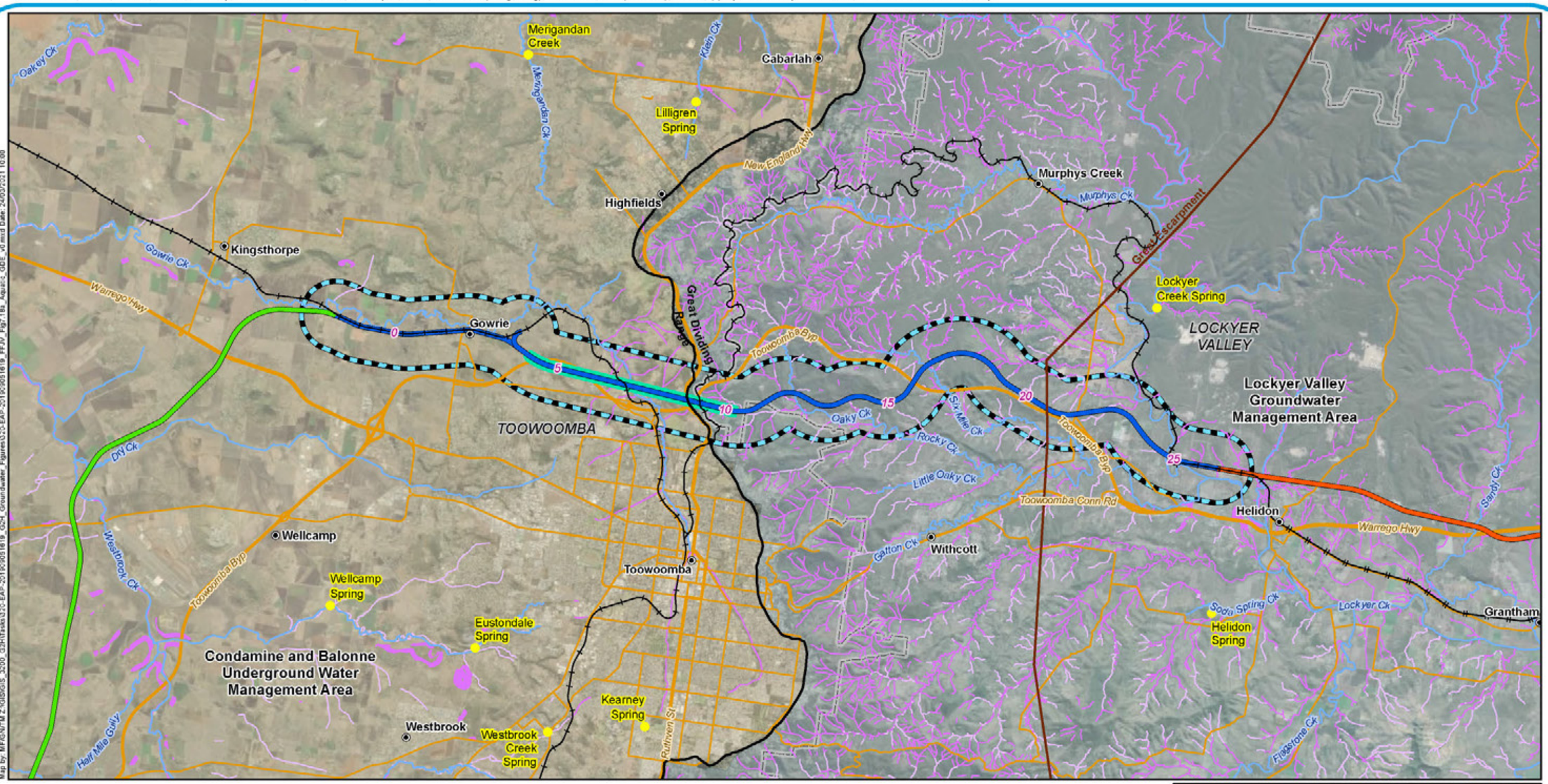
The locations of potential terrestrial GDEs are shown on Figure 7.19. Mapped terrestrial GDEs are primarily located in the groundwater study area from Ch 8.5 km to Ch 19 km, and with Lockyer Creek on the eastern end of the groundwater study area (Ch 24 km to Ch 26 km).

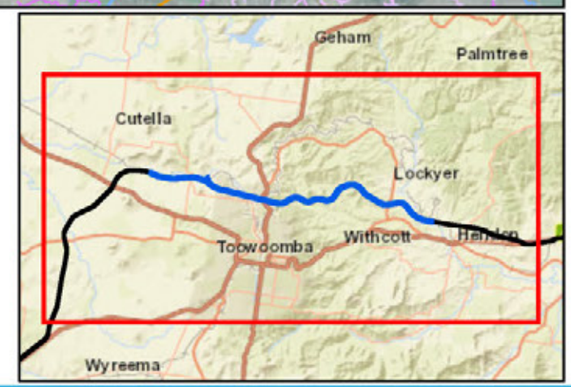
Ground-truthing of these environments was not undertaken for the EIS; therefore, it has been assumed for the purposes of the EIS, that the modelled extent of the terrestrial GDEs are accepted as true presence, and thus form a potentially sensitive receptor. Further investigation, post-EIS, will be undertaken during optimal conditions to confirm the presence of mapped terrestrial GDEs in the groundwater study area.

7.6.3 Potential subterranean groundwater dependent ecosystems

No potential subterranean GDEs were identified within the groundwater study area from review of the Atlas (BoM 2019) and regional studies.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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Legend

- Spring
- 5 Chainage (km)
- Localities
- Great Dividing Range
- Great Escarpment
- Tunnel
- B2G project alignment
- G2H project alignment
- H2C project alignment
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

A3 scale: 1:120,000
0 1 2 3 4 5km

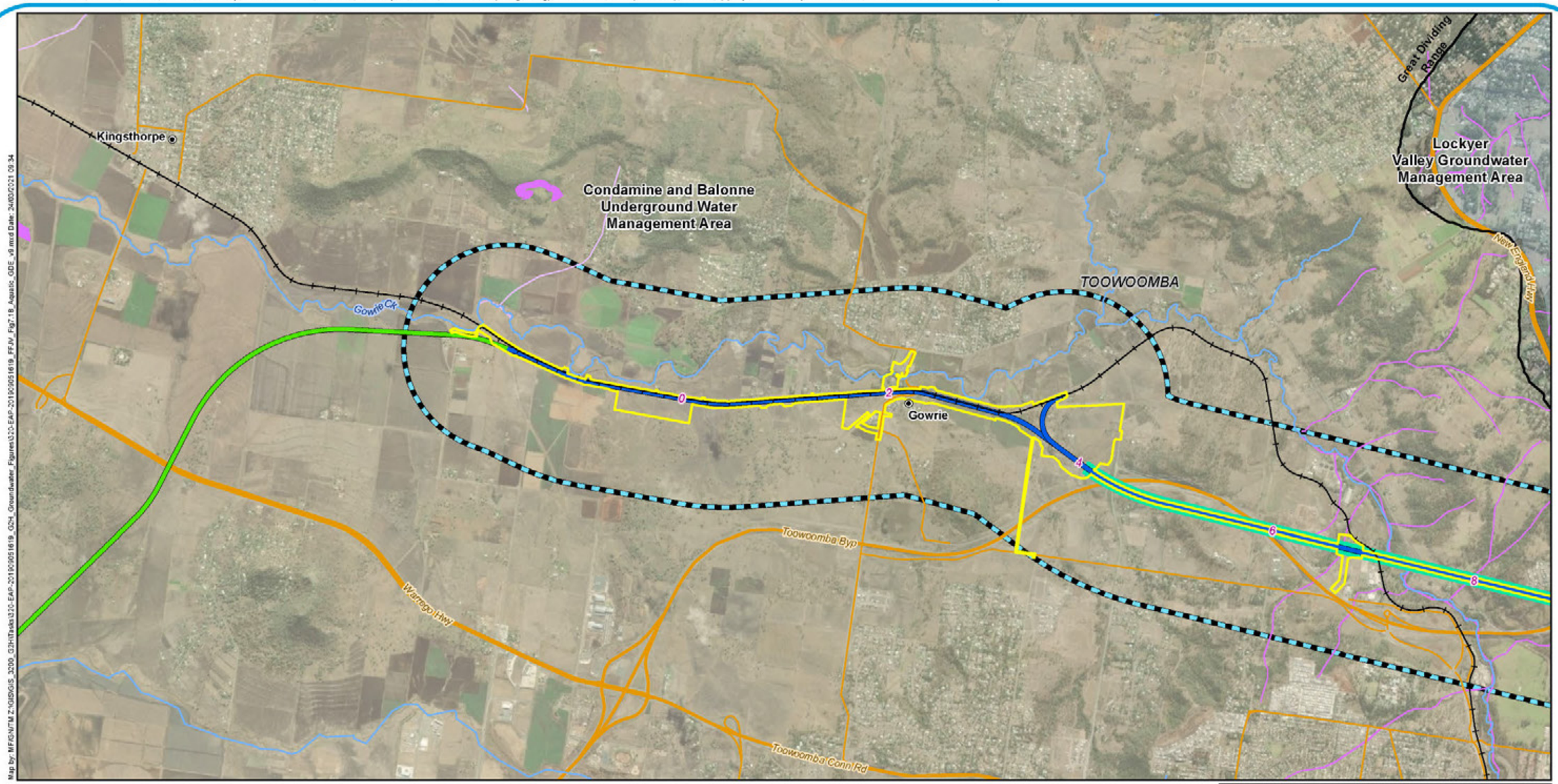
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.18a: Aquatic GDEs

Map by: MF/GIS/TM Z:\GIS\GIS_3200_03\HiTasks\3120-EAP-20190305\619_0224_Groundwater_Figures\3120-EAP-20190305\619_FF\V_Fig7.18a_Aquatic_GDE_v0.mxd Date: 24/03/2021 10:00

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
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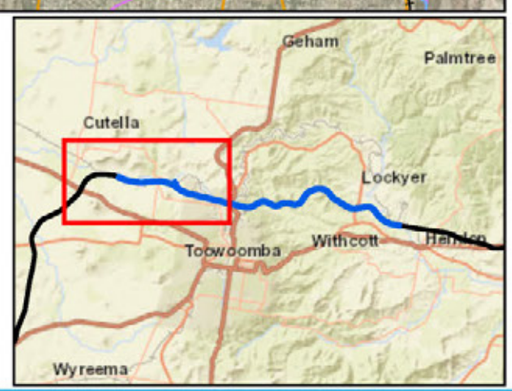


Legend

- 5 Chainage (km)
- Localities
- Great Dividing Range
- Tunnel
- B2G project alignment
- G2H project alignment
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- EIS disturbance footprint
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:40,000

0 0.5 1 1.5 2 2.5km

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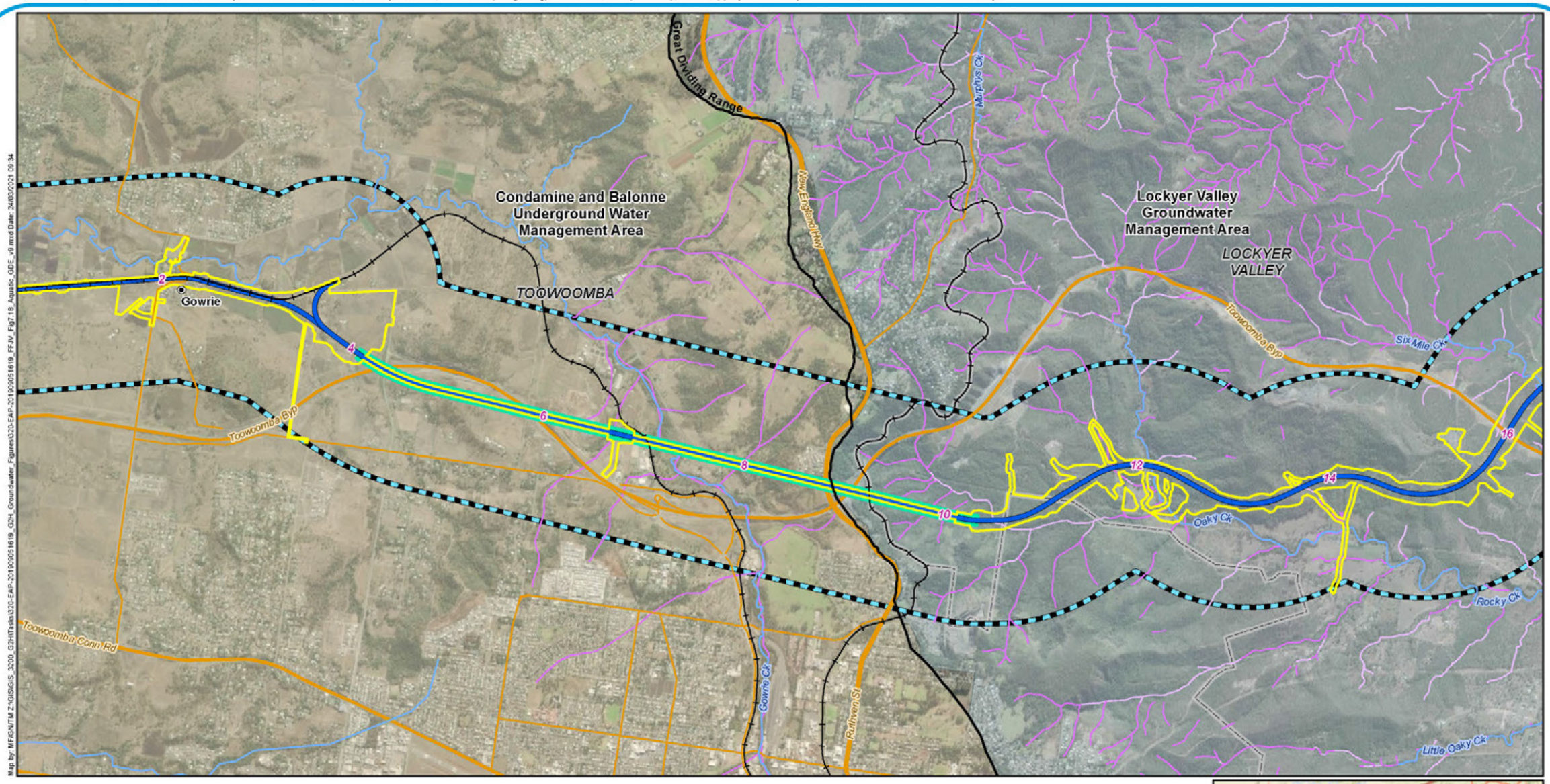
Issue date: 24/03/2021 Version: 9
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 7.18b: Aquatic GDEs

Map by: MFIGNITM Z:\GIS\GIS_3200_G2H\Tasks\320-EAP-20190905\619_G24_Groundwater_Figures\320-EAP-20190905\619_FFJV_Fig7.18_Aquatic_GDE_v9.mxd Date: 24/03/2021 09:34

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



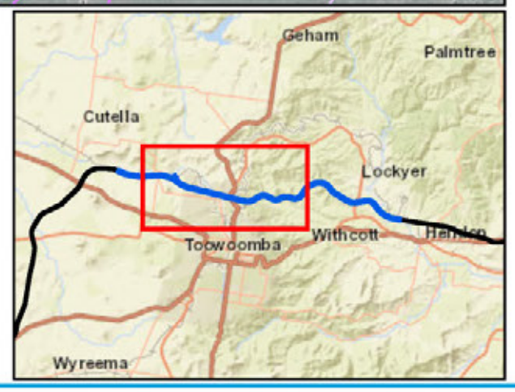
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Legend

- 5 Chainage (km)
- Localities
- Great Dividing Range
- Tunnel
- G2H project alignment
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- EIS disturbance footprint
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:40,000

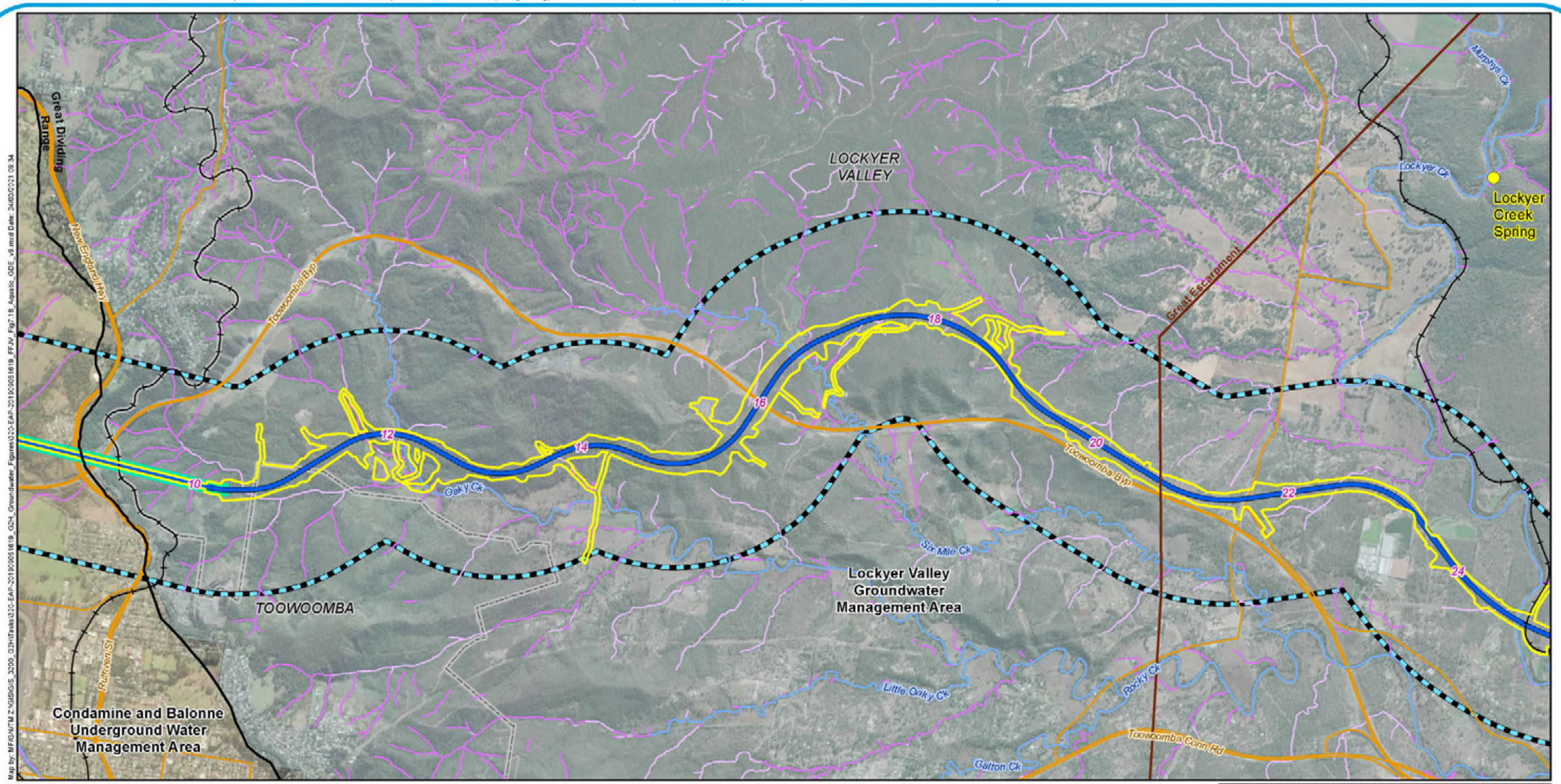
0 0.5 1 1.5 2 2.5 km

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Gowrie to Helidon
Figure 7.18c: Aquatic GDEs

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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

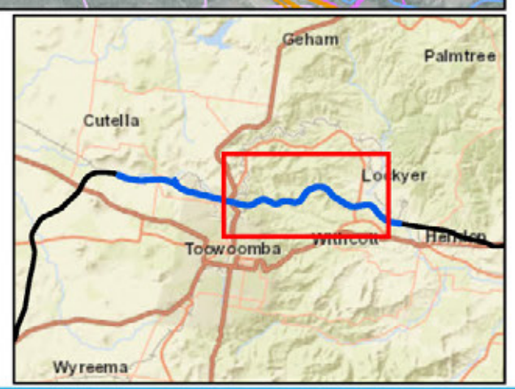


Legend

- Lockyer Creek Spring
- 5 Chainage (km)
- Great Dividing Range
- Great Escarpment
- Tunnel
- G2H project alignment
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- EIS disturbance footprint
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:40,000

0 0.5 1 1.5 2 2.5 km

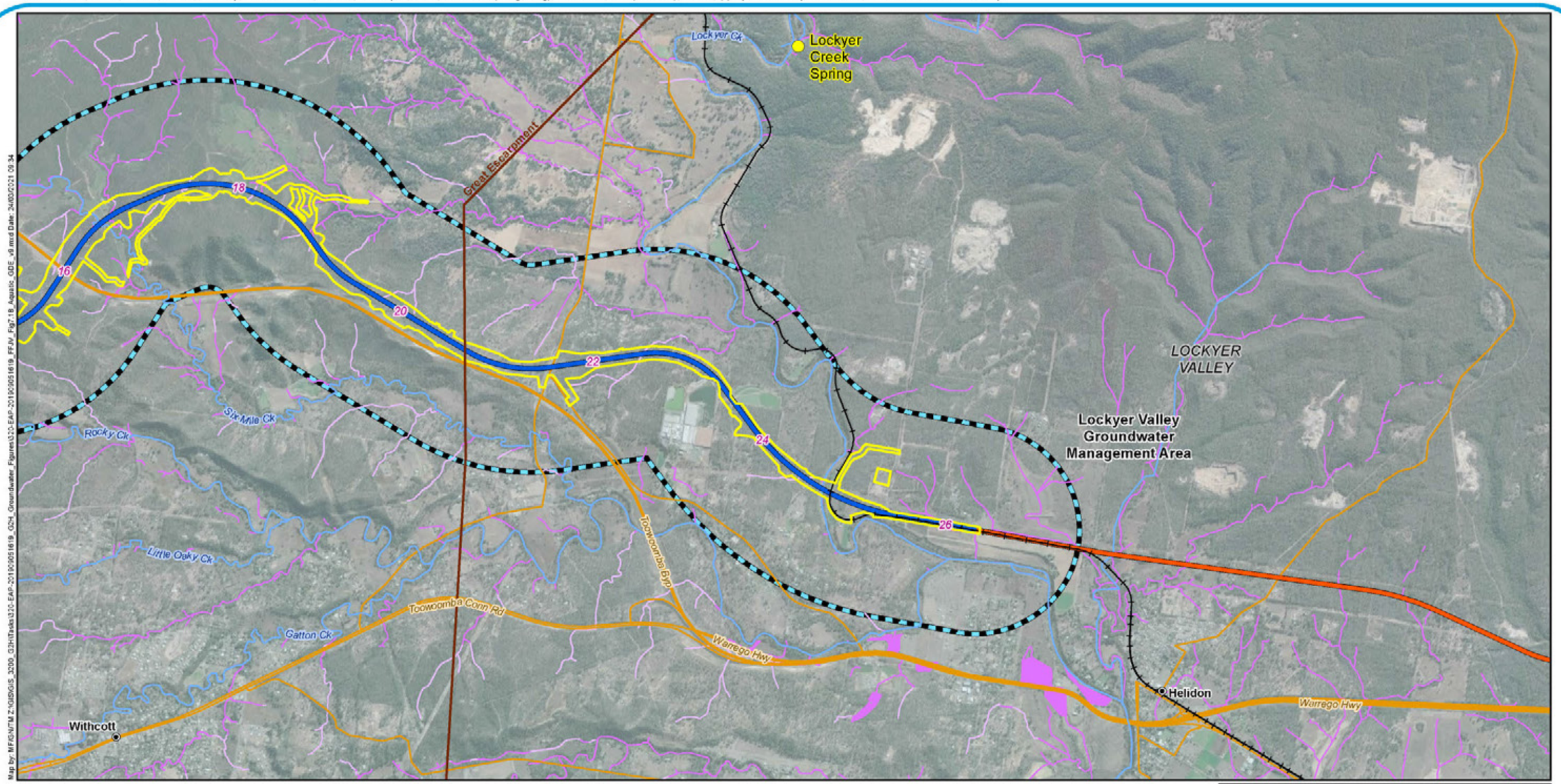
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.18d: Aquatic GDEs

Map by: MFE\\NUMTZ\GIS\GIS_3200_G2H\Tasks\320-EAP-20190905\619_G24_Groundwater_Figures\320-EAP-20190905619_FFJV_Fig7.18_Aquatic_GDE_d9.mxd Date: 24/03/2021 09:34

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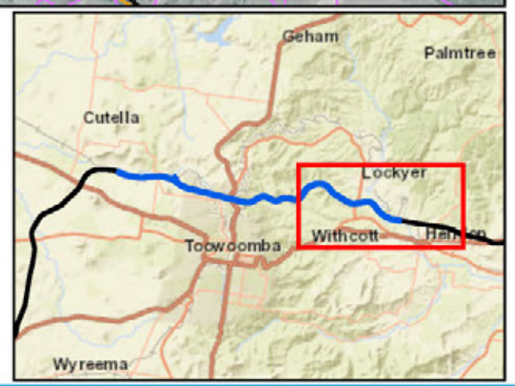
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Legend

- Lockyer Creek Spring
- 5 Chainage (km)
- Localities
- Great Escarpment
- G2H project alignment
- H2C project alignment
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- EIS disturbance footprint
- Local Government Areas
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



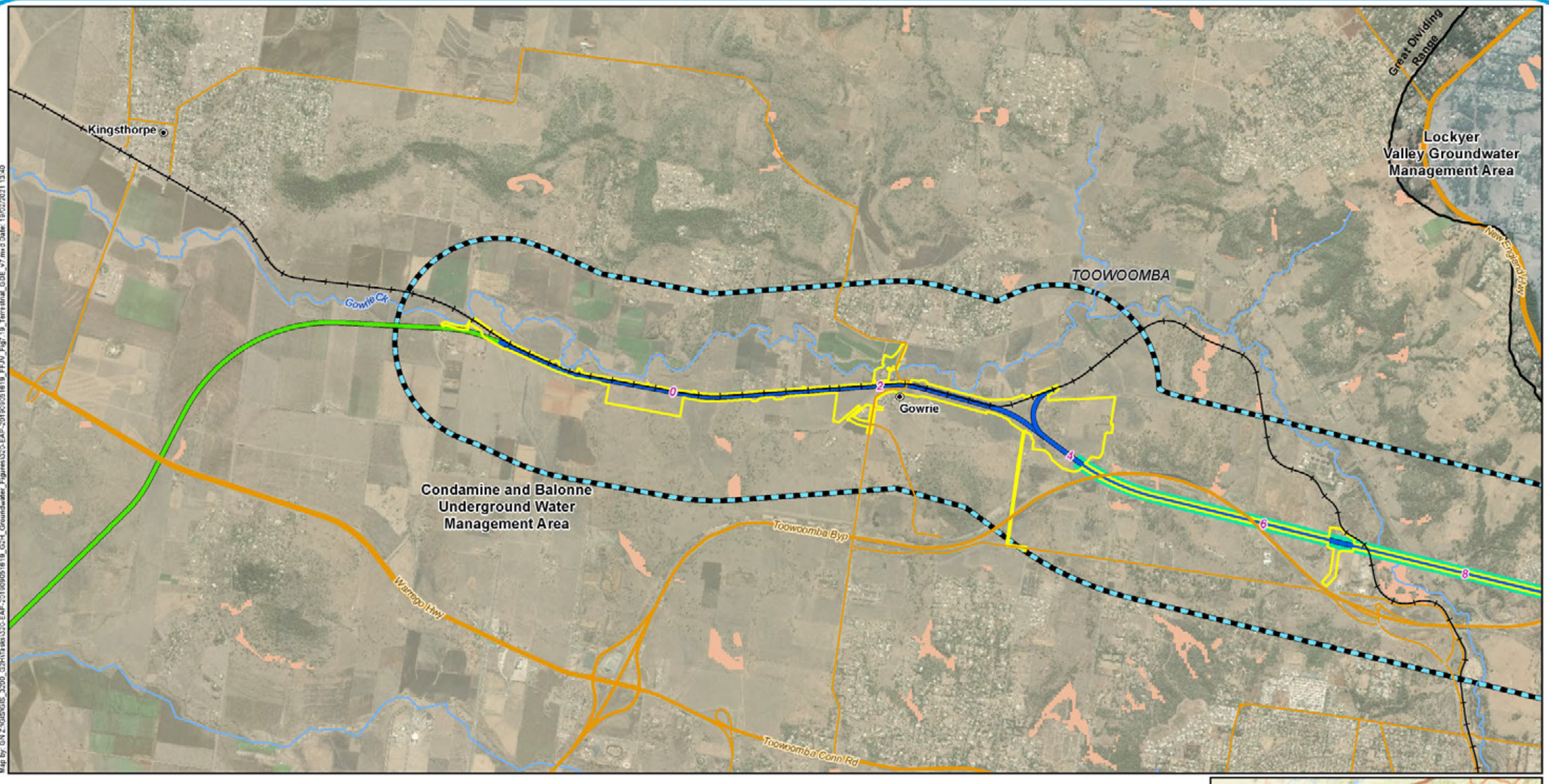
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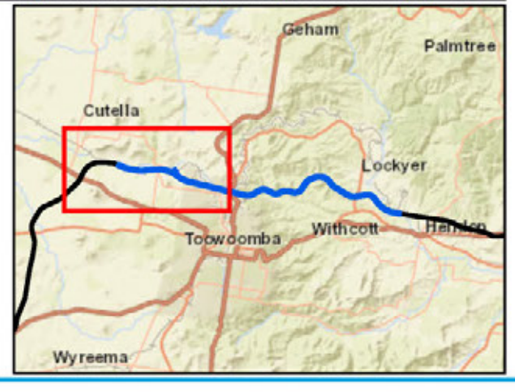
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.18e: Aquatic GDEs

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community





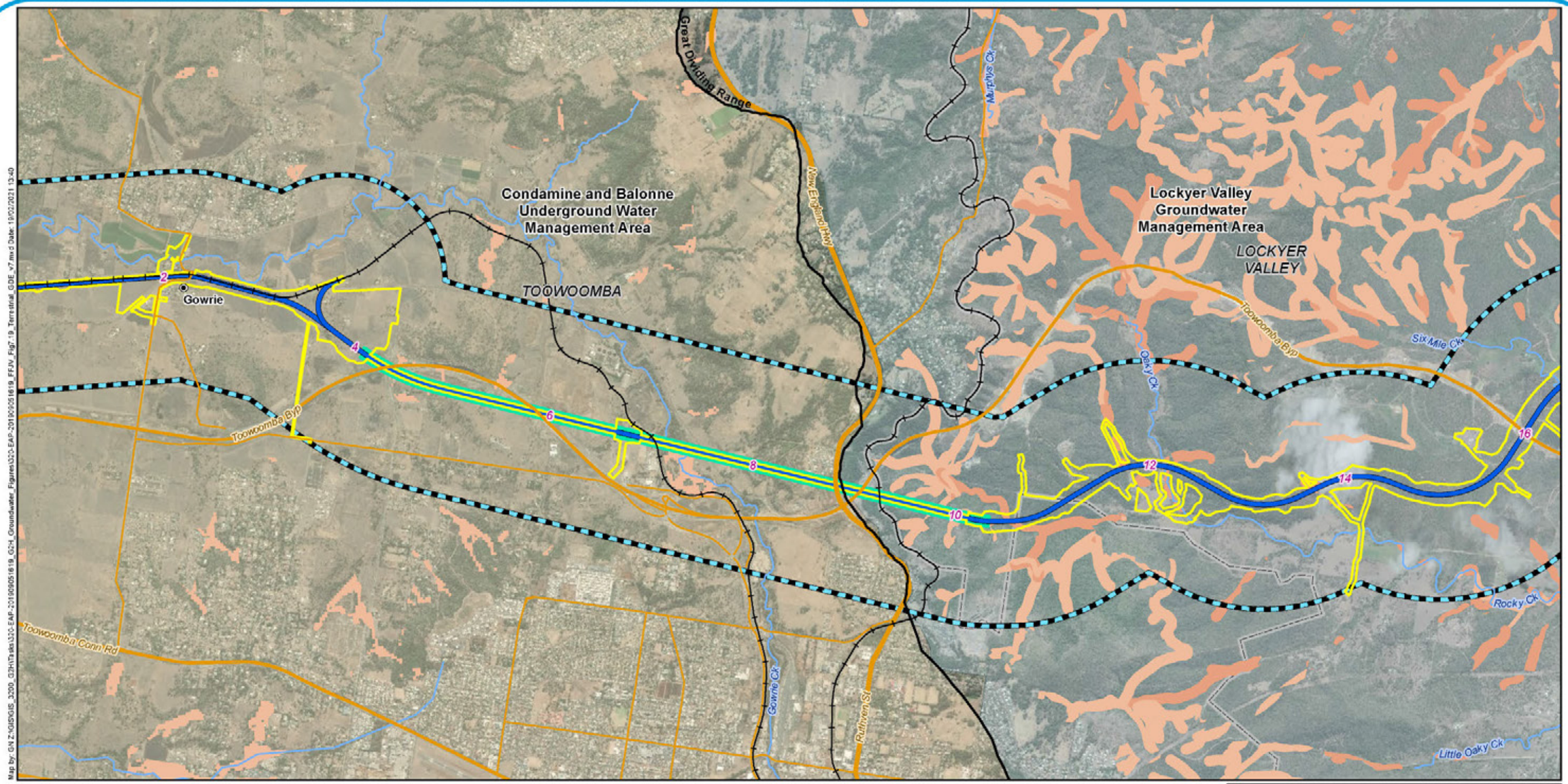
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.19a:
Terrestrial GDEs

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



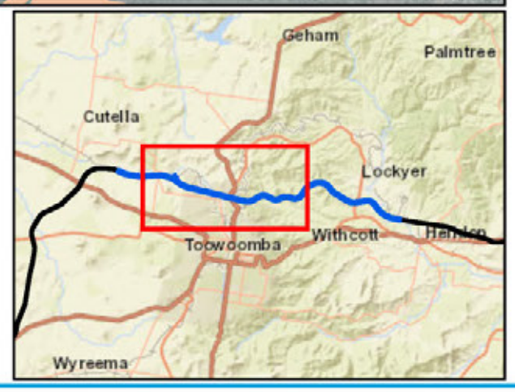
Map by: GN Z:\GIS\GIS_3200_G2H\Tasks\320-EAP-20190905\619_G2H_Groundwater_Figures\320-EAP-20190905619_FFJV_Fig7-19_Terrestrial_GDE_v7.mxd Date: 19/02/2021 13:40

Legend

- 5 Chainage (km)
- Localities
- G2H project alignment
- Great Dividing Range
- Existing rail
- Tunnel
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Terrestrial GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



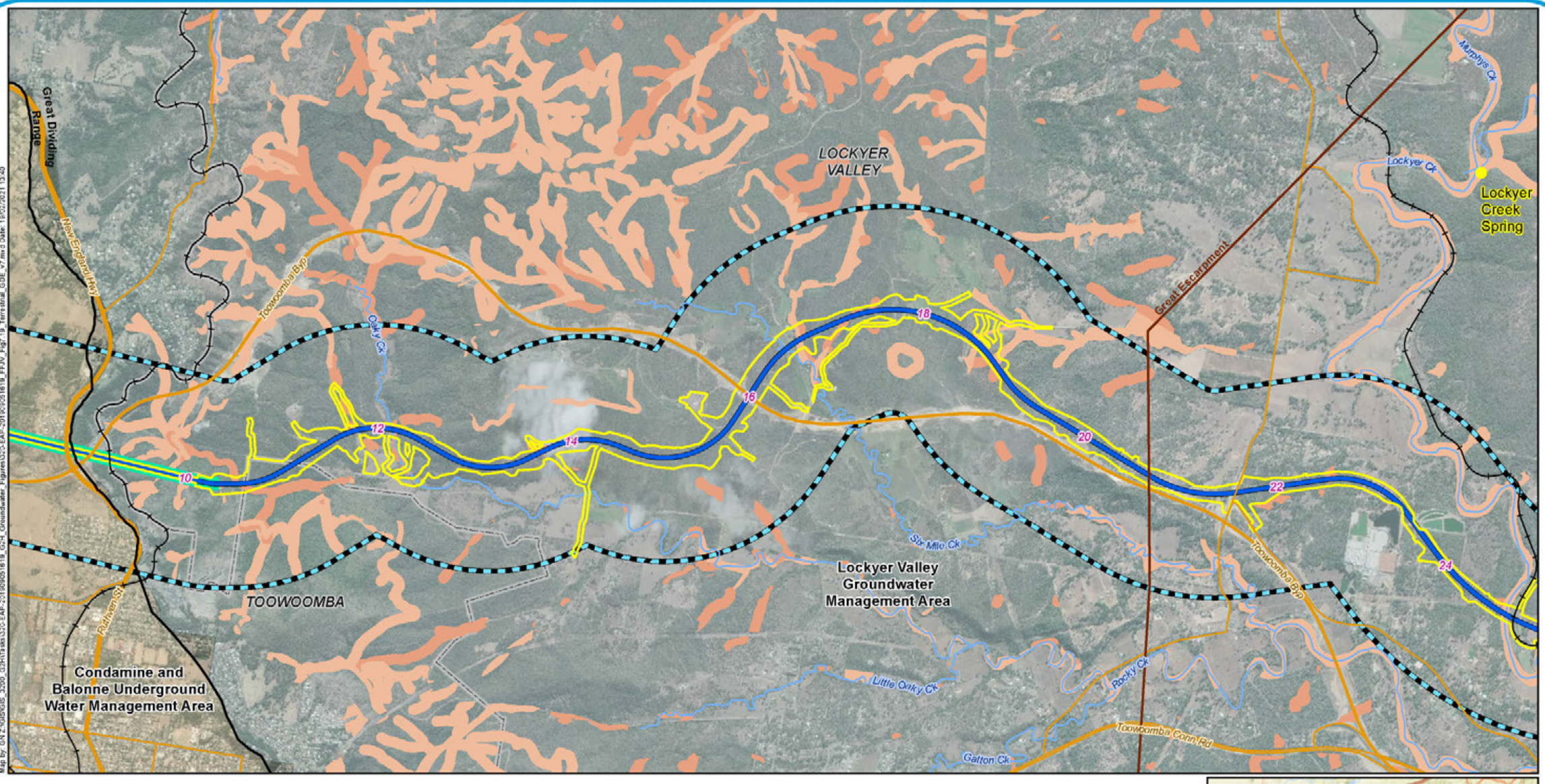
A3 scale: 1:40,000
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 7.19b: Terrestrial GDEs

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

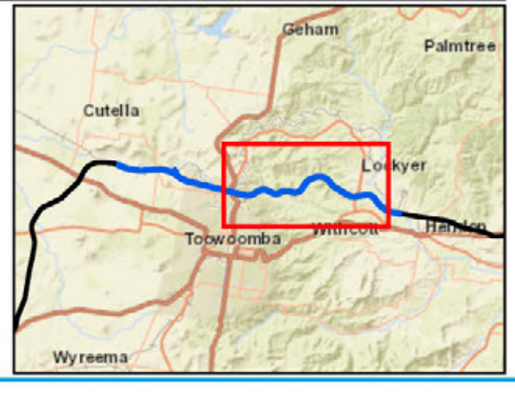


Legend

- Lockyer Creek Spring
- 5 Chainage (km)
- G2H project alignment
- Great Dividing Range
- Great Escarpment
- Existing rail
- Tunnel
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Terrestrial GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:40,000
0 0.5 1 1.5 2 2.5km

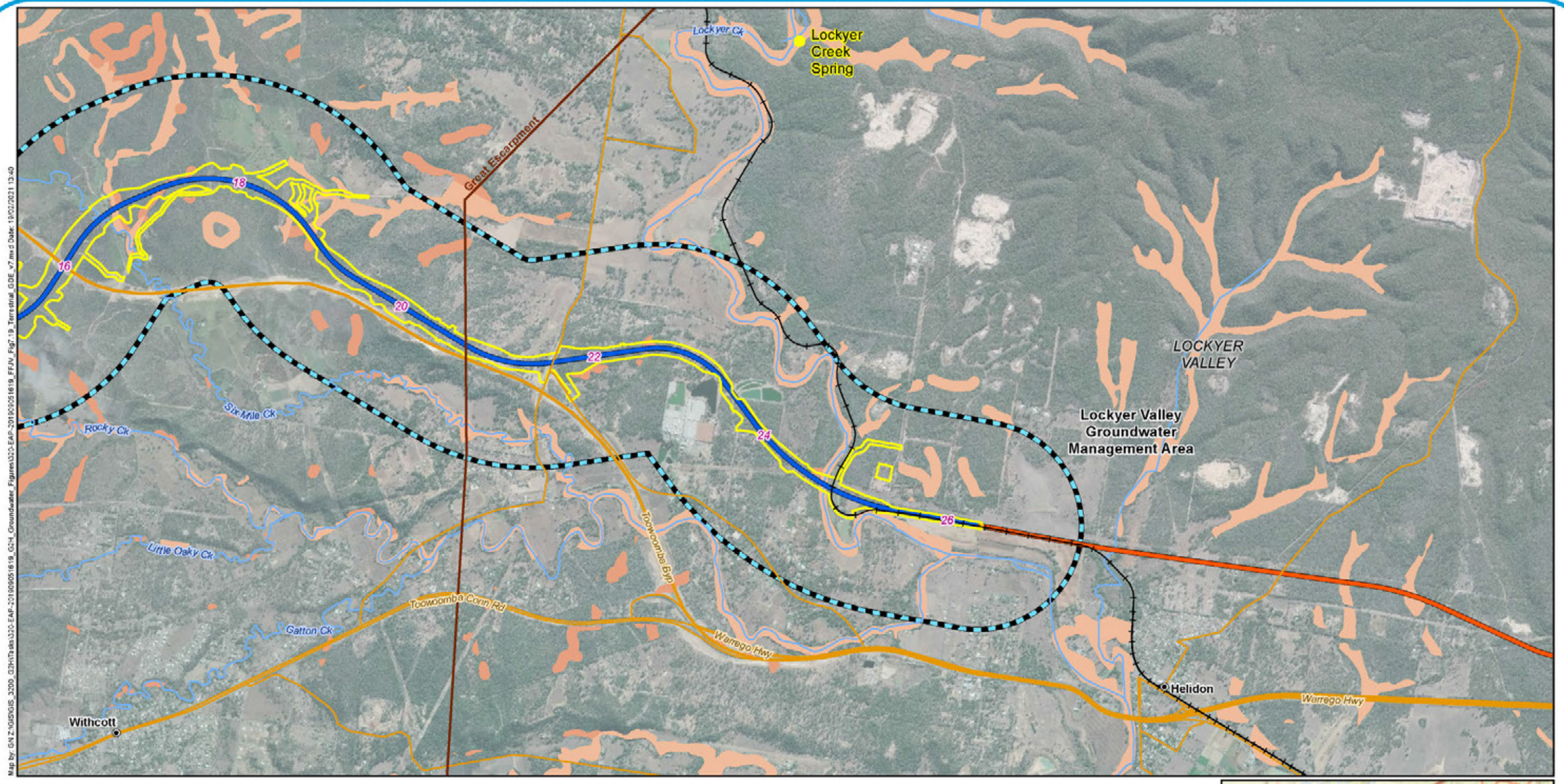
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Gowrie to Helidon
Figure 7.19c: Terrestrial GDEs

Map by: GN Z:\GIS\GIS_3200_G2H\Tasks\320-EAP-20190905\619_G2H_Groundwater_Figures\320-EAP-20190905619_FFJV_Fig7-19_Terrestrial_GDE_v7.mxd Date: 19/02/2021 13:40

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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



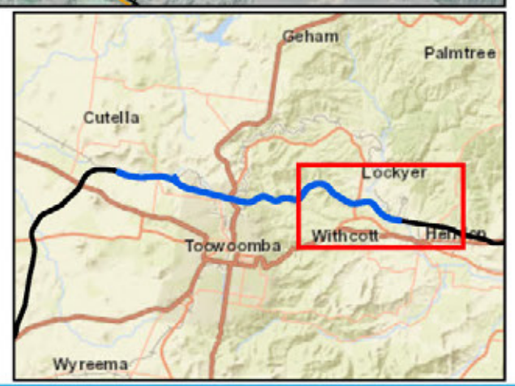
Map by: GN Z:\GIS\GIS_3200_G2H\Tasks\320-EAP-20190905\619_G2H_Groundwater_Figures\320-EAP-20190905619_FFJV_Fig7.19_Terrestrial_GDE_v7.mxd Date: 19/02/2021 13:40

Legend

- Lockyer Creek Spring
- 5 Chainage (km)
- Localities
- G2H project alignment
- H2C project alignment
- Great Escarpment
- Existing rail
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area

Terrestrial GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:40,000
0 0.5 1 1.5 2 2.5km

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Gowrie to Helidon
Figure 7.19d: Terrestrial GDEs

8 Environmental values

8.1 Environmental values

Queensland water quality (including water in rivers, watercourses, wetlands, lakes and groundwater) is protected under the EPP (Water and Wetland Biodiversity). This policy provides a framework for identifying EVs and establishing water quality guidelines and objectives to enhance or protect Queensland waters.

This section identifies and describes groundwater related EVs within the Project groundwater study area. For this assessment the 'values', as defined in the EPP (Water and Wetland Biodiversity), are those attributes of the groundwater systems within the groundwater study area that are important to be protected or enhanced.

The Project is situated across both the Condamine River Basin and the Brisbane Basin (Lockyer Creek sub-basin), separated by the GDR. Relevant areas under the EPP (Water and Wetland Biodiversity), identified in accordance with Schedule 1, include:

- The western extent of the Project (approximately Ch -1.76 km to Ch 10.2 km): located, including the majority of the Toowoomba Range tunnel, within the Gowrie Creek catchment, part of the Upper Oakey sub-catchment, of the Condamine River Basin. Relevant EVs and WQOs are described in the Draft Murray-Darling Basin environmental values and water quality objectives (DES 2018a) and Healthy Waters Management Plan (HWMP): Condamine River Basin (DES 2019)
- The eastern extent of the Project (approximately Ch 10.2 km to Ch 26.2 km): located east of the GDR in the Lockyer Creek catchment (inclusive of Lockyer Creek, Rocky Creek, Oaky Creek, Six Mile Creek), part of the Brisbane Basin. Relevant EVs and WQOs are described in the Department of Environment and Resource Management document: *Lockyer Creek environmental values and water quality objectives* (DERM, 2010).

Groundwater EVs associated with the Condamine River sub-basin are defined by aquifer type and are shown in Figure 17 and 18 in the HWMP: Condamine River sub-basin (DES 2019) and Figure 22 and 23 in the Draft Murray-Darling Basin environmental values and water quality objectives (DES 2018a). Both guidelines provide EVs for alluvium and Toowoomba Region Basalts in the Condamine River sub-basin. There is no direct reference to the MRV in either guideline therefore EVs and WQOs for the Toowoomba Region Basalts have been adopted.

The guidelines for the Lockyer Creek catchment (DERM 2010) provide EVs and WQOs for Lockyer Creek alluvium and Gatton Creek alluvium, which includes Oaky Creek, Rocky Creek and Six Mile Creek.

The EVs associated with groundwater to be protected or enhanced in the groundwater study area are listed in Table 8.1 and discussed further in Table 8.2. EVs for surface water features in proximity to the Project disturbance footprint are presented in Chapter 13: Surface water and hydrology.

Table 8.1 Summary of EVs for groundwater relevant to the Project

Environmental value	Definition
Aquatic ecosystems	'A community of organisms living within or adjacent to water, including riparian or foreshore area' (EPP (Water and Wetland Biodiversity), schedule 2). The intrinsic value of aquatic ecosystems, habitat and wildlife in watercourses and riparian areas. For example, biodiversity, ecological interactions, plants, animals, key species (such as turtles, platypus, seagrass and dugongs) and their habitat, food and drinking water. Watercourses include perennial and intermittent surface waters, groundwaters, tidal and non-tidal waters, lakes, storages, reservoirs, dams, wetlands, swamps, marshes, lagoons, canals, natural and artificial channels and the bed and banks of watercourses.
Irrigation	Suitability of water supply for irrigation. For example, irrigation of crops, pastures, parks, gardens and recreational areas.
Farm water supply/use	Suitability of domestic farm water supply, other than drinking water. For example, water used for laundry and produce preparation.
Stock watering	Suitability of water supply for production of healthy livestock.

Environmental value	Definition
Aquaculture	Health of aquaculture species and humans consuming aquatic foods (such as fish, molluscs and crustaceans) from commercial ventures.
Drinking water supply	Suitability of raw drinking water supply. This assumes minimal treatment of water is required, for example, coarse screening and/or disinfection.
Industrial use	Suitability of water supply for industrial use — for example, food, beverage, paper, petroleum and power industries. Industries usually treat water supplies to meet their needs.
Cultural, spiritual and ceremonial values	Cultural, spiritual and ceremonial values of water mean its aesthetic, historical, scientific, social or other significance, to the past, present or future generations.

Table 8.2 Summary of environmental values, water quality objectives and relevance to the Project

Environmental value	WQOs/Guidelines to assess WQOs	Evaluation of relevance to the Project
Groundwater – Aquatic & Terrestrial Ecosystems	**Lockyer Creek catchment:** WQOs defined in Tables 2b for the Lockyer Creek and Gatton Creek alluvium in the Lockyer Creek environmental values and water quality objectives (DERM 2010). **Condamine River catchment:** WQOs defined in Tables 13 for the Oakey Creek alluvium in the Condamine River Basin: aquatic ecosystem water quality objectives (DES 2018b). WQOs defined in Table 32 for the Toowoomba region basalts in the HWMP: Condamine River Basin (DES 2019)	**Potential aquatic GDEs:** Regional aquatic GDE data was evaluated in Section 7.6.1 which indicated there are numerous moderate and low potential aquatic GDEs in the groundwater study area. These include Gowrie Creek, Oaky Creek, Six Mile Creek and Lockyer Creek (and their tributaries). There are no high potential aquatic GDEs traversed by or in close proximity to the Project (Figure 7.18). The closest spring is Lockyer Creek Spring located in Lockyer Creek, approximately 3.2 km from the alignment (Ch 23 km). There are no Wetlands of International Importance (Ramsar wetlands) within the groundwater study area. There are no high ecological significant wetlands located within the groundwater study area. There is the potential for low to moderate GDEs to be impacted by dewatering or changes in groundwater quality during the construction phase of the Project. Mitigation measures to minimise such impacts are discussed further in Section 11. **Potential terrestrial GDEs:** Regional terrestrial GDE data was evaluated in Section 7.6.2 which indicated moderate potential GDEs are traversed at Ch 4.4 km and Ch 6.2 km and Ch 24.2 km. Low potential GDEs are traversed at Ch 10.6 km, Ch 16.6 km and Ch 19.4 km. Therefore, there is the potential for such GDEs to be impacted by dewatering or changes in groundwater quality during the construction phase of the Project. Mitigation measures to minimise such impacts are discussed further in Section 11. There are no high potential terrestrial GDEs traversed by the alignment. This EV is considered relevant to the Project.
Groundwater - Irrigation	ANZG 2018 Guidelines - Section 4.2.3.3 and Table 4.2.2. i.e. The threshold salinity tolerances for plants grown in loamy to clayey soils (considered the primary soil conditions traversed by the rail alignment) are 600 µS/cm to 7,200 µS/cm as stated in Section 4.2.4 of the ANZG guidelines (2018).	Groundwater used for irrigation is the main EV for the region, particularly from shallow aquifers such as the alluvium units and MRV (refer Section 7.5 and 7.5.2). Section 4.2.4 of the ANZG (2018) states that the threshold salinity tolerances (presented as EC in the guidelines) for plants grown in loamy to clayey soils are 600 µS/cm to 7,200 µS/cm. Loamy to clayey soils are considered to be the primary soil condition in the groundwater study area. Based on regional mean groundwater salinity data, the main aquifers in the Project (alluvium units, Marburg Subgroup and MRV) are suitable for irrigation. The maximum EC value recorded across the Project bores (from the 6 bores sampled out of 12 installed along the alignment) was 5,690 µS/cm (based on one round of sampling in October 2018), indicating that groundwater quality at these locations is generally suitable for irrigation. The EC is up to 2,350 µS/cm across alluvium units and 7,520 µS/cm in the MRV in the general groundwater study area (based on the Queensland Globe database values summarised in Table 7.9). This EV is considered relevant to the Project.
Groundwater - Farm Supply/use	ANZG guidelines (2018)	The salinity in the groundwater study area is variable, with salinity ranging from 1,000 to 6,000 mg/L across the main aquifers (alluvial units, Marburg Subgroup and the MRV) (refer to Section 7.3 and 7.3.7). This generally precludes groundwater from being suitable for farm supply uses such as laundry or produce preparation. Regionally, the shallow alluvium and hydraulically connected creeks are considered of significance to this environmental value (i.e. Lockyer Creek and its tributaries). This EV is considered relevant to the Project.

Environmental value	WQOs/Guidelines to assess WQOs	Evaluation of relevance to the Project
Groundwater - Stock Water	ANZG guidelines (2018) i.e. Median faecal coliforms of < 100 organisms per 100 ml The water quality tolerances of livestock vary between livestock types (e.g. beef cattle have no adverse effects up to a TDS of 4,000 mg/L, whereas dairy cattle can only tolerate up to 2,500 mg/L TDS.	The review of licence allocations and water use discussed in Section 7.5 and 7.5.2 indicates stock water is another important EV for the region, particularly in the MRV unit. Section 4.3.3.5 of the ANZG (2018) states that a loss of production and a decline in animal health occurs if stock are exposed to high salinity water for prolonged periods. Salinity less than 4,000 mg/L is considered acceptable for livestock except for dairy cattle and poultry. Dairy cattle require salinity less than 2,500 mg/L and poultry require less than 2,000 mg/L. The regional and site-specific salinity values indicate that groundwater is generally suitable for stock watering from the alluvium units (mean 740 mg/L), Gatton Sandstone (mean 1,570 mg/L), Marburg Subgroup (mean 1,380 mg/L), MRV (mean 860 mg/L) and WCM (mean 520 mg/L). Salinity across all main aquifers within 5 km of the alignment ranged between 250 and 5,000 mg/L. Salinity across Project bores ranged between 920 and 3,420 mg/L. This EV is considered relevant to the Project.
Aquaculture	ANZG guidelines (2018)	This environmental value is not considered applicable to in-situ groundwater and more directly applicable to surface water. The nearest registered springs are located within 4 km of the alignment and they are Lockyer Creek Spring and Helidon Spring. Groundwater seepage from the alluvium or incised Clarence-Morton Basin sedimentary units into watercourses can deliver short duration baseflow into rivers and creeks immediately following heavy rains or flooding. However, after larger flood events suitability of these waters for recreation may be limited by other factors. This value is more common for surface water features that are accessible for recreational use and visual interaction; but can be affected by groundwater quality if they are a receiving waterbody (i.e. groundwater baseflow). There is currently no evidence to suggest that groundwater is directly used for recreational or aesthetic purposes in the groundwater study area as a result this EV is not considered relevant to the Project.
Groundwater - Drinking Water	ANZG guidelines (2018) ADWG (2011) HWMP (Condamine River) – Table 61	The suitability of water for human consumption is defined in the Australian Drinking Water Guidelines (NHMRC 2011). Salinity less than 600 mg/L is considered good quality and up to 900 mg/L is fair quality. Salinity greater than 900 mg/L is considered poor quality and greater than 1,200mg/L is unacceptable for consumption. The regional and site-specific salinity values indicate groundwater is generally suitable for human consumption across the main aquifers, including the alluvium units (mean salinity of 740 mg/L), Gatton Sandstone (mean salinity of 1,570 mg/L), Marburg Subgroup (mean salinity of 1,380 mg/L), MRV (mean salinity of 860 mg/L) and WCM (mean salinity of 520 mg/L). Salinity across all main aquifers within 5 km of the alignment ranged between 250 and 5,000 mg/L. Salinity across Project bores ranged between 920 and 3,420 mg/L. Based on the salinity data presented in Section 7.3.7, the aquifers relevant to the study would be suitable for drinking water without treatment. As a result, this EV is considered relevant to the Project.
Industrial	Applicable WQOs to protect this EV are variable between different industries and are considered on a case-by-case basis.	Industrial use covers less than 4% of the MRV, 11% of the Marburg Subgroup and 5% of the WCM aquifers and all groundwater across alluvium units is used for irrigation (refer Section 7.5 and 7.5.2). As a result, this EV is not considered relevant to the Project.

Environmental value	WQOs/Guidelines to assess WQOs	Evaluation of relevance to the Project
Cultural and Spiritual	Protect or restore cultural, spiritual and ceremonial values consistent with approved policies and plans. Aboriginal Waterways Assessments may provide information to support the cultural, spiritual and ceremonial value.	Regionally, the Condamine-Balonne River and Lockyer Creek catchments have cultural and spiritual values recognised EVs for all relevant aquifers traversed by the Project. This EV is considered relevant to the Project.

8.2 Water quality objectives

WQOs are long-term goals for water quality management that provide quantitative levels or written statements for specific indicators of water quality (i.e. salinity or pH) to protect environmental values.

A summary of the WQOs relevant to the Project are presented in Table 8.3 and are in accordance with the Lockyer Creek (DERM 2010) and Condamine River catchment (DES 2018a and 2019) guidance documents. The 20th and 80th percentiles of current conditions (i.e. July 2010 and May 2018) have been adopted as the guideline value by DES.

Groundwater quality data collected to date (feasibility design phase) and the ongoing investigations and monitoring will allow for a baseline dataset to be established from which WQOs can be assessed against and site-specific trigger levels can be developed.

Table 8.3 Groundwater water quality objectives for the Project

Parameter	Percentiles	Gatton Creek catchment	Lockyer Creek catchment	Condamine River Basin
		Rocky Creek, Oaky Creek and Six Mile Creek alluvium	Lockyer Creek alluvium	Toowoomba region basalts
EC (µS/cm)	20th	1,050	1,050	660
	80th	1,200	3,400	1,750
pH	20th	7.7	7.7	7.5
	80th	8.2	8.2	8.2
SiO_2 (mg/L)	20th	30	30	20
	80th	40	50	47
Total Ions (mg/L)	20th	740	730	-
	80th	860	2,160	-
TDS (mg/L)	20th	580	610	-
	80th	670	1,880	-
Na (mg/L)	20th	70	70	66
	80th	90	360	147
K (mg/L)	20th	0.7	1.5	-
	80th	1.4	3.8	-
Ca (mg/L)	20th	50	40	16
	80th	70	130	100
Mg (mg/L)	20th	60	45	7
	80th	70	160	116
Fe (mg/L)	20th	0.01	<0.01	0.00
	80th	0.06	0.04	0.05
HCO_3 as bicarbonate (mg/L)	20th	390	320	180
	80th	470	650	530
Cl (mg/L)	20th	140	150	88
	80th	170	850	356
NO_3 as N (mg/L)	20th	<0.1	0.5	0.5
	80th	4.8	24.5	33
SO_4 (mg/L)	20th	10	10	3.4
	80th	20	50	22.0

Parameter	Percentiles	Gatton Creek catchment	Lockyer Creek catchment	Condamine River Basin
		Rocky Creek, Oaky Creek and Six Mile Creek alluvium	Lockyer Creek alluvium	Toowoomba region basalts
RAH (meq/L)	20th	-1.9	-13.4	-
	80th	-0.7	0.7	-
SAR	20th	1.5	1.5	1.3
	80th	1.9	6.4	6.2
Hardness	20th	330	290	85
	80th	410	860	708

Table notes:

RAH = residual alkali hazard; SAR = sodium absorption ratio.
The 20th and 80th percentiles of current conditions are being used as a guideline value
Lockyer Creek catchment environmental value documents (DERM, 2010) and Regional groundwater chemistry zones: Queensland Murray-Darling Basin (DES 2018a)

The WQOs of the Toowoomba region basalts were compared with project groundwater quality data (refer Table 8.2). Project bores are not screened within the alluvium unit therefore the WQOs of the Toowoomba region basalts were used for comparison. Groundwater quality across project bores is generally between the 20th and 80th percentile WQOs however EC is generally greater than the 80th percentile.

9 Groundwater modelling

9.1 Construction methodology

Construction of the Project will involve a combination of earthworks for cuts, bridges, viaducts, and embankments to ensure required grade for the rail alignment and construction of the Toowoomba Range tunnel. The proposed construction activities for the Project with potential to interface with groundwater are summarised in Table 9.1.

Table 9.1 Summary of construction activities for the Project

Activity	Description
Embankments	Volumes of material emplaced and compacted to raise the profile of the railway alignment to meet design specifications. A total of 15 embankments are proposed with total length of 15.41 km. Embankment lengths range between 160 and 1,550 m.
Cuts/portals	Removal of soil and rock to maintain the grade of the alignment design. Cuts are proposed in all the main geological units. The Project comprises 14 deep cut locations with at least 8 cuts anticipated to encounter groundwater. Cut lengths range between 90 m and 870 m (total cut length of 6.65 km).
Toowoomba Range Tunnel	Approximately 6.24 km long through the GDR (diameter of 13 m). Construction will include tunnel boring machine (TBM) and road-header methods.
Bridge, viaducts, and pilings	13 bridges (including 2 road over rail bridges) totally approximately 6.7 km in length are proposed to cross watercourses and roads. Cast in Place (CIP) or driven pilings are to be emplaced for each bridge/viaduct. The bridges and viaducts are in areas where there are watercourses, which range between 24 m and 1,840 m in length.

A profile of the rail alignment which presents the surface geology, locations of cuts, bridges, fill, and bore locations is shown on Figure 10.1.

9.2 Conceptual groundwater models

A conceptual understanding of the hydrogeological regimes in the groundwater study area are presented on Figure 9.1. Conceptualisation is divided broadly into two sections of the Project:

- Ch -1.76 km to Ch 26.2 km – the entire Project (refer Figure 9.1)
- Ch 4.0 km to Ch 10.2 km –the Toowoomba Range tunnel (refer Figure 9.2).

The conceptualisations are a representation of the groundwater systems which incorporate an interpretation of the geological and hydrogeological conditions. The conceptualisations consolidate the current understanding of the key processes of each groundwater system, including the influence of stresses, to assists in the understanding of potential changes/impacts on the systems from the Project.

The conceptual site model of the Project (refer Figure 9.1) shows the alignment initially traverses the MRV to Ch 4.0 km, where the Toowoomba Range tunnel (refer Figure 9.2) commences and crosses the Koukandowie Formation. It is conceptualised that there is a shallow layer of the MRV which has low hydraulic conductivity (confining layer) and there is a higher conductive layer of MRV below the confining layer, this has been referred to as the shallow and deep MRV layers in Section 9 and 10. Groundwater is shallow within the shallow MRV layer and deeper in the Koukandowie Formation and follows topography. The tunnel ends at Ch 10.34 km at the GDR where the underlying geology changes to Gatton Sandstone.

These conceptual models were developed based on the feasibility design stage works and ARTC commit to updating these models to incorporate the results of the recent geotechnical and hydrogeological investigations (Golder 2020c/d). The updated conceptual models will then be utilised to refine the existing predictive groundwater model for the Final EIS (refer Section 9.5); this approach will allow for the predicted impacts in Section 10.2 and Section 10.3 to be re-assessed with more robust and comprehensive groundwater data before construction commences.

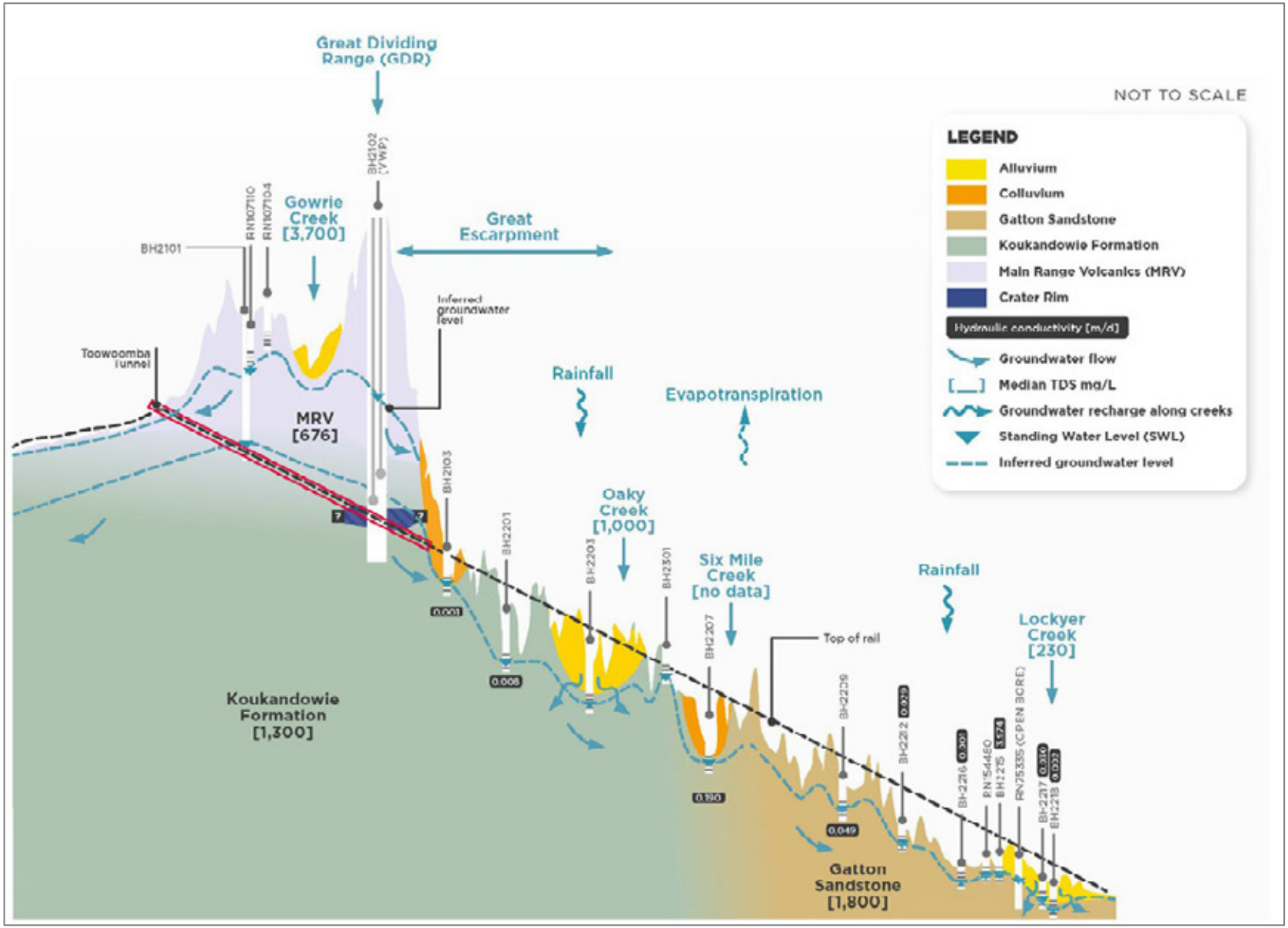


Figure 9.1 **Conceptualisation of the Project**

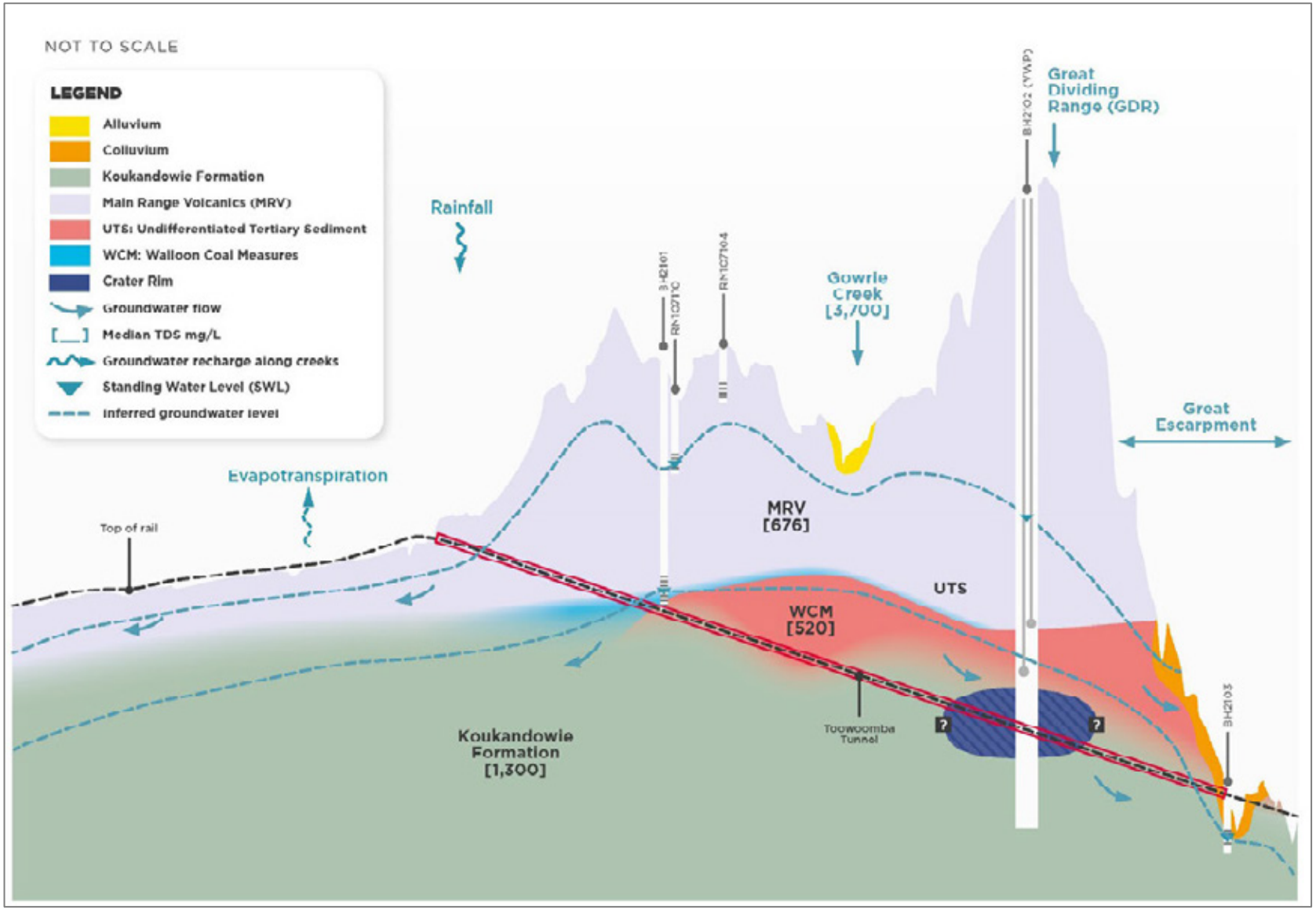


Figure 9.2 **Conceptualisation of the Toowoomba Range tunnel**

9.3 Predictive modelling of Toowoomba Range tunnel

A groundwater model is a simplification of a complex system and its behaviour developed to gain an understanding of likely responses to future changes of the system and understanding the uncertainty in those responses. A numerical predictive model was developed to support the feasibility design and to provide an initial assessment of potential groundwater ingress and drawdowns associated with the Toowoomba Range tunnel and ventilation shaft, tunnel portals, and cuts of the Project. The detailed methodology and modelling are discussed in detail in Appendix A. Numerical models are a simplified representation of a real system and therefore, include inherent uncertainties.

The predictive model was developed using USGS MODFLOW code and GMS 10.4 as the graphical user interface. The model was used to estimate preliminary drawdown and inflows analyses for the MRV, Koukandowie Formation (Marburg Subgroup) and colluvium to inform an assessment of the potential to construct the Toowoomba Range tunnel (undrained), and adjacent portals (drained) and cut and cover (drained) and the intermediate ventilation shaft (undrained).

Results of the predictive modelling have been used to evaluate potential impacts on groundwater in the groundwater study area, identify gaps, and develop mitigation and management measures. The main potential impact is from groundwater drawdown during the construction and operation phases and these are discussed in detail in Sections 10.2 and 10.3. The results have been used to inform the significance-based impact assessment completed as part of this groundwater technical report.

The Marburg Subgroup comprises the Koukandowie Formation and Gatton Sandstone members. The Marburg Subgroup nomenclature was adopted for the predictive groundwater model (Golder 2020); for the impact assessment, Koukandowie Formation was adopted because the impacts (tunnel) are generally within this member of the subgroup.

9.3.1 Methodology and model construction summary

The model was constructed with 11 layers that represent six hydrostratigraphic units of variable thickness obtained from the Project's geological model. The three-dimensional (3D) model domain allowed for simulations of groundwater movement in both the horizontal and vertical planes to identify potential impacts of the Project on local groundwater resources.

The reference design elements of the Project simulated are summarised in Table 9.2.

Table 9.2 Summary of reference design aspects modelled

Design aspect	Project chainage (km)		Length (m)	Tentative construction/ excavation dates*		Permanent Lining*		Permanent drained condition
	Start	Finish		Start	Finish	Start	Finish	
Western portal	3.70	4.10	400	June 2022	February 2023	NA		Drained
TBM tunnel	4.10	9.76	5660	May 2023	November 2024	Progressively lined		Undrained, limit of 0.3 L/s
Mined tunnel	9.76	10.235	475	October 2023	July 2024	July 2023	August 2024	
Cut and cover	10.235	10.34	105	May 2023	October 2023	January 2025	July 2025	Drained
Eastern portal	10.34	10.40	60	June 2022	February 2023	NA		Drained
Intermediate ventilation shaft	6.83	6.929	99	March 2022	August 2023	August 2023	October 2024	Undrained, limit of 0.0062 L/s

Table notes:

TBM – tunnel boring machine NA – not applicable

* Dates are indicative

The MRV and Koukandowie Formation have been modelled as continuous layers spanning the entire model domain. The MRV groundwater system has been simplified and is represented in the model across four layers:

- Model layer 1 - 2: Shallow MRV aquifer (near surface flow regime with groundwater levels that generally correlate well with surface topography)
- Model layer 3: Low conductivity MRV aquifer (separates the shallow and deep layers of the MRV)
- Model layer 4: Deep, high conductivity MRV aquifer (near the base of the MRV)
- Model layer 5: combination of the high conductivity MRV aquifer, WCM, UTS, and crater rim units in a localised area west of the GDR. In this area, the hydraulic characteristics of these units are assumed to be homogenous and transversely isotropic in this area.
- Model layers 6 – 11: Koukandowie Formation

Additionally, a localised weathered horizon that overlies fresh sandstone and underlies colluvium in the eastern valley (eastern portal) has been included in the model (refer Figure 9.5). The hydraulic characteristics have been assumed to be the same as the colluvium.

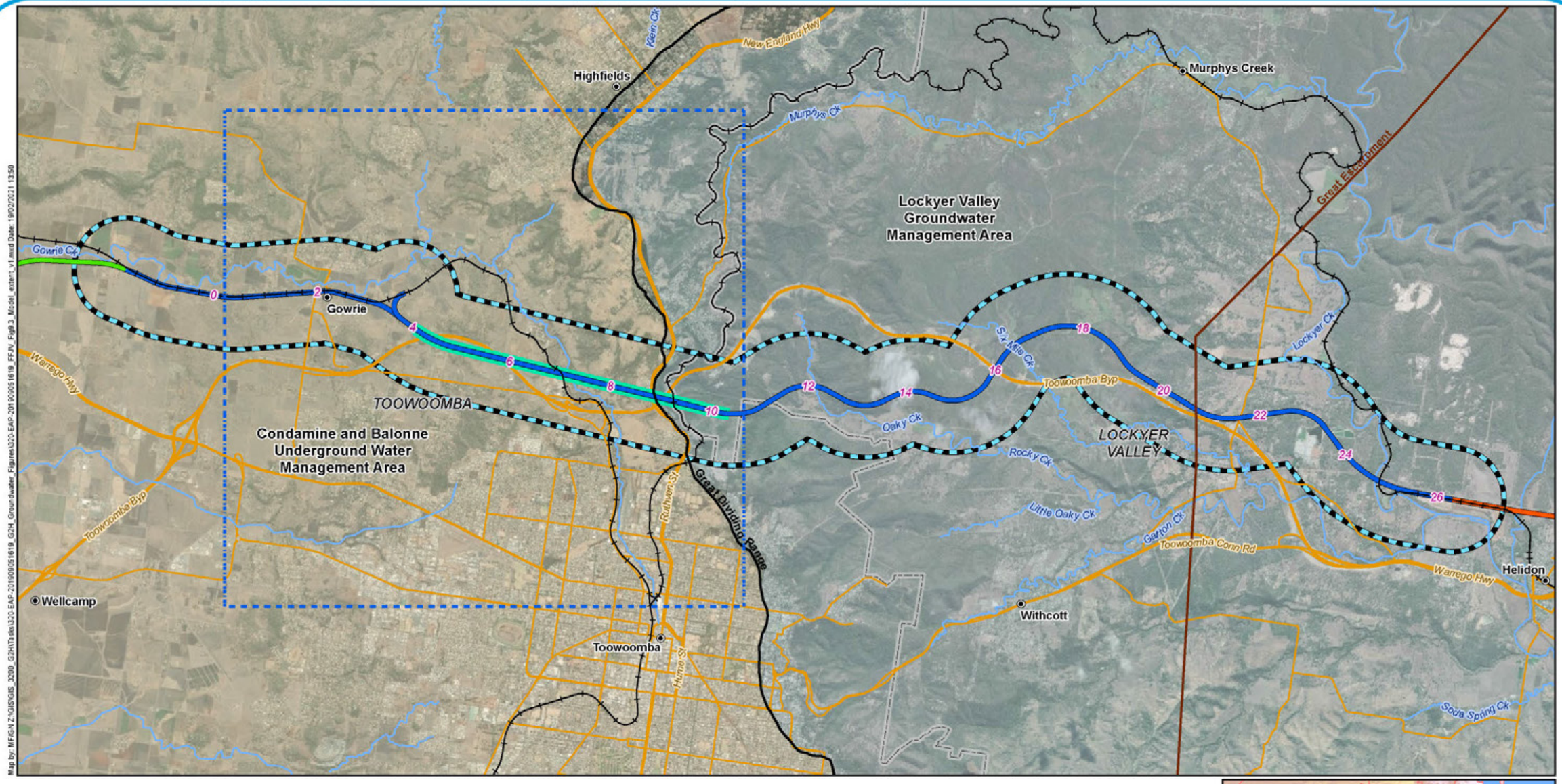
The modelled tunnel alignment is located from Ch 4.10 to Ch 10.34 km (refer Table 9.2) and is anticipated to encounter:

- MRV – Ch 4.10 to Ch 4.53 km and Ch 8.45 km to Ch 9.05 km
- Koukandowie Formation – Ch 4.53 to Ch 8.45 km and Ch 9.05 km to Ch 10.00 km
- Crater rim – Ch 8.61 km to Ch 8.87 km
- Colluvium – Ch 10.00 km to Ch 10.34 km.

The model domain has a length, from west to east, of 10.0 km and 9.5 km in the north-south direction, as depicted on Figure 9.3. The base of the model domain is at 250 m AHD and the top surface is defined by the ground surface elevation. Figure 9.4 shows the isometric view of the model and Figure 9.5 depicts a long section view of the predictive model layers.

The model grid spacing is, for the majority of the domain, 65 m by 65 m; spacing is refined to approximately 20 m by 20 m along the alignment. The grid was further refined along the tunnel, and laterally around the shaft location, to approximately 18 m by 21 m.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Map by: MFIGN Z:\GIS\GIS_3200_G2H\Tables\320-EAP-20190905\619_G2H_Groundwater_Figures\320-EAP-20190905\619_FFJV_Fig9.3_Model_extent_v1.mxd Date: 19/02/2021 13:50

Legend

- 5 Chainage (km)
- Localities
- B2G project alignment
- G2H project alignment
- H2C project alignment
- Existing rail
- Tunnel
- Groundwater predictive model domain
- Great Dividing Range
- Great Escarpment
- Major roads
- Minor roads
- Watercourses
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area
- Groundwater study area
- Local Government Areas



A3 scale: 1:80,000

0 1 2 3 4 5km

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Integrating Community, Environment and Engineering

Issue date: 11/02/2021 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 9.3: Model extent

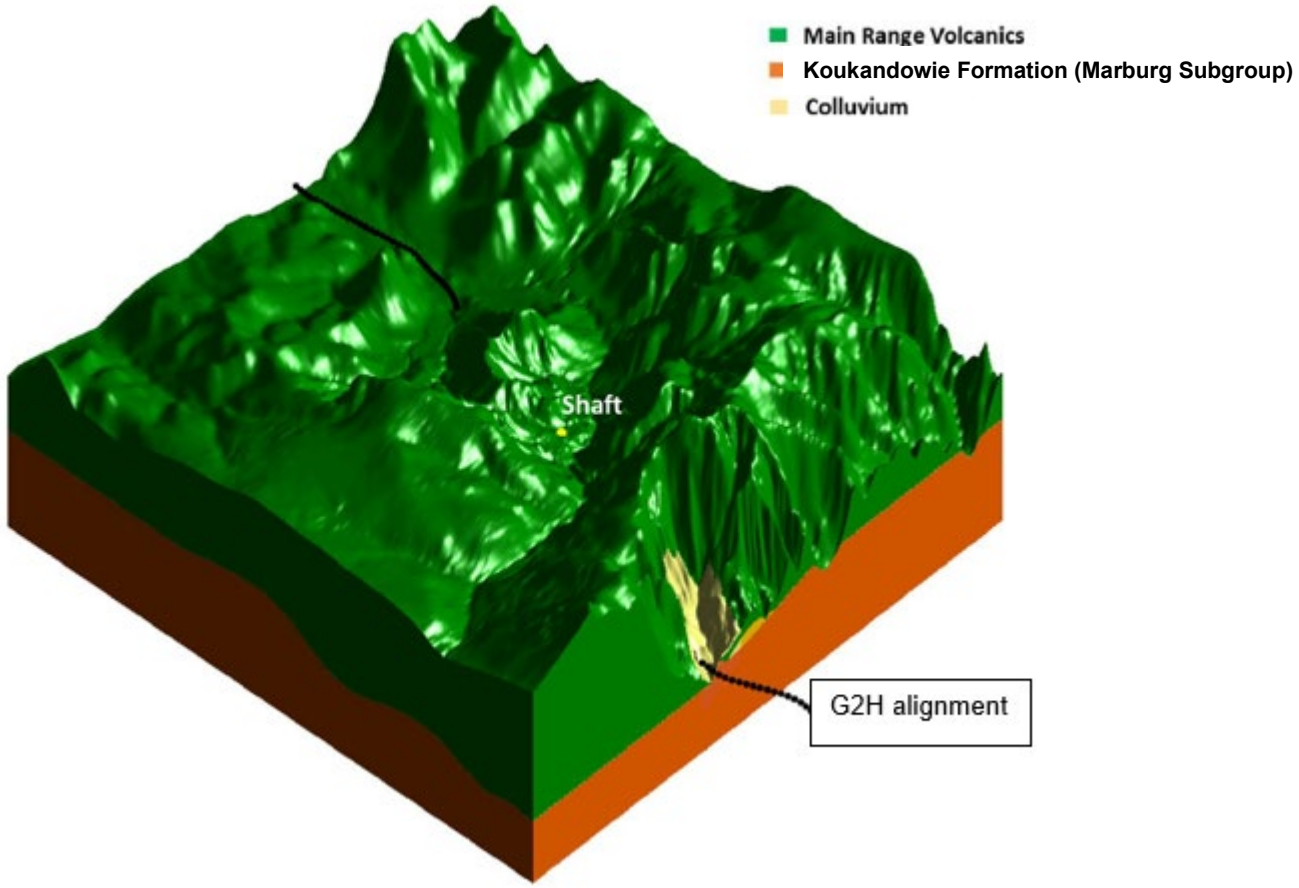


Figure 9.4 Isometric view of groundwater model illustrating layering of the model

Source: Golder 2020a

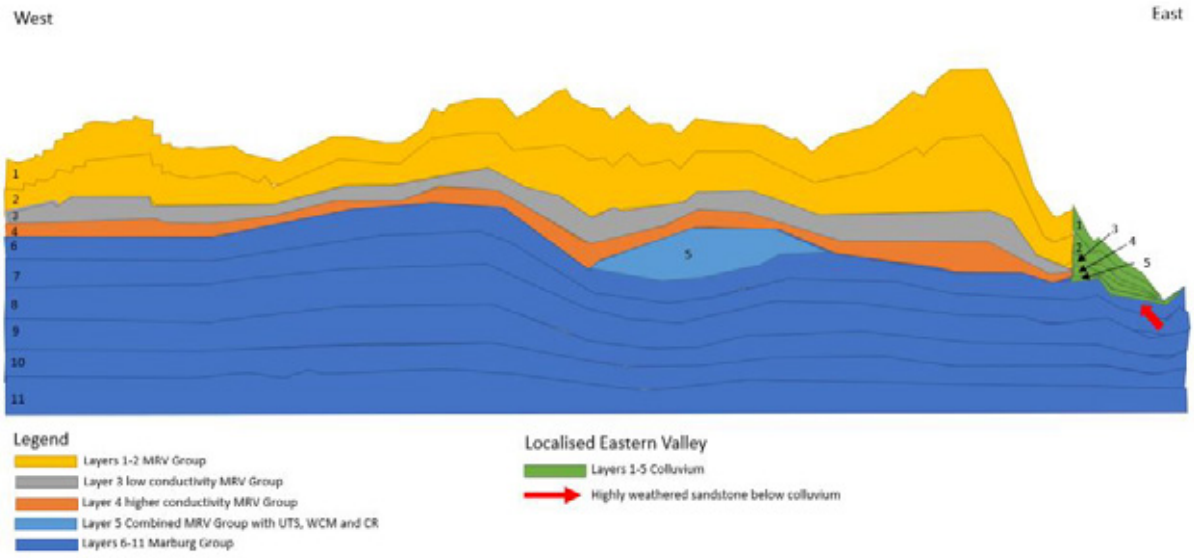


Figure 9.5 Long section of predictive model layers

Source: Golder 2020a

9.3.2 Boundary conditions

Boundary conditions in the model are summarised below and discussed further in Appendix A.

Constant head boundaries have been applied around the perimeter of the shallow layers (model layers 1 and 2) in the MRV. The boundary head used in the model is derived from the correlation between topography and water levels.

No flow boundaries were assigned around the perimeter of the following model layers:

- Layer 3: Low conductivity confining layer in the MRV
- Layer 4: High conductivity layer at the base of the MRV

These layers are modelled as unconfined aquifers conceptualised to receive most inflow from rainfall recharge; the model boundaries for Layers 3 and 4 are considered to be sufficiently distant from the tunnel so as to not require specified head boundaries to stimulate throughflow in response to tunnel-induced drawdown (required if these layers were modelled as confined).

- Layers 6 – 11 Koukandowie Formation (Marburg Subgroup)
- Base of the model domain (it is assumed the base is impermeable and groundwater does not flow to/from 250 m AHD).

There are colluvial deposits of varying thickness east of the GDR, at the eastern portal, and most colluvium is expected to be located above the water table. A constant head boundary was applied along the eastern edge of the colluvium with head value equal to the base elevation of the colluvium.

The tunnel and associated ventilation shaft excavation have been simulated as a time-dependent boundary condition. The intermediate ventilation shaft has been modelled as a rectangular cell with a cell size of approximately 18 m by 21 m and a depth of 93 m at completion. The deepening of the shaft excavation has also been simulated as a time dependent boundary condition. The tunnel has been divided into rectangular prisms (cells) with a cell size of approximately 18 m by 21 m and a height of 30 m.

Surface waterbodies intercepted within the modelling domain (Ch 4.10 to Ch 10.25 km) were represented as MODFLOW drain cells. This assumes discharge occurs when the computed water level is higher than ground surface elevation. The only watercourse intercepted within the model domain is Gowrie Creek at Ch 7.2 km.

As groundwater from the MRV is heavily utilised for water supply in the Toowoomba area, four groundwater supply bores have been included in the model (with a simplified distribution) that extract groundwater from model Layer 4 (high conductivity layer at the base of the MRV) to represent groundwater use in the groundwater study area. The simplified distribution of water supply bores that source water from model Layer 4 is depicted on Figure 9.6.

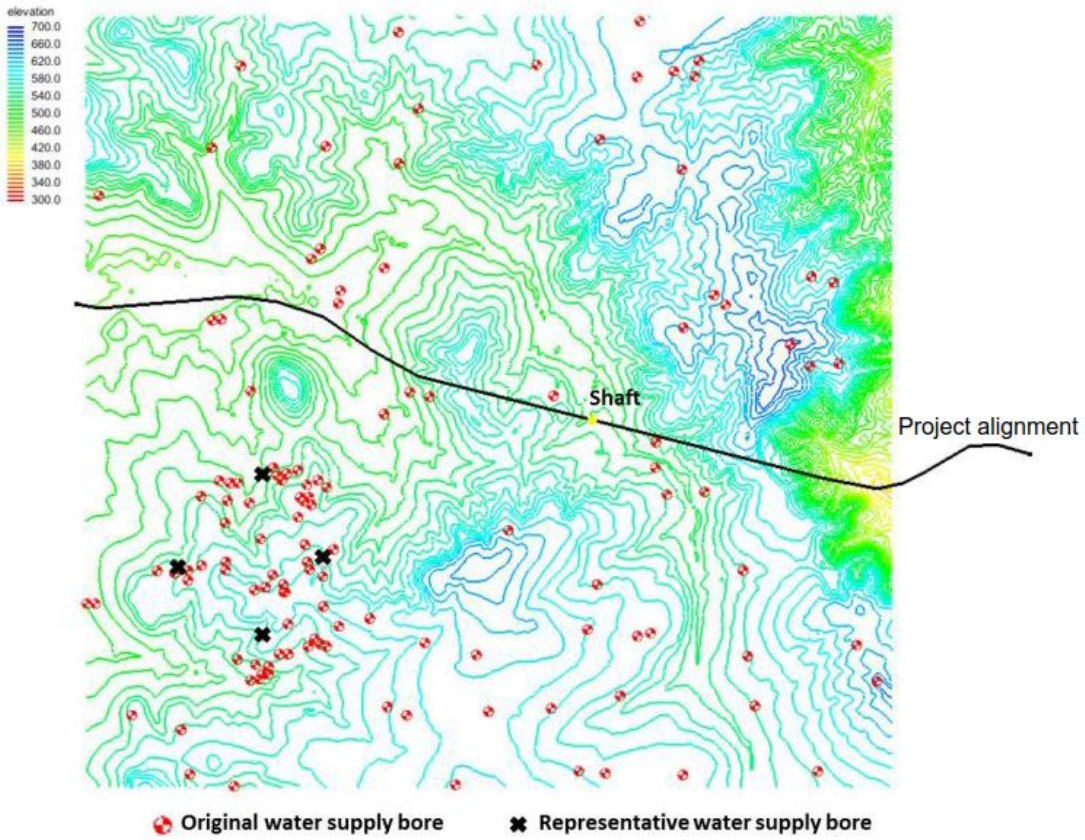


Figure 9.6 **Water supply bore distribution actual (red dots) vs simplified distribution (black crosses)**

9.3.3 Model calibration

The model was calibrated using groundwater level data from Project bores and long-term groundwater monitoring bores in the Queensland Globe database (summarised in Table 9.3). The initial hydraulic conductivity parameters and recharge rates were based on median preliminary hydrogeological design parameters values included in Table 9.3. Specific yield values were not adjusted for calibration as field observations were not available.

Figure 9.7 compares observed and calibrated groundwater level, which shows a good correlation. Figure 9.8 shows calibrated groundwater levels have a reasonable match with observed data in most of the monitoring bores.

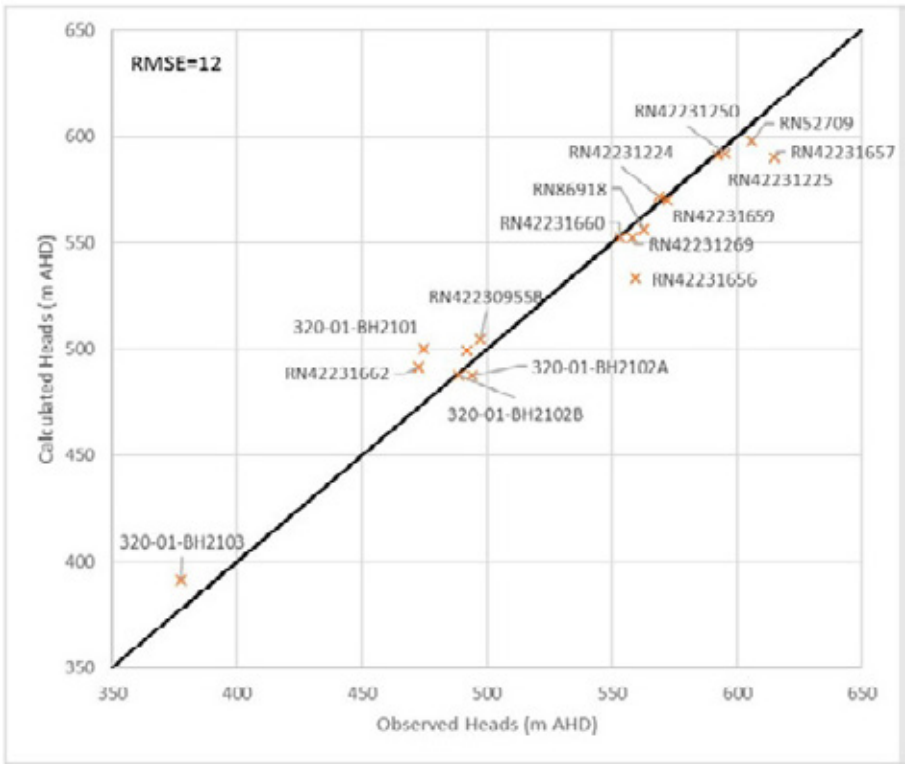


Figure 9.7 **Observed and calibrated groundwater level elevation**

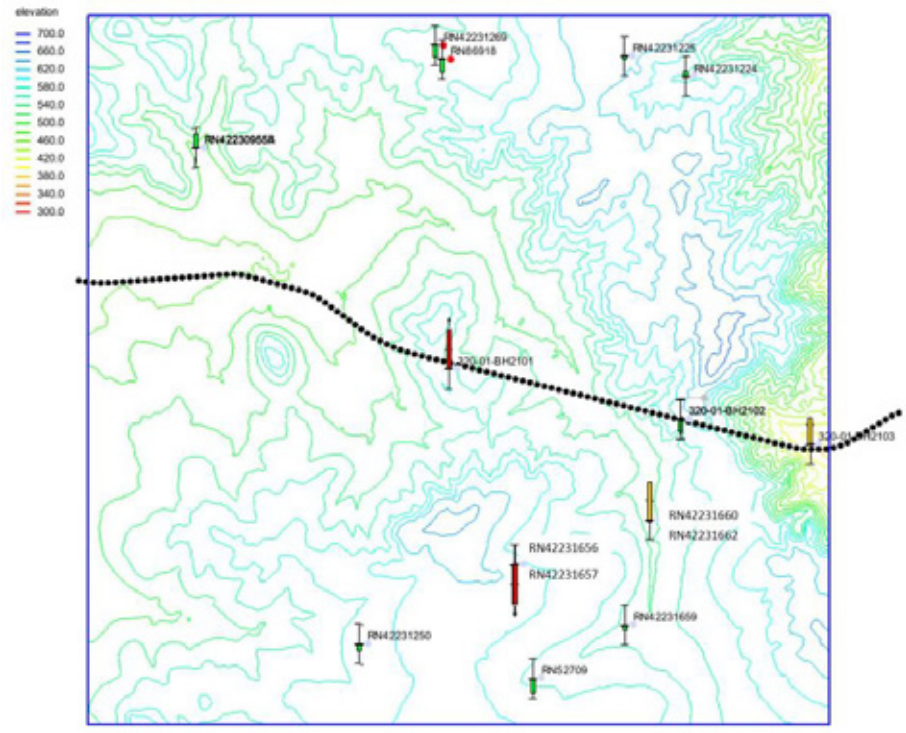


Figure 9.8 **Model calibration results**

Figure notes:

The length of the bar reflects the head difference between observed water level and simulated water level. The colours represent the following:

(1) green bar: head difference from 0 to 10 m
(2) yellow bar: head difference from 10 to 20 m
(3) red bar: head difference more than 20 m.

The assumption of multiple layers with variable hydraulic conductivities in the MRV has successfully reproduced the large water level differences between registered bores RN42231660 and RN42231662 and between RN42231656 and RN42231657. However, groundwater levels in Project bores 320-01-BH2101, 320-01-BH2103 and registered bore RN42231662 have been overestimated by 25, 13 and 19 m respectively. Groundwater levels have been underestimated in registered bores RN42231656 and RN42231657 by approximately 25 m.

Further refinement of the simulated groundwater level for Project bores 320-01-BH2101 and 320-01-BH2103 would require adjusting the geological model and hydraulic conductivity values to allow for spatial variation in hydraulic conductivity however there is insufficient information available to support this.

9.3.4 Hydrogeological design parameters

Hydraulic properties were estimated for input parameters into the MODFLOW models using results from aquifer hydraulic conductivity tests undertaken at Project bores (refer Section 5.3). Hydraulic characteristics of an aquifer define the attributes of the unit which permit groundwater to flow and the likely pathways of flow. There are various methods to ascertain aquifer hydraulic characteristics from a groundwater bore. Hydraulic conductivity tests were undertaken as a component of the feasibility design geotechnical investigation in the form of slug tests (refer Section 5.3).

A slug test is the addition or removal of a known volume of water (a 'slug') from a bore while measuring the recovery of the bore's water level over a period of time. The results of the slug tests performed at Project bores were considered with regional literature values particularly where limited or no tests were performed for a specific hydrostratigraphic unit within the groundwater study area. Each hydrostratigraphic unit is considered in isolation to determine the most accurate value for input into the model. That is, one value for each test (and rock type) was determined from the average value of different interpretations.

As a result of assessment of the relevant literature data and site-specific hydraulic conductivity values, a hydraulic conductivity value was then assigned to each model layer/hydrostratigraphic unit. The typical hydraulic conductivity values selected are the average hydraulic conductivity values from site-specific results based on various interpretations and are considered representative of the unit being modelled within the groundwater study area.

Yield and rainfall recharge values for each aquifer is discussed in detail in Section 7.1 for each aquifer. Table 9.3 presents the preliminary hydrogeological design parameters values.

Table 9.3 Preliminary hydrogeological design parameters

Formation	Hydraulic property	Number of samples	Lower	Mean	Upper
Alluvium	Hydraulic conductivity (m/s)	107	2.6×10^{-4}	6.8×10^{-4}	1.4×10^{-3}
	Vertical hydraulic conductivity (m/s)	Estimate	2.6×10^{-6}	6.8×10^{-5}	1.4×10^{-3}
	Specific yield (L/s)	Estimate	0.05	0.10	0.15
	Rainfall recharge (mm/year)	2,677	3.9	10.7	32.5
MRV	Hydraulic conductivity (m/s)	67	1.3×10^{-7}	1.2×10^{-5}	5.3×10^{-5}
	Vertical hydraulic conductivity (m/s)	Estimate	2.6×10^{-9}	6.0×10^{-7}	2.7×10^{-6}
	Specific yield (L/s)	Estimate	0.01	0.10	0.15
	Rainfall recharge (mm/year)	48	11.3	25.8	41.4
UTS	Hydraulic conductivity (m/s)	16	6.0×10^{-11}	1.0×10^{-9}	4.0×10^{-8}
	Vertical hydraulic conductivity (m/s)	Estimate	6.0×10^{-11}	1.0×10^{-9}	4.0×10^{-8}
	Specific yield (L/s)	Estimate	0.03	0.07	0.12
	Rainfall recharge (mm/year)	-	-	-	-

Formation	Hydraulic property	Number of samples	Lower	Mean	Upper
WCM	Hydraulic conductivity (m/s)	82	1.2×10^{-9}	1.0×10^{-7}	9.1×10^{-6}
	Vertical hydraulic conductivity (m/s)	Estimate	2.4×10^{-12}	1.0×10^{-9}	4.6×10^{-7}
	Specific yield (L/s)	Estimate	0.005	0.035	0.05
	Rainfall recharge (mm/year)	90	1.3	3.5	9.7
Koukandowie Formation	Hydraulic conductivity (m/s)	68	2.9×10^{-8}	1.0×10^{-7}	1.3×10^{-6}
	Vertical hydraulic conductivity (m/s)	Estimate	5.8×10^{-11}	1.0×10^{-9}	6.5×10^{-8}
	Specific yield (L/s)	Estimate	0.015	0.05	0.10
	Rainfall recharge (mm/year)	21	1.6	2.7	5.9
Gatton Sandstone	Hydraulic conductivity (m/s)	92	2.0×10^{-8}	1.7×10^{-7}	1.3×10^{-6}
	Vertical hydraulic conductivity (m/s)	Estimate	4.0×10^{-11}	1.7×10^{-9}	6.5×10^{-8}
	Specific yield (L/s)	Estimate	0.015	0.05	0.10
	Rainfall recharge (mm/year)	242	1.1	3.6	10.2

The hydrogeological parameters used in the model are provided in Table 9.4. The adopted values are based on the model calibration undertaken (discussed in Section 9.3.3).

Table 9.4 Hydrogeological parameters applied in the model based on model calibration

Hydrostratigraphy	Horizontal hydraulic conductivity (m/s)	Vertical hydraulic conductivity (m/s)	Specific yield (L/s)	Vertical modelled layer
MRV	1.2×10^{-5}	6.0×10^{-7}	0.10	Layer 1 – 2
Low conductive MRV layer	1.2×10^{-8}	5.8×10^{-10}	0.10	Layer 3
High conductive MRV layer	4.6×10^{-5}	2.3×10^{-6}	0.10	Layer 4
WCM	1.0×10^{-7}	1.0×10^{-9}	0.04	Layer 5
UTS	1.0×10^{-7}	1.0×10^{-9}	0.07	Layer 5
Crater rim	1.2×10^{-5}	6.0×10^{-7}	0.10	Layer 5
Koukandowie Formation	1.0×10^{-7}	1.0×10^{-9}	0.05	Layer 6 - 11
Colluvium	1.2×10^{-5}	6.0×10^{-7}	0.10	Layer 1 – 5 Eastern Valley

9.3.5 Model assumptions

The main model assumptions, in addition to the approach detailed in Section 9.3.1, are listed below:

- The hydrostratigraphic units of WCM, UTS and crater rim are assumed to be homogenous and transversely isotropic with respect to hydraulic material characteristics.
- Groundwater recharge and maximum evapotranspiration rates were adjusted during initial model calibration resulting in spatially variable recharge rates applied across the model domain surface. The mean recharge rate of the calibrated model is within the range provided in Table 9.3.
- Time discretisation is designed based on the excavation schedule and grid size to accommodate the different excavation, lining requirements and proposed rates of excavation. An increment of 13.39 days was adopted over the first 281 days after the beginning of excavation of the portals, after than an increment of 1.78 days has been adopted to allow simulation of the rates of excavation of the tunnel and the associated ventilation shaft
- The allowable limit on permanent leakage rates through the segmental lining of 0.3 L/s and 0.0062 L/s in total are assumed to be distributed evenly along the tunnel and the associated ventilation shaft, respectively

- The excavation direction for the western tunnel portal and the Toowoomba Range tunnel is from west to east. The mined tunnel and cut and cover are also assumed to be excavation from west to east.
- The Toowoomba Range tunnel excavation rate assumed is 10.5 m per day and 1.7 m per day for the mined tunnel.

9.3.6 Model results

Results of the predictive modelling have been used to evaluate potential impacts on groundwater resources in the groundwater study area. The main potential impact is groundwater drawdown during the construction and operation phase and these are discussed in detail in Section 10.2.1.1 and 10.3.1.1.

9.3.6.1 Groundwater inflow

The groundwater inflow resulting from the Toowoomba Range tunnel design was predicted for short-term (construction phase, up to two years) and long-term (operational phase, 20 years). Predicted long-term (operational) inflow to the tunnel is an average and will vary with season, where dry months can result in lower inflow rates and significant and extended rainfall events can result in higher inflows.

Short-term (construction phase)

The predicted groundwater inflow, over time, from each groundwater unit is shown on Figure 9.9 and the inflow to each tunnel feature is shown on Figure 9.10. The maximum inflow rates to each tunnel feature are summarised in Table 9.5. Total predicted volumes of groundwater inflow for each aquifer have been estimated, for each Water Plan of relevance, to inform of impact on groundwater resources (Table 9.5). Based on water entitlement data (refer Section 7.5.2), the Toowoomba City Basalts sub-area represents the largest volume of allocations in the groundwater study area (3,812.7 ML) compared to the Toowoomba North Basalts (13 ML) and Toowoomba South Basalts (96 95 ML) and that of the Water Plan (GABORA) 2017 (36.5ML/yr) Therefore, it is important to understand the potential impact of groundwater drawdown from the Project on such resources.

The maximum inflow to the tunnel during construction is predicted to be approximately 113.7 L/s (at 107 weeks). This comprises 79.7 L/s due to drainage in the MRV near the advancing face of the TBM portion of the tunnel (where permanent segments are not yet in place) and 34 L/s in the colluvium due to drainage of the mined tunnel.

The maximum predicted groundwater inflows are conservative estimates do not include control measures that may be implemented during construction (conservative approach). This includes measures such as operating the TBM in closed mode or probing and grouting ahead of excavation.

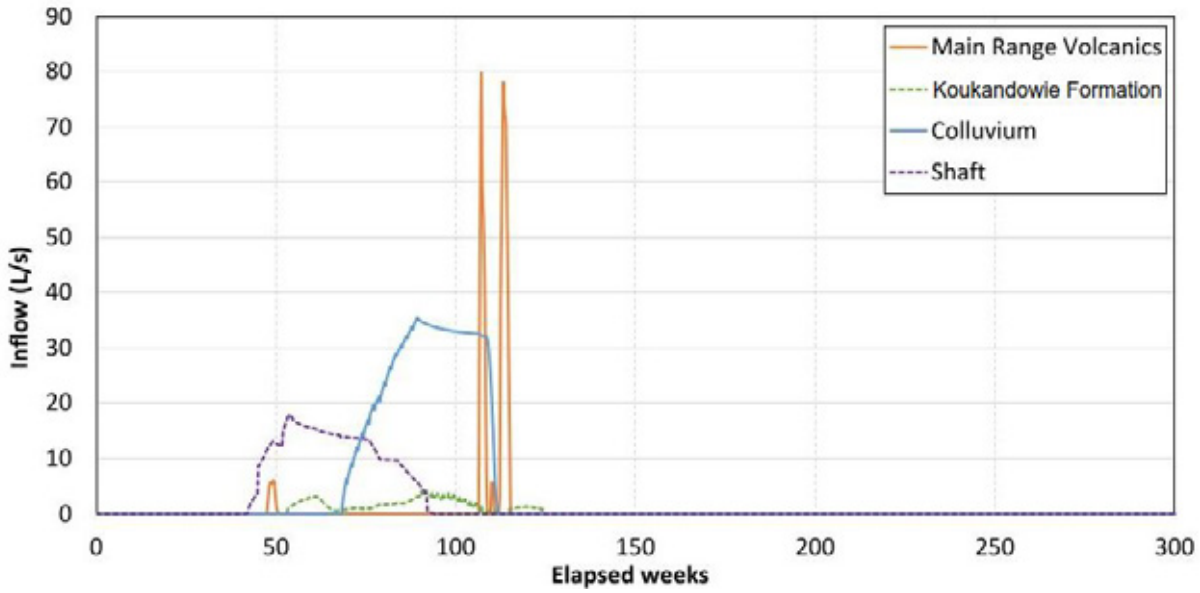


Figure 9.9 **Predicted construction phase groundwater inflow for each unit**

Source: Golder 2020a

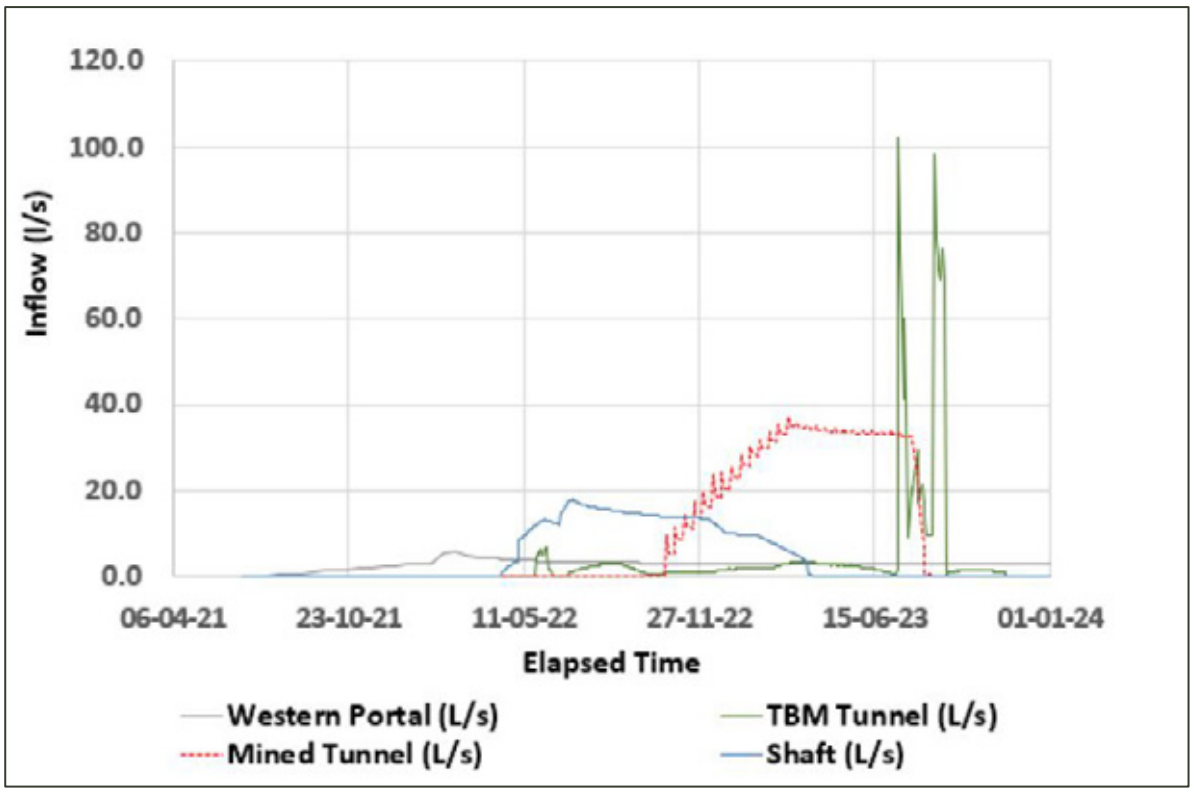


Figure 9.10 **Predicted construction phase groundwater inflow for each tunnel feature**

Source: Golder 2020a

Table 9.5 **Predicted maximum groundwater inflow - construction phase**

Design feature	Chainage (km)		Estimated maximum short-term groundwater inflow (L/s)	Elapsed time of maximum inflow (since excavation commenced) in weeks
	Start	Finish		
Western tunnel portal cut	3.7	4.1	6	31
Toowoomba Range tunnel (TBM)	4.1	9.76	100	107
Toowoomba Range tunnel (mined)	9.76	10.23	37	88
Intermediate ventilation shaft	6.83	6.83	17	58

The construction phase predicted total volumetric take per aquifer by Water Plan and sub-areas is presented Table 9.6.

Table 9.6 Total predicted inflow volumes – construction phase

Water Plan	Management area / unit	Sub-area / unit	MRV inflow (ML)	Koukandowie Formation inflow (ML)	Colluvium inflow (ML)
Water Plan (GABORA) 2017	Hutton Groundwater Unit	Eastern Downs Marburg	-	169.1	-
		Murphys Creek Marburg	-		-
Water Plan (Condamine and Balonne) 2019	Condamine and Balonne Underground Water Management Area	Toowoomba South Basalts limitation area	379.9	-	-
		Toowoomba City Basalts	349.0	-	-
Water Plan (Moreton) 2007	Lockyer Valley Groundwater Management Area	Implementation Area 2B	96.8	-	688.4
Total predicted inflows			825.7	169.1	688.4

Table note:
ML – megalitres

Long-term (operation phase)

Predicted long-term groundwater inflow to the western tunnel portal is 2.6 L/s. The inflow to the tunnel (0.30 L/s) and intermediate ventilation shaft (0.006 L/s) is equal to the allowable limit on permanent leakage, which was applied as a boundary condition in the model.

Total predicted volumes of groundwater inflow for each aquifer have been estimated, for each Water Plan of relevance, to understand the impact on groundwater resources for the operation phase (long-term) of the Project. The total groundwater inflows are presented for a combined 20 years in Table 9.7 and further detail is included in Appendix A.

It should be noted that these estimates are conservative, will be refined for the Final EIS, and do not consider any water control mitigation techniques that are likely to be used for construction such as operation the TBM in closed mode, or any probing and grouting ahead of the excavation.

Table 9.7 Total predicted inflow volumes – operation phase (20 years)

Water Plan	Management area / unit	Sub-area / unit	MRV inflow in ML/yr (ML/20 yrs)	Koukandowie Formation inflow in ML/yr (ML/20 yrs)	Colluvium inflow in ML/yr (ML/20 yrs)
Water Plan (GABORA) 2017	Hutton Groundwater Unit	Eastern Downs Marburg	-	8.8 (175.8)	-
		Murphys Creek Marburg	-		-
Water Plan (Condamine and Balonne) 2019	Condamine and Balonne Underground Water Management Area	Toowoomba South Basalts	76.3 (1,524.8)	-	-
		Toowoomba City Basalts	6.9 (138.3)	-	-
Water Plan (Moreton) 2007	Lockyer Valley Groundwater Management Area	Implementation Area 2B	1.3 (25.6)	-	0.7 (13.5)
Total inflow			84.5 (1,688.7)	8.8 (175.8)	0.7 (13.5)

Table note:
ML – megalitres
The value in parentheses is included in the total for the Condamine and Plan Underground Water Management area of the Water Plan (Condamine and Balonne) 2019.

9.3.6.2 Groundwater level drawdown

Groundwater level drawdown is the lowering of hydraulic head in an aquifer due to construction activities such as tunnelling and cutting as part of the Project. Localised groundwater level drawdown also occurs as a result of groundwater extraction typically via pumping by landholders. The groundwater level drawdown resulting from construction of the Toowoomba Range tunnel and associated design features was estimated based on the groundwater inflow rates modelled in Section 9.3.6.1. Groundwater inflow to the tunnel is a loss to the groundwater unit and this causes the groundwater level in the unit to lower (groundwater drawdown). The modelled groundwater inflow or loss to the overall groundwater unit can provide an indication of groundwater drawdown. Potential impacts related to groundwater drawdown during construction and operations are discussed in Section 10.2.1.1 and 10.3.1.1, respectively. This includes figures illustrating the predicted extent of drawdown based on a 1 m contour threshold.

Each groundwater unit responds differently due to the hydraulic properties of the aquifer and as a result, the following groundwater units were assessed separately:

- Shallow MRV (typical value of hydraulic conductivity)
- Deep MRV (high conductivity layer)
- Koukandowie Formation (shown as the Marburg subgroup - Figure 9.11 through Figure 9.18).

The groundwater level drawdown figures show drawdown contours (e.g. 5 m or 10 m) with registered groundwater bores (1 m drawdown contours are discussed further Sections 10.2.1.1 and 10.3.1.1).

A 5 m drawdown contour the output for the feasibility stage modelling, as depicted in the Figure 9.11 through Figure 9.18.

The 5 m drawdown contour is considered insufficient to conservatively identify all of the potential groundwater users that may be affected by the Project. As such, a 1 m drawdown contour was applied as a conservative approach to identify all potentially impacted groundwater users; these contours are discussed further in Sections 10.2.1.1 and 10.3.1.1. ARTC have committed to refine these model predictions to better understand the impacts on groundwater and their significance; these predictions will be included in the Final EIS (refer Section 9.5).

The contour extent indicates areas where groundwater level drawdown, relevant to the aquifer type may occur. Registered bores within the predicted groundwater drawdown extent in the groundwater study area are provided in Table 10.5 and Section 10.2.1.1. It is acknowledged that not all groundwater bores may be represented in these figures, as outlined in Section 7.5.1.

Detailed discussion for impacts associated with the predicted drawdown are included in Section 10.2 and Section 10.3.

Short-term (construction phase)

The maximum groundwater level drawdown from construction of the western tunnel portal occurs at 34 weeks, the intermediate ventilation shaft at 62 weeks, and the tunnel at 107 weeks.

The maximum groundwater inflow to the western tunnel portal occurs at 34 weeks within the shallow MRV and the associated predicted groundwater level drawdown is shown on Figure 9.11. Groundwater drawdown reaches 5 m and is localised to the western portal.

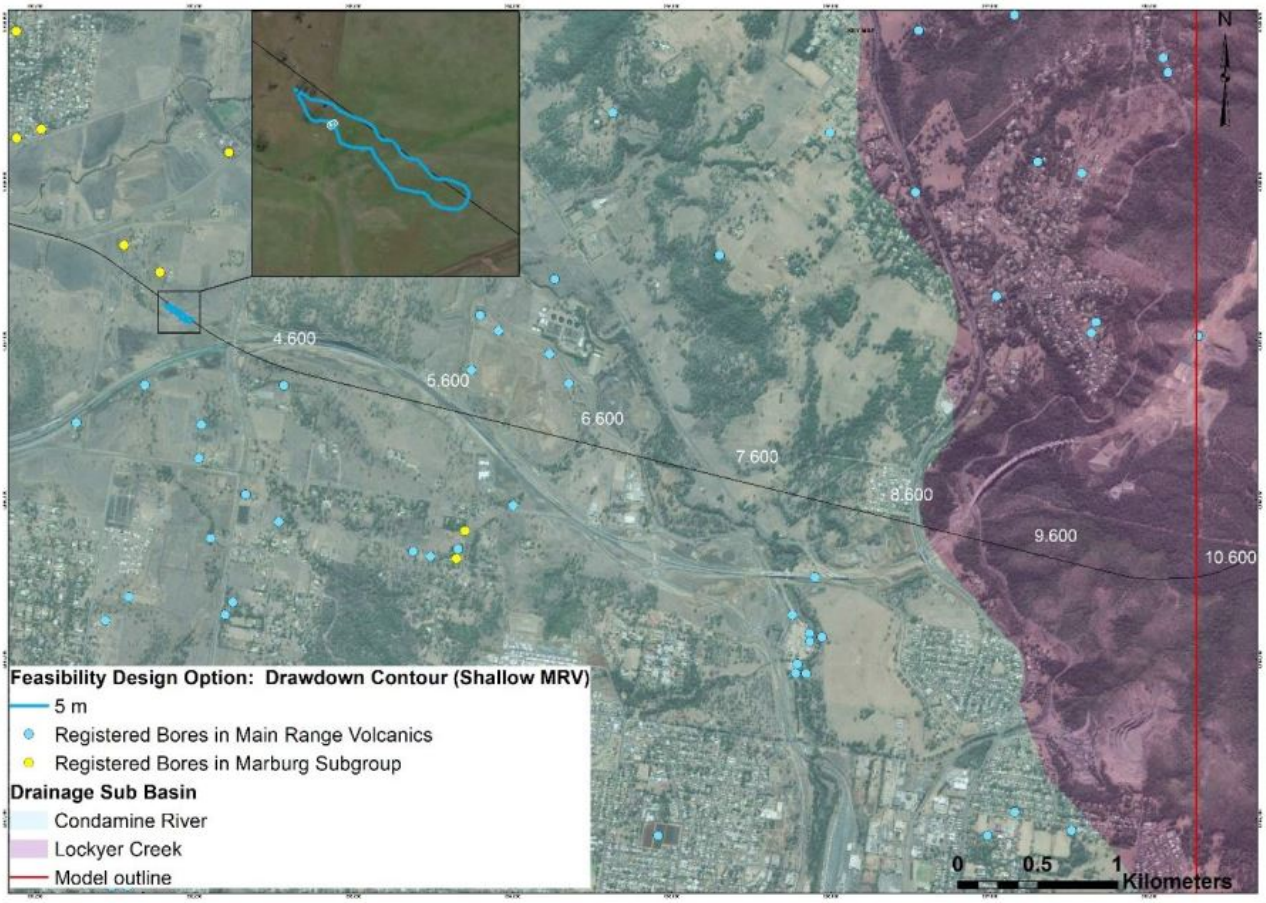


Figure 9.11 Western portal – Modelled groundwater level drawdown at 34 weeks (shallow MRV)

The maximum groundwater inflow to the intermediate ventilation shaft occurs at 62 weeks, which intercepts all modelled aquifers (shallow and deep MRV and Koukandowie Formation). The resulting groundwater level drawdown is shown on Figure 9.12 through Figure 9.14. Groundwater level drawdown is localised to the intermediate ventilation shaft (Ch 6.83 km).

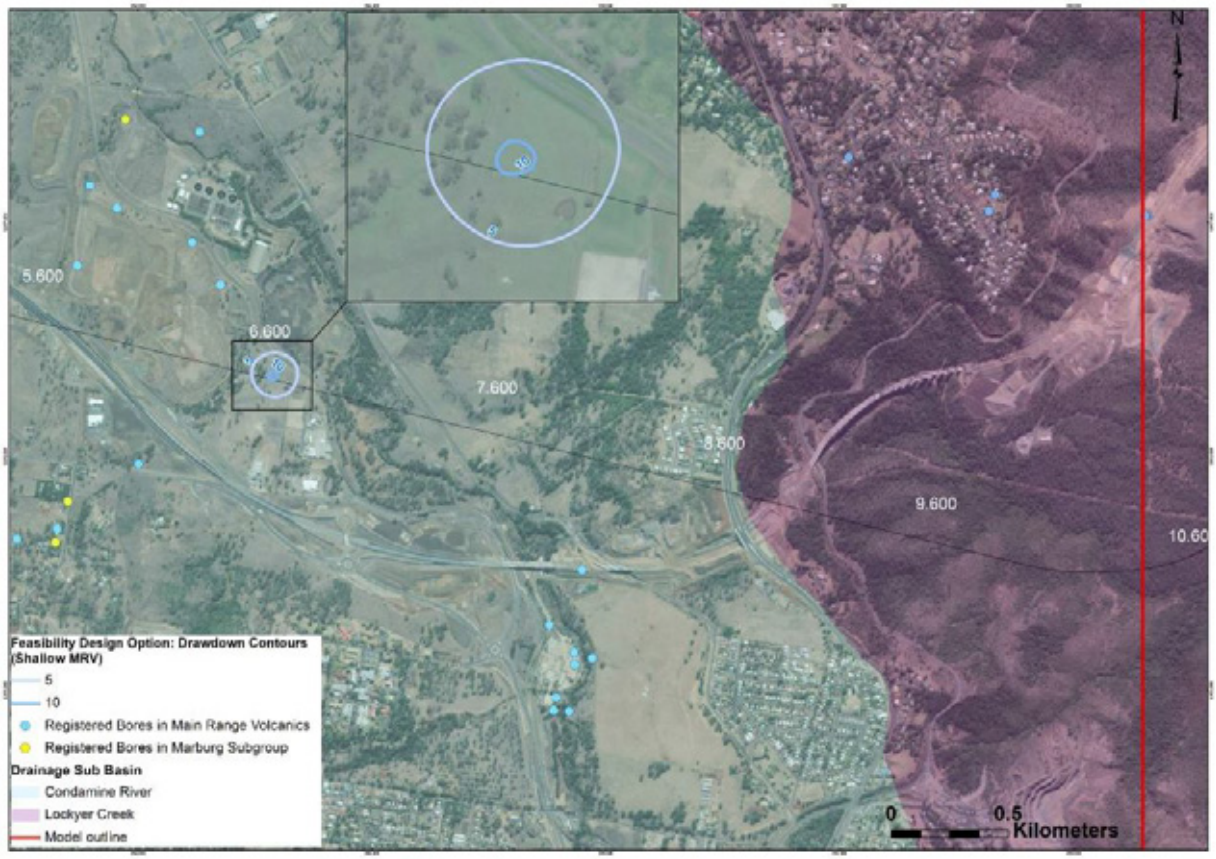


Figure 9.12 **Intermediate ventilation shaft – Modelled groundwater level drawdown at 62 weeks (shallow MRV)**



Figure 9.13 **Intermediate ventilation shaft – Modelled groundwater level drawdown at 62 weeks (deep MRV)**

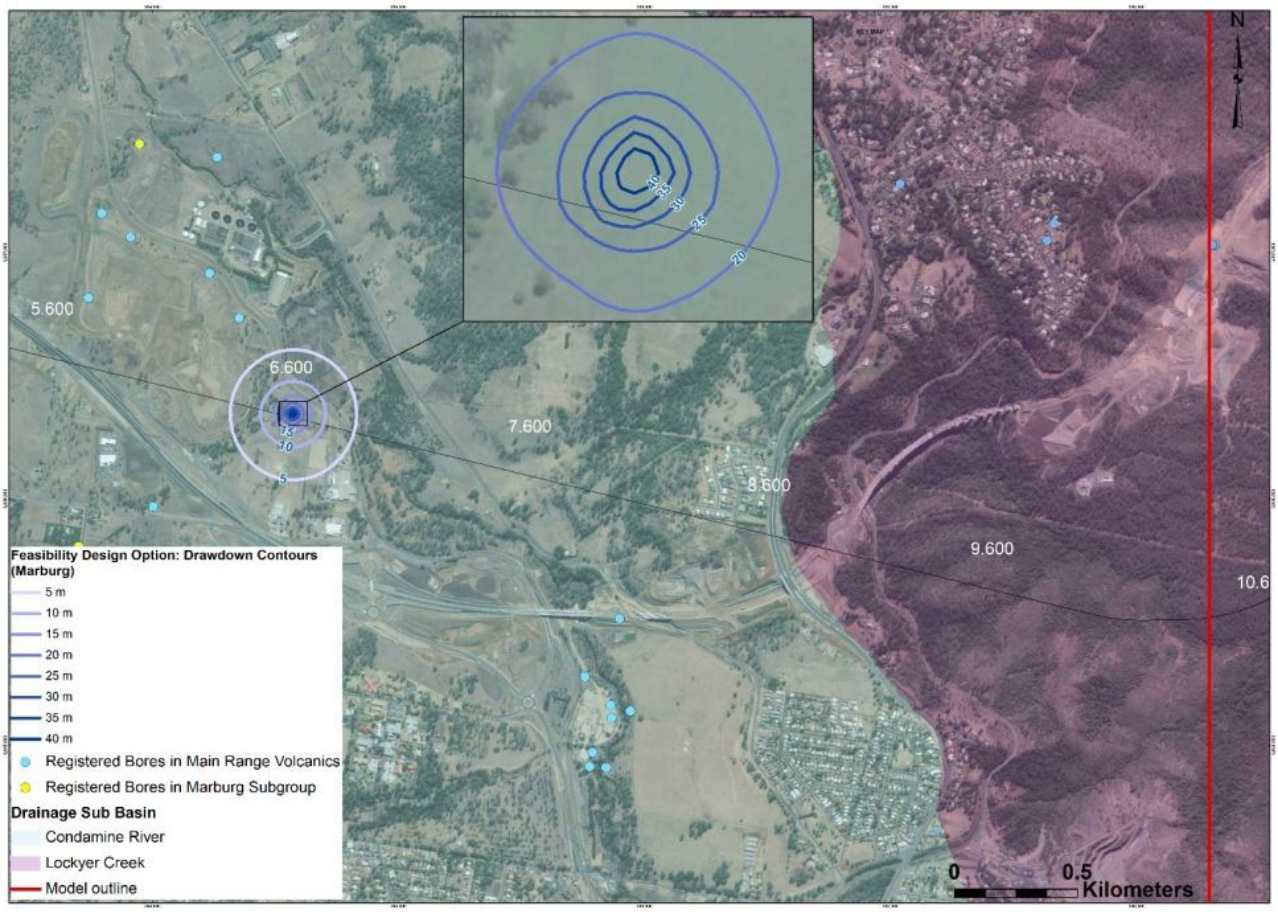


Figure 9.14 **Intermediate ventilation shaft – Modelled groundwater level drawdown at 62 weeks (Koukandowie Formation)**

Groundwater level drawdown during tunnel construction is shown on Figure 9.15 through Figure 9.17. The figures depict groundwater drawdown at approximately 107 weeks, which is when a combined maximum groundwater inflow to the tunnel occurs, due to:

- The mined tunnel (at the eastern end of the tunnel) has been fully excavated
- The TBM tunnel intersects the high permeability MRV
- Induced drawdown of the Koukandowie Formation due to tunnel construction/excavation.

Groundwater level drawdown in the shallow MRV is limited to the shaft and portals at this time. The predicted groundwater drawdown for the deep MRV includes a drawdown of 5 m south of the tunnel within the groundwater study area. The groundwater drawdown predicted for the Koukandowie Formation is most significant, at depths of ~40 m at the tunnel; the drawdown reaches depths up to 5 m at the southern extent of the groundwater study area. The conservative 1 m drawdown predicted impact areas for each unit are presented in Section 10.2 and for the deep MRV and Koukandowie, include an area outside of the groundwater study area, south of the tunnel.

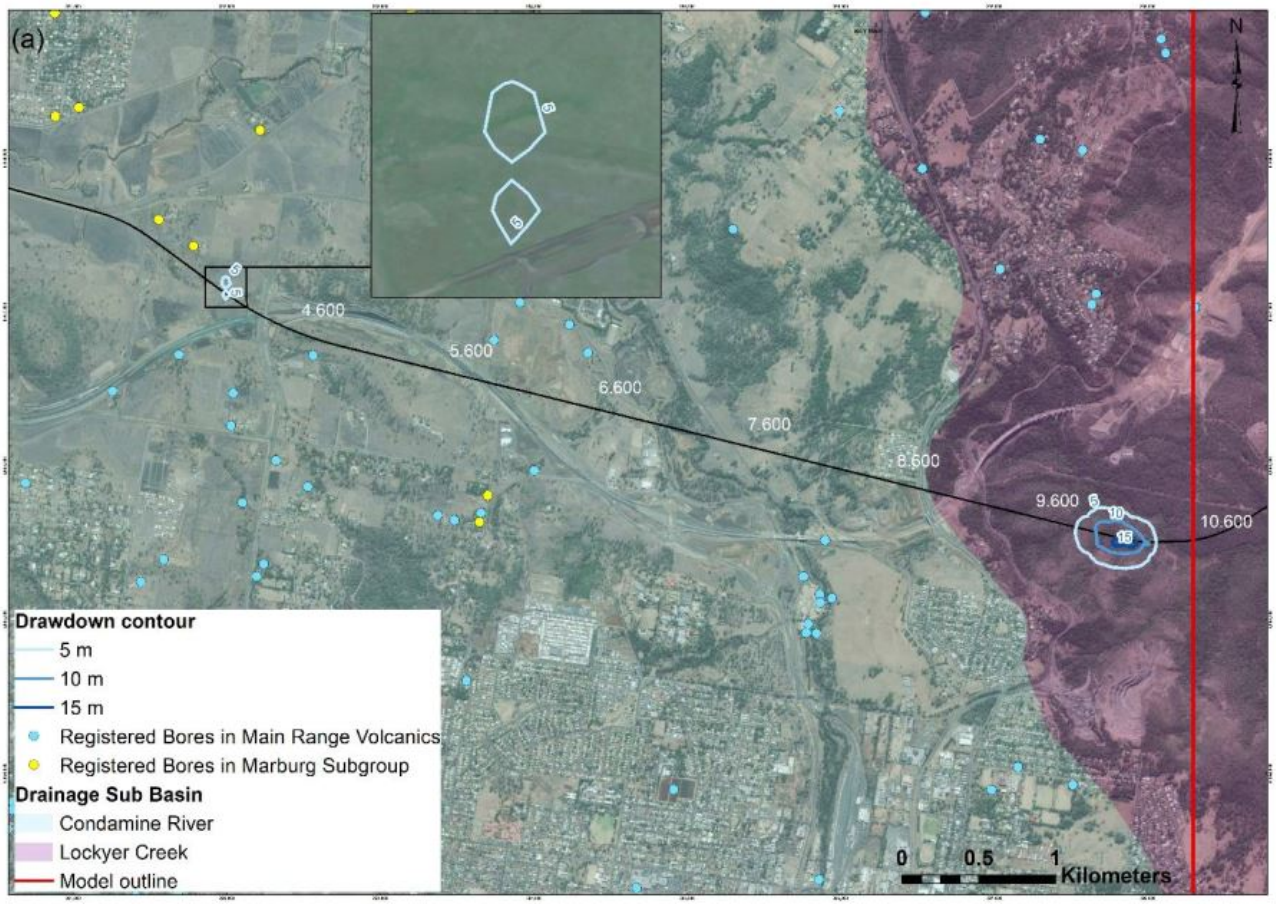


Figure 9.15 **Modelled groundwater level drawdown at 107 weeks (shallow MRV)**

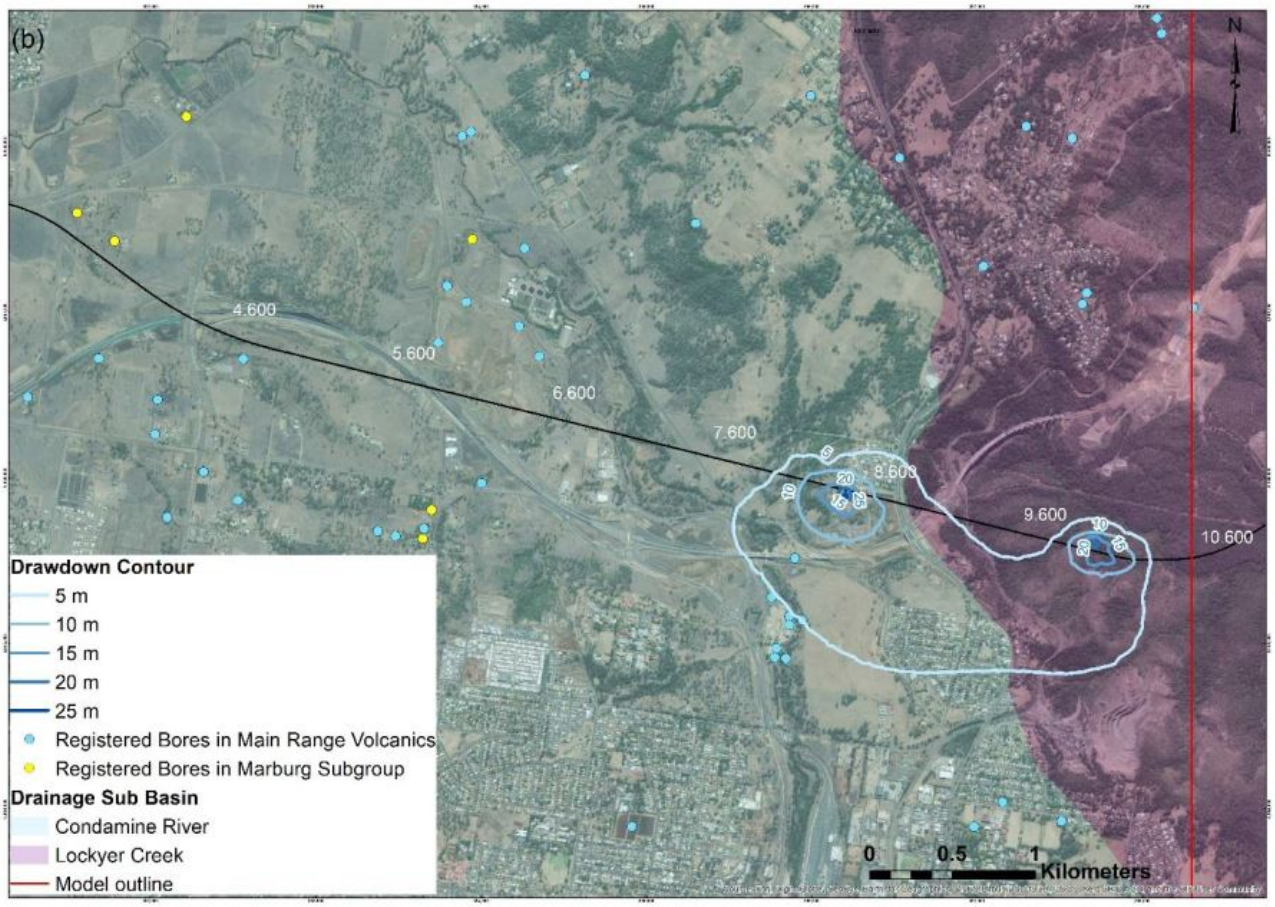


Figure 9.16 **Modelled groundwater level drawdown at 107 weeks (deep MRV)**

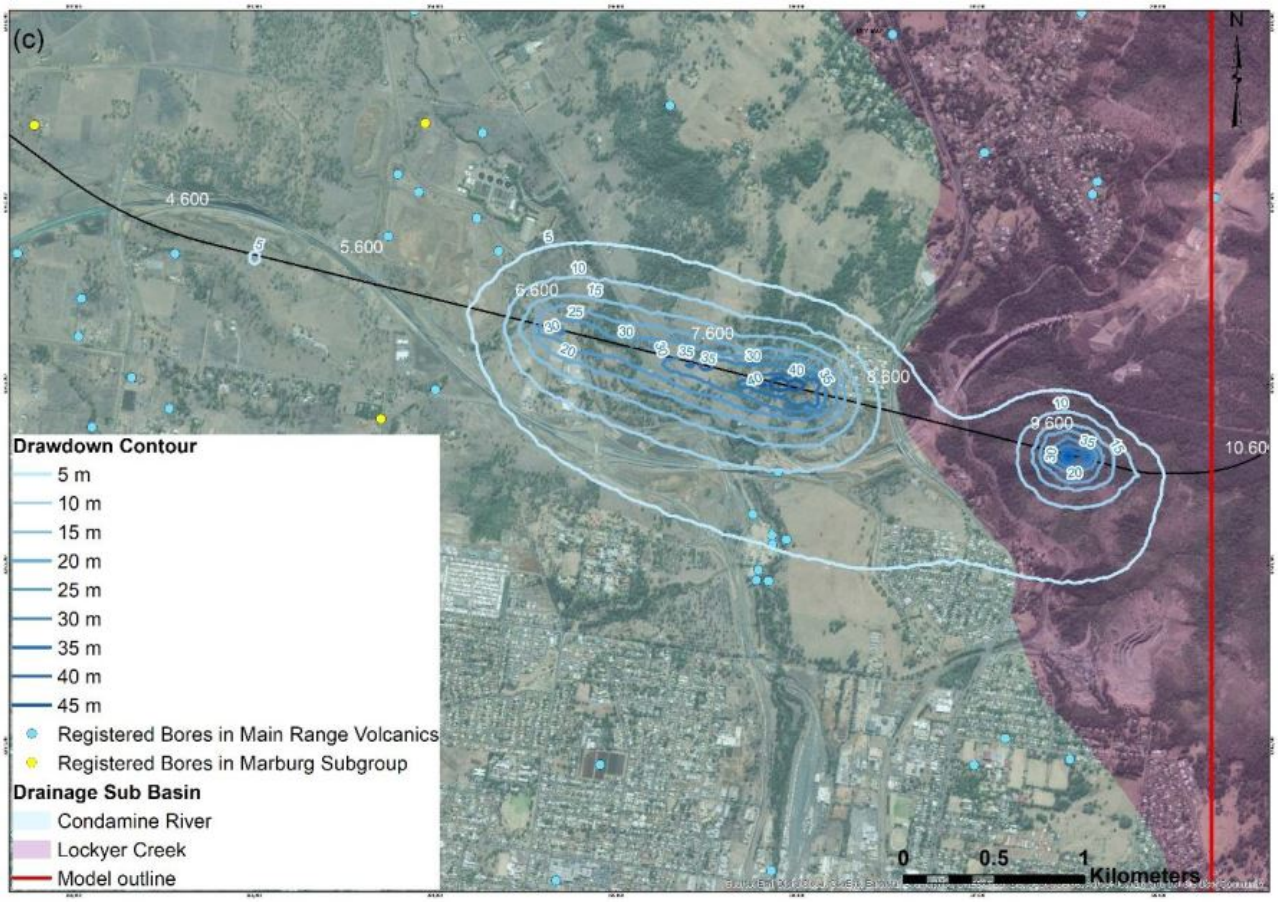


Figure 9.17 **Modelled groundwater level drawdown at 107 weeks (Koukandowie Formation)**

Long-term (operation phase)

The long-term predicted groundwater level drawdown (modelled as 20 years elapsed time) is depicted on Figure 9.18 and is negligible across all groundwater units. Groundwater drawdown is predicted to be limited to the western portal and along the tunnel, within the Project disturbance footprint. The maximum predicted drawdown of 5 m (shallow MRV) is limited to the western portal due to its drained design. No long-term impact on the deep MRV is predicted; this unit is anticipated to recover after construction is complete. The long-term groundwater level drawdown is expected to recover along the tunnel alignment, except at the drained western portal, as the tunnel is designed as undrained.

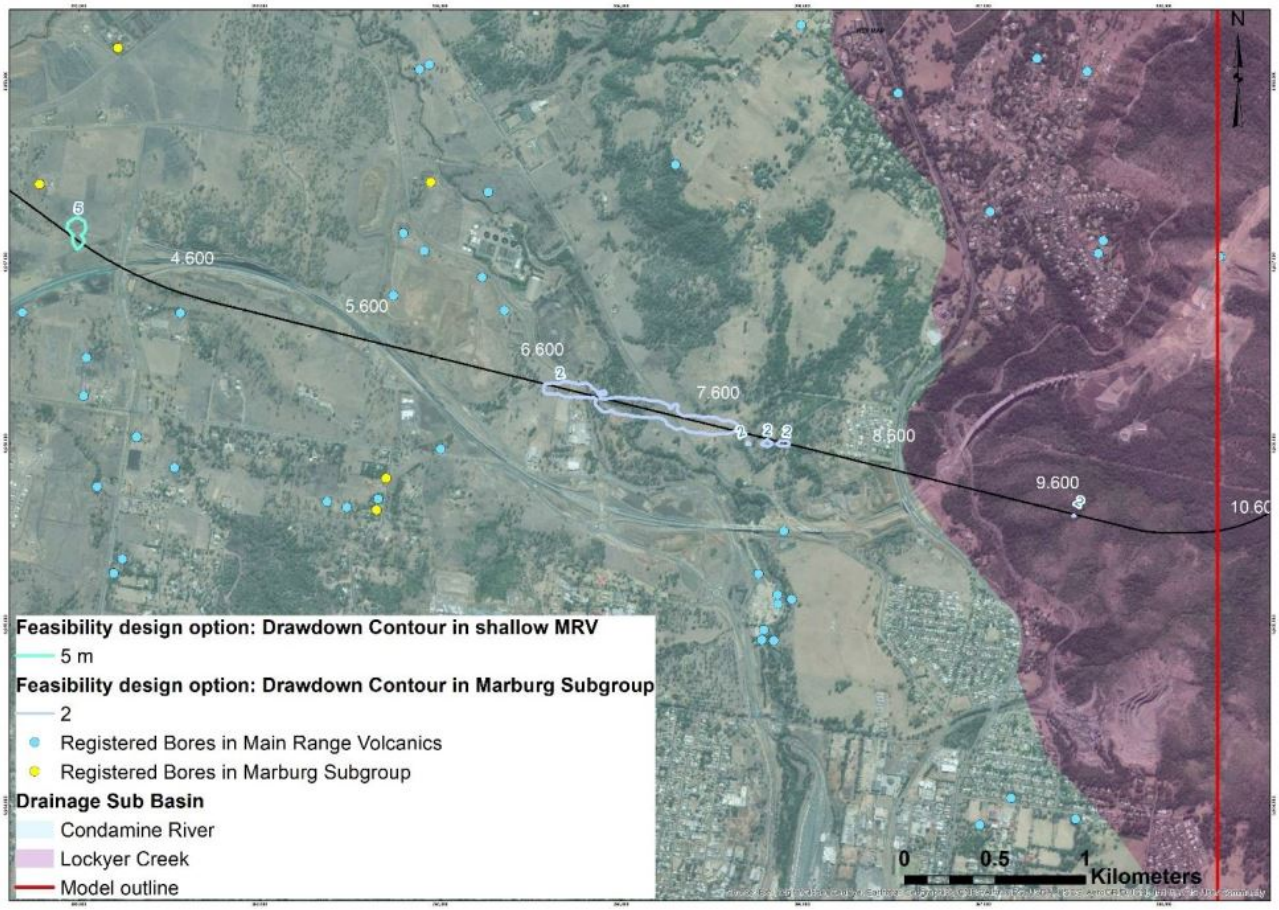


Figure 9.18 **Predicted operation phase (elapsed 20 years) groundwater level drawdown (green is shallow MRV; gray is Koukandowie Formation)**

9.3.6.3 Groundwater quality of inflows to Toowoomba Range tunnel

Groundwater quality of inflows was assessed using data from the Queensland Globe database along the tunnel (Ch 2.4 km and Ch 11.45 km and within 4 km of the tunnel centreline). Groundwater quality results indicate:

- Groundwater in the MRV is fresh to brackish (TDS ranging between 194 and 2,730 mg/L)
- Groundwater in the Koukandowie Formation is fresh (TDS ranging between 474 and 1,071 mg/L)
- Groundwater across the MRV and Koukandowie Formation is slightly alkaline (pH ranging between 7.8 and 8.1)
- Metals concentrations are low across the MRV and Koukandowie Formation.

Project specific data was obtained from Project bore 320-01-BH2201, screened in the Koukandowie Formation (below an alluvial unit), indicate groundwater is brackish (calculated TDS of 1,700 mg/L) and slightly alkaline (pH of 8.04).

Based on available groundwater quality data (including Project bores and the Queensland Globe database), the quality of inflows to the Toowoomba Range tunnel, portals, and associated cuts during construction and operation is expected to be fresh to brackish, sodium-chloride dominant and neutral to slightly alkaline (refer Section 7.3). Water quality is expected to vary seasonally due to rainfall infiltration (dilution effect) and a first flush (higher concentrations of analytes) after the dry season. Further, the geology and hydrogeology of the Project area and key units being intersected (refer Section 6.2 and 7.1) are anticipated to comprise variable quality in at least the MRV. Recently completed geotechnical and hydrogeological investigations (Golder 2020c/d) indicate groundwater quality in proximity to the tunnel is consistent with the concentrations above. The results of the post-feasibility investigations will be presented in the Final EIS.

9.3.7 Sensitivity analysis

A sensitivity analysis was undertaken to account for the effects of structural features and parameter sensitivity on groundwater inflow and drawdown predictions. A sensitivity analysis determines how different values of an independent variable affect a particular dependant variable under a given set of assumptions. In context of the predictive groundwater model for the Project, the sensitivity analysis can identify sources of uncertainty in the model so that parameters can be refined as further data becomes available (e.g. following further field investigations). A summary of approach and outcomes is discussed below; further details can be found in Appendix A.

Two scenarios, defined in Table 9.8, were applied to the existing groundwater model for the sensitivity analysis. Structural features were not considered in the sensitivity analysis because the final lining of the tunnel will be installed during construction.

Table 9.8 Sensitivity analysis scenarios

Scenario number	Definition	Details
1	Applying preliminary hydrogeological parameters	Refer to Table 9.3
2	Increasing hydraulic conductivity in the MRV	Increasing the horizontal hydraulic conductivity of the low conductive layer in the MRV to 1.2 x 10^{-6} m/s (increased by one order of magnitude).
3	Increasing hydraulic conductivity in the Koukandowie Formation	Increasing the hydraulic conductivity in the Koukandowie Formation for the upper layer applied in the model (the layer the Toowoomba Range tunnel is intercepted) to the upper limit of 1.0 x 10^{-6} m/s.

9.3.7.1 Sensitivity analysis of groundwater inflow

Sensitivity analysis of predicted groundwater inflow was undertaken for the construction and operation phases (elapsed time of 20 years). A summary is provided below and further discussion is provided in Appendix A.

Short-term (construction phase)

Construction phase sensitivity analysis was undertaken and the maximum groundwater inflow to the tunnel was assessed (refer Table 9.9). The analysis suggests there is limited impact to groundwater inflow to the tunnel when the preliminary hydrogeological parameters are applied (Scenario 1). Increasing the hydraulic conductivity in the low conductivity MRV (Scenario 2) has the most significant impact and increases inflow to the TBM portion of the tunnel by 21 per cent and to the intermediate ventilation shaft by 101 per cent.

Table 9.9 Construction phase sensitivity analysis of groundwater inflow (maximum results)

Scenario	Maximum short-term groundwater inflow in L/s [% difference to design option in Table 9.5]			
	Western tunnel portal cut	Toowoomba Range tunnel (TBM)	Toowoomba Range tunnel (mined)	Intermediate ventilation shaft
Design (Table 9.5)	6.0	100	37	17
1	5.7 [-5]	102.1 [+2]	32.9 [-11]	15.2 [-11]
2	8.5 [+42]	121.4 [+21]	42.7 [+15]	34.1 [+101]
3	2.5 [-58]	23.8 [-76]	31.9 [-14]	12.3 [-28]

Long-term (operation phase)

Operation phase sensitivity results (Table 9.10) suggest there is no impact to groundwater inflow when preliminary hydrogeological parameters are applied (Scenario 1). Increasing the hydraulic conductivity in the MRV (Scenario 2) has the most significant impact to groundwater inflow and increases inflow to the western tunnel portal by 77 per cent. Increasing the groundwater inflow to the Koukandowie formation (Scenario 3) marginally decreases the groundwater inflow at the western tunnel portal.

Table 9.10 Operation phase sensitivity analysis of groundwater inflow

Scenario	Long-term groundwater inflow (elapsed time of 20 years) in L/s [% difference to design option in Section 9.3.6.1)		
	Western tunnel portal cut	Toowoomba Range tunnel	Intermediate ventilation shaft
Design (refer Section 9.3.6.1)	2.60	0.30	0.006
1	2.6 [0]	0.30 [0]	0.006 [0]
2	4.6 [+77]	0.30 [0]	0.006 [0]
3	2.5 [-4]	0.30 [0]	0.006 [0]

9.3.7.2 Summary

Groundwater level drawdown was assessed for sensitivity analysis scenario 2 and 3 as they have the most significant impact on groundwater inflow. Increasing hydraulic conductivity in the MRV and Koukandowie Formation significantly increases the groundwater drawdown depth and extent in the deep MRV and Koukandowie Formation during construction. There is limited impact on long-term groundwater drawdown extent.

9.3.8 Model limitations

The limitations of the groundwater model used for estimating tunnel and portal cut inflows and drawdown of the groundwater table include:

- The materials have been assumed to be saturated only. The effects of variability in saturation of soil and rock on groundwater flow and recharge have been neglected however this is a conservative assumption.
- The low conductivity confining layer in the MRV that has been interpreted as being laterally extensive in the model and may not be present in some areas, which could significantly affect the inflow and drawdown due to tunnel drainage
- The tunnel design indicates the eastern section of tunnel (between Ch 8.6 km and Ch 8.9 km) is likely to encounter crater rim materials. The information about the extent and the hydrogeological properties of crater rim is very limited.

9.3.9 Model reliability

The sensitivity analysis suggests applying preliminary hydrogeological parameters to the model (refer Table 9.3) has limited impact to groundwater inflow. Increasing the hydraulic conductivity of the MRV and Koukandowie Formation has the most significant impact and governs the groundwater inflow rates to the tunnel and associated features. The hydraulic conductivity values applied in the model were determined using available monitoring data and literature values and the model was then calibrated based on available groundwater level, recharge and yield values (refer Section 9.3.3). The calibration indicated good comparison between modelled and observed groundwater level.

Based on the model calibration and sensitivity analysis, the aquifer parameters applied in the model are considered representative of the units encountered by the tunnel. Further, the groundwater model is used as a tool to enhance the design and is expected to be refined in the detailed design phase (as more data is made available based on field investigations). The groundwater model is considered an adequate tool for the purpose of the feasibility design. However, post-feasibility design phase investigations will be utilised to update the conceptual models (refer Section 9.2) and refine the simulations resultant from the predictive model for the Final EIS (refer Section 9.5).

9.4 Groundwater inflow to cuts along the alignment

The Project includes various cuts, embankments and bridges/viaducts which will cut into various groundwater units. This will create groundwater flow pathways and potentially cause groundwater seepage. The Project proposes 14 cuts, 15 embankments and 13 bridges (including two road bridges) (details provided in Table 9.11). The cut lengths range between 90 and 870 m and embankment lengths range between 160 and 1,550 m. Bridges and viaducts totalling approximately 6.7 km in length are proposed to traverse the floodplains of Lockyer Creek and the bridge length ranges between 24 m and 1,840 m.

Groundwater inflow to cuts along the alignment were estimated using an analytical solution based on the following the assumptions:

- Slope cuts are permanently drained
- Geological material is homogenous and isotropic
- Rock below the bottom of the slope cut is impermeable
- Groundwater recharge is not included in this analysis
- Analysis is based on typical values of hydrogeological design parameters (refer Table 9.4)
- Each cut is divided into 10 m intervals for calculation.

9.4.1 Methodology

Groundwater seepage from the proposed alignment cuts were estimated using the method described by Nguyen and Raudkivi (1983). The approach is based on a Laplace type formulation based on the Dupuit–Forchheimer assumption and provides estimation of the phreatic surface and the flow rate as a function of time. The Laplace formulation is based on steady state boundary conditions in an aquifer. The Dupuit-Forcheeimer assumption states that groundwater flows horizontally in an unconfined aquifer and that the groundwater discharge is proportional to the saturated aquifer thickness. This assumption requires that the water table is relatively flat, and that groundwater is hydrostatic (equipotential lines are vertical). This work was published in the 1800s by Dupuit and Frochheimer. A schematic of the Dupuit-Forchheimer assumption is shown as Figure 9.19. Seepage was calculated using inferred groundwater levels at 10 m intervals along the length of each cut.

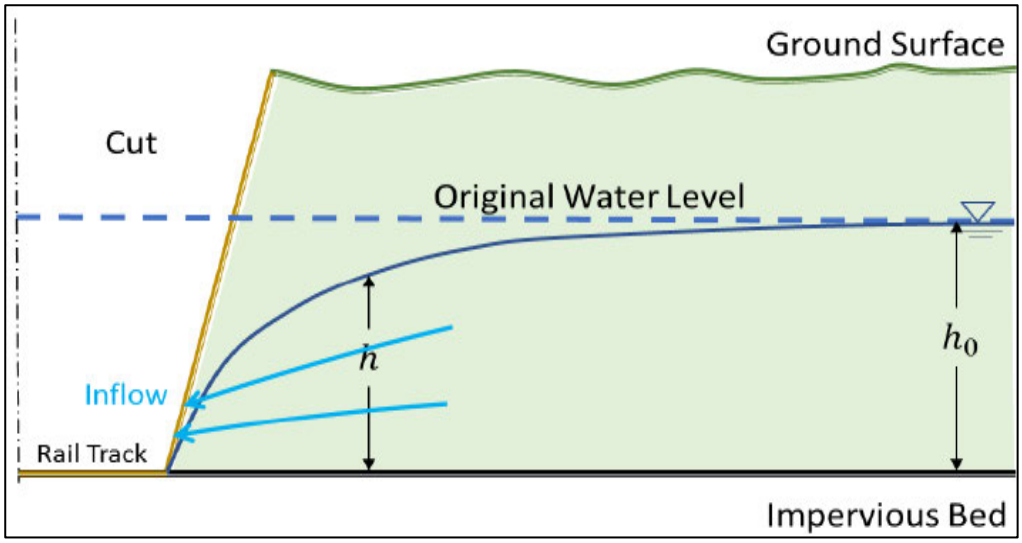


Figure 9.19 **Seepage flow analytical model for cuts along the Project where h_0 is the undisturbed (ambient) piezometric water level and h is the piezometric head**

Source: Golder 2020a

9.4.2 Model cuts

There is a total of 14 proposed deep cuts (greater than 10 m deep) along the alignment and eight deep cuts are expected to intercept groundwater (the eight cuts are summarised in Table 9.11). The western tunnel portal was modelled part of the Toowoomba Range tunnel (refer Section 9.3) and the remaining deep cuts were modelled using the method described by Nguyen and Raudikivi (1983).

Table 9.11 **Project cuts modelled**

Location	Cut ID	Chainage (km)	Aquifer	Closest watercourse/Project bore (distance to alignment)	Cut length (m)
Western tunnel portal cut[a]	320-C3	3.61	MRV	Gowrie Creek (690 m) BH2101 (1,870 m)	490
Eastern tunnel portal cut	320-C4	10.34	Colluvium	Gowrie Creek (2,040 m) BH2102 (1,500 m) BH2103 (300 m)	60
Cuts along the alignment	320-C5	10.57	Koukandowie Formation	Gowrie Creek (2,400 m) BH2103 (100 m)	310
	320-C6	11.16	Koukandowie Formation	Gowrie Creek (2,940 m) BH2103 (660 m) BH2201 (680 m)	430
	320-C9	14.07	Koukandowie Formation	Rocky Creek (520 m) BH2203 (250 m)	30
	320-C10	14.33	Koukandowie Formation	Rocky Creek (500 m) BH2203 (460 m)	1,390
	320-C11	17.56	Koukandowie Formation	Six Mile Creek (770 m) BH2302 (230 m)	260
	320-C12	19.41	Gatton Sandstone	Six Mile Creek (1,250 m) BH2209 (490 m)	260

Table note:

a. Modelled as part of the Toowoomba Range tunnel (refer Section 9.3)

The primary objectives of the predictive modelling include:

- Assess potential groundwater drawdown due to drainage of cuts
- Estimate groundwater seepage rates for cuts
- Assess groundwater quality parameters to inform the design for earthworks, bridges, viaducts and cuts
- Assess changes in flow regime and potential impacts to water resources in the region.

The model was set up to represent the range of hydrogeological conditions expected during Project development. A summary of the modelled cut locations and the corresponding design details is presented in Table 9.12.

Table 9.12 Design details of modelled cuts

Cut ID	Location along rail alignment (Ch km)	Median centreline elevation along cut (m AHD)	Average cut depth (m)	Maximum cut depth (m)	Median groundwater elevation at cut (m AHD)	Estimated depth of cut below the median groundwater elevation (m)
320-C3[a]	3.61	492.0	15.2	20.1	499.6	7.6
320-C4	10.25	393.6	20.6	70.1	410.7	17.1
320-C5	10.58	387.4	10.6	22.7	388.4	1
320-C6	11.17	377.3	14.7	31.6	388.7	11.4
320-C9	14.08	335.3	4.2	23.3	338.1	2.8
320-C10	14.33	321.9	15.1	28.0	330.4	8.5
320-C11	17.52	279.7	27.4	45.3	301.1	21.4
320-C12	19.35	251.7	11.7	24.3	257.3	5.6

Table note:

a. Modelled as part of the Toowoomba Range tunnel (refer Section 9.3)

9.4.3 Modelled seepage rate results

The seepage rate estimate for each deep cut is provided in Table 9.13. Modelled seepage rates indicate there is limited seepage into deep cuts (less than 0.1 L/s). Seepage from cuts will likely report to cess drains, which are surface drains located to the side of the tracks

Table 9.13 Estimated seepage rates for cuts likely to intersect groundwater

Cut ID	Geology	Total seepage rate: 1 year after construction (L/s)	Total seepage rate: long term (elapsed 20 years) (L/s)
320-C4 (eastern tunnel portal)	Colluvium	<0.1	<0.1
320-C5	Koukandowie Formation	<0.1	<0.1
320-C6	Koukandowie Formation	<0.1	<0.1
320-C9	Koukandowie Formation	<0.1	<0.1
320-C10	Koukandowie Formation	<0.1	<0.1
320-C11	Koukandowie Formation	<0.1	<0.1
320-C12	Gatton Sandstone	<0.1	<0.1

The median estimated groundwater level at each cut (refer Table 9.12) is below the base elevation, excluding C12, where the median groundwater level is estimated to be approximately 1 m above the base of the cut.

Regional groundwater levels may rise temporarily above the base of the cut as a result of groundwater level fluctuations in response to rainfall patterns. In addition, water which infiltrates following large rainfall events may form temporary perched groundwater systems adjacent to cuts which result in temporary inflows, particularly through rock joints in relatively more permeable horizons overlying lower permeability perching units. For cuts located in the Koukandowie Formation and the Gatton Sandstone, temporary inflows as a result of either an increase in the regional groundwater level and/or the formation of temporary perched systems are likely to be less than 1 L/s at their peak, with the duration of inflow from these temporary perched systems likely to be less than 1 month.

For the eastern tunnel portal and adjacent cut and cover tunnel, the excavation will be in the colluvium, within the Koukandowie Formation and the Gatton Sandstone units located at the base of the excavation or at shallow depth below the excavation. The colluvium is interpreted to have a significantly higher hydraulic conductivity than the Koukandowie Formation and the Gatton Sandstone, and thus there is potential for greater inflow as a result of temporary increases in regional groundwater level than for cuts in less permeable formations. The groundwater level observed in the area of the eastern tunnel portal in borehole BH2016 was approximately 2 m below the base of the excavation between September and December 2019. The groundwater level during this period is likely to be below the long-term median groundwater level due to characteristically low rainfall received prior to and during the sampling period.

Based on local topography and subsurface geology and likely high specific yield of the colluvium, it is predicted that the long-term median groundwater level is unlikely to be above the base of the excavation. As a result, the long-term inflow is expected to be low despite the high hydraulic conductivity of colluvium. Temporary inflows following increases in groundwater level due to rainfall are estimated to be, at their upper limit, in the range of 2 to 5 L/s. These peak inflows would be of relatively short duration (potentially up to a month). However temporary inflows are likely to continue at decreasing rates over longer periods than in formations with lower storage capacity due to the relatively high specific yield of the colluvium.

9.4.3.1 Groundwater quality of seepage

Groundwater quality of seepage was assessed by analysing data from the Queensland Globe database (655 records assessed in total) and Project borehole 320-01-BH2201 (located at Ch 11.9 km between Cut 320-C6 and 320-C7). The groundwater quality data indicates groundwater seepage salinity could range from fresh to brackish with salinity ranging between 118 and 12,500 µS/cm. Groundwater quality at Project bore 320-01-BH2201 is brackish (2,640 µS/cm and TDS of 1,700 mg/L) and slightly alkaline (pH value of 8.04).

Estimated inflow rate for cuts in rock is generally low (less than 0.1 L/s or less than 9 kL/day) and consequently evaporative deposition of salt could occur on batters and at the base of cuts.

9.4.4 Model limitations

The following limitations of this method are noted:

- The assumption of an impervious bed below the rail track may result in lower flow rate estimates
- The analytical solution does not account for rainfall effects on seepage rate, where periods of low rainfall will result in lower seepage and extended periods of high rainfall will result in higher seepage rates
- Structural features have not been included in this analysis; this could potentially increase the seepage rate as structure features can potentially be a conduit for groundwater inflow
- Seepage from perched groundwater has not been included in the analysis, which can potentially increase the seepage rate if perched groundwater is encountered at a cut.

9.5 Refinement of the predictive model

It is recognised that the existing numerical groundwater model was specifically developed to assess the feasibility design. The resultant Class 1 model was utilised to undertake an assessment of the potential groundwater impacts (related to the feasibility stage). This approach (model classification) was considered sufficient as a starting point for the Project based on the approach that a higher classification model would be developed as more site-specific data is collected and used (Barnett, et al, 2012).

To provide further confidence in ARTC's groundwater impact assessment, allowing for optimum impact avoidance, mitigation, or management, a robust approach for the refinement of the potential groundwater impact assessment of the Project has been developed. It is recognised that there are limitations to the existing model predicted 1-m drawdown contours that are extensive in the model domain such that they are considered to be an overestimation of the impact, and unlikely to present in real life.

A staged-approach has been developed to ensure the correct scientific development, refinement of model parameters (boundaries and layers), and peer review. This approach will promote a new integrated surface water - groundwater model that is fit-for-purpose to assess potential impacts on groundwater resources and users that can be updated as new information becomes available. The envisaged stages to construct and calibrate a robust predictive integrated surface water - groundwater model for inclusion in the Final EIS, which will assess the detailed Project design, include:

1. Review and assessment of all geological and hydrogeological data, (site-specific, more regional, point source and transitional (since 2018)), from the ongoing geotechnical and hydrogeological investigations
2. Review, assess, and refine the existing conceptual groundwater model with all of the available data, including structural geology (faults, geotechnical parameters with depth, etc.)
3. Collaborate with key stakeholders on approach
4. Construct a new integrated surface water - groundwater predictive model and simulate scenarios to refine the predicted impacts in this report.

FFJV propose to incorporate pilot points into the predictive model at various distances from the tunnel, based on available long-term hydrographs, across the extent of the model domain. This approach will allow for the estimation of the expected time of drawdown at a specific location/bore. That is, as per discussions around the 1-m drawdown contours, while the predicted drawdown contour is extensive, the actual timing and duration for a bore to be impacted the 1-m drawdown may be estimated via pilot points.

ARTC are working with DRDMW to ensure that their refined model predictions will be completed and included in the Final EIS to better understand the impacts on groundwater and their significance.

10 Potential impacts

The Project includes several activities which have potential to impact on the groundwater regime. These activities include earthworks (cut and fill sections), drainage construction, haul road and access track construction, track laying, bridge and viaduct pilings and tunnel and portal construction.

The potential impacts of the Project on groundwater are discussed below in terms of impacts on groundwater resources and groundwater quality. Mitigation measures developed to minimise impacts on groundwater are presented in Section 11.

10.1 Project elements relevant to potential groundwater impacts

The proposed 28 km length of new dual-gauge rail line will be constructed across the landscape using a combination of cuttings, embankments, bridges, viaducts, and a 6.24 km tunnel through the GDR. The locations of proposed structures along the Project alignment are presented on Figure 10.1. To facilitate the design, the Project will also require changes to the local road network.

Although final design details may change, the current design elements most relevant to the groundwater study are summarised in Table 10.1. These elements, and additional design and construction elements that may also impact on groundwater, are described further in the following sections.

Table 10.1 Summary of key design elements with potential to impact on groundwater and assumptions

Design element	Description	Assumptions
Embankments	Embankments will be required along the alignment. Maximum height of bank 33.3 m (at Ch 17.03 km). Average embankment depth: 6.3 m. Total embankment length: 15.4 km.	Possibility of compaction with localised, temporary i) increases to groundwater elevations and ii) changes of groundwater flow patterns. Potential to restrict overland flow with localised, temporary i) increases to groundwater elevations (mounding) and groundwater flow patterns and ii) changes in groundwater quality (salinity). Shallow perched groundwater may be intersected but result in relatively small and temporary inflows. Groundwater mounding upstream can potentially cause sedimentation, which can restrict recharge to the underlying unit (including alluvium underlying the Gowrie Creek floodplain or Lockyer Creek).
Cuts/portals	Cuts will be required along the alignment to maintain grade. Total length of cut sections: 6.65 km. Maximum depth of cut 45.7 m at Ch 17.73 km. Several deep cuts greater than 10 m are required to be advanced through the MRV (1), Koukandowie Formation (7), and the Gatton Sandstone (4).	Cuts typically through sedimentary rocks. Limited number and depth of cuts in colluvial sediments except for the eastern tunnel portal which is considered to encounter 5-15 m of colluvial sediments. The western tunnel portal is anticipated to require a box cut through residual soils and basalts where fractured groundwater conditions are expected with highly variable groundwater levels. Cuttings less than 10 m deep unlikely to intersect significant depth below water table. Preliminary inflow estimates (Golder 2020b) typically less than 0.1 L/s in six cut sections anticipated to intersect groundwater. Shallow perched groundwater may be intersected but result in relatively small and temporary inflows.
Viaducts and bridges	13 structures totalling 6.7 km in length.	Used to span significant watercourses and floodplains, roads, and terrain.

Design element	Description	Assumptions
Tunnelling	Approximately 6,240 m long (Ch 4.10 km to Ch 10.34 km) TBM and road header or mining construction techniques. Maximum rock thickness above tunnel crown approximately 226 m.	Approximately 75-80% of the tunnel is likely to be fully constructed within the upper portion of the Koukandowie Formation. Undrained tunnel. The majority of the tunnel will likely be below the local groundwater levels, except for the western tunnel portal. Preliminary estimates of pre-development groundwater levels along the tunnel indicate a maximum water column height above the tunnel of approximately 100 m.

10.1.1 Site clearing and grading

Site clearing and grading activities could potentially impact on shallow groundwater resources due to:

- Removal of vegetation reducing evapotranspiration, which can influence the groundwater discharge (i.e. result in higher groundwater levels)
- Compaction of ground resulting in reduced groundwater recharge
- Alteration of possible existing areas where ponding surface water occurs naturally, which could reduce groundwater recharge in these areas.

The Project site clearing includes removal of vegetation and debris and is planned to occur prior to the main earthworks. Where required, ARTC will seek vegetation clearing permits and implement management measures to minimise impacts to environmental values (i.e. native fauna and water quality).

All turf, topsoil and other organic and unsuitable material will be stripped from the disturbance footprint (apart from nominated no-go zones). Wherever practical and appropriate, such material will be stockpiled and recycled within the Project corridor. For example, cleared vegetation will be mulched, stockpiled, and managed to facilitate re-use and to prevent combustion.

Access roads will be required along the alignment to allow drainage, earthworks, tunnel, portal, and bridge/viaduct structure crews to access work locations.

Temporary site drainage and water management controls will be installed in order to minimise any runoff and sedimentation from the proposed activities to existing watercourses, and disturbance to the water quality of existing watercourses.

Overall, a limited area is proposed to be cleared and graded for construction purposes when compared to the large aquifer extents. The Project disturbance footprint is considered negligible against the recharge surface area of the alluvial aquifers which underlay the Project. Consequently, there is likely to be little impact on groundwater resources.

Placeholder

Figure 10.1 Alignment profile schematic

10.1.2 Embankments

Proposed embankments are summarised in Table 10.2. Embankments have the potential to obstruct natural drainage pathways resulting in more frequent inundation of areas upstream of the embankments. This more frequent inundation could result in groundwater mounds forming underneath these areas. Groundwater mounding may also result from the compacting of soils following the addition of embankment soils. Groundwater mounding upstream can also potentially cause sedimentation of recharge areas.

Groundwater depressions may form as a result of mounding in areas which formerly received recharge (down gradient of the emplaced embankments). Groundwater inundation could potentially have long-term impacts on soil salinity and in extreme cases can affect embankment stability.

The anticipated subgrades for embankments are generally either residual soil overlying Gatton Sandstone or colluvial material overlying Koukandowie Formation.

Table 10.2 Summary of embankment details

Embankment	Chainage start (km)	Chainage end (km)	Length (m)	Maximum depth (m)	Unit	Groundwater encountered[1]	Surface water inundation risk
320-E1	-1.76	-0.58	1,180	2.6	MRV	No	Gowrie Creek during flood – effects of cracking clays subsoil (shrink swell potential)
320-E2	-0.34	2.22	2,560	3.2	MRV	No	
320-E3	2.33	3.61	1,280	3.7	MRV	No	Potential Inundation of slopes from local creek during flood event, effects of cracking clay subsoil (shrink swell potential).
320-E4	10.4	10.57	170	14.4	Koukandowie Formation	No	None
320-E5	10.88	11.16	280	21.6	Koukandowie Formation	Yes	
320-E6	11.59	12.37	780	5.8	Koukandowie Formation with Alluvium	No	
320-E7	12.75	13.15	400	33.3	Koukandowie Formation	Yes	
320-E8	14.04	14.07	30	18.5	Koukandowie Formation	No	
320-E9	14.1	14.33	230	12.3	Koukandowie Formation	No	
320-E10	15.72	17.56	1,840	33.7	Alluvium and Koukandowie Formation	Yes	
320-E11	17.82	19.41	1,590	26.2	Gatton Sandstone	Yes	

Embankment	Chainage start (km)	Chainage end (km)	Length (m)	Maximum depth (m)	Unit	Groundwater encountered[1]	Surface water inundation risk
320-E12	19.67	20.36	690	25.6	Gatton Sandstone	Yes	
320-E13	20.5	20.55	50	9.5	Gatton Sandstone	No	
320-E14	20.66	26.25	110	23.8	Gatton Sandstone	Yes	

10.1.3 Viaducts and bridges

The Project includes the following structures:

- One rail bridge at Gowrie Creek
- Ten viaducts
- Two road bridges (Gowrie Junction Road and McNamaras Road).

The bridge sections and viaducts have structural support from Cast-in-Place pilings. For road bridges, the general approach for configuration has been to adopt standard Prestressed Concrete Super-T girders. The general approach to rail bridges is based on Standard Prestressed Concrete slab spans and Super-T girders are used wherever possible.

The expected subgrade for the proposed piling works includes:

- Marburg Subgroup – interbedded sedimentary sandstone/siltstone/claystone
- Marburg Subgroup – Gatton Sandstone
- MRV
- Colluvium
- Alluvium.

Pilings associated with ground improvement works is proposed to stabilise sub-surface conditions at viaduct and bridge sections. The piling works include Cast in Place technique with concrete emplaced via a Tremie line or other pumping method. This technique allows for the removal of augered soil/rock while pumping concrete or grout through the hollow stem to stabilise the ground.

The pilings will have span lengths ranging from 4 to 46 m and will be installed to depths ranging from 5 to 35 mbgl with pile diameters of 800 mm to 2,200 mm. No piling activities are proposed in channels or within the riparian zone of any watercourses; or in a known wetland.

The potential impacts of the piling work during construction activities, on groundwater resources, may include:

- Alteration of aquifer parameters (lower permeability) – the potential impact of altered aquifer parameters is considered limited due to the small area of influence within the saturated sediments compared to the overall extent of alluvium aquifer. This will be a temporary/localised construction impact.
- Altered groundwater flow patterns (mounding or drawdown up and down gradient of the piles; upward leakage along the pile/soil interface) – with spacing of the piles such that throughflow in the hydrostratigraphic units intersected by the piles, groundwater flow patterns will not be markedly influenced. Spacing will be sufficient such that mounding (on the upgradient side) or dewatering (due to a reduction in the throughflow on the downgradient side of structures) is not expected to occur.
- Reduction in groundwater resources through extraction of wet soil/rock during piling – the potential reduction in groundwater levels due to water being brought to surface is considered limited as the Cast in Place augering method allows for concrete slurry to be pumped through the hollow stem auger. As a result, the Cast in Place method restricts the amount of groundwater brought to surface.

Based on previous experience, only minor volumes of groundwater (within the wet sediment/soil/rock) will be brought to surface, some 5 to 10 litres per 20 m deep auger hole. It is therefore likely that using the proposed piling methodology, active dewatering is not anticipated and the minor amounts of groundwater (as a slurry with soil/rock) will be managed at each pile/drill site.

10.1.4 Cut sections

There are 14 deep cut sections where at least eight are anticipated to intersect groundwater (details in Table 9.11). Table 9.12 provides the maximum cut depth and the estimated depth of the cut below groundwater level, this ranges between 1 and 21 m below groundwater level. Eight cut sections were considered in predictive modelling (Golder 2020b) as potentially intersecting groundwater (refer Sections 9.3 and 9.4) with long-term inflow rates in the order of less than 0.1 L/s at those locations (refer Table 9.13). Sections of deep cuts (greater than 10 m) are shown on Figure 10.1.

10.1.5 Tunnelling

The Project proposes a single-track undrained tunnel through the GDR to facilitate the required gradients for this area due to the undulating terrain. The current tunnel drive length is approximately 6,240 m with a maximum cover of approximately 220 m. The typical tunnel internal diameter is 10.83 m and the excavated cross section is approximately 117.5 m^2. An intermediate ventilation shaft connected to the tunnel (also to be undrained), approximately 17 m internal diameter and 100 m deep, is provided approximately halfway between the western and eastern tunnel portals (Ch 6.83 km). The tunnel is mainly located in the MRV for the west and potentially central sections; and in the Koukandowie Formation in the east. The proposed tunnel requires TBM and mining (road header) techniques. A single pass precast reinforced concrete segmental lining will be used for support of an excavated tunnel constructed by a shielded TBM.

Undrained tunnels are designed as a watertight structure, which aim to limit groundwater ingress into the tunnel and aim to minimise groundwater level drawdown, as a result of the tunnel operation, via diminished groundwater seepage allowed into the tunnel. Undrained tunnels constructed by mined tunnel methods typically comprise a groundwater resisting membrane and cast in-situ reinforced concrete lining. To withstand the hydraulic pressures from the groundwater on the watertight tunnel lining, undrained tunnels are typically circular in cross section, or some form of elliptical shape with significant amounts of reinforcement required.

A conventional shaft sink (Ch 6.83 km) has been adopted for the construction of the intermediate ventilation shaft at Cranley, to consist of temporary support installed from the top down, and a permanent reinforced concrete lining constructed from the bottom up. It is proposed the shaft will commence construction from the top down prior to the tunnel (as shown in Table 9.2). The ventilation shaft is to be installed at a depth of approximately 100 mbgl through the MRV, UTS, WCM, and Koukandowie Formation and is anticipated to intersect the aquifers of the MRV and sedimentary aquifer of WCM and Koukandowie Formation. Groundwater exclusion for the ventilation shaft is likely to comprise installation of a grouted plug from ground surface through the MRV, UTS, WCM to seal off high groundwater potential inflow areas expected within the top of the profile (MRV/UTS).

It is likely a flexible sheet type water resistant membrane will be used to waterproof the tunnel. The purpose of the waterproof membrane is to assist with the long-term durability of the concrete secondary lining, including all fixings installed into the concrete.

The eastern tunnel portal (Ch 10.34 km to Ch 10.40 km) includes significant depths of colluvium where significant works are required to undertake the cut-and-cover section (Ch 10.235 km to Ch 10.34 km with total length of 105 m) and an approximately 475 m long section to be mined from the TBM to the portal face (Ch 9.76 km to Ch 10.235 km).

During construction and operation of the TBM, stormwater will be pumped to the western portal to a water treatment plant (WTP). During operation, stormwater will be diverted away from the tunnel and any water that falls within the tunnel portals will be captured by purpose-built sumps and not directed through the tunnel. Any water collected inside the tunnel (groundwater, washdown, firefighting etc) will be collected via drainage pits throughout the tunnel and connected longitudinally by a drainage pipe. Collected water will be conveyed via gravity to the tunnel collection sump(s) located at the eastern tunnel portal. This water will likely be processed through a WTP which will include hydrocarbon separation. The collection sump will also likely include a 'first flush' tank that will collect the first quantity of water which is expected to contain the majority of pollutants. Any separated pollutants will be held for collection by a licensed waste contractor. Provision has been made for the collection and treatment of water from the tunnel. The extent of treatment of the water from the tunnel will depend greatly on the quality of the groundwater ingress. Water treatment facilities are likely to include:

- Screening treatment
- Detention tanks
- Aeration/flocculation tanks
- Chemical treatment (if warranted)
- Water pumping facilities
- Sludge storage.

10.1.6 Construction water supply

An estimate of water requirements for the construction period is presented in Table 10.3 and is shown in Figure 10.2 and Figure 10.3. Each construction activity will involve different quantity, quality, and flow rates of water to achieve the planned construction tasks. Potential water sources have been investigated including extraction of groundwater or surface water. This will be further explored prior to construction in consultation with local councils and landholders. Overall, approximately 700 ML of water is required for construction of the Project.

Table 10.3 Preliminary estimated of water requirements and potential water sources for construction activities

Construction activity/ process	Uses	Requirement	Quality required	Flow rate	Potential sources[a]	Approx. volume (ML)[a]
Earthworks	Material conditioning, general dust suppression and haul road maintenance	High	Low	High	Recycled water, dams or bores	448
Concrete (proposed batch plant)	Bridge and culvert locations	Medium	High	Low	Town mains (Gowrie area) or urban utilities (Lockyer Valley) due to quality requirements	31
Track works	Ballast dust suppression during ballasting and regulating activities	Medium	Low	Low	Recycled water, dams or bores	0.225
Tunnel excavation	Dust suppression, cooling the TBM, water for drilling, compaction				The majority of this water will be recycled groundwater collected from the tunnelling construction activities, reducing the volume of water required from external sources	189

Table note:

a Potential water sources and estimated volumes are preliminary only

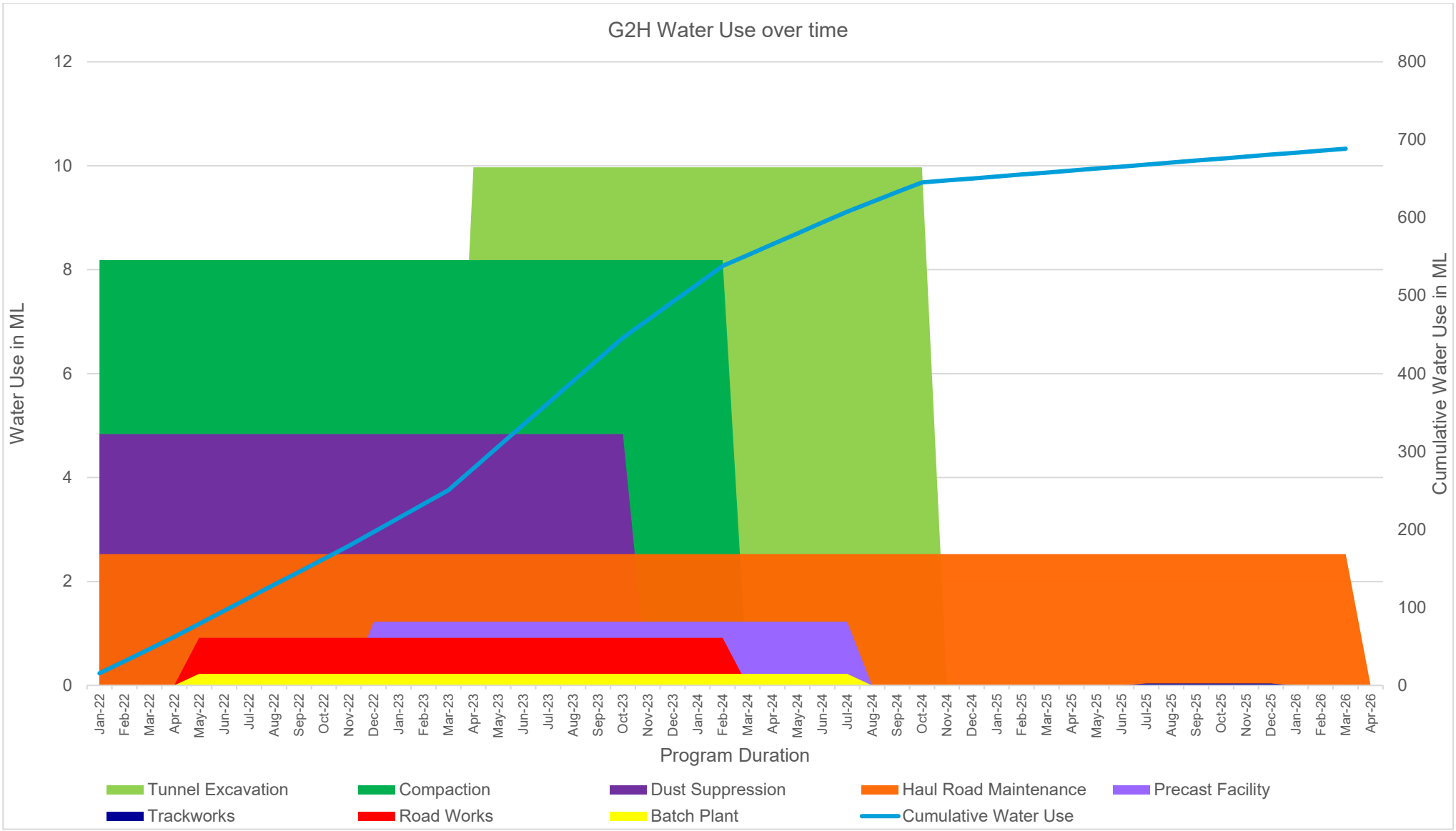


Figure 10.2 **Preliminary estimate of construction water requirements over time**

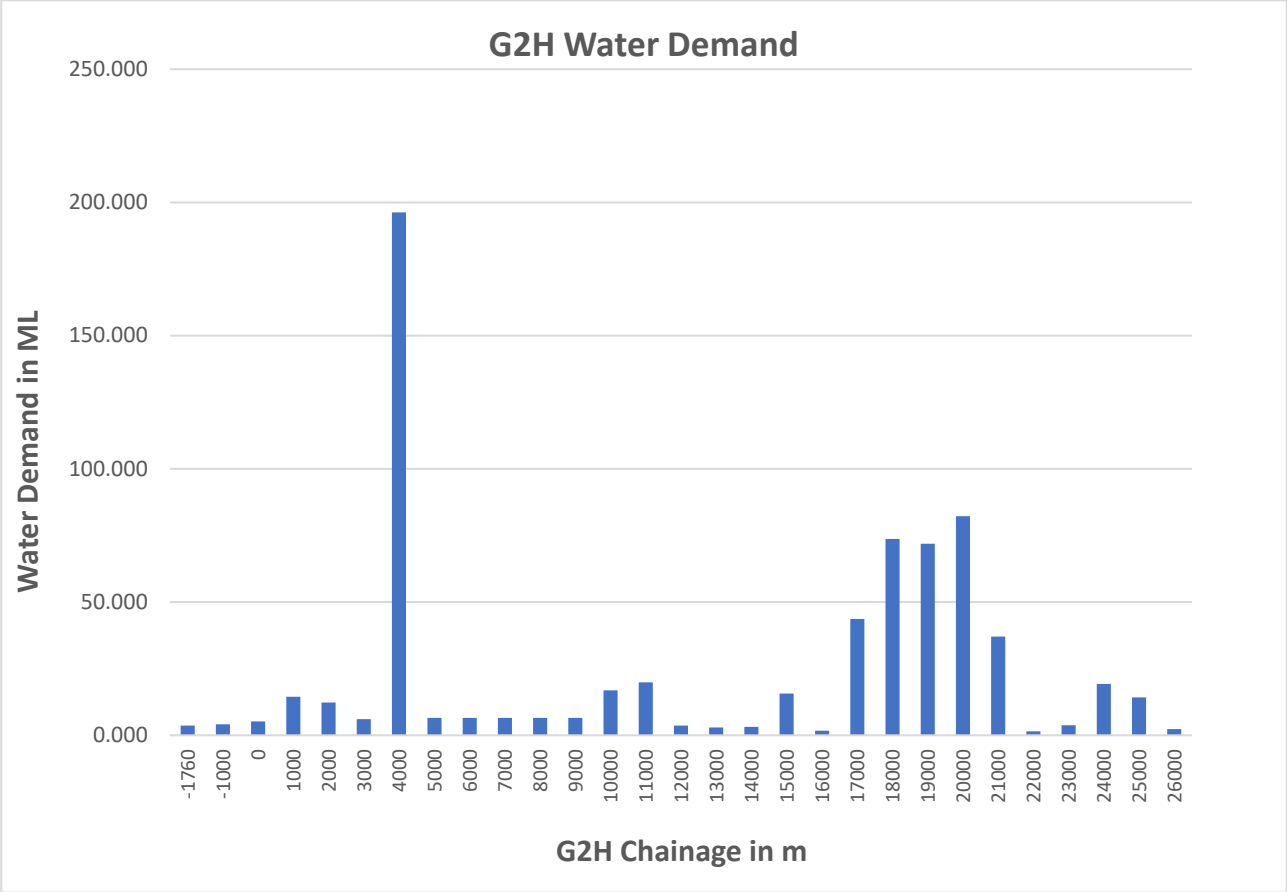


Figure 10.3 Preliminary water demand along the alignment

Water is required for tunnel construction activities including dust control, drilling, and cooling the TBM at an estimated rate of 200 m^3/day. The water demand for the tunnel is indicative only and will be confirmed during detailed design.

Potential water sources have been investigated and include harvesting of groundwater recovered from the tunnel drive, Toowoomba Regional Council's Wetalla wastewater treatment plant, potentially Withcott Seedlings treated water ponds, private bores and connection to town water. This will be further explored prior to construction in consultation with DRDMW Water Services, local councils, landholders and other relevant stakeholders, including required water authorisations under the Water Act (refer Section 10.2.1.7). Where water is not available, it will be transported to the site via tanker truck and stored in temporary storage tanks.

10.1.7 Drainage infrastructure

There are several new drainage structures proposed to transverse drainage across the Project and are proposed to be comprised of reinforced concrete pipe or reinforced concrete box culverts.

The locations of the new culverts have been selected to maintain the existing flow paths and minimise the potential impacts to flood depths upstream and downstream of the culverts where constructing across floodplains.

Existing drainage paths above cuttings will be diverted to the nearest cross-drainage structure though a catch drain where practical to minimise flow into cuttings and subsequent size of cutting drainage. Drainage channels are provided along the cutting benches, which connect to batter chutes, which flow to the base of the cutting. A larger cutting (cess) drain is provided in the base of each cut adjacent to the rail embankment.

Cess drains, which are surface drains located to the side of the tracks, will be used to remove water that percolates through the ballast and flows along the capping layer towards the outside of the track formation. The cess drains may also collect seepage from the deep cuts and in the portals.

10.2 Construction phase potential impacts

The Project includes several activities which have potential to impact on the groundwater regime. These activities include earthworks (cut and fill sections), drainage construction, haul road and access track construction, track laying, bridge and viaduct pilings, and tunnel and portal construction. The potential impacts of the Project on groundwater are discussed below in terms of impacts on groundwater resources and groundwater quality.

10.2.1 Water resources

10.2.1.1 Dewatering

Active dewatering is the process of actively pumping groundwater to locally lower groundwater levels in proximity to excavation or other sub-surface works to temporarily create a dry working environment. Dewatering may also occur passively during construction which includes seepage into cuts insufficient to require being pumped out. Dewatering may be required where sub-surface works encounter groundwater, primarily during construction. Reduced groundwater levels from dewatering during construction of cuts and the tunnel has the potential to impact groundwater users, surface water flow (Gowrie Creek located in proximity to the location of the shaft) and GDEs.

Cuts along the alignment

Reduced groundwater levels from dewatering during construction of cuts has the potential to impact groundwater users (e.g. registered bores and surface water flows). Dewatering has the potential to result in temporary drawdown of localised groundwater levels. This drawdown has the potential to temporarily affect the availability of groundwater from registered bores in proximity to the works, not otherwise decommissioned by the Project. Drawdown also has potential to affect surface water features and GDEs within the radius of influence.

Deep cuts with potential to intersect groundwater (bridges, viaducts, and piling sections) may potentially result in drawdown of groundwater levels due to seepage into the cuts. Predictive modelling (refer Section 9.4) suggests the construction phase seepage resulting from the cuts is less than 0.1 L/s. Seepage from cuts will likely report to cess drains, which are surface drains located to the side of the tracks.

Construction design of cuts includes drainage measures to prevent degradation of the exposed rock face and ensure long-term stability. Cut specific drainage measures which have been implemented include:

- Strip drains and weep holes to be applied in conjunction with any shotcrete facing
- Bunds (500 mm minimum, with catch drain) specified at the crest of the slope where the existing topography is likely to cause run off into the cut face and the slope of the drain is between 1 in 100 and 1 in 200
- Sub-surface drainage, in the form of sub-horizontal drains, to control porewater pressures at the batter face. This will most likely apply for cuttings located in either the Koukandowie Formation or WCM, which may contain layers of extremely weathered mudstone, claystone or coal seams
- Sub-horizontal drains have been nominated where the groundwater level is identified to potentially rise above the base of the cut.

Toowoomba Range tunnel

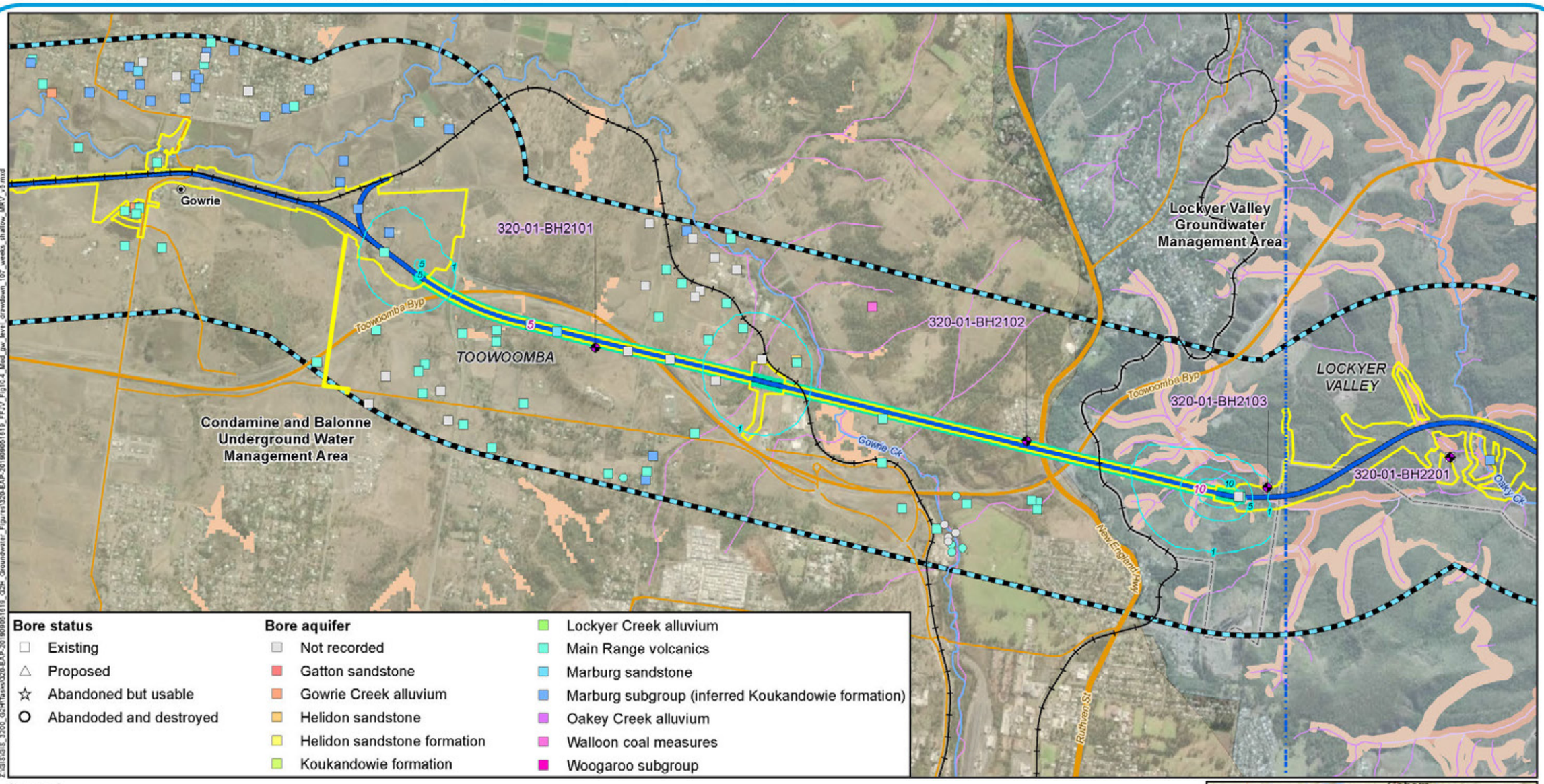
Preliminary estimates of groundwater inflows and drawdowns have been undertaken to inform assessment of the potential to construct the Toowoomba Range tunnel and portals as permanently undrained structures.

The predictive modelling of the Toowoomba Range tunnel (refer Section 9.3.6.1) suggests the maximum tunnel seepage (inflow estimates) rates during construction are predicted to be 100 L/s for the TBM portion of the tunnel and 37 L/s for the mined portion (at 107 weeks) (refer Figure 10.4, Figure 10.5 and Figure 10.6). The intermediate ventilation shaft is expected to have a maximum seepage rate of 17 L/s during construction (at 62 weeks) (refer Figure 10.7, Figure 10.8 and Figure 10.9). The western portal is expected to see maximum inflows at 34 weeks (refer Figure 10.10).

The resulting groundwater drawdown was then assessed for each unit (shallow MRV (typical value of hydraulic conductivity), deep MRV (high conductivity layer), and the Koukandowie Formation).

These preliminary drawdown extents for the Project are considered the base-case. Sensitivity analyses were undertaken to understand the potential for increased conductivity and permeability within the fractured MRV and Koukandowie Formation (discussed in Section 9.3.7). Increasing the permeability MRV and Koukandowie Formation results in higher groundwater seepage rates and an increase in the drawdown extent. Ongoing and future investigations are anticipated, along with refinement of the predictive groundwater model (refer Section 9.5) to confirm risks posed to groundwater drawdown impacts from increased permeabilities and on potential GDEs and surface water features are acceptable. The outcomes of these refinements will be included in the Final EIS.

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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



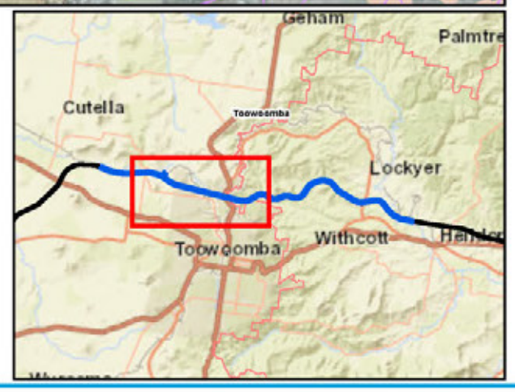
Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

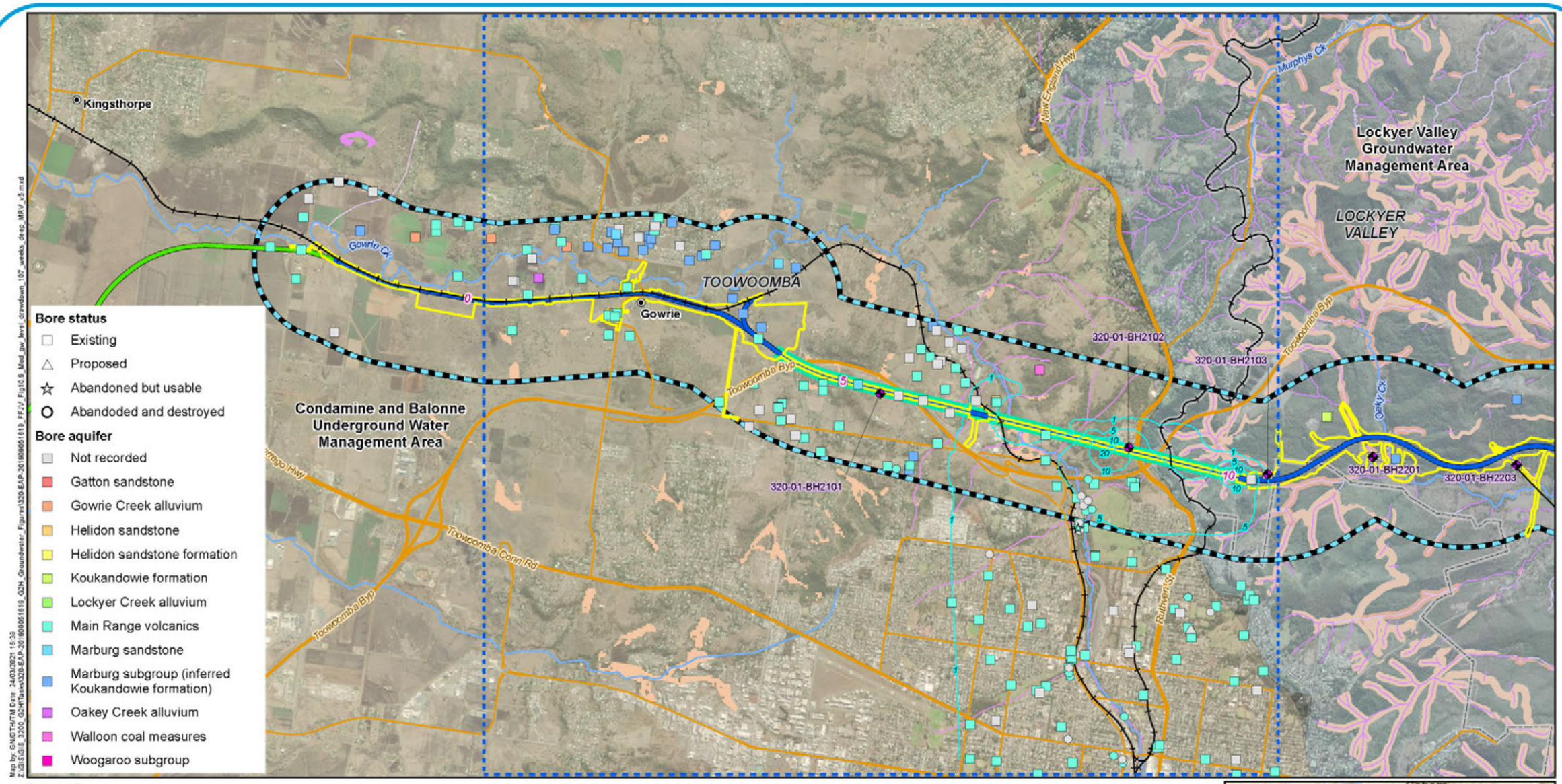
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Map by: GNGTH/TM Date: 24/03/2021 15:23
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Gowrie to Helidon
Figure 10.4: Modelled groundwater level drawdown at 107 weeks (shallow MRV)

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



Legend

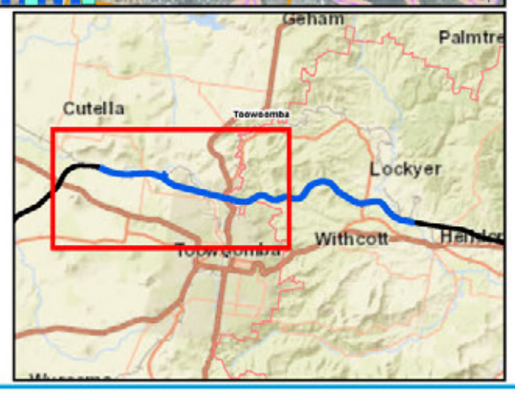
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- B2G project alignment
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:52,000

0 0.5 1 1.5 2 2.5km

Future Freight
Integrating Community, Environment and Engineering

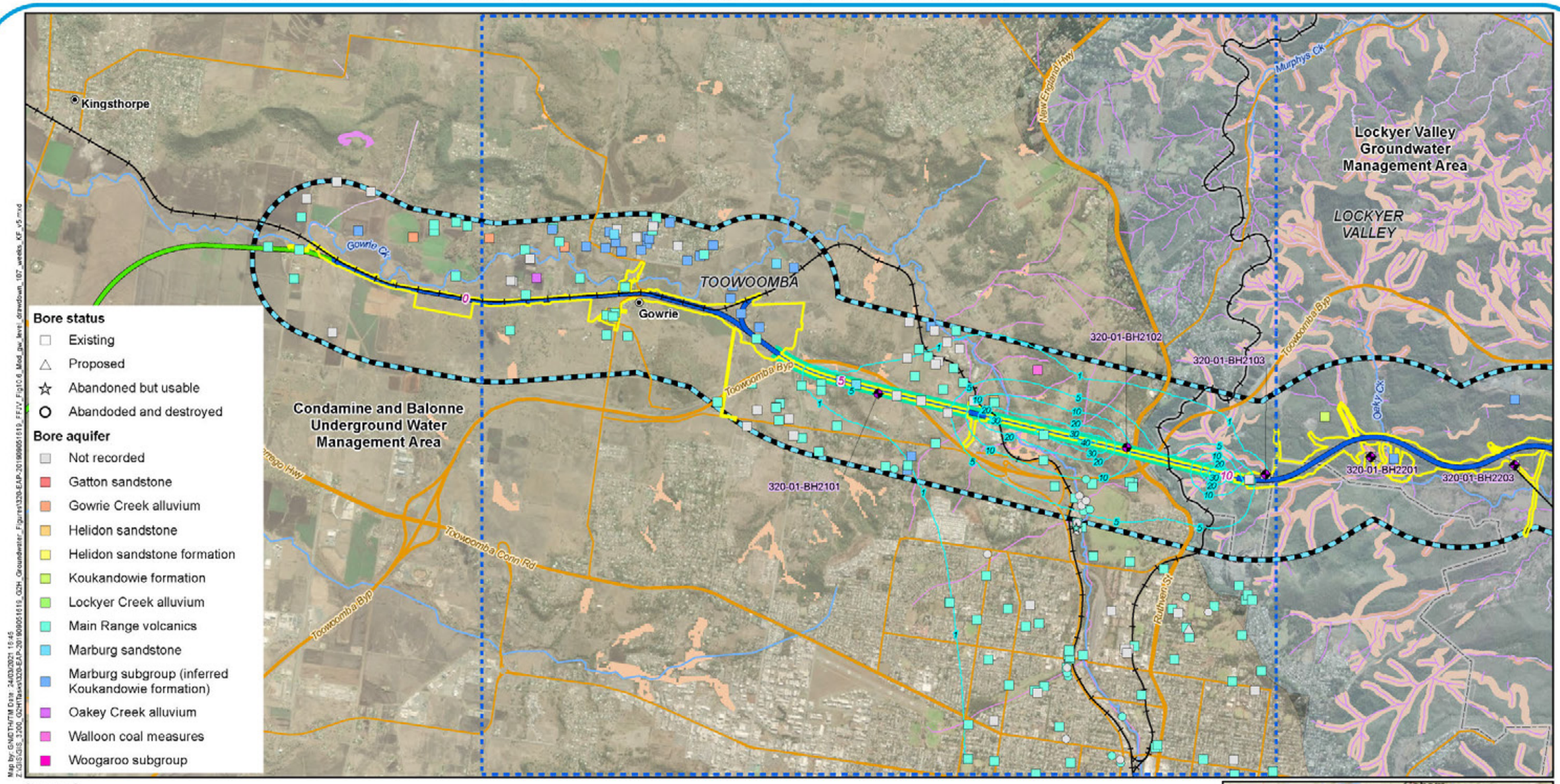
Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 10.5:

Modelled groundwater level drawdown at 107 weeks (deep MRV)

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



Legend

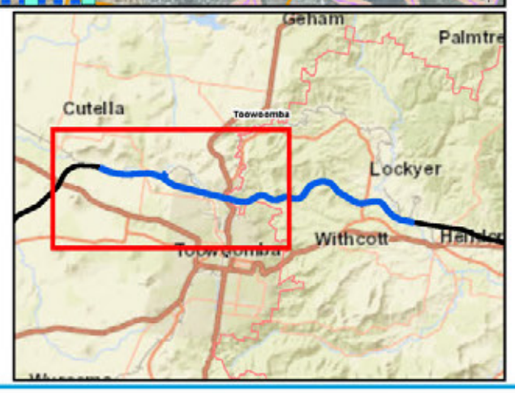
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- B2G project alignment
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE

- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:52,000

0 0.5 1 1.5 2 2.5km

Future Freight
Integrating Community, Environment and Engineering

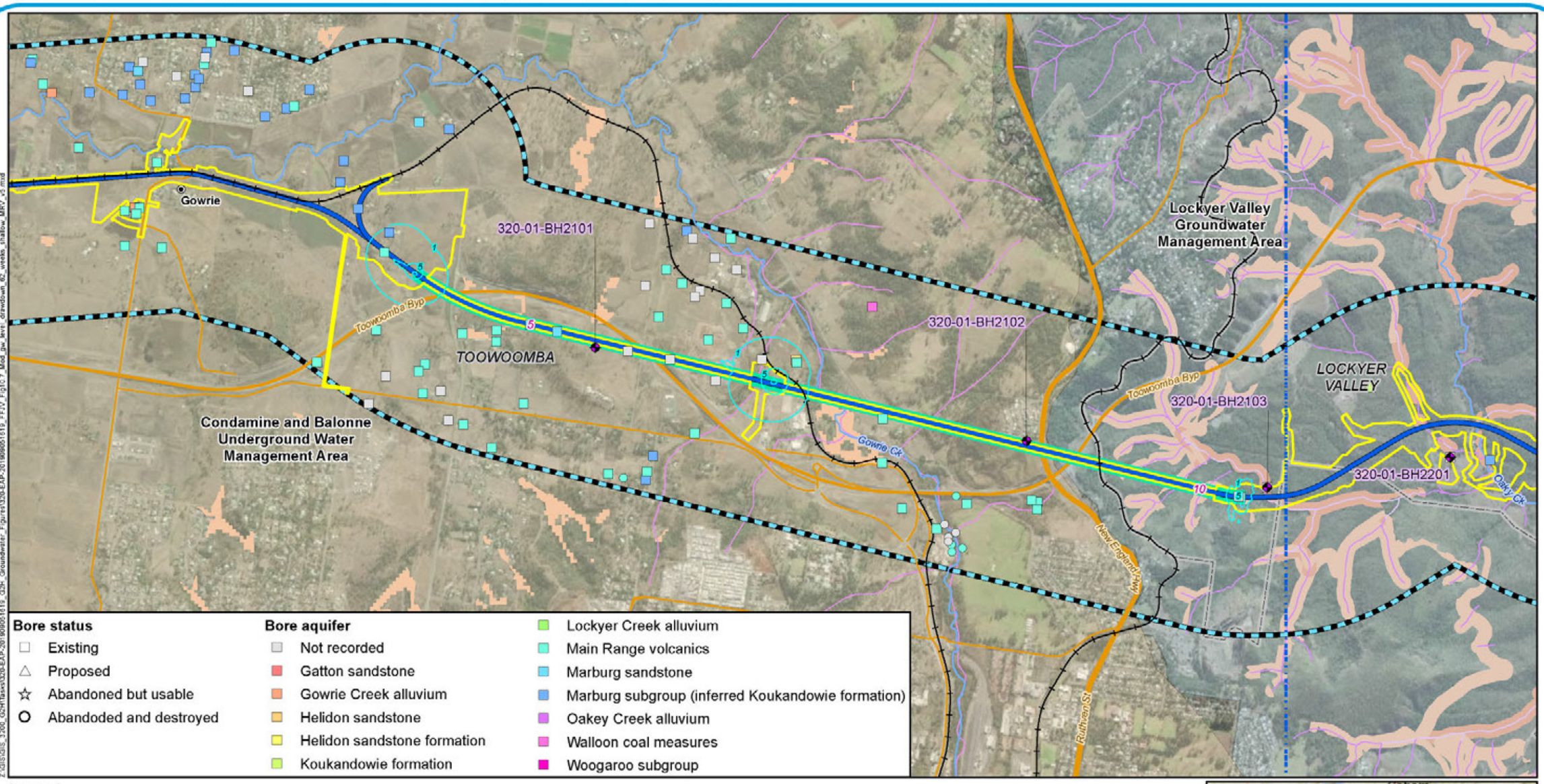
Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 10.6:

Modelled groundwater level drawdown at 107 weeks (Koukandowie Formation)

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



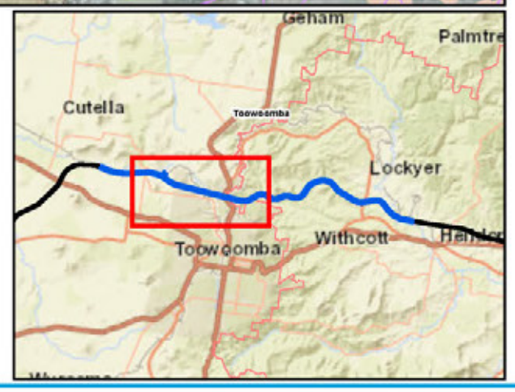
Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

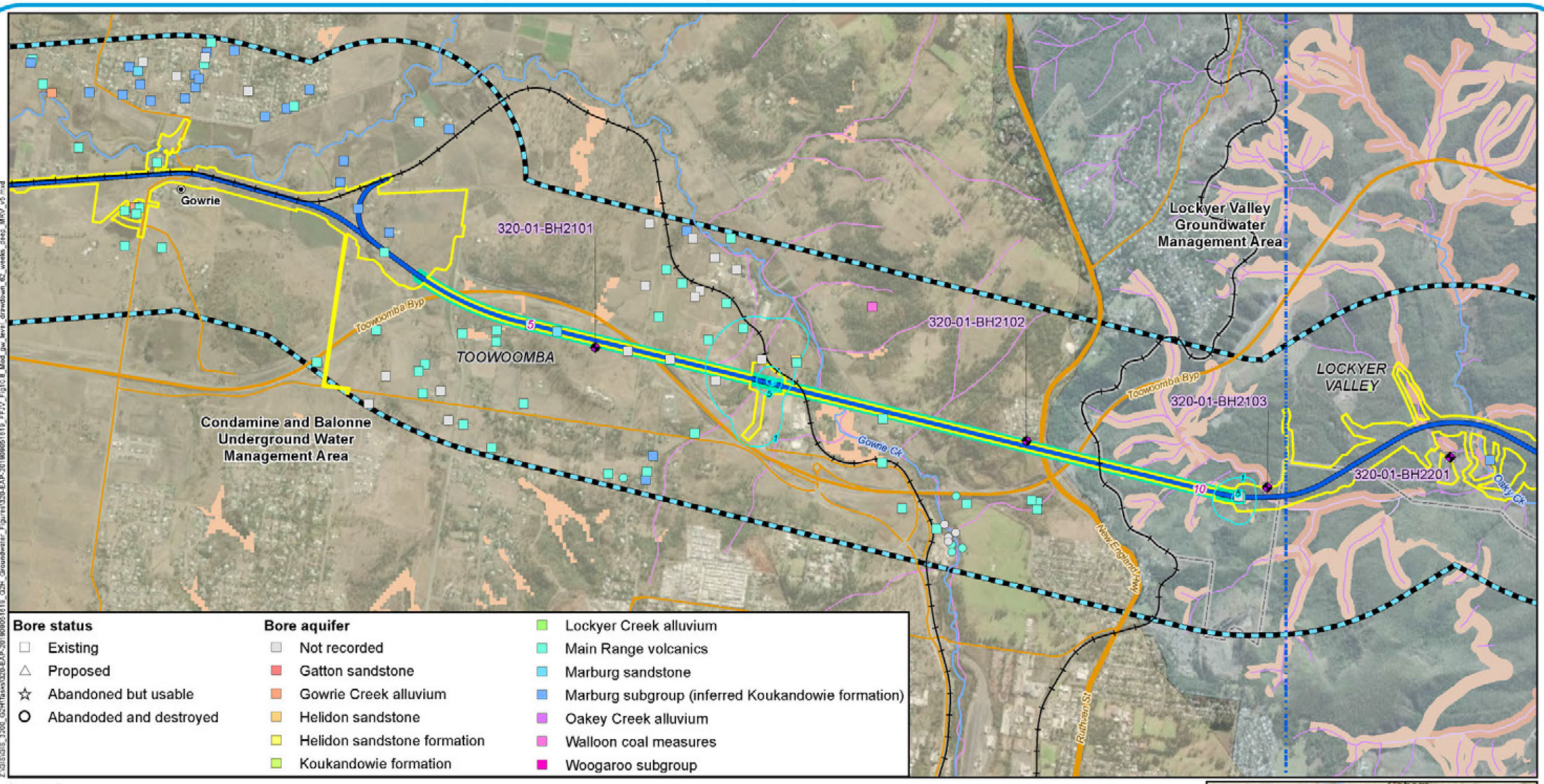
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 10.7: Modelled groundwater level drawdown at 62 weeks (shallow MRV)

Map by: GNGTH/TM Date: 24/03/2021 15:26
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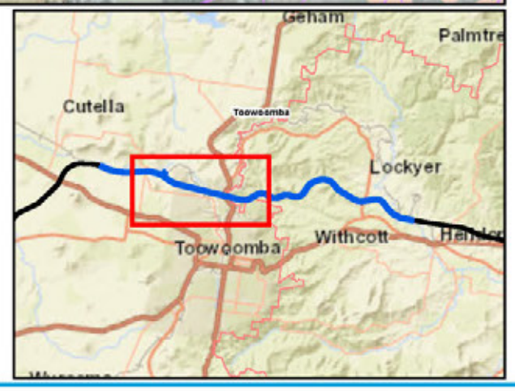
Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

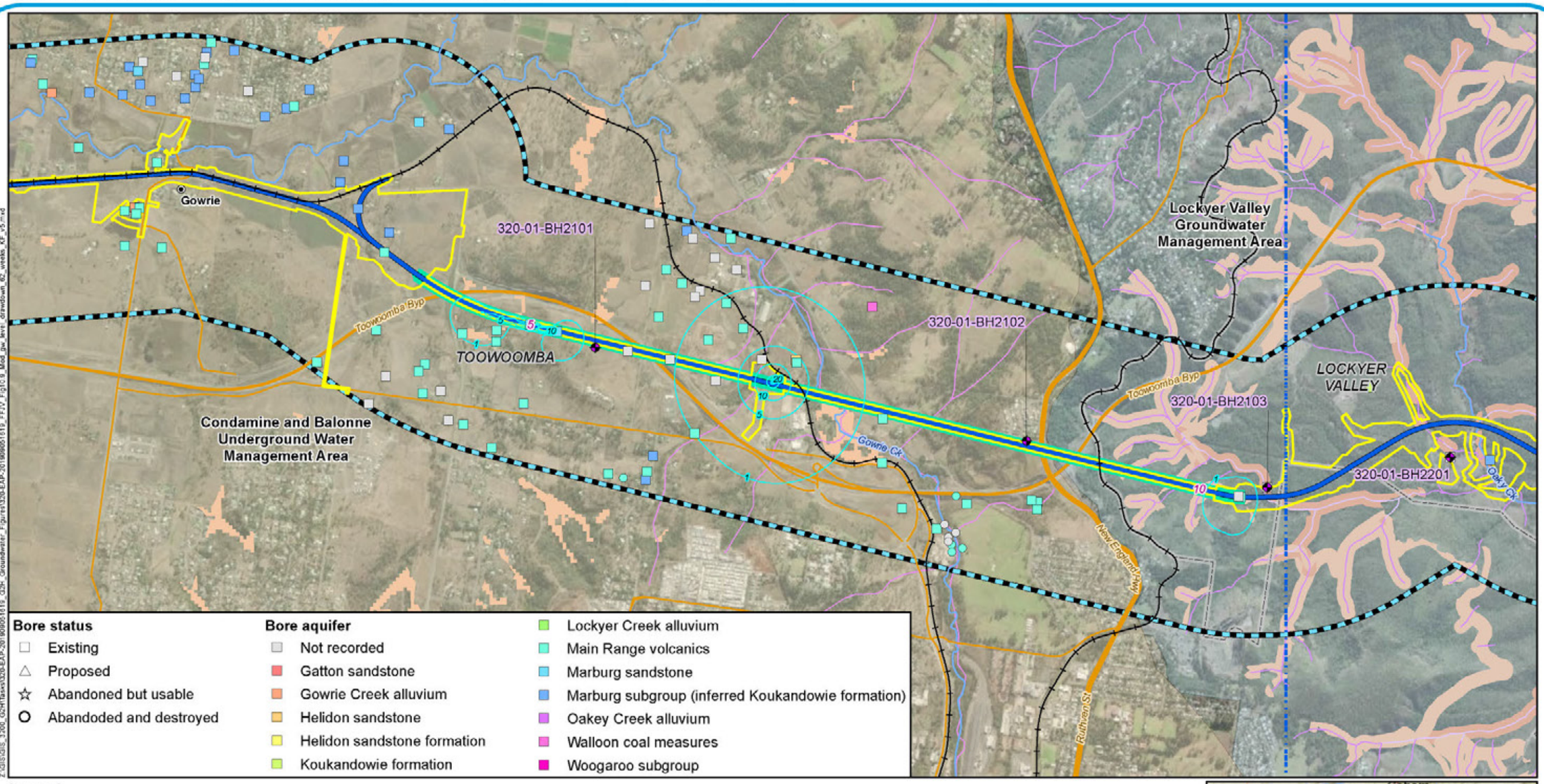
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Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 10.8: Modelled groundwater level drawdown at 62 weeks (deep MRV)

Map by: GNGTH/TM Date: 24/03/2021 15:26
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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



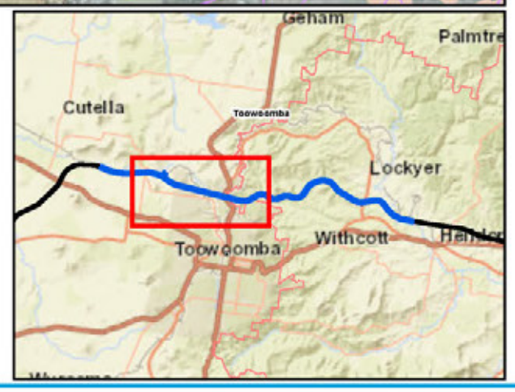
Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
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- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
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- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
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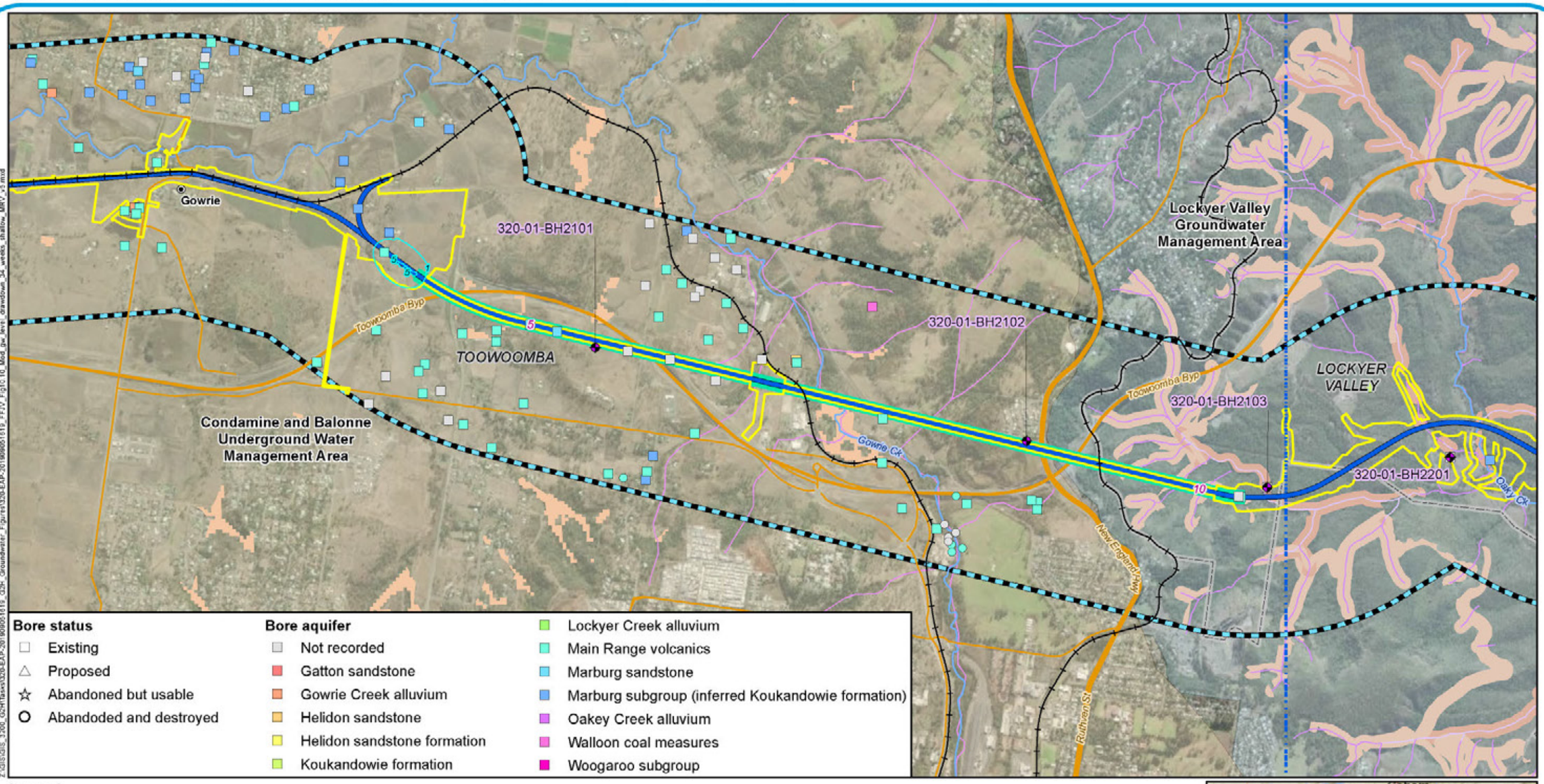
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Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 10.9: Modelled groundwater level drawdown at 62 weeks (Koukandowie Formation)

Map by: GNGTH/TM Date: 24/03/2021 15:30
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Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



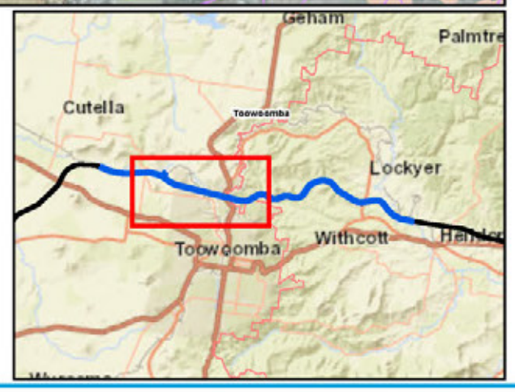
Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
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- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 10.10: Modelled groundwater level drawdown at 34 weeks (shallow MRV)

Map by: GNGTH/TM Date: 24/03/2021 15:29
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Loss or damage to existing landholder bores

There is a potential for existing landholder bores to be damaged, destroyed, or to become inaccessible within the construction footprint. Registered bores with potential to be impacted by construction of the Project are discussed in the subsections below.

Registered bores within the construction footprint

Registered bores within the construction footprint are summarised in Table 10.4. The potential exists for these bores to become inaccessible, or more difficult to access, due to the construction works blocking previous access routes or no access being available if within exclusion zones associated with the operating rail corridor. It is likely that some of these bores will be decommissioned according to the Minimum Construction Requirements for Water Bores in Australia – Edition 4 (National Water Commission 2020).

There are two registered bores (RN107110 and RN107104) that are above the tunnel by approximately 60 and 80 m respectively. The aquifer intercepted by these bores has not been identified however the bores are screened in basalt, which corresponds to the MRV observed in this area. The tunnel can potentially impact on bores above it by water level drawdown during construction as the construction footprint for the tunnel is volumetric and will not include the property above the tunnel.

Table 10.4 Existing registered bores within the construction footprint

Bore	Chainage (km)	Lot/Plan	Bore role	Nearby Project structure
RN56783	2.0	122/AG3560	-	320-E2 and 320-E3
RN66497	3.6	2/RP192838	-	Western tunnel portal cut
RN71234	3.9	21/RP34896	-	Western tunnel portal cut
RN172858	3.9	2/RP192838	Sub-artesian monitoring	Western tunnel portal cut
RN107110	5.7	78/SP154249[a]	-	Toowoomba Range tunnel
RN107104	6.1	12/SP189517[a]	Water supply	Toowoomba Range tunnel
RN173879	10.5	120/CC675	Sub-artesian monitoring	Eastern tunnel portal cut
RN106596	12.3	354/CH312304	Water supply	Oakey Creek viaduct
RN173876	13.9	245/CC315	Sub-artesian monitoring	Withcott Viaduct 2
RN173875	15.6	6/SP186716[a]	Sub-artesian monitoring	Cut (320-C10)
RN173799	19.8	213/SP200754	Sub-artesian monitoring	320-E12
RN173798	21.1	169/SP200753	Sub-artesian monitoring	Murphys Creek Viaduct
RN173154	21.5	4/SP200753[a]	Water supply	Withcott Seedlings Viaduct
RN75289	23.6	18/SP105106	Water supply	Withcott Seedlings Viaduct
RN75335	23.9	18/SP105106	Water supply	Withcott Seedlings Viaduct
RN173801	24.8	452/SP117138	Sub-artesian monitoring	Lockyer Creek Viaduct

Table notes:

"-" data not provided in the Queensland Globe database
a land parcel is within the Toowoomba Bypass footprint

Registered bores potentially impacted by groundwater level drawdown

After predictive modelling of the impacts of deep cuts and the Toowoomba Range tunnel on groundwater resources (refer Section 9.3), the predicted impact area (drawdown contour) was assessed against licensed groundwater extraction bores and other registered bores in order to identify the areas (real property) potentially impacted by the Project. This has been undertaken to better understand the potential impacts on groundwater users.

Predicted groundwater drawdown extents along with registered bores and GDEs are mapped in Figure 10.4 to Figure 10.10 . Table 10.5 summarises the registered bores (reported as existing) and their reported uses within the various drawdown extents within the groundwater study area. The table also includes bores within the drawdown extent resulting from the sensitivity analysis (discussed in Section 9.3.7). It is proposed that all bores within the predicted drawdown extent are included in the indicative groundwater monitoring network (refer Table 11.3).

The maximum predicted groundwater level drawdown extent for tunnel construction (at 107 weeks) is shown on Figure 10.4 through Figure 10.6. Groundwater level drawdown in the shallow MRV is limited to the shaft and portals at this time.

The predicted groundwater drawdown for the deep MRV includes a drawdown of 5 m south of the tunnel in the groundwater study area; the 1 m predicted drawdown contour includes an area outside of the groundwater study area, south of the tunnel (refer Figure 10.5).

The groundwater drawdown predicted for the Koukandowie Formation is most significant, at depths of ~40 m at the tunnel. The drawdown reaches depths up to 5 m at the southern extent of the groundwater study area; similar to the deep MRV at this time, the 1 m predicted drawdown contour includes an area outside of the groundwater study area, south of the tunnel (refer Figure 10.6).

There are 82 registered bores located within the predicted 1 m drawdown contour extent for both the deep MRV and the Koukandowie Formation of which 66 are reported to exist. Of these 66 existing bores, 56 are reported to source groundwater from the MRV. One bore is reported to be existing but usable (MRV) and one proposed bore is reported to be located just south of the southern groundwater study area boundary. The bores predicted to be impacted by a 1 m drawdown of water levels that extend beyond the groundwater study area for the deep MRV and Koukandowie Formation are presented in Appendix B.

The predicted 1-m drawdown contours are extensive in the model domain such that they are considered to be an overestimation of the impact, and unlikely to present in real life. ARTC have committed to refine these model predictions to better understand the impacts on groundwater and their significance; these predictions will be included in the Final EIS (refer Section 9.5). The refinement of the predictive model will confirm the predicted drawdown contours, spatially as well as in time. That is, while the 1 m predicted drawdown contour is extensive, the actual timing and duration for a bore to be impacted by this drawdown can be estimated.

Table 10.5 Registered bores within the predicted groundwater drawdown extents (construction)

Elapsed time since excavation commenced	Modelled aquifer	Drawdown depth (m)	Number of existing registered bores within the drawdown extent	Existing registered bore	Reported bore aquifer	Screened depth (m)	Reported bore use
34 weeks with increased conductivity in the MRV (refer Section 9.3.7)	Shallow MRV	5	1	172858[a]	-	-	-
62 weeks	Koukandowie Formation	5	3	94667 119852 137355	- Helidon Sandstone MRV	12 564 5	- Water supply Water supply
62 weeks with increased conductivity in the MRV (refer Section 9.3.7)	Shallow MRV	5	1	172858[a]	-	-	-
	Deep MRV	5	4	119498 94668 107105 38619	MRV MRV - MRV	52 24 15 6.4	Water supply - - -
		> 5	3	94667 119852 137355	- Helidon Sandstone MRV	12 564 5	- Water supply Water supply
	Koukandowie Formation	5	7	107104[a] 119498 107105 38619 94668 94669 172057	- MRV - MRV MRV MRV MRV	14 52 15 6.4 24 12 37	Water supply Water supply - - - - Water supply
		> 5	5	119852 137355 172118 94667 38341	Helidon Sandstone MRV MRV MRV MRV	564 5 48 6.4 6.4	Water supply Water supply Water supply - -

Elapsed time since excavation commenced	Modelled aquifer	Drawdown depth (m)	Number of existing registered bores within the drawdown extent	Existing registered bore	Reported bore aquifer	Screened depth (m)	Reported bore use
62 weeks with increased conductivity in the Koukandowie Formation (refer Section 9.3.7)	Shallow MRV	5	1	94667	-	12	Sub-artesian monitoring
	Deep MRV	5	3	94667 119852 137355	- Helidon Sandstone MRV	12 564 5	- Water supply Water supply
	Koukandowie Formation	5	2	94668 107105	- -	5 5	Water supply Water supply
		> 5	3	94667 119852 137355	- Helidon Sandstone MRV	- 564 5	- Water supply Water supply
107 weeks	Deep MRV	> 5	4	172088 172183 172086 172087	MRV	25 24 24 30	Sub-artesian monitoring Water supply Sub-artesian monitoring Sub-artesian monitoring
	Koukandowie Formation	> 5	2	64098 172088	MRV	110 25	Unknown Sub-artesian monitoring
			3	172086 172087 172182	MRV	24 30 72	Sub-artesian monitoring Sub-artesian monitoring Great Artesian Basin monitoring
			1	172183	MRV	24	Water supply
			1	94667	Unknown	12	Unknown
			4	119497 119852 137168 137355	MRV Helidon Sandstone MRV MRV	10 564 12 5	Water supply Water supply Water supply Water supply

Table notes:

Data source: Queensland Globe database

a Bore is within the temporary and permanent footprint and likely to be decommissioned

Registered bores potentially impacted by vibration

The main construction activities to cause vibration impacts include:

- Blasting
- Tunnel construction equipment
- Standard construction activities associated with site establishment, earthworks, drainage works, rail and road civil works, and construction of structures (e.g. use of earth moving machinery, vibratory rollers, piling rig, hydraulic hammers, etc.).

A construction vibration impact assessment has been completed in accordance with the DTMR *Transport Noise Management Code of Practice: Volume 2 – Construction Noise and Vibration* (DTMR 2015) (CoP Vol 2). The sensitive receptors assessed include infrastructure, critical habitats and outdoor recreational areas however groundwater bores were not specifically assessed. The vibration assessment does refer to general buried pipework which includes masonry, plastic, metal, or steel construction. Groundwater bores are comparable to such structures and the recommended vibration setback distance is 5 m.

There are 16 existing registered bores within the construction footprint (summarised in Table 10.4) and of these bores there are seven bores (summarised in Table 10.6) near areas potentially impacted by vibration (including the western and eastern tunnel portal cuts, Toowoomba Range tunnel and cut 320-C10). Bores within the construction footprint are likely to be decommissioned and as such they are of low risk.

There is potential for bores above the tunnel to be impacted by vibration however the clearance between the top of the tunnel and bottom of the bore is greater than 60 m, which suggests potential vibration impacts are low.

Table 10.6 Existing registered bores within the construction footprint near critical vibration areas

Bore	Distance to Project alignment (m)	Chainage (km)	Lot/Plan	Bore role	Nearby Project structure
RN107104	7	6.1	172/RP220582	Water supply	Toowoomba Range tunnel
RN172858	10	3.9	2/RP192838	Sub-artesian monitoring	Western tunnel portal cut
RN107110	20	5.7	58/AG228	-	Toowoomba Range tunnel
RN173879	70	10.5	120/CC675	Sub-artesian monitoring	Eastern tunnel portal cut
RN173875	110	15.6	-	Sub-artesian monitoring	Cut (320-C10)
RN71234	120	3.9	21/RP34896	-	Western tunnel portal cut
RN66497	865	3.6	2/RP192838	-	Western tunnel portal cut

Table notes:

"-" data not provided in the Queensland Globe database

Unregistered bores

While the potential for the Project to impact on licensed groundwater extraction bores and registered bores has been assessed, there is potential for unregistered landholder bores to be present within the Project disturbance footprint and/or the predicted groundwater impact extent. Impacts are likely to be similar to those noted above for registered bores, based on depth (source aquifer) and proximity to construction activities.

Mitigation measures to prevent impact on such unregistered groundwater bores are presented in Section 11.

10.2.1.2 Groundwater dependent ecosystems and springs

The springs identified in Section 7.6.1 were mapped with the MRV drawdown extents (refer Figure 10.4, Figure 10.5, Figure 10.7, Figure 10.8 and Figure 10.10) as the MRV is the primary source aquifer for springs within the groundwater study area. It is noted that no source aquifer is reported for the Helidon Spring, or anecdotally reported springs, within 5 km east of the alignment. The springs are not within the predicted groundwater drawdown extent.

The GDEs mapped within the groundwater drawdown contours are summarised in Table 10.7. The GDEs are associated with tributaries of Gowrie Creek and Rocky Creek and are likely recharged by shallow alluvium units. It is unlikely the drawdown in the MRV and Koukandowie Formation will impact the mapped GDEs however there is potential connectivity between the shallow units and the MRV.

Table 10.7 Summary of groundwater dependent ecosystems within groundwater drawdown contours during construction

Duration	Unit	Drawdown contour depth (m)	GDEs within drawdown extent
34 weeks	Shallow MRV	5	None
	Deep MRV	5	None
62 weeks	Shallow MRV	5	Moderate potential GDE – terrestrial Tributary of Rocky Creek
	Deep MRV	5	Moderate potential GDE – terrestrial Tributary of Rocky Creek
	Koukandowie Formation	5 – 11	Moderate potential GDE – terrestrial Tributary of Gowrie Creek
107 weeks	Shallow MRV	5	Moderate potential GDE – aquatic Moderate potential GDE – terrestrial Tributary of Rocky Creek
		5 – 10	Moderate potential GDE – aquatic Moderate potential GDE – terrestrial Tributary of Rocky Creek
	Deep MRV	5	Moderate potential GDE – aquatic Moderate potential GDE – terrestrial Tributary of Rocky Creek and Gowrie Creek
		5 – 6	Moderate potential GDE – aquatic Moderate potential GDE – terrestrial Tributary of Rocky Creek
	Koukandowie Formation	5	Moderate potential GDE – aquatic Moderate potential GDE – terrestrial Tributary of Rocky Creek and Gowrie Creek
		5 – 10	Moderate potential GDE – aquatic Moderate potential GDE – terrestrial Tributary of Rocky Creek and Gowrie Creek

10.2.1.3 Embankments

The potential significance of impact is dependent on the embankment (i.e. height), compressibility of the underlying materials (i.e. clay, silt and sand content of the alluvial sediments) and depths to groundwater. Most embankments are located over competent rock with anticipated subgrades for embankments either residual soil overlying Gatton Sandstone or colluvial material overlying Koukandowie Formation.

Obstruction of natural drainage pathways due to embankments can potentially result in more frequent inundation of areas upstream of the embankment, this can result in potential groundwater mounding beneath inundated areas. Groundwater mounding can lead to long-term operational impacts on soil salinity and may affect the stability of the embankment.

The potential for mounding and damming of groundwater may be greater in areas of shallower groundwater in colluvial or alluvial sediments local to active channels (such as Gowrie Creek, Oaky Creek, Rocky Creek and Six Mile Creek), although viaducts/bridges are typically proposed in these areas.

Potential for groundwater mounding at embankments was calculated using estimated current groundwater levels and an estimate of the potential increase in levels based on records of groundwater level variations from historical flood events (Golder 2020b). Assessment of available records and calculations indicate embankments intersect the following units:

- MRV: fracture permeability and low effective porosity may result in potential groundwater level rise between 1.2 m and 15.1 m, rapidly or delayed, dependent on connectivity of fractures following large rainfall/flood events
- Sedimentary units east of the GDR: low effective porosity may result in potential groundwater level rise between 1.0 m and 3.5 m, likely delayed following large rainfall/flood events
- Floodplains overlying deep alluvium (e.g. Gowrie Creek): potential groundwater level increase of up to 10 m is anticipated.

Three embankment locations (320-E1, 320-E2, and 320-E3), depicted on Figure 10.1, are the most likely to see a rise in groundwater level (within 2 m of ground surface) (Golder 2020a). These embankments overly the Gowrie Creek floodplain, which is subject to inundation during flooding. Diversion drains are proposed at locations where the rail embankment will be placed over existing flow paths to ensure inundation extent and frequency are comparable with existing conditions. The embankments have been designed to sustain flood levels up to the 1% AEP event. Refer to EIS Chapter 13: Surface water and hydrology for more details regarding flooding.

Overall, there is the potential for embankments to effect groundwater levels and/or the hydraulic properties of the aquifer(s) locally across some sections of the Project (as described above). It is anticipated that ongoing and further geotechnical investigations will confirm the potential risk and inform final design. This includes design measures and/or strategies to avoid, mitigate and manage impacts.

10.2.1.4 Subsidence/settlement

There is limited potential for construction phase (more than 1 year after completion of slope cuts) localised drawdown to occur as a result of dewatering from cuts. Groundwater drawdown can result in settlement of compressible substrates and possible damage to adjacent structures, i.e. proposed bridges or embankments.

Early drawdown effects due to seepage into cuttings and the tunnel has the potential to cause settlement of compressible materials, and damage to buildings or other structures within areas of settlement (including rail/road and pipelines). The greatest potential risk occurs where groundwater is shallow, soils are compressible, and buildings/structures are nearby; for example, areas within proximity to the Gowrie Creek floodplain. In such locations viaducts/bridges are typically proposed.

In the area of the Toowoomba Bypass, subsidence potential is considered limited to the western portal of the Toowoomba Range tunnel; all other Project crossing locations are to be either bridges or well below the bypass where impact is not anticipated.

Some locations for cuts are expected to be below the water table and eight deep cuts were selected for modelling to estimate the potential drawdown amount and lateral drawdown extent (refer Section 9.4). These deep cuts are located within competent substrate including basalt and sandstone where the likelihood of settlement is less probable than in unconsolidated substrates.

Deep cuttings in high relief areas are typically in more competent bedrock sediments and so the risk of settlement is reduced. Reduced groundwater levels due to dewatering and/or seepage into the tunnel and shaft are not considered to present a risk of settlement due to the competent sedimentary bedrock material being tunnelled (that is, MRV and Koukandowie Formation).

Overall, the potential for settlement and damage to buildings and properties due to subsidence from drained cuttings and undrained intermediate shaft and tunnel appears to be low. It is anticipated that the potential for settlement will be confirmed as part of ongoing geotechnical investigations and will inform final design.

10.2.1.5 Vegetation removal and surface disturbance

A limited area is proposed to be cleared and graded for construction purposes when compared to the large aquifer extents due to the linear nature of the Project. The disturbance footprint considered negligible against the recharge surface area of the aquifers which underlay the Project. Consequently, there is likely to be little impact on groundwater resources.

10.2.1.6 Bridge and viaduct pilings

Changes to groundwater levels may occur during installation of pilings for bridge construction. Any such changes will be temporary, localised and small based on construction design (i.e. diameter, depth and spacing of piles).

10.2.1.7 Construction water supply

Water will be required for dust control, site compaction and reinstatement during construction. ARTC recognises water sourcing and availability is critical to supporting the construction program for the Project. Sources of construction water (including potable water demand) will be finalised as the construction approach is refined during the detail design and tender phases of the Project (post-EIS) and will be dependent on:

- Climatic conditions in the lead up to construction
- Confirmation of private water sources made available to the Project by landholders under private agreement
- Confirmation of access agreement with local governments for sourcing of mains water.

The hierarchy of preference for accessing of construction water is generally anticipated to be as follows:

a) Capture, treat (where applicable) and reuse groundwater inflow from construction of the western tunnel portal and the Toowoomba Range tunnel

b) Commercial water supplies, including recycled water, where capacity exists: existing infrastructure, well understood water systems, available water volumes known, existing (in place) licensing

c) Public surface water storages (e.g. dams and weirs)

d) Existing registered and licensed bores (under agreement with licence holders)

e) Privately held water storages (e.g. dams or ring tanks, under private agreement)

f) Permanently flowing watercourses (Under DRDMW license requirements)

g) Town water (for specific, essential uses only).

An assessment of the suitability of each source will need to be made for each construction activity requiring water, based on the following considerations:

- Legal access
- Volumetric requirement for the activity (e.g. camps require potable water)

- Water quality requirement for the activity
- Source location relative to the location of need.

The buying or sharing of groundwater from existing water license/entitlement/permit is an option to be considered in the instance bore water is selected as a preferred source of construction water.

Temporary water permits could provide a suitable water supply option for the construction phase of the Project. Water permits are issued for temporary projects having a foreseeable conclusion date and anticipated to have short-term impacts on the resource. Normally, water permits are granted up to a maximum timeframe of three years and cannot be renewed, transferred, or amended. However, the viability of this option will need to be reviewed during the pre-construction phase to confirm the volume, if any, of available allocations to support the temporary permit.

Where it is determined that construction water will be sourced from an existing bore (private or ARTC) an amendment under the Act may be required; that is, the current purpose of the bore (e.g. irrigation, domestic use) may not allow the water to be used for construction. Further, a water licence may be required for any new groundwater bores; though, as noted previously, groundwater allocations under the relevant water plan are predominantly exhausted.

Potential impacts to groundwater elevations may occur where bore water is sourced to supply water for construction activities. However, if groundwater is considered for sourcing of construction water, it will be sourced from existing registered and licensed bores. Therefore, the volumes extracted would be within the existing licensing limits and the extent of drawdown experienced would be localised and consistent with that which is currently permissible for each registered bore.

10.2.1.8 Existing water entitlements

There are eight land parcels within the Project disturbance footprint that are linked to a water entitlement under the Water Act, refer Table 10.8. These water entitlements will expire as a result of the land acquisition process (i.e. the water entitlement is linked to a land parcel being acquired (in full or part) for the Project). The landholder has 60 days to reinstate the water licence.

There is the potential for the water entitlements to be purchased by ARTC as part of the land acquisition process, or for compensation to be sought, due to the expiration of the water licence. There are also several water licences on adjacent properties to the Project, where construction water may also be sourced. This includes Lot 924 on SP154259, with the attached water licence (83456R) allowing for the take of groundwater for an urban purpose. The water allocation is for 3,800 megalitres per year (ML/yr) from the Main Range Volcanics (Toowoomba City Basalts) and is applicable to Toowoomba Regional Council.

Table 10.8 Land parcels with water entitlements under the Water Act 2000 directly impacted by the Project

Water source	Licence details	Water use	Associated land parcels	Annual allocation
Water Plan (Condamine and Balonne) 2019				
Groundwater*	Licence to take water (404530)—Toowoomba South Basalts Groundwater, Upper Condamine Basalts, Main Range Volcanics	Irrigation	26/RP24609	35 ML
Groundwater	Licence to take water (4171R)—Toowoomba North Basalts Groundwater, Upper Condamine Basalts, Main Range Volcanics	Irrigation	2/RP138824	0 ML
Groundwater	Licence to take water (48082R)—Toowoomba South Basalts Groundwater, Upper Condamine Basalts, Main Range Volcanics	Stock intensive	35/AG4088	1 ML
Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017				
Groundwater	Licence to take water (48082R)—Eastern Downs Marburg, Hutton, Marburg subgroup	Irrigation	26/RP24609	5 ML

Water source	Licence details	Water use	Associated land parcels	Annual allocation
Groundwater	Licence to take water (48082R)—Eastern Downs Marburg, Hutton, Marburg subgroup	Irrigation	2/RP40070	10 ML
Water Plan (Moreton) 2007				
Surface water	Licence to take water (18927G)—Upper Lockyer Ck (Gat) Wac	Irrigation	1/CH3133; 111/CC794; 197/CH31508; 54/CA311531	15 ha
Surface water	Licence to take water (25397G)—Upper Lockyer Ck (Gat) Wac,	Irrigation	13/CH31259; 51/CC835	4 ha
Groundwater	Licence to take water (48322G)—Murphys Creek Marburg, Hutton	Domestic supply	153/CH31327	Unknown

Table note:

* partially impacted

10.2.2 Water quality

10.2.2.1 Contamination

During the construction phase, potential sources of contamination to groundwater could occur due to:

- Unintended spills and leaks of hydrocarbons (oils, fuels and lubricants) and other chemicals related to use of heavy plant and equipment and fuel storages
- Water mixtures and emulsions related to washdown areas
- Upward seepage along piles/soil interfaces of saltier groundwater from the deeper confined aquifers into the fresher alluvium aquifers
- Discharge of groundwater seepage from tunnel and cuts
- Heavy metals entering watercourses from rail grinding and welding
- Compounds leaching from ballast materials
- Salts mobilised from surface soils or shallow groundwater changes
- Disturbance of contaminated lands near watercourses resulting in contaminated runoff entering watercourses and potentially to recharge areas
- Inadequately treated dewatering of tunnel infrastructure may result in hydrocarbons being introduced to the Gowrie Creek catchment at the western tunnel portal and to the unnamed tributary of Rocky Creek at the eastern portal.

Direct infiltration of contaminants through the ground surface in areas of low relief with shallow water levels are likely to be reduced due to the dominant fine-grained sediments of the soil profile (clays and silts). This has potential to occur beneath the watercourses encountered by the Project and at Ch 10 km, Ch 12 km and between Ch 19 and 24 km, which are underlain by alluvium, MRV, Koukandowie Formation or Gatton Sandstone.

Excessive amounts of water applied during construction phases of the Project have the potential to infiltrate past the root zone and contribute to rising water tables/levels in shallow aquifers. Leakage from water storage areas may also contribute to rising water levels.

Potential contamination of the shallow aquifers could occur via inflow into bridge pile boreholes which intersect the water table. This source of contamination is considered unlikely as pilings will be grouted to surface for ground stability and therefore not anticipated to act as a conduit for surface contaminants to groundwater resources.

Groundwater bores installed for environmental monitoring or water supply have the potential to create a vertical pathway between aquifers if not installed correctly or if the bores deteriorate due to abandonment. Potential impacts may include:

- Mixing of different hydraulic heads
- Mixing of different groundwater qualities
- Contamination of non-flowing bores from surface runoff into the bore
- Uncontrolled flow and wastage from groundwater under pressure.

10.2.2.2 Bridge and viaduct pilings

A rotary drill rig will be used to drill bored piers, with prefabricated reinforcement cages lowered into the pile before a wet concrete slurry is placed via Tremie or pumping. The alkaline wet concrete slurry may affect groundwater quality (for example pH and salinity) immediately adjacent to the piles whilst curing occurs (that is, drying and hardening of the concrete). Any such changes are likely to be temporary, localised and small given the small contact areas of piling surfaces and groundwater compared to the scale of the groundwater flow systems.

10.2.2.3 Toowoomba Range tunnel

Based on available groundwater quality data, groundwater quality of inflows to the Toowoomba Range tunnel and associated cuts during construction and operation is expected to be fresh to brackish, sodium-chloride dominant and neutral to slightly alkaline (more detail in Section 9.3.6.2). Water quality values may vary seasonally due to first flush events.

During construction via the TBM any water collected inside the tunnel (groundwater seepage, stormwater carry-in, wash-down, firefighting etc.) will be collected and treated in a WTP at the western tunnel portal to manage water quality. The treated water will be reused, where applicable to support construction (subject to water quality requirements).

10.2.2.4 Cuts

The groundwater quality of seepage to the cuts is expected to be brackish and slightly alkaline (refer Section 9.4.3.1). The estimated inflow rate to cuts in rock during construction is low (less than 0.1 L/s) and consequently evaporative deposition of salt could occur on batters and at the base of cuts. This would be more severe where the salinity is higher at the cut location, for example, cuts into a localised area of reduced groundwater quality downstream of headwaters where connectivity with Quaternary aquifers is expected to decrease.

Seepage from cuts will likely report to cess drains, which are surface drains located to the side of the tracks.

10.3 Operation phase potential impacts

This section provides a discussion of the potential impacts on groundwater resources and related environmental values as a consequence of operation of the Project.

10.3.1 Water resources

The operation phase will include maintenance activities for key infrastructure including the Toowoomba Range tunnel and bridges and structures. Numerical modelling (refer Section 9.3 and Section 9.4) indicates there is long-term seepage from the cuts and tunnel, which can potentially cause operation phase impacts.

10.3.1.1 Dewatering

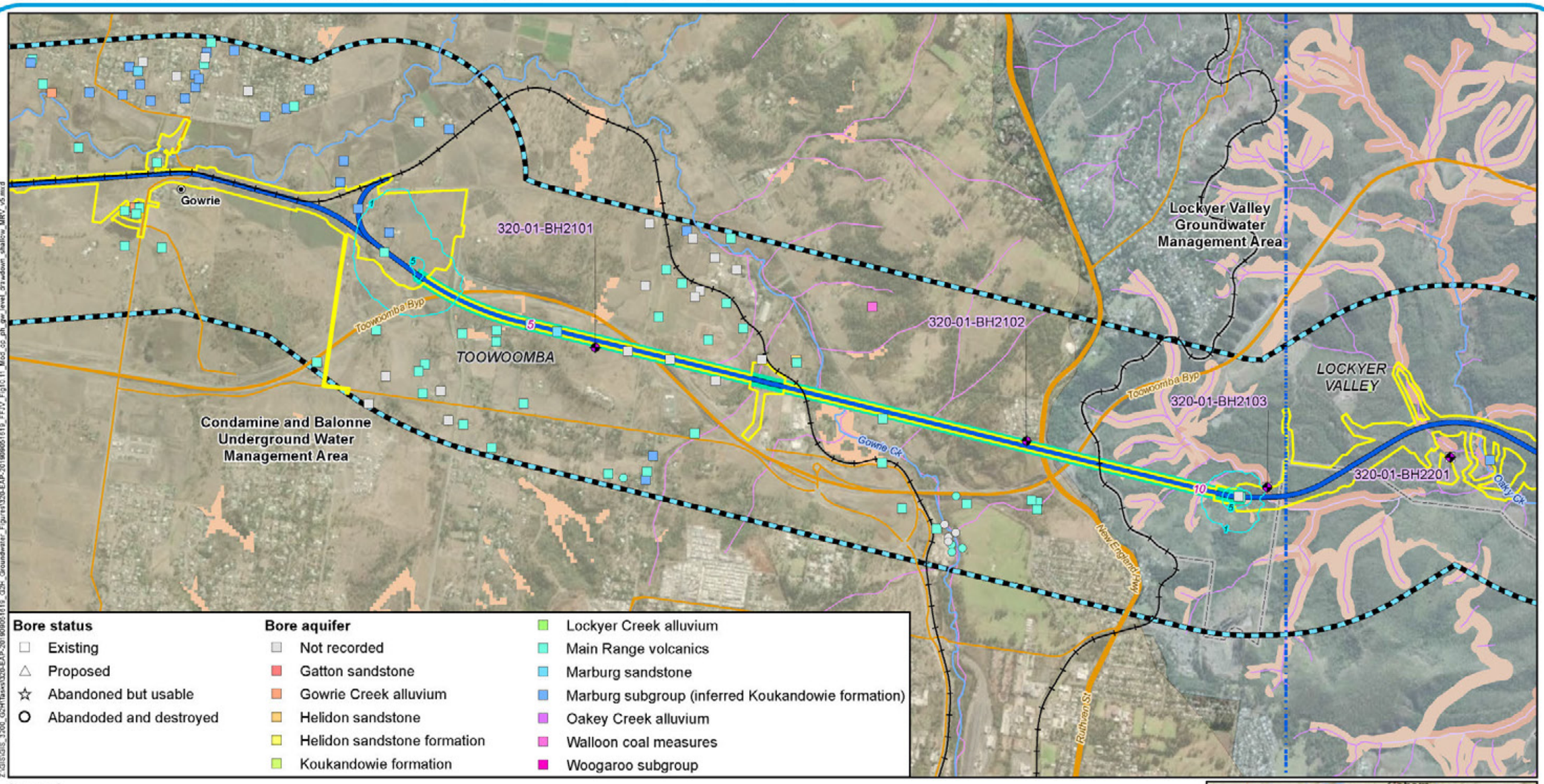
Predictive modelling of the Toowoomba Range tunnel (refer Section 9.3.6.1) suggests the operational groundwater inflow to the tunnel is expected to be 0.30 L/s and 0.006 L/s to the intermediate ventilation shaft. The resulting groundwater drawdown was then assessed for each major unit: shallow MRV (typical value of hydraulic conductivity), deep MRV (high conductivity layer), and the Koukandowie Formation).

Figure 10.11 to Figure 10.13 present the operational groundwater drawdown extents. Registered groundwater bores and GDEs have also been included in the figures. Section 10.3.1.2 includes the predicted drawdown extents and potentially impacted bores.

These preliminary drawdown extents are considered a base-case. There is potential for increased conductivity and permeability within the fractured MRV and Koukandowie Formation, which when assessed in the predicted modelling sensitivity analysis (refer Section 9.3.7), the groundwater seepage rates into the tunnel may be higher rates and increased drawdown extents than those discussed above. Sensitivity analyses scenarios undertaken as a component of the predictive modelling indicate that an increase of the hydraulic conductivity in the MRV by one order of magnitude (Scenario 2, Section 9.3.7.1) has the most significant impact and increases and increases inflow to the western tunnel portal by 77%.

The predicted impacts will be refined via updated modelling, as described in Section 9.5 for the Final EIS.

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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

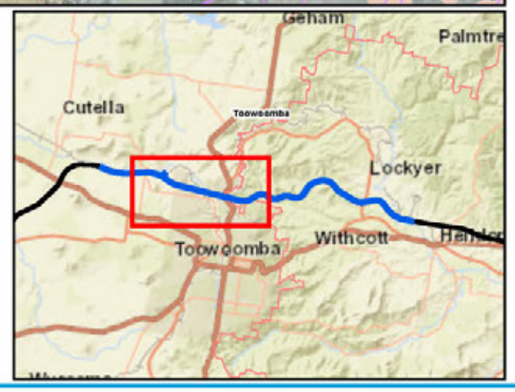
Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

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Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

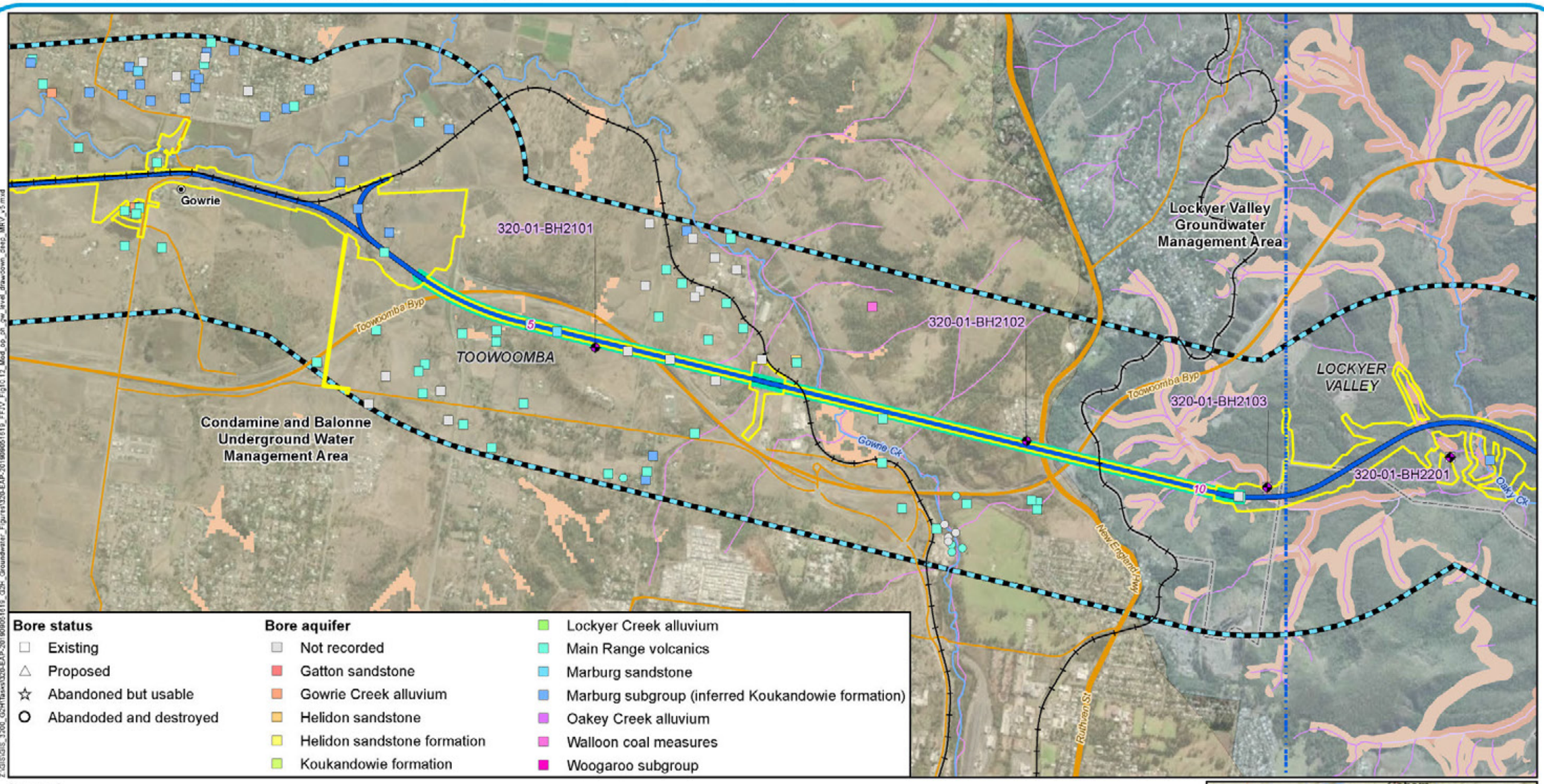
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Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 10.11: Modelled long-term (operation phase) groundwater level drawdown (shallow MRV)

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Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Map by: GNGTH/TM Date: 24/03/2021 15:34
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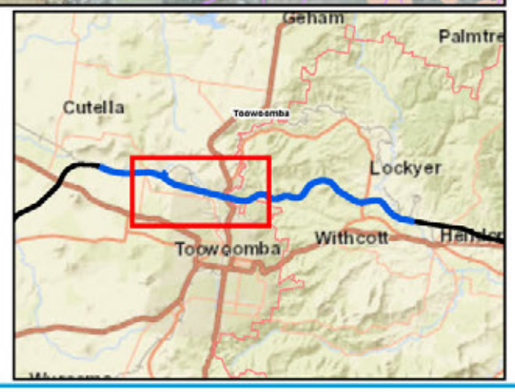
Legend
- Project bores
- 5 Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas

Note: modelled contours are not available (no drawdown predicted) for this figure.

- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



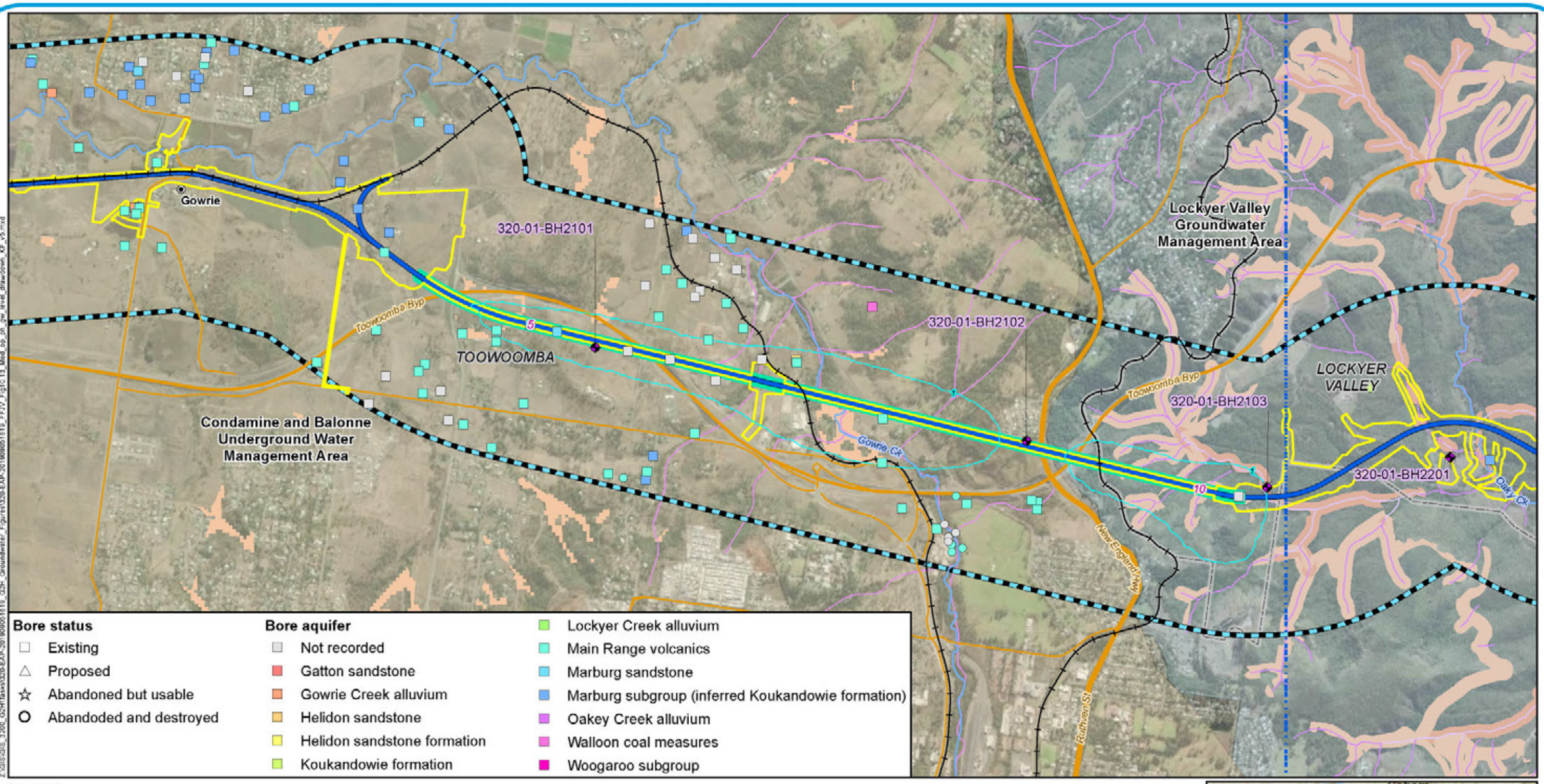
A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon
Figure 10.12: Modelled long-term (operation phase) groundwater level drawdown (deep MRV)

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community



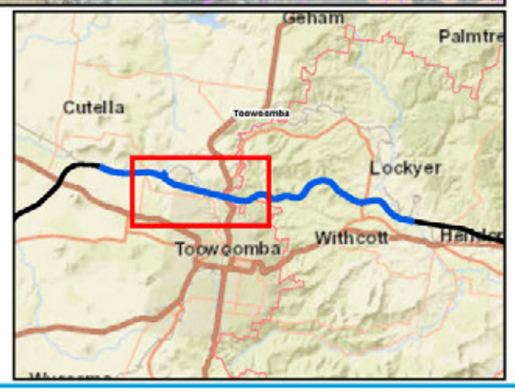
Bore status
- Existing
- Proposed
- Abandoned but usable
- Abandoded and destroyed

Bore aquifer
- Not recorded
- Gatton sandstone
- Gowrie Creek alluvium
- Helidon sandstone
- Helidon sandstone formation
- Koukandowie formation
- Lockyer Creek alluvium
- Main Range volcanics
- Marburg sandstone
- Marburg subgroup (inferred Koukandowie formation)
- Oakey Creek alluvium
- Walloon coal measures
- Woogaroo subgroup

Legend
- Project bores
- Chainage (km)
- Localities
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater predictive model domain
- Contour
- G2H project alignment
- Tunnel
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Condamine and Balonne Underground Water Management Area
- Lockyer Valley Groundwater Management Area

Aquatic GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

Terrestrial GDE
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



A3 scale: 1:30,000
0 0.3 0.6 0.9 1.2 1.5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 24/03/2021 Version: 5
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 10.13: Modelled long-term (operation phase) groundwater level drawdown (Koukandowie Formation)

Map by: GNGTH/TM Date: 24/03/2021 15:37
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10.3.1.2 Loss or damage to existing landholder bores

There is a potential for existing landholder bores to be damaged, destroyed, or to become inaccessible during operation. Registered bores were identified within the groundwater study area in Section 7.5.1.

Registered bores within the Project permanent footprint

Existing registered bores within the permanent disturbance footprint are summarised in Table 10.9. All bores within the permanent footprint are also in the construction footprint (refer Table 10.4) and are to be decommissioned during construction (excluding bores located above the tunnel) to enable construction of the Project and are not considered to be impacted by the operation of the Project.

Table 10.9 Registered bores within the construction and permanent footprint

Bore	Project chainage (km)	Lot/Plan	Bore role	Nearby Project structure
RN56783	2.0	122/AG3560	-	320-E2 and 320-E3
RN66497	3.6	2/RP192838	-	Western tunnel portal cut
RN71234	3.9	21/RP34896	-	Western tunnel portal cut
RN172858	3.9	2/RP192838	Sub-artesian monitoring	Western tunnel portal cut
RN173879	10.5	120/CC675	Sub-artesian monitoring	Eastern tunnel portal cut
RN173875	15.6	6/SP186716[a]	Sub-artesian monitoring	Cut (320-C10)
RN173799	19.8	213/SP200754	Sub-artesian monitoring	320-E12
RN173798	21.1	169/SP200753	Sub-artesian monitoring	Murphys Creek Viaduct
RN173154	21.5	4/SP200753[a]	Water supply	Withcott Seedlings Viaduct
RN75289	23.6	18/SP105106	Water supply	Withcott Seedlings Viaduct
RN75335	23.9	18/SP105106	Water supply	Withcott Seedlings Viaduct
RN173801	24.8	452/SP117138	Sub-artesian monitoring	Lockyer Creek Viaduct

Table notes:

"-" data not provided in the Queensland Globe database

a land parcel is within the Toowoomba Bypass footprint

Registered bores potentially impacted by groundwater level drawdown

After predictive modelling of the impacts of deep cuts and the Toowoomba Range tunnel and portals on groundwater resources (refer Section 9.3), the modelled impact area was assessed against licensed groundwater extraction bores and other registered bores in order to identify the areas (real property) potentially impacted by the Project. This has been used to better understand the potential impacts on groundwater users.

Figure 10.11 to Figure 10.13 present the predicted drawdown extent during operation. The predicted drawdown extent for the shallow MRV is limited to the portals due to their drained design; there is no predicted groundwater drawdown in the deep MRV. Predicted drawdown for the Koukandowie Formation is limited to within approximately 400 m from the tunnel.

Unregistered bores

While the potential for the Project to impact on licensed groundwater extraction bores and registered bores has been assessed, there is potential for unregistered landholder bores to be present within the groundwater study area and the predicted impact extent. Mitigation measures to prevent impact on such unregistered groundwater bores is presented in Section 11.

10.3.1.3 Groundwater dependent ecosystems and springs

The springs identified in Section 7.6.1 were mapped with the operational MRV drawdown extents (refer Figure 10.11 to Figure 10.13) as the MRV is the primary source aquifer for springs within the groundwater study area. It is noted that no source aquifer is reported for the Helidon Spring (or anecdotally reported springs) just east of the alignment. The operational groundwater drawdown extent for the shallow and deep MRV unit does not include any springs.

There are no GDEs mapped within the long-term (operational) groundwater drawdown contours.

10.3.1.4 Embankments

There is potential for raised groundwater levels due to long-term surface loading of alluvial soils from embankments and other constructions along the rail alignment where groundwater is shallow. Possible areas for compressible alluvial soils include localised portions of Gowrie, Oaky, Rocky, Six Mile and Lockyer creeks. It is expected these impacts will be localised due to the linear nature of the Project and the typical depth to groundwater, based on available information, being greater than 5 mbgl in the alluvium. Further, the main watercourse crossings are via viaducts and bridges rather than embankments (as shown in Figure 10.1).

10.3.1.5 Bridge and viaduct pilings

Pilings may change groundwater flow patterns. Such changes would be very localised and small given the diameter and spacing of pilings compared to regional flow patterns. Long-term impacts on groundwater flow are not anticipated given the spacing of the pilings for the rail alignment and that all footings will be established above the high water bank.

10.3.1.6 Operation water supply

The tunnel requires potable water for operation and maintenance activities. The main identified potable water requirements for the tunnel are listed below:

- Tunnel Control Centre amenities (1 L/s)
- Fire water tanks infill (6 L/s for 24-hour refill)
- WTP (2 L/s to be confirmed)
- Tunnel washdown (unknown although assumed to be non-determining).

A desktop assessment has been undertaken to identify the nearest existing potable water infrastructure that can potentially supply water to the tunnels. Hydraulics and adequacy of the existing infrastructure to supply the required flow and pressure have not been undertaken because this process is generally a component of the new connections work that is undertaken by the utility provider.

Groundwater has not been considered as a potable water source during operation and therefore there are no potential groundwater impacts associated with operation water supply.

10.3.2 Water quality

There is potential for water quality impacts during operation as a result of the following:

- Oil and grease spills (potential for oil and grease from rollingstock to enter the watercourses after heavy rainfall events without appropriate controls)
- Heavy metals from maintenance (including rail grinding and welding)
- Compounds leaching from ballast materials
- Accidental spills from freight carriages during routine operation (e.g. coal dust)

- Infrastructure impacts – with the introduction of bridge or culverts within waterways, should these structures fail, there is the potential for impacts to water quality either from potential contaminants (debris) or from detained water flushing from collapsed structures.
- General maintenance - maintenance of the rail line or machinery near waterways has the potential to mobilise sediments from disturbed areas and increase the potential for litter or rubbish to enter waterways. Furthermore, oils and greases and other contaminants such as metals have the potential to enter waterways from spills, and for impact from the use of environmental toxicants (such as use of inappropriate biocides) to maintain operating infrastructure areas. These activities have the potential to impact nearby waterways, through discharge points without appropriate mitigation.

In the instance a spill or leak occurs from normal operational activities, the impact is likely to be superficial in nature and not expected to impact on shallow aquifers. Spill kits and environmental response equipment will be stored at areas of heavy plant, for example a repair shop or plant/equipment storage shed.

10.3.2.1 Tunnel

Based on available groundwater quality data, groundwater quality of inflows to the Toowoomba Range tunnel and associated cuts during operation is expected to be fresh to brackish, sodium-chloride dominant and neutral to slightly alkaline (more detail in Section 9.3.6.2). Water quality values may vary seasonally due to rainfall infiltration diluting levels. Estimated long-term (operation) inflow rates for the tunnel and the associated ventilation shaft is low (inflow to the tunnel is expected to be 0.30 L/s and 0.006 L/s to the shaft).

During operation any water collected inside the tunnel (groundwater seepage, stormwater carry-in, wash-down, firefighting etc.) will be collected and treated in a WTP at the eastern tunnel portal. The target water quality of the WTP has not been decided and will be confirmed during detailed design.

10.3.2.2 Cuts

The groundwater quality of seepage to the cuts is expected to be brackish and slightly alkaline (more details in Section 9.4.3.1). Estimated operation inflow rate for cuts in rock is low (less than 0.1 L/s) and consequently evaporative deposition of salt could occur on batters and at the base of cuts. This would be more severe where the salinity is higher at the cut location. Further, seepage from cuts will likely report to cess drains, which are surface drains located to the side of the tracks.

11 Mitigation

This section identifies and discusses appropriate mitigation measures for the prevention or minimisation of the groundwater impacts documented in Section 10.

Mitigation measures will be included in the draft Outline Environmental Management Plan (draft Outline EMP) (refer EIS Chapter 23: Draft Outline Environmental Management Plan). The document describes how an action might impact on the natural environment in which it occurs and provides clear commitments on how those impacts will be avoided, minimised and managed. A Construction Environmental Management Plan (CEMP) will be prepared to capture all mitigation measures that are required to be implemented prior to, or during construction of the Project. The draft Outline EMP presented in the Project EIS (refer EIS Chapter 23: Draft Outline Environmental Management Plan) will be used as a basis for the CEMP. An Operational Environmental Management Plan will be prepared for the operation phase of the Project based on the data collected during the baseline and construction phases. The groundwater management and monitoring plan (GMMP) (refer Section 11.3) will inform the groundwater aspects of the draft Outline EMP, CEMP and Operational Environmental Management Plan (OEMP).

11.1 Design considerations

The mitigation measures presented in Table 11.1 have been incorporated into the Project design. These design measures have been identified through collaborative development of the design and consideration of environmental constraints and issues. These design measures are relevant to both construction and operational phases of the Project.

Table 11.1 Initial mitigation measures (design considerations)

Aspect	Initial mitigations
Water resources	The Project generally aligns with the Gowrie to Grandchester future State transport corridor. This corridor was initially identified in the Gowrie to Grandchester Rail Corridor Study in 2003. This rail corridor was subsequently identified as a 'future public passenger transport corridor' in September 2005 in the Public Passenger Transport Guideline made under the *Transport Planning and Coordination Act 1994*. The alignment (both lateral and vertical) has been designed to minimise earthworks, reducing the potential to impact water resources (for example dewatering of cuttings and embankment placement). To maintain the required gradient, bridges and viaducts (refer Figure 10.1) are proposed which will minimise the use of cuts and embankments and therefore minimise impacts to existing surface hydrology, with no footings proposed within the channel of a watercourse or wetland. This reduces the risk of altering shallow groundwater levels and recharge patterns. Undrained tunnel design to limit groundwater ingress into the tunnel and ensure the existing groundwater surrounding the tunnel is not drawn down during operation of the tunnel.
Water quality	The disturbance footprint defined in Project design has aimed to minimise clearing extents to that required to construct and operate the works. During construction and operation any water collected inside the tunnel (groundwater seepage, stormwater carry-in, wash-down, firefighting etc.) will be collected and treated in a WTP at either the western tunnel portal or the eastern tunnel portal. The water will be reused for construction activities or discharged to the surrounding environment (including the potential for reinjection), volumes and receiving water quality dependant. The target water quality for discharge to the surrounding environment will be suitable to not impact on the existing quality. With additional baseline data, appropriate environmental values and WQOs will be confirmed.

These elements will be refined during detailed design and incorporated in the final design of the Project and form the basis for the CEMP and OEMP to avoid and/or mitigate impacts.

11.2 Proposed mitigation measures

In order to manage and mitigate Project impacts on groundwater a number of additional mitigation measures have been proposed for implementation in future phases of Project delivery, as presented in Table 11.2. These proposed mitigation measures have been identified to address to Project specific issues and opportunities, address legislative requirements, accepted government plans, policy, and practices.

Table 11.2 identifies the relevant Project phase, the aspect to be managed, and the proposed mitigation measure, which is then factored into the assessment of residual significance in Table 12.1.

These proposed mitigation measures have been considered in the GMMP (refer Section 11.3) which will be a subplan to the draft Outline EMP, the CEMP and the OEMP in accordance with the Project phase during which they are to be implemented:

- Detailed design /Pre-construction
- Construction
- Operation.

Table 11.2 Groundwater mitigation measures

Delivery phase	Aspect	Proposed mitigation measures
Detailed design	Interaction with groundwater by elements of the Project	■ Further geotechnical and hydrogeological investigations will be undertaken in parallel to the detail design process to ensure site-specific conditions are reflected in the final design solution. Investigations will be targeted to specific locations, such as: – Toowoomba Range tunnel, portals, and shaft – Deep cut sections – Locations of significant fill – Fault/dyke/fracture structures, and – To better understand the hydraulic conductivity of the Koukandowie Formation of the Marburg Subgroup, WCM, and colluvium deposits ■ Additional aquifer permeability tests are ongoing prior to final design to understand the structural elements, hydraulic connectivity between units, and aquifer characteristics (compartmentalisation) which may result in cut/tunnel inflow seepage rates higher than expected, increased regional or localised groundwater drawdown and/or impacts on EVs. Specifically, to continue collection and assessment of baseline groundwater monitoring data (levels and quality) along the tunnel alignment to confirm seasonal variation and inform detailed design (groundwater levels) and the WQOs for the GMMP. There is limited local data along the Toowoomba Range tunnel aspect; groundwater levels in the Marburg Subgroup/Koukandowie Formation may be higher than estimated. Additional monitoring bores along the tunnel alignment (~400 m intervals) and at every cut identified to intersect groundwater and inclusion into the baseline monitoring program (levels and quality) will establish groundwater levels prior to final design (and may identify perched aquifers). Continuous collection of groundwater levels in monitoring bores along the tunnel alignment at each cut location anticipated to intersect groundwater will allow for assessment of recharge rates to better understand the hydrogeological regime's response in highly conductive zones to large rainfall events. This data will limit risks to over/under designing the tunnel and cuts. ■ Site inspections of proposed cut locations will be conducted to visually examine surface outcrops for sulphide minerals or remnant products indicative of sulphide mineralisation. This would inform the need for management of potential ARD from cuttings in sedimentary units prior to construction works. ■ Predictive numerical modelling will be refined using additional information obtained from further geotechnical and hydrogeological investigations, and updates to the sensitivity analyses and hydraulic conductivity parameters, in addition to finalised tunnel, portal, and cut dimensions. This revised modelling will be completed for the Final EIS to better understand seepage estimates and groundwater level variation resultant from the tunnel, portals, and cuts. Seepage analysis will be used to advise of construction of the tunnel, drainage blanket specifications, or alternative design controls, for deep cuts into hard rock. ■ Undertake a landholder bore survey to verify the number of bores within, and directly adjacent to, the Project disturbance footprint, bores above the Toowoomba Range Tunnel and, where applicable, the drawdown extents modelled for the Project. The survey may a bore assessment with due consideration of the Queensland Government's *Guideline Bore Assessments* (ESR/2016/20051). The assessment will aim to: – Provide a measure of security for ARTC and the bore owners by providing information about the current condition and pumping capacity for a water bore – Provide a reference point for comparison with subsequent bore assessments to assist in the negotiation of make-good arrangements and assist in the development of groundwater data modelling – Assist in resolution of any future disputes that may arise between bore owners and ARTC following a bore assessment or in the negotiation of a make-good arrangement.

Delivery phase	Aspect	Proposed mitigation measures
	Impacts to registered and unregistered bores	■ Landowners affected by the Project will be consulted to confirm the location of registered bores and to establish the presence of any unregistered bores within the Project disturbance footprint that may be decommissioned to enable construction and operation of the Project. Where a groundwater bore is expected to be decommissioned or have access to it is impaired as result of the Project, 'make good' measures will be agreed in consultation with the affected landowner and may include monetary compensation developed on a case-by-case basis. ■ Procure access agreements to existing registered groundwater bores included in the GMMP (refer Table 11.3).
	Sourcing of construction water	■ The construction water requirements (i.e. volumes, quality, demand curves, approvals requirements and lead times) will be confirmed as the construction approach is refined. The ultimate water sourcing strategy for the Project will be documented in a Construction Water Plan developed for the Project. The Construction Water Plan will be developed involving all levels of government, specifically DRDMW Water Services, and other entities. In developing the Construction Water Plan, ARTC will investigate and assess sustainable water solutions to support the Project that will not impact on the function of business, industry and communities along the Project alignment. Sources of construction water will be finalised as the construction approach is refined during the detail design and tender phases of the Project (post-EIS) and will be dependent on: – Climatic conditions in the lead up to construction – Confirmation of private water sources made available to the Project by landowners under private agreement – Confirmation of access agreement with local governments for sourcing of mains water. ■ The use of groundwater to supplement the construction demand for the Project may be considered if private owners of licensed/registered bores have capacity under their water licence or entitlement that they wish to sell to, or trade with, ARTC under a private agreement. Discussions with private water owners may include an accompanying officer from DRDMW Water Services and amendments to existing water authorisations.
	Groundwater quality	■ Continue collection of baseline groundwater monitoring data (levels and quality) from monitoring bores established for the Project through the EIS process, as well as from additional bores installed through the detail design process, in accordance with the pre-construction/baseline phase GMMP (refer Section 11.3). Data will be collected to provide a robust dataset for characterisation of the primary aquifers of relevance over a time sufficient to identify seasonal variation trends. Continuous and repeated quality sampling of groundwater along the portals, tunnel, and deep cuts will provide site specific quality with respect to magnesium, DO, calcium concentrations, groundwater aggressivity and scaling potential prior to final design. ■ Groundwater monitoring and sample collection will be conducted in accordance with recognised groundwater sampling guidelines such as *Monitoring and Sampling Manual* (DES, 2018e) and *Groundwater Sampling and Analysis – A Field Guide* (Geoscience Australia, 2009). ■ Collected data will be used to establish a groundwater condition baseline for the Project against which construction phase impacts can be monitored and compared (refer Section 10.2.1). Baseline groundwater monitoring data will be used to: – Derive location/bore specific groundwater monitoring procedures – Establish location/bore specific impact thresholds – Establish responses to impact threshold exceedances, including 'make good' agreements. These details will be incorporated into future revisions of the GMMP, which will be subject to approval from DRDMW and DES prior to implementation. ■ A Contaminated Land Management Sub-plan will be developed and incorporated into the CEMP. This Sub-plan will document management controls for works on land that is known or suspected of being contaminated and outline the process to identify, document and manage contaminated sites (refer EIS Chapter 9: Land resources)

Delivery phase	Aspect	Proposed mitigation measures
		▪ Refine the design of the WTP, including the target water quality of treated water disposal, based on additional groundwater quality (baseline) data.
Pre-construction	Impacts to bores	▪ There are 16 registered bores within the Project disturbance footprint, two of which are located above the tunnel. With the exception of the bores above the tunnel, these bores, plus unregistered bores that also occur within the Project disturbance footprint, are likely to be decommissioned for the progression of the Project. Bores identified within the construction footprint will be decommissioned in accordance with the *Minimum Construction Requirements for Water Bores in Australia – Edition 4* (National Water Commission, 2020). Where a groundwater bore is expected to be decommissioned or have access to it impaired as result of the Project, 'make good' measures will be agreed in consultation with the affected landowner and may include monetary compensation developed on a case-by-case basis. ▪ Confirm vibration impacts to existing registered bores that are not planned to be decommissioned (refer Table 10.6). The high-risk bores are RN107110 and RN107104 (above the Toowoomba Range tunnel). The construction contractor will undertake vibration monitoring to assess whether the vibration from the works meet the criteria.
	Sourcing of construction water	▪ Private agreements will be negotiated to secure access to registered bores for use of sustainable groundwater supplies during construction, if required by the Project as part of the construction water strategy (refer above).
Construction	Water resources	▪ The construction phase GMMP will be implemented (refer above and Section 10.2.1) ▪ Opportunities to re-use/recycle water during construction will be identified and implemented where feasible. ▪ Implement the relevant measures agreed with the individual bore owners regarding 'make good' measures. ▪ Continue to engage with the community and the bore owners regarding the construction schedule, in particular the tunnelling activities.
	Groundwater quality	▪ Suspected contaminated soils or materials, if encountered, will be managed in accordance with the unexpected finds protocol/procedure documented in the Contaminated Land Management Sub-plan. ▪ Opportunities to treat and re-use contaminated materials within the rail corridor will be assessed and subjected to a risk assessment. ▪ Vehicle and plant maintenance will be undertaken in designated laydown areas, on hardstand surfaces. This will minimise risk of contaminants from incidental spills or leaks (accidental discharge) from entering aquifers via infiltration or surface runoff. ▪ Refuelling will only occur at designated locations within the Project footprint and sited at suitable separation distances from sensitive receptors, including surface water features and drainage lines. These refuelling locations will be equipped with on-site chemical and hydrocarbon absorbent socks/booms and spill kits. ▪ Bulk storage areas for dangerous goods and hazardous materials will be located away from areas of social and environmental receptors such that offsite impacts or risks from any foreseeable hazard scenario will not exceed the dangerous dose for the defined land use zone (i.e. either sensitive, commercial/ community, or industrial, in accordance with the intent of the State Planning Policy). ▪ A Hazardous Materials Management Sub-plan will be prepared and implemented as a component of the CEMP. The Sub-plan will be required to: – Identify the materials required to be stored and used in support of construction, including volumes of each – Identify the laydown areas that will be used for storage of hazardous materials and designated locations for storage of hazardous within the bounds of those laydown areas – Specify how dangerous goods and hazardous materials will be handled, stored and transported for the Project – Describe the response procedures in the event of an incident involving hazardous materials or dangerous goods – Establish the waste storage and disposal procedures for hazardous materials and dangerous goods.

Delivery phase	Aspect	Proposed mitigation measures
		■ Chemicals stored and handled as part of construction activities will be managed in accordance with: – The WHS Act and Regulation, – AS 2187 Explosives – storage, transport and use – AS 1940:2017 Storage and Handling of Flammable and Combustible Liquids – AS 3780:2008 The Storage and Handling of Corrosive Substances – The requirements of chemical safety data sheets. ■ Spill kits will be available at all work fronts and laydown areas in the event of a spill or leak. All vehicles and machinery will have dedicated spill kits. These refuelling locations will be equipped with on-site chemical and hydrocarbon absorbent socks/booms and spill kits. ■ Drilling and excavation activities during construction will make use of drilling fluids and chemicals that are environmentally neutral and biodegradable. Mobile plant, drill rigs and equipment will be maintained in accordance with manufacturer requirements and inspected frequently to minimise breakdowns and decrease the risk of contamination. ■ All excavated material which is suspected to contain sulphides will be stockpiled, lined and covered and managed to minimise rainfall infiltration and leaching. Where possible, treatment and onsite reuse is preferred to off-site disposal. A case-by-case assessment of the suitability of material for treatment and reuse will be required, in accordance with the Project's spoil management strategy (EIS Appendix T: Spoil management strategy).
	Encountering PASS and/or ARD	■ All excavated material which is suspected to contain sulphides will be stockpiled, lined and covered and managed to minimise rainfall infiltration and leaching. Where possible, treatment and onsite reuse is preferred to off-site disposal. A case-by-case assessment of the suitability of material for treatment and reuse will be required, in accordance with the Project's spoil management strategy (refer EIS Appendix T: Spoil management strategy). ■ If ARD potential is identified through pre-construction investigations (refer above), seepage water from the relevant deep cuts will be sampled at weekly intervals to monitor for the occurrence of acid rock oxidation. This monitoring will involve the on-site screening of the seepage water for pH (trending down) and EC (trending up) and comparison to the baseline groundwater results. Further laboratory analyses for the key analytes (i.e. pH, TDS, EC, TSS, alkalinity, and dissolved metals) will be undertaken if pH and EC trends indicate the potential for oxidation occurring and will be used to validate the presence or absence of ARD potential to mitigate potential leachate to the environment. ■ If ARD-contaminated discharge water/leachate is found to be generated from the deep cuts, this water will be impounded in ponds and neutralised via treatment with hydrated lime or dilution prior to release into the surrounding catchment or other discharge mechanism.
Operation	Impacts to bores	■ The operation phase GMMP will be developed in consultation with the relevant regulatory agencies to specify the groundwater monitoring requirements, if any, over the initial operation years of the Project (refer Section 11.3). The need for monitoring during operation will be informed by groundwater observations and data collected during construction of the Project.
	Groundwater quality	■ Before a train travels on the Inland Rail network, operators will ensure that the classes of dangerous goods, and the identification numbers of vehicles carrying dangerous goods, are recorded in the train consist documentation. Dangerous goods will be loaded, labelled, and marshalled in accordance with the Australian Code for the Transport of Dangerous Goods by Road and Rail. ■ Groundwater infiltration into the Toowoomba Range tunnel and associated ventilation shaft will be captured and treated in the WTP at the eastern tunnel portal, prior to release in accordance with relevant approval conditions. ■ Potential deep cut seepage water will be monitored and discharged in accordance with the Surface Water Sub-plan, as confirmed during detailed design.

Delivery phase	Aspect	Proposed mitigation measures
		■ Groundwater quality will be monitored in accordance with the operation phase GMMP, assessed against trigger and threshold levels and contingency measures followed (as required). ■ Appropriate controls are to be in place to prevent environmental incidents including leaks/spills from refuelling activities and locomotive operations and to protect the environment in the event of an incident. All fuel and chemical spills will be dealt with in a manner consistent with relevant health and safety guidelines. ■ Procedures for the management of hazardous chemical spills and leaks will be developed and incorporated into the OEMP for the Project. These procedures will be in accordance with ARTC's Work Instruction for Chemicals (WHS-WI-214) and Emergency Management Plan (RLS-PR-044) (available on ARTC's extranet). ■ The ARTC's Work Instruction for Chemicals (WHS-WI-214) (available on ARTC's extranet) will be applied for all maintenance activities requiring the transport of dangerous goods within the rail corridor. The Work Instruction will include the following control measures to reduce the risk associated with dangerous goods storage: – Where practical, dangerous goods will be transported in their original packaging and stored separately from one another on the vehicle, specifically detonators – All dangerous goods will be adequately restrained within the vehicle's confines to prevent movement during transit, e.g. gas bottles restrained to headboard or in designated ventilated storage compartments – The combined (aggregate) quantity of dangerous goods will not exceed 1,000 L or kg – Any individual receptacle used for transporting dangerous goods will have capacity less than 500 L or kg or dangerous goods licencing for both the vehicle and driver will apply – All vehicles carrying mixed loads of dangerous goods will display the appropriate mixed class placard at least on the front and rear of the vehicle ■ The vehicle will be fitted with appropriate safety equipment for the load as per ARTC operation procedures, including double sided triangle reflector signals, fire extinguisher(s) and personal protection equipment.
	Water resources	■ Groundwater levels will be monitored in accordance with the operation phase GMMP, assessed against trigger and threshold levels and contingency measures followed (as required).

11.3 Groundwater management and monitoring program

The GMMP provides an ongoing assessment of the potential impacts identified in Section 10 through the Project lifecycle. The GMMP incorporates principles of performance assessment and adaptive management, a structured, iterative process of decision making. The GMMP is considered dynamic and will be assessed and updated after each phase of works (pre-construction/baseline, construction, and operation) such that the subsequent phase's GMMP is based on the outcomes of the previous phase. This process of GMMP development and development over sequential Project phases is shown on Figure 11.1.

The indicative pre-construction/baseline monitoring program's primary objective is to develop a robust baseline dataset from which all subsequent monitoring will be assessed against for impact identification. This dataset will also inform of site-specific WQO trigger values and water level thresholds. The pre-construction/baseline monitoring program is to be developed and implemented at least during the detail design stage (as soon as practical) to inform proposal-design aspects and ensure a suitable groundwater baseline dataset is established (to provide information on seasonal variation, recharge, repeated quality and level data) before construction works commence.

The baseline/pre-construction dataset will be the reference dataset for future groundwater monitoring and, as such, may be supplemented with existing groundwater data inclusive of, but not limited to, representative data from local councils, recent studies, etc. The baseline dataset will be compiled, and the construction phase GMMP developed, prior to the commencement of the construction phase of the proposal to allow for assessment of the data, including trends, and to develop groundwater quality trigger levels and groundwater level thresholds (warning and action levels).

Project bores form part of the indicative baseline groundwater monitoring network. A single round of groundwater sampling and analysis was undertaken as a component of the feasibility design investigations (refer Section 5). It is proposed that additional bores in potentially impacted areas are monitored. This includes bores located in areas where the following impacts have been predicted:

- Groundwater seepage
- Groundwater level drawdown
- Groundwater level rise.

An indicative minimum baseline network of monitoring bores is summarised in Table 11.3. The indicative bore network will be revised after completion of the predictive model updates to ensure the network can validate the model. In consultation with DRDMW, ARTC will identify the preferred groundwater bores and seek permission from the bore owners to undertake the required monitoring.

In addition to existing bores, it dedicated environmental monitoring bores may be installed in areas where access to existing bores is not achievable or where materials will be stored and in locations identified to intersect groundwater, in order to provide adequate coverage up and down the hydraulic gradient of these areas. Groundwater monitoring and management measures are discussed further below. The monitoring network will be subject to landholder negotiations and access and will be refined during the detailed design phase.

Further, additional monitoring bores along the tunnel alignment will establish groundwater levels along the tunnel prior to final design (and may identify perched aquifers). Noting that nine monitoring bores were establishing along the tunnel alignment as part of the recently completed detailed geotechnical investigations and these bores are currently subject to ongoing monitoring (e.g. water level and water quality). The indicative baseline monitoring bore network will be re-assessed upon completion of refinement of the predictive model to ensure the network is comprehensive such that predicted impacts along with early warning monitoring points can be identified prior to construction.

The baseline dataset will be compiled, and the Construction GMMP developed based on this information, prior to the commencement of the construction of the Project. The following provides a framework for groundwater level and quality monitoring, data management and reporting from which the baseline dataset and Construction GMMP will be developed.

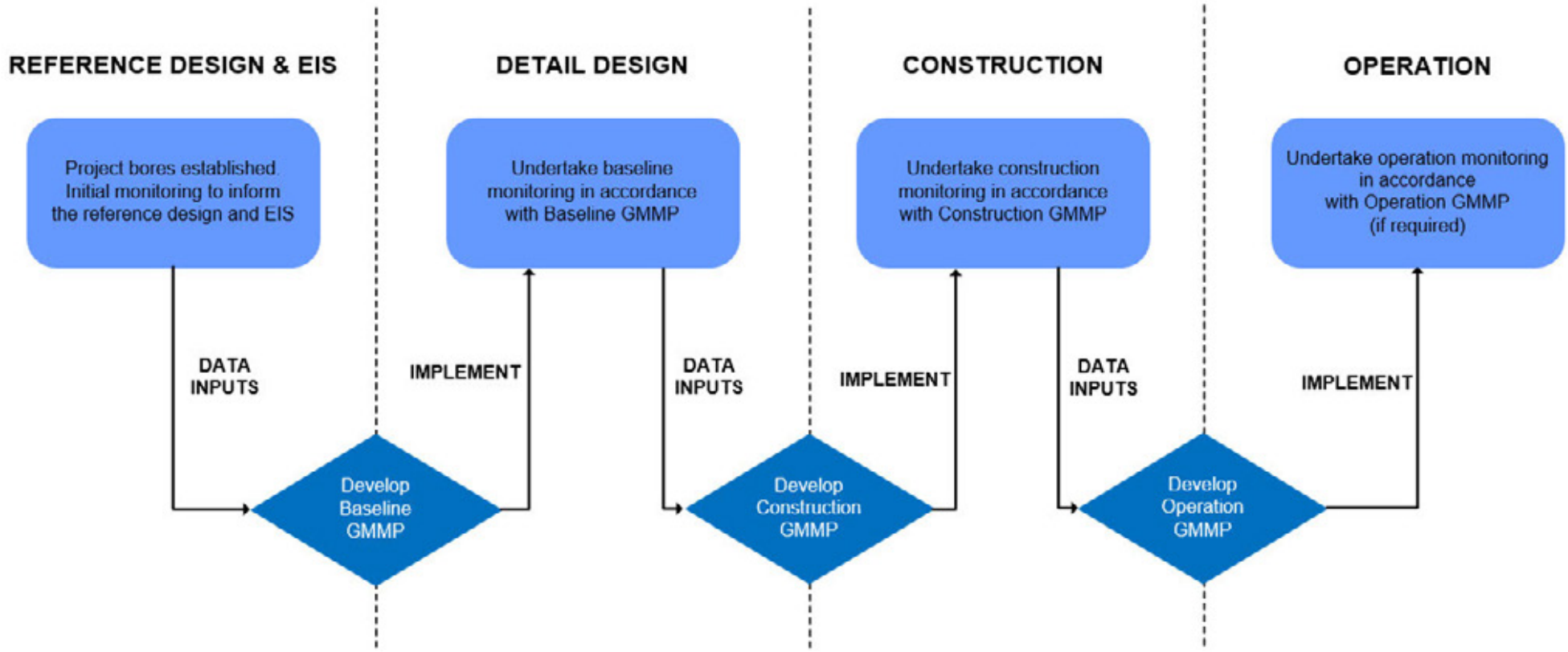


Figure 11.1 **Development and implementation of the Groundwater Management and Monitoring Program over sequential Project phases**

Table 11.3 Indicative minimum groundwater monitoring network

Project feature	Chainage (km)	Length (m)	Maximum depth (m)	Bore	Bore screened aquifer	Screened depth top (m)	Screen depth bottom (m)	Reason for monitoring
Bores within predicted impact areas								
320-E1	-1.76	1,180	2.6	RN94161	Marburg Subgroup	101	133	Predicted rise in groundwater level (refer Section 10.1.2)
320-E2	-0.34	2,560	3.2	RN56783	MRV	22.5	24.4	
320-E3	2.33	1,280	3.7	RN56783	MRV			
Western tunnel portal cut (320-C3)	3.61	490	21.6	RN66497	Marburg Subgroup	44	49	Predicted seepage/drawdown (refer Section 9.4)
				RN71234	Marburg Subgroup	63	68	
				RN172858 (BH2002)	MRV	14	20	
				BH2101	Koukandowie Formation	105	117	
Eastern tunnel portal cut (320-C4)	10.34	60	15.5	RN173879 (BH2103)	Koukandowie Formation	17	26	
				BH2102	MRV	VWP		
320-C5	10.57	310	23.5	RN173879 (BH2103)	Koukandowie Formation	17	26	Predicted seepage (refer Section 9.4)
320-C6	11.16	430	31.6	RN173879 (BH2103)	Koukandowie Formation	17	26	
				BH2201	Koukandowie Formation	14	20	
320-C9	14.07	30	23.1	BH2203	Koukandowie Formation	12	20	
320-C10	14.33	1,390	28.5	RN173875 (BH2301)	Koukandowie Formation	11	20	
				BH2203	Koukandowie Formation	12	20	
320-C11	17.56	260	45.7	RN106018	Unknown	Not reported	Not reported	
320-C12	19.41	260	29.4	BH2209	Gatton Sandstone	14	20	
Toowoomba Range tunnel	4.10	6,240	NA	RN107110	MRV	15	30	Predicted seepage/drawdown (refer Section 9.4)
				RN107104	MRV	14	35	
Bores within predicted groundwater level drawdown extent								
Intermediate ventilation shaft (predicted impact at elapsed 62 weeks)	6.83	NA	100	RN119498	MRV	52	67	Predicted groundwater level drawdown due to the shaft (refer Section 10.2.1.2)
				RN107104	MRV	14	35	
				RN38619	MRV	6.4	79.9	
				RN94668	MRV	24	30	
				RN94669	MRV	12	30	
				RN172057	MRV	37	49	
				RN172118	MRV	48	64	
				RN38341	MRV	6.4	49.4	

Project feature	Chainage (km)	Length (m)	Maximum depth (m)	Bore	Bore screened aquifer	Screened depth top (m)	Screen depth bottom (m)	Reason for monitoring
Toowoomba Range tunnel (predicted impact at elapsed 107 weeks)	4.10	6,240	NA	RN172088	MRV	25	31	Predicted groundwater level drawdown in the deep MRV (refer Section 10.2.1.2)
				RN172183	MRV	84	95	
				RN172086	MRV	24	30	
				RN172087	MRV	30	36	
				RN64098	MRV	110		Possible groundwater level drawdown in the Koukandowie Formation (refer Section 10.2.1.2)
				RN172088	MRV	25	31	
				RN172086	MRV	24	30	
				RN172087	MRV	30	36	
				RN172182	MRV	72	83	
				RN172183	MRV	84	95	
				RN94667	MRV	12	30	
				119497	MRV	10	40	
				119852	Helidon Sandstone	564	657	
Project bores								
320-E10	15.72	1,840	33.7	BH2207	Koukandowie Formation	7	10	Project bores
320-E14	20.66	110	13.9	BH2212	Gatton Sandstone	11.4	20.9	
320-E14	20.66	110	13.9	BH2215	Gatton Sandstone	11	20	
320-E14	20.66	110	13.9	BH2216	Gatton Sandstone	14	20	
320-E14	20.66	110	13.9	BH2217	Gatton Sandstone	11.5	20.5	
320-E14	20.66	110	13.9	BH2218	Gatton Sandstone	14	20	
Optional additional bores within the construction footprint								
Bridge	12.3	N/A	N/A	RN106596	Marburg Subgroup	11	88	Registered bores within construction footprint
Bridge	21.5	N/A	N/A	RN173154	Gatton Sandstone	127	139	
Bridge	23.6	N/A	N/A	RN75289	Helidon Sandstone	21.3	43.9	
Bridge	23.9	N/A	N/A	RN75335	Helidon Sandstone	12.8	37.8	

11.3.1 Groundwater level monitoring

Groundwater levels for bores within the indicative minimum network are to be monitored using automated pressure transducers/level loggers to record measurements at least every six hours. Particularly this is required to establish the baseline groundwater dataset from which potential impacts can be assessed and threshold levels developed for the construction and operation of the Project.

Manual measurements on all bores is proposed monthly during establishment of the baseline dataset to allow for quality control checks against the pressure transducers as this will be the basis of comparison for the Project. Pressure transducer data will be downloaded on a bimonthly basis, during the baseline program, to coincide with quality monitoring and manual water level measurements.

Data collected during the baseline groundwater monitoring program will account for natural (seasonal) or anthropogenic fluctuations of groundwater levels prior to construction. This is important for the colluvium and MRV aquifer as the water levels in this unit are key to the design, construction, and operation of the Project, are the most likely to vary over time due to climate and local groundwater abstraction; and will allow for identification of non-project related influences on groundwater levels. For example, dewatering/pumping for construction works/water supply being undertaken for works at Commodore Mine expansion project may create an area of influence measurable in proximity to the Project with potential to impact on groundwater resources and/or private bores. This information is important to capture to ensure discernibility between the impacts of the Project and those from other influences.

The baseline monitoring program will be completed in sufficient time prior to commencement of construction works to allow for assessment of the data, including trends, to develop groundwater level thresholds (warning and action levels); the construction phase GMMP will also be developed at this time. Groundwater level measurements are to remain ongoing in the transition from detailed design into construction.

After completion of baseline monitoring program, and with consideration of the final detailed design, the frequency and location of level measurements can be reviewed and amended for suitability to achieve the objectives of the groundwater monitoring Program for the construction stage of the Project. The shallow aquifer data will be considered together with regular surface water level monitoring data to inform the local hydraulic connectivity between surface water and shallow groundwater in the Project footprint.

11.3.2 Groundwater quality monitoring

The baseline groundwater monitoring program is to include the indicative bores in Table 11.3 at a minimum to characterise the local groundwater quality prior to construction activities. The quality data collected during the baseline program will be used to assess potential impacts of the Project on local groundwater resources through all stages of the Project (construction and operation). Groundwater quality samples are to be collected for field and laboratory analyses on a bimonthly basis (to coincide with the manual groundwater level measurement baseline program).

The baseline groundwater quality program will be continuously ongoing to account for and allow characterisation of natural (seasonal) and/or anthropogenic variation prior to commencement of construction activities. This is especially applicable to the shallow aquifers hydraulically connected to surface water as after the dry season (negligible recharge) a first-flush/flow of recharge to these sediments can result in markedly different quality from data collected within and after the wet season. In addition, the baseline quality dataset will indicate the potential for ARD prior to construction works and inform the suitability of local groundwater for construction water purposes.

Field parameters to be collected during sampling include pH, EC, temperature, redox potential, and dissolved oxygen. The following analytical suite is suggested for laboratory analyses for the baseline groundwater quality dataset and is considered sufficient to identify potential ARD and suitability of groundwater for construction water purposes:

- pH, EC and TDS
- Major anions (bicarbonate, chloride, sulfate)
- Major cations (calcium, magnesium, sodium, potassium and silicon)
- Dissolved and total metals (aluminium, arsenic, boron, cadmium, chromium, copper, manganese, lead, nickel, selenium, molybdenum, silver, zinc, iron, and mercury)
- Nutrients (ammonia, nitrite, nitrate, total nitrogen, total phosphorus).

The baseline monitoring program will be completed in sufficient time prior to commencement of construction works to allow for assessment of the data, including trends, to develop groundwater quality trigger levels (warning and action levels); the construction phase GMMP will also be developed at this time. Groundwater quality monitoring events are to remain ongoing between project phases.

After completion of baseline monitoring program, and with consideration of the final detailed design, the frequency and location of groundwater quality sample events can be reviewed and amended for suitability to achieve the objectives of the groundwater monitoring program for the construction stage of the Project. The shallow aquifer data will be considered together with regular surface water quality monitoring data to inform the local hydraulic connectivity between surface water and shallow groundwater relevant to the Project.

Groundwater quality data (post-baseline) will be analysed for trends and compared to the baseline dataset to identify potential impacts of the Project on groundwater quality.

Groundwater monitoring and sample collection will be conducted in accordance with recognised groundwater sampling guidelines such as Monitoring and sampling manual (DES 2018c) and Groundwater Sampling and Analysis – A Field Guide (Geoscience Australia 2009*)* unless an updated version is available prior to commencement of the baseline monitoring program.

11.3.3 Data management and reporting

The following data and reporting requirements would be implemented:

- All groundwater data will be validated with suitable quality assurance and quality control (quality assurance/quality control (QA/QC)) protocols applied
- Monitoring data will be assessed on a quarterly basis initially to identify trends and compare to trigger levels (baseline and pre-construction)
- After baseline, where consecutive data points for the same bore(s) over a six-month period indicate divergence from the baseline trends or previous data, consideration of verification sampling to confirm the accuracy of the data will be undertaken and the bore data will be further investigated to determine appropriate actions. This may include more rigorous monitoring or trigger a re-assessment of impacts/or mitigation measures.
- Reporting will be completed on an annual basis and present the assessment of water levels and water quality trends, including hydrographs and hydrochemical plots. The annual assessment will recommend if the location and frequency of monitoring needs to be modified to ensure the objectives of the monitoring plans for the relevant stage of the Project are achieved.

It is noted that additional groundwater level data can be used to refine the predictive model as the Project progresses.

11.3.3.1 Construction Groundwater Management and Monitoring Program

The construction GMMP will be developed using a risk-based approach with monitoring and sampling requirements dependent on the likelihood of construction activities encountering groundwater and the location of such activities. Monitoring will be localised to areas where construction activities have potential to impact on groundwater quality and/or levels, as identified in Section 10.2. The localised task and risk-based monitoring will be performed at locations (distance and depth/aquifer) up- and down-gradient of the site where construction activities are occurring, as appropriate. For example, where construction activities are surficial in nature and localised, monitoring of deep aquifers may not be warranted; however, surficial construction tasks may require TDS and pH monitoring within the alluvial aquifers to ensure the baseline levels are not impacted as a result of local works (task-specific monitoring).

The surface water monitoring program for the Project will be utilised to inform and compliment the construction phase GMMP. For example, in the instance a surface water sample, in an area of known hydraulic connectivity with the alluvial aquifers, returns an elevated result during construction phase, this may trigger a groundwater sample to be procured from the local alluvial aquifer to inform of any impacts. However, if surface water quality results are within/below acceptable values, sampling of the alluvial aquifers in this area may not be warranted, construction task, WQO, and residual significance-dependant.

11.3.3.2 Operation Groundwater Management and Monitoring Program

The operation GMMP will be based on groundwater data and observations collected during construction of the Project. Monitoring may be warranted over the initial years of construction if construction data indicates that local groundwater conditions are yet to return to baseline and/or stabilise following completion of construction activities. Monitoring may also be warranted in response to a spill/incident. Operation monitoring results will be assessed against the construction GMMP and baseline dataset, as appropriate.

11.3.4 Summary

A summary of the monitoring and requirements of the GMMP is presented in Table 11.4.

Table 11.4 Summary of Groundwater Monitoring and Management Program requirements for each Project delivery phase

GMMP requirements	Pre-construction/baseline	Construction	Operation
Groundwater level monitoring	▪ Pressure transducers/level loggers record measurements six hourly intervals ▪ Pressure transducer data downloaded every two months ▪ Manual measurements monthly	Subject to DRDMW/DES approval of the GMMP	Subject to DRDMW/DES approval of the GMMP
Groundwater quality monitoring	▪ Every two months	Subject to DRDMW/DES approval of the GMMP	Subject to DRDMW/DES approval of the GMMP
Reporting	▪ Quarterly data comparison ▪ Annual reporting	Subject to DRDMW/DES approval of the GMMP	Subject to DRDMW/DES approval of the GMMP

12 Impact assessment

As discussed in Section 3.3, a qualitative impact assessment using the significance assessment approach has been adopted for evaluating potential impacts to groundwater resources from the Project, as described in Section 10. A summary of the significance assessment is provided in Table 12.1.

For each of the potential impacts discussed in Section 10, the initial significance assessment was undertaken on the assumption that the design considerations (or initial mitigation) factored into the feasibility design phase (refer Table 12.1) have been implemented.

Proposed mitigation measures, including those listed in relevant subplans (including the GMMP), were then applied as appropriate to the phase of the Project to reduce the level of potential impact and are detailed in Section 11 (refer Table 11.2).

The residual significance level of the potential impacts was then reassessed after mitigation and management measures were applied. The pre-mitigated significances were compared to the residual significance for each potential impact on groundwater values to assess the effectiveness of the mitigation and management measures.

12.1 Temporary impacts

Many of the potential impacts with respect to groundwater are considered temporary in nature and associated with the construction phase of the Project with the likelihood of a material impact on current groundwater conditions and users considered to be moderate (loss of registered bores, groundwater level decreases due to dewatering for construction) to low (groundwater flow patterns).

Final construction design, engineering controls and monitoring are generally considered to adequately mitigate potential impacts to groundwater. However, it is noted that additional investigations and assessment of potential drainage/dewatering impacts associated with Toowoomba Range tunnel and deep cut sections is proposed to further refine current understanding (as described in this groundwater technical report) and inform detailed design.

12.2 Long-term impacts

The main potential long-term impacts identified beyond the construction stage are:

- Changes to groundwater levels and flow associated with groundwater mounding near embankments and ongoing dewatering/draining of the Toowoomba Range tunnel and deep cuts
- Management of discharge from dewatering/drainage of the tunnel and deep cuts.

The design, engineering controls and monitoring are generally considered to adequately mitigate potential impacts to groundwater. However, additional investigations and assessment is proposed to further refine current understanding (as described in this groundwater technical report) and inform final design with respect to i) potential drainage/dewatering impacts of the tunnel and deep cuts, and ii) potential groundwater mounding near significant embankments.

Table 12.1 Significance assessment summary for groundwater

Potential impact	Phase	Initial significance[a]			Application of proposed mitigation measures presented in Table 11.2, by aspect[b]	Residual significance[c]	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
Decommissioning of registered and unregistered bores (through acquisition or loss of access)	Construction	Moderate	Moderate	Moderate	Water resources (preconstruction and construction)	Low	Low
	Operations		Moderate	Moderate		Low	Low
Altered groundwater levels (increase or decrease) affecting groundwater users (bores and GDEs) due to embankments and seepage to cuts/portals	Construction	High	Moderate	High	Water resources (detailed design, preconstruction, construction)	Moderate	Moderate
	Operations		Low	Moderate		Moderate	Moderate
Subsidence/consolidation due to groundwater extraction, dewatering/seepage or loading	Construction	Moderate	Moderate	Moderate	Water resources (detailed design, preconstruction, construction) Water quality (preconstruction)	Low	Low
	Operations		Low	Low	-	Low	Low
Reduced groundwater levels affecting groundwater users (bores and GDEs) due to the Toowoomba Range Tunnel	Construction	High	Moderate	High	Water resources (detailed design, preconstruction, construction)	Moderate	Moderate
	Operations		Low	Moderate		Moderate	Moderate
Contamination or water quality degradation of groundwater resources requiring remediation from spills or induced flow, bore hole intersections. Upwards leakage along pile/soil interfaces	Construction	Moderate	High	High	Water quality (detailed design, preconstruction, construction)	Moderate	Moderate
	Operations		Low	Low	-	Low	Low
ARD from cuts and tunnel impacts on environmental values (i.e. GDEs)	Construction	Moderate	Moderate	Moderate	Water quality (preconstruction, construction)	Low	Low
	Operations		Low	Low	-	Low	Low
Vegetation removal and surface alteration affecting recharge/discharge, increasing associated salinity risks	Construction	Moderate	Moderate	Moderate	Water resources (preconstruction)	Low	Low
	Operations		Low	Low	-	Low	Low

Table notes:

a. Includes implementation of initial mitigation specified in Table 11.1
b. Proposed mitigation, as identified in Table 11.2
c. Assessment of residual significance once the initial and additional mitigation measures have been applied.

12.3 Cumulative impacts

Cumulative impacts are the successive, incremental, and combined impacts of an activity when added to other existing or planned projects and activities (IFC 2013). For the Project, a CIA was undertaken where potential groundwater impacts of the Project were assessed together with existing or planned surrounding activities (as outlined in Section 3.4). Cumulative impacts to groundwater are most likely occur where multiple projects intersect and/or take groundwater from the same aquifer units.

For a full assessment of cumulative impacts relevant to the Project refer EIS Chapter 22: Cumulative impacts.

12.3.1 Surrounding projects and timeline relationships

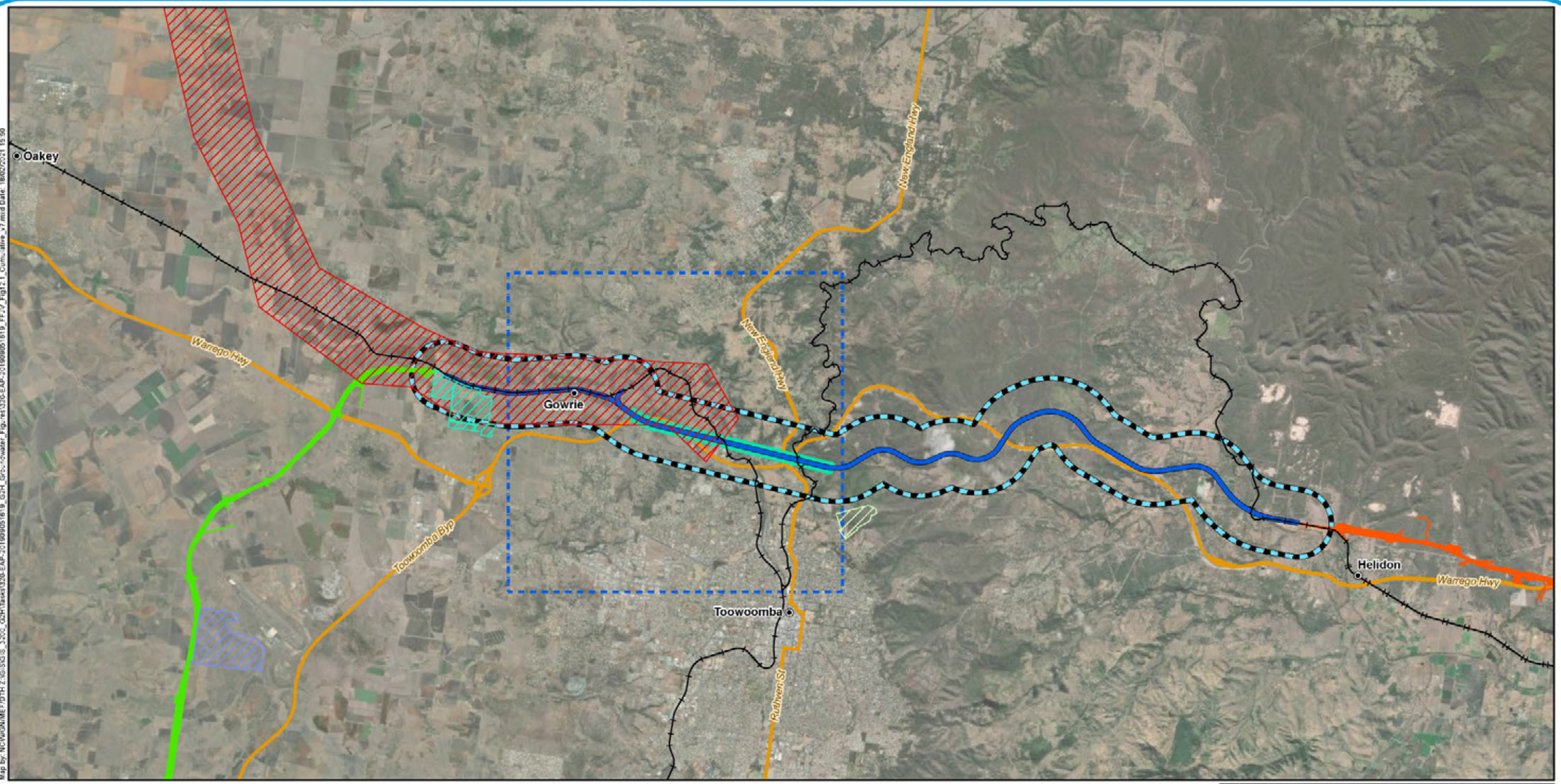
Projects and operations within and surrounding the groundwater study area are depicted on Figure 12.1. Due to the localised potential groundwater impacts associated with the Project, only applicable projects and operations (with potential impacts on groundwater) in Table 12.2 have been considered for this CIA. Other projects are considered too distant compared to the localised nature of potential groundwater impacts, and/or the scope of the surrounding projects were such that there is negligible potential to impact on groundwater.

Table 12.2 Applicable projects and operations considered for the cumulative impact assessment

Project and proponent	Location	Description	Approvals status	Timeline	Relationship to the Project
NSW/QLD Border to Gowrie (ARTC)	Rail alignment from NSW/QLD Border to Gowrie	▪ 216 km single-track freight railway as part of the ARTC Inland Rail Program ▪ Establishment of approximately 145 km of new rail corridor and utilisation of approximately 71 km of existing rail corridor ▪ Construction of rail infrastructure, culverts, bridges, viaducts and crossing loops ▪ Five crossing loops, each 2,200 m in length ▪ Ancillary works including road and public utility crossings and realignments.	EIS being prepared by ARTC	Construction: 2021 – 2026 Operation: >50 years	Potential overlap of construction finalisation of B2G and commencement of G2H
Helidon to Calvert (ARTC)	Rail alignment from Helidon to Calvert	▪ 47 km single-track dual-gauge freight rail line to accommodate double stack freight trains up to 1,800 m long ▪ 850 m tunnel through the Little Liverpool Range ▪ Construction of rail infrastructure, culverts, bridges, viaducts and crossing loops ▪ Connection to the existing West Moreton System railway line ▪ Ancillary works including road and public utility crossings and realignments.	EIS being prepared by ARTC	Construction: 2021 – 2026 Operation: >50 years	Potential overlap of construction finalisation of G2H and commencement of H2C
Defence Housing Australia Mount Lofty Development	Mount Lofty	▪ Former rifle range redeveloped into a master-planned residential community comprising of 342 lots. Some lots will be retained by DHA on which homes will be built for Defence members and their families with remaining lots available for public purchase.	Development application lodged in June 2018. Development in progress.	2019+	Potential groundwater drawdown impacts. The 5 m drawdown extent within the deep MRV and Koukandowie Formation during construction is approximately 1 km from the western boundary of the proposed development.

Project and proponent	Location	Description	Approvals status	Timeline	Relationship to the Project
Wetalla Water Pipeline (New Acland Coal Pty Ltd)	From the Wetalla Wastewater Reclamation Facility in Toowoomba to the New Acland Mine, 35 km northwest of Toowoomba	▪ A 45 km underground water pipeline to supply up to 5,500 ML of treated wastewater to the New Acland coal mine.	EIS approved with conditions in 2008.	The Wetalla Water Pipeline has been completed. To support water requirements for the extension of coal production at the New Acland Mine (until 2042).	The development is located within the western portion of the Project.
InterLinkSQ	Global Logistics Centre and Industrial Park	▪ 200 hectares of land area ▪ 24-hectare intermodal facility with rail, hardstand and industrial land ▪ 24/7 operations with residential buffers ▪ Zoned medium impact industry ▪ Intermodal, transport, logistics and warehousing	Approval has been granted for the development. Construction commenced on Stage 1 in early 2017.	2017-2037	The development is located at Ch 1.0 km. There is limited potential for impacts at this location as there is no proposed tunnelling or cuts.
Asterion Medicinal Cannabis Facility	Wellcamp, Queensland	▪ A high-tech medicinal cannabis cultivation, research and manufacturing facility. The project involves construction of a 40-ha glasshouse to produce 20,000 plants per day at full capacity. Medicinal-grade cannabis grown at the facility will be manufactured into a range of medicinal products, including single patient packs, cannabis oils, gels, salts and related products, destined solely for the medicinal market. This facility is anticipated to be the largest facility of its kind in the world.	Under construction.	2020 - 2021	The development adjoins the Project footprint 1 km south of Toowoomba–Cecil Plains Road The source of the water supply for the facility is unable to be confirmed. The projected size of the facility is anticipated to require large volumes of water that if sourced from bores/municipal supplies that draw from the Water Plan (Condamine and Balonne) 2019 may overlap with the Project.

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



Map by: NCW\GIS\MEF\DTH Z:\GIS\GIS_3200_G2H\Tasks\3200_G2H_Groundwater_Figures\3200-EAP-20190905 1619_G2H_Groundwater_Figures\3200-EAP-20190905 1619_FF.V_Fig12.1_Cumulative_v7.mxd Date: 18/02/2021 15:50

Legend

- Localities
- G2H project alignment
- Existing rail
- Major roads
- Groundwater predictive model domain
- Tunnel
- Groundwater study area

Projects

- Border to Gowrie
- Helidon to Calvert
- Asterion Medicinal Cannabis Facility
- DHA Mount Lofty Development
- Interlink SQ - Global Logistics Centre
- Wetalla Water Pipeline



A3 scale: 1:125,000

0 1 2 3 4 5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 16/02/2021 Version: 7
Coordinate System: GDA 1994 MGA Zone 56

Gowrie to Helidon

Figure 12.1:
Projects surrounding the proposal - cumulative assessment

12.3.2 Assessment of potential cumulative impacts

Cumulative impacts to groundwater would most likely occur where multiple projects intersect and/or abstract groundwater from the same shallow aquifer units. Key cumulative impacts for consideration are provided in Table 12.3.

Table 12.3 Summary of potential cumulative impacts

Project	Potential cumulative impact	
	Groundwater levels	**Groundwater quality/ contamination**
NSW/QLD Border to Gowrie (ARTC)	Potential overlap of impacts from dewatering and cuttings which intersect shallow aquifers (MRV, Gatton Sandstone and alluvium units). Potential to overlap is primarily at the start and end of construction activities of the projects where the Project abuts these other ARTC projects. Possible subsequent impacts on groundwater users.	Potential cumulative impacts on shallow aquifers from derailments and tunnel incidents, spills/leaks from heavy machinery, drill rigs and storage of fuels etc.
Helidon to Calvert (ARTC)		
Defence Housing Australia Mount Lofty Development	Potential for groundwater drawdown to cause settlement at the proposed development. Groundwater drawdown can result in settlement of compressible substrates and possible damage to adjacent structures. The 5 m drawdown extent (construction phase) within the deep MRV and Koukandowie Formation is approximately 1 km from the western boundary of the proposed development. The potential for settlement and damage to buildings and properties due to subsidence from drained cuttings and the undrained tunnel appears to be low. It is anticipated that the potential for settlement will be confirmed as part of ongoing geotechnical investigations and will inform final design.	
InterLinkSQ	Limited potential for impacts at this location as there is no proposed tunnelling or cuts.	
Wetalla Water Pipeline (New Acland Coal Pty Ltd)	Limited potential for impacts at this location as the pipeline is complete.	Potential cumulative impacts on shallow aquifers in the Project footprint from pipeline leaks.
Asterion Medicinal Cannabis Facility	There may be a brief overlap in 2021 between the conclusion of construction for the Asterion Medicinal Cannabis Facility and the commencement of early works activities for the Project. Water source for this facility has not been identified. Potential overlap of impacts from dewatering if Asterion is using bore water under a new license/ allocation or municipal water supplies sourced from the MRV (that have increased licensed volume where the predicted drawdown from additional allocations has increased). Possible subsequent impacts on groundwater users.	No impact anticipated.

A qualitative significance assessment has been applied for evaluating cumulative impacts from the Project and surrounding projects. The qualitative assessment assigns a relevance factor of 1 (low), medium (2) or 3 (high) to the potential cumulative impacts for each of the following aspects:

- The probability of the impact
- The duration of the impact
- The magnitude/intensity of the impact
- The sensitivity of receiving environment.

The significance of the cumulative impact is then determined by summing the relevance factors. The impact categories are as follows:

- Low (relevance sum 1-6) – Negative impacts should be managed by standard environmental procedures. Special approval conditions are unlikely. Monitoring required as part of the general Project monitoring.
- Medium (relevance sum 7-9) - Mitigation measures likely required and specific management practices to be applied. Specific approval conditions are likely.
- High (relevance sum 10-12) - Alternative actions should be considered and/or mitigation measures applied to demonstrate improvement. Specific approval conditions are likely and targeted monitoring is required.

Based on the above methodology the cumulative groundwater impacts for the Project are summarised in Table 12.4.

Table 12.4 Summary of the cumulative impact assessment

Cumulative impact	Aspect	Relevance factor	Sum of relevance factors	Impact significance	Comments	Mitigation measures
Change in groundwater levels	Probability of impact	1	6	Low	Localised impacts on shallow groundwater levels considered unlikely to be compounded within the vicinity of where the Project interfaces with B2G and H2C. Overlap of construction activities at the ends of the Project with B2G or H2C projects exist. The Project predicted 5 m drawdown extent (construction phase) within the deep MRV and Koukandowie Formation is approximately 1 km from the western boundary of the proposed Mt Lofty development. No anticipated impacts with the InterLinkSQ project due to no deep cuts or tunnel in proximity. Potential overlap of construction activities from G2H with commencement of operations for Asterion. The operation of this facility is expected to require significant volumes of water.	Adherence to dewatering and water supply mitigation measures discussed in Section 11. Adherence to the CEMP/GMMP to respond effectively to groundwater level drawdown triggers. The potential for settlement and damage to buildings and properties of the proposed Mt Lofty development due to subsidence from drained cuttings and the undrained tunnel appears to be low. It is anticipated that the potential for settlement will be confirmed as part of ongoing geotechnical investigations and will inform final design. Confirm water source for Asterion and any predicted groundwater impacts, if any.
	Duration of the impact	2				
	Magnitude/intensity of the impact	1				
	Sensitivity of receiving environment	2				
Groundwater quality and contamination	Probability of impact	1	6	Low	Primarily related to the shallow alluvial aquifer where potential intersections by excavations and contaminant spills can impact water quality for all identified projects. Overlap of construction activities at the ends of the Project with either ARTC projects exist.	Implementation of the GMMP to identify and respond to triggers being breached. Adherence to the CEMP to prevent and respond effectively to spills and leaks.
	Duration of the impact	2				
	Magnitude/intensity of the impact	1				
	Sensitivity of receiving environment	2				

13 Conclusions

To meet the study scope and objectives outlined in the ToR (refer Table 1.2), the groundwater impact assessment provides a description of the existing hydrogeological environment and an assessment of the potential impacts of the Project on that environment. A staged approach was adopted for development of the groundwater study including a desktop study, review of geotechnical site investigation information and reports, a groundwater impact assessment and a significance assessment.

The potential impacts of the Project on groundwater levels, flow and quality were discussed in Section 10 and a significance assessment carried out (refer Section 12), with the key conclusion being:

- A moderate residual significance risk was identified for the potential of reduced groundwater levels to impact groundwater users (bores and potential GDEs) due to the Toowoomba Range tunnel and associated cuts and portals. Ground-truthing of GDEs is required to confirm GDEs exist within predicted drawdown extents. Continued baseline groundwater level monitoring will confirm groundwater levels at the tunnel and inform additional investigations and predictive model refinement.
- A moderate residual significance risk during the construction phase was identified for potential contamination, or degradation of groundwater quality, including from spills and uncontrolled releases, water mixtures and emulsions from washdown areas, and wastewater from construction sites
- Low residual significance risks were identified as being low for all other potential impacts including loss of registered bores due to destruction or loss of access, changes to groundwater levels due to loading from embankments (i.e. upstream mounding and damming, and downstream groundwater level reductions), ARD from cuts and vegetation removal. Proposed additional geotechnical works, including investigation and monitoring of groundwater levels at deep cuttings, Toowoomba Range tunnel and areas of foundation treatment in low lying floodplain areas will further inform detailed design.

An indicative groundwater monitoring program (refer Section 11.3) is proposed to provide an on-going assessment of the potential impacts of the Project on the identified groundwater EVs and WQOs. The program includes an indicative monitoring bore network (refer Table 11.3) for periodic water level and groundwater quality monitoring.

A CIA was undertaken (refer Section 12.3.2) that considered the adjoining ARTC rail alignments and surrounding developments. The CIA identified a low significance due to adoption and implementation of mitigation measures.

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APPENDIX

N

Groundwater Technical Report

Appendix A Inland Rail Section 320—Gowrie to Helidon Hydrogeological Interpretive Report

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



REPORT

Inland Rail Section 320 - Gowrie to Helidon Hydrogeological Interpretive Report

100% Feasibility Design Stage

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Table of Contents

1.0 INTRODUCTION 8

1.1 Background 8

1.2 Objective 8

1.3 The G2H Alignment 8

2.0 REVIEWED INFORMATION 8

3.0 PHYSIOGRAPHIC SETTINGS 9

3.1 Climate 9

3.2 Topography and Drainage 11

3.3 Land Use and Cover 12

4.0 STRATIGRAPHY AND GEOLOGICAL PROCESSES 15

4.1 Geological Structures 19

5.0 REGIONAL HYDROGEOLOGY 20

5.1 Hydrostratigraphy 20

5.1.1 Shallow Unconfined or Perched Aquifer in the Colluvium/Alluvium 20

5.1.2 MRV Aquifer (Fractured Basalt Aquifer) 21

5.1.3 Sedimentary Rock Aquifers 21

5.2 Groundwater Level and Flow 22

5.2.1 Groundwater Levels in Quaternary Aquifers 22

5.2.2 Groundwater Levels in the MRV Aquifer 23

5.2.3 Groundwater Levels in the Sedimentary Rock Aquifer 24

5.2.4 Groundwater Level Divide 28

5.2.5 Wetland Springs 28

5.3 Groundwater Recharge 30

5.4 Groundwater Chemistry 31

5.5 Groundwater Use 33

6.0 CONCEPTUAL HYDROGEOLOGICAL MODELS 33

6.1 Hydrogeological Parameters 33

6.1.1 Hydraulic Conductivity - Site Specific Testing 34

6.1.2 Hydraulic Conductivity - Results from other Investigations....36
6.1.3 Estimated Vertical Hydraulic Conductivity and Specific Yield....39
6.2 Observed and Inferred Groundwater Levels....40
7.0 GROUNDWATER LEVEL DRAWDOWN AND INFLOW MODELLING....43
7.1 100% Feasibility Design Option....43
7.1.1 Methodology....44
7.1.2 Model Calibration....49
7.1.3 Groundwater Inflow Estimates....52
7.1.4 Groundwater Level Drawdown Estimates....55
7.1.5 Sensitivity Analysis....62
7.1.6 Model Limitations....65
7.2 Cuts Along the Alignment....66
7.2.1 Design Assumptions....66
7.2.2 Methodology....67
7.2.3 Seepage Rate Estimates....67
7.2.4 Limitations....68
8.0 HYDROGEOLOGICAL DESIGN CONSIDERATIONS....69
8.1 Design Groundwater Levels for Toowoomba Tunnel....69
8.2 Groundwater Quality and Durability Considerations for Toowoomba Tunnel....69
8.2.1 Groundwater quality....69
8.2.2 Groundwater Aggressivity and Scaling Potential....70
8.3 Groundwater Quality for Seepage to Cuts....71
8.4 Potential for Groundwater Level Mounding along Embankments....71
8.5 Groundwater Aggressivity for Bridge Sub-structures....73
9.0 RISK AND MITIGATION....74
10.0 IMPORTANT INFORMATION RELATING TO THIS REPORT....77
11.0 REFERENCES....77
12.0 GLOSSARY....80

TABLES

Table 1: Long-term mean monthly rainfall summary statistics for 'Moyola' Australian Bureau of Meteorology station number 041369 for the years between 1972 and 2018. 9

Table 2: Watercourses intersected by the Project alignment 12

Table 3: Percent land use by area (within 5-kilometre corridor of G2H alignment) 12

Table 4: Anticipated geological model for the Toowoomba Tunnel 15

Table 5: Registered groundwater monitoring bores by formation for the Project alignment 22

Table 6: Wetland Springs 28

Table 7: Clarence-Moreton Bioregion rainfall recharge estimates (Australian Government, 2014) 30

Table 8: Hydraulic test results summary from FFJV 2018 investigations (Golder, 2019) 34

Table 9: Summary of hydrogeological conductivity measurements from Clarence Moreton Bioregional Assessment 37

Table 10: Estimated Vertical Hydraulic Conductivity and Specific Yield 40

Table 11: Locations where cuts are anticipated to encounter the groundwater table 43

Table 12: Feasibility Design Option 43

Table 13: Hydrogeological parameter used in the model 50

Table 14: Total predicted inflow volumes 54

Table 15: Inflow estimates under scenarios for sensitivity analysis 63

Table 16: Maximum inflow estimates under scenarios for sensitivity analysis during construction phase 63

Table 17: Estimated long-term average seepage rate into slope cuts with groundwater intersection along the proposed G2H alignment 68

Table 18: Classification of water based on concentration in Total Dissolved Solids (TDS). (Fetter, 2002) 70

Table 19: Estimated characteristics of groundwater in the Main Range Volcanics and Sedimentary rock aquifers to inform durability assessment 71

Table 20: Estimated groundwater level mounding at selected embankment locations 72

Table 21: Estimated characteristics of groundwater at proposed bridge locations along the G2H rail alignment to inform durability assessment 73

Table 22: Risks Identified and Mitigation 74

FIGURES

Figure 1: Monthly rainfall and evaporation statistics 10

Figure 2: Annual residual rainfall and cumulative residual deficit (cumulative deviation from average) for 'Helidon Post Office' Australian Bureau of Meteorology station number 040096, record period between 1896 and 2018. 11

Figure 3: Land use of the Gowrie to Helidon Rail corridor 14

Figure 4: Stratigraphy of the Clarence-Moreton sedimentary basin (Rassam et al 2014) 17

Figure 5: Long-term groundwater monitoring in the Main Range Volcanics west of the Toowoomba Range 24

Figure 6: Long-term groundwater monitoring in the Sedimentary rock aquifers east of the Toowoomba Range 25

Figure 7: Mean groundwater level in shallow Sedimentary rock aquifers during the drought period between 2000 to 2007 (Cui *et. al.*, 2018) 26

Figure 8: Section 320 FFJV Investigation and Registered Bore Locations 27

Figure 9: Section 320 wetland spring locations and groundwater divide 29

Figure 10: Piper diagram classified by hydrostratigraphic units 32

Figure 11 Hydraulic conductivity profile along 320-10-BH2101 36

Figure 12: Statistical distribution of permeability test results of the Clarence Moreton Basin and FFJV Investigations (Sections 310, 320, 330 and 340). 37

Figure 13: Preliminary estimates of pre-development groundwater level along the alignment between Chainage 3.500 to 10.450 km prior to tunnel construction 42

Figure 14: Isometric view of the groundwater model illustrating material layering of the model. 45

Figure 15: Modelled Area and Water Plan. 46

Figure 16: Long Section view of the numerical model illustrating the vertical discretization layering of the model 47

Figure 17: Water supply bores identified within the modelling domain. The red dots show the locations of registered water supply bores. The black crosses show the locations of representative water supply bores. ..49

Figure 18: Observed versus calculated heads 51

Figure 19: Result of model calibration. The length of the bar shows the head difference between computed water level and simulated water level. The green bar, yellow and red bar represent the head difference from 0 to 10 m, from 10 to 20 m and more than 20m, respectively. Modelled and observed values for each bore are presented in Figure 18. 52

Figure 20: Estimated tunnel inflow rates for the 100% Feasibility Design option for geology units (western/eastern portals not included) 53

Figure 21: Estimated inflow rates for the 100% Feasibility Design option for the main tunnel structures 55

Figure 22: Estimated drawdown contours in (a) shallow MRV, (b) deep MRV and (c) Marburg Subgroup at elapsed time of 107 weeks (i.e. time of maximum inflow rate) 57

Figure 23: Estimated drawdown contours for the western portal in shallow MRV at elapsed time of 34 weeks (i.e. time of maximum inflow rate) 58

Figure 24: Estimated drawdown contours for the shaft in shallow MRV at elapsed time of 62 weeks (i.e. completion of the shaft excavation) 59

Figure 25: Estimated drawdown contours for the shaft in deep MRV at elapsed time of 62 weeks (i.e. completion of the shaft excavation) 60

Figure 26: Estimated drawdown contours for the shaft in Marburg Subgroup at elapsed time of 62 weeks (i.e. completion of the shaft excavation) 61

Figure 27: Estimated drawdown contour in shallow MRV (light green) and Marburg Subgroup (light blue) at elapsed 20 years 62

Figure 28: Estimated 5 m drawdown at elapsed 20 years in (a) shallow MRV and (b) deep MRV under Scenario 1-B. 65

Figure 29: Seepage flow analytical model for cuts along the G2H rail track alignment where h0 is the undisturbed (ambient) piezometric water level and h is the piezometric head 67

APPENDICES

APPENDIX A
Hydrographs from 2018 FFJV Investigations

APPENDIX B
Groundwater Level Summary

APPENDIX C
Groundwater Chemistry

APPENDIX D
Groundwater Levels with Relation to Earthworks and Cut Locations

APPENDIX E
Inferred Groundwater Chemistry at Proposed Bridge Locations

APPENDIX F
Hydraulic Testing Results

APPENDIX G
PPP Extended Geotech Program Data

APPENDIX H
Important Information Relating to this Report

ABBREVIATIONS

3D ..... three-dimensional

AHD …… Australian height datum

AL …… Aluminium

B …….. Boron

BoM ..... Bureau of Meteorology

CA …….. Calcium

CL …….. Chloride

CO3 …… Carbonate

CR ..... Crater Rim materials

CRD ..... cumulative rainfall deficit

CU …….. Copper

DES ..... Department of Environment and Science (Queensland)

DNRME ..... Department of Natural Resources, Mines and Energy (Queensland)

EC ..... electrical conductivity

EIS ..... environmental impact statement

EPP .....environmental protection policy

GW ..... Groundwater

F …….. Fluorine

FE …… Iron

FFJV ..... Future Freight Joint Venture

HCO3 …….. Bicarbonate

IAA ..... immediately affected area

IESC ..... Independent Expert Scientific Panel on Coal Seam Gas and Large Coal Mining Development

K …….. Potassium

km ..... kilometres

L ..... litres

L/s ..... litres per second

LAA ..... long-term affected area

MRV ..... Main Range Volcanics

m ..... metres

m AHD .....metres Australian Height Datum

m bgl .....metres below ground level

m/d ..... metres per day

MG ……Magnesium

mg/L ..... milligrams per litre

mm ..... millimetres

MN ……Manganese

m/s ..... metres per second

NA …….. Sodium

NO3 ……..Nitrate

pH ……potential hydrogen

PO4 ……..Phosphate

ppm .....parts per million

QR .....Queensland Rail

the Range …….the Great Dividing Range

RN .....Registered Number

SAR …….sodium absorption ratio

SI ..... soil investigation

SIO2 ……Silicon dioxide

SO4 …….Sulphate

TBM .....tunnel boring machine

TDS ..... total dissolved solids

TV ..... Toowoomba Volcanics

UTS ..... Undifferentiated Tertiary Sediments

Water Act..... .Water Act 2000

WCM ..... ….Walloon Coal Measures

ZN ……..Zinc

1.0 INTRODUCTION

1.1 Background

The G2H Project is one of 13 projects that form part of the Inland Rail Program. The Project comprises a single 28 km long dual gauge track with three crossing loops to accommodate double stack freight trains up to 1,800 m in length, including a future requirement to accommodate trains up to 3,600 m in length. The section connects with the eastern end of the proposed Border to Gowrie (B2G) Inland Rail Project, adjacent to the QR Western Line approximately 3.7 km west of Gowrie. The alignment then travels east parallel to the QR Western Line before diverging south east through the Toowoomba Range with an approximately 6,240 m long tunnel. On the eastern side of the tunnel, the alignment continues down the Toowoomba Range, past Postmans Ridge, after which it parallels the QR Main Line of the West Moreton System to connect with the proposed Helidon to Calvert (H2C) Project, to the north of Helidon.

1.2 Objective

This report provides 100% Feasibility Design advice regarding estimated inflows and ***groundwater level drawdown***[1] associated with the tunnel drained in parts, ventilation shaft, rail earthworks cuttings and an assessment of ***groundwater*** quality parameters to inform feasibility design for earthworks, bridges and tunnelling along the G2H Section 320.

1.3 The G2H Alignment

The Gowrie to Helidon project area consists of an approximately 28 km route that extends in an east-south easterly direction between Gowrie (western terminus) and Helidon (eastern terminus) townships in Southeast Queensland. The planned route consists almost exclusively of greenfield areas with limited brownfield sections at both ends, where the new line will tie into Section 310 – Border to Gowrie at the west and Section 330 – Helidon to Calvert at the east.

2.0 REVIEWED INFORMATION

Completed scope from the Phase 2 Feasibility Design geotechnical investigation (Golder, 2018c) at the time of this updated report includes:

- Rotary and core drilling at:
  - 9 bridge locations,
  - 2 cut locations, and
  - 3 locations within 250 m of the Toowoomba Range tunnel.
- Information was available from 12 ***groundwater*** monitoring bores equipped with standpipe piezometers and automatic water level probes recording ***groundwater level*** at half hourly intervals at the time of reporting. These bores included 320-01-BH2201, 320-01-BH2209, 320-01-BH2212, 320-01-BH2217, 320-01-BH2218, 320-01-BH2103, 320-01-BH2201, 320-01-BH2207, 320-01-BH2215, 320-01-2216, 320-01-BH2101 and 320-01-BH2102 (refer to Figure 8-1 and 8-2).
- Borehole ***permeability*** testing including:
  - water pressure testing of the Main Range Volcanic Basalt at two depth intervals near the tunnel invert level,
  - falling head testing of the Main Range Volcanics at 1 bore, and
  - slug testing in 5 monitoring bores.

[1] Terms in bold and italics are listed in the Glossary

- ***Groundwater*** sampling for water chemistry analysis.

Data records and information gained from the above investigations are used to inform the hydrogeological assessment. Selected results from the site investigation are presented in this report. Selected information from boreholes 320-02-BH3068, 320-02-BH2016, 320-02-BH2017 at the Eastern Portal from the PPP Extended Geotech Program is also used in this report, with relevant results referenced and appended.

Site investigation data were complemented with data obtained from the following publicly available data sources to assess the regional hydrogeology and ***groundwater*** conditions and to fill in data gaps:

1) Australian Government Bureau of Meteorology (BoM) Climate statistics for Australian locations.

2) Conceptual modelling for the Clarence-Moreton Bioregion, Product 2.3 from the Clarence-Moreton Bioregional Assessment, 19 January 2017 (Australian Government, 2018a).

3) Observations analysis, statistical analysis and interpolation for the Clarence-Moreton Bioregion, Product 2.1 – 2.2 from the Clarence-Moreton Bioregional Assessment, 6 October 2016 (Australian Government, 2018b).

4) Geology of the Ipswich and Brisbane 1:250 000 Sheet Areas (Geological Survey of Queensland & Cranfield, L. C, 1973).

5) Water bore data with stratigraphic descriptions and ***groundwater*** quality data (DNRME, 2018).

3.0 PHYSIOGRAPHIC SETTINGS

3.1 Climate

The rail corridor passes through a region that is characterised by a sub-tropical to temperate climate, with a typically drier mild winter and wetter hot summer. The region is also influenced by large scale atmospheric circulation drivers, particularly the El Niño Southern Oscillation, leading to high variability and the occurrence of droughts and floods (BoM, 2018).

The Moyola BoM weather station (041369) is northwest of Toowoomba on the west side of the Toowoomba Range near the Project alignment and has long term statistical climate data (1972-2018). Table 1 provides long-term mean monthly rainfall summary statistics for the Moyola BoM station. Statistical results from this station reports an annual rainfall range from 342.0 mm to 1111.4 mm, a mean annual rainfall of 703.4 mm and a median annual rainfall of 658.2 mm (BoM, 2018b).

Table 1: Long-term mean monthly rainfall summary statistics for 'Moyola' Australian Bureau of Meteorology station number 041369 for the years between 1972 and 2018.

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	88.4	94.7	63.2	40.1	49.1	33.1	34.1	25.8	30.5	64.7	86.3	92.7
Lowest	5.2	0.0	2.4	0.0	1.2	0.0	0.0	0.0	0.0	0.5	6.0	0.0
10th %ile	27.3	19.8	11.8	3.7	5.4	3.4	2.1	3.1	2.6	15.1	29.1	37.4
Median	72.0	83.8	53.6	27.1	32.6	24.1	28.6	23.8	25.6	54.4	77.4	75.8
90th %ile	157.2	169.4	124.1	79.5	89.6	77.6	72.1	56.4	69.9	122.0	165.2	172.0
Highest	371.2	347.2	185.5	287.6	378.6	149.6	135.8	88.2	95.2	196.0	293.2	373.0

Notes: Source – Bureau of Meteorology (2018). Lowest and highest monthly values are in blue and red, respectively.

Figure 1 reports the mean monthly pattern of rainfall for Moyola Station (1972 to 2018) and rainfall data from the Helidon Post Office (1870 to 2018) compared to mean monthly evapotranspiration data from Toowoomba Airport Station (2009 to 2018). The Moyola Station and the Toowoomba Airport Station are west of the Toowoomba Range while the Helidon Post Office Station is to the east of the base of the Toowoomba Range near Helidon. The weather station at Helidon Post Office typically reports greater monthly precipitation than to the west of the Toowoomba Range except in May, October and November. As there is no evaporation data available for the Moyola Station, the nearest available evapotranspiration data recorded at the Toowoomba Airport station is shown. Though the data is obtained from different stations and for different periods and therefore not directly comparable, the data would suggest that evapotranspiration exceeds rainfall for the areas of the Project alignment to the east and west of the Toowoomba Range.

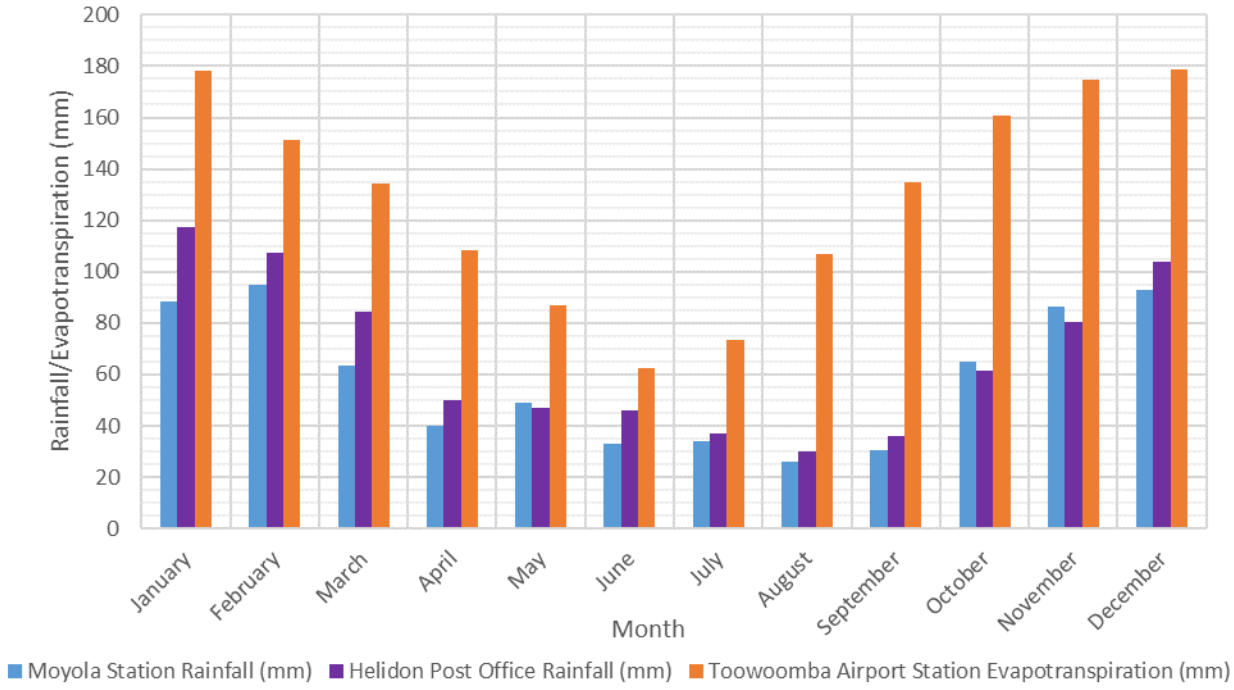


Figure 1: Monthly rainfall and evaporation statistics

The Helidon Post Office BoM weather station (040096) is located at the base of the Toowoomba Range to the east of the Project alignment and has a longer period of rainfall record (1871 to 2018) than Moyola station (1972 to 2018). Records from the Helidon Post Office BoM weather station have been used to develop the Cumulative Rainfall Deficit (CRD).

Annual rainfall records were used to calculate rainfall residuals by subtracting the yearly average from each years' total rainfall. The Cumulative Rainfall Deficit (CRD) has been calculated by taking the ten year running average of the rainfall residuals (Figure 2). The CRD shows the long-term trends in rainfall patterns. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. CRD and ***groundwater level*** data are generally well correlated, with ***groundwater levels*** expected to rise during periods of rising CRD (regional scale ***groundwater recharge***) and decline during periods of declining CRD (drought conditions).

Some long-term trends occur at Helidon and likely along the entire G2H rail corridor. The CRD residual underwent multiple cycles, the cycle generally decreases from 1900 to 1944, increases from 1944 to 1956, decreases again from 1990 to 2009 and increases from 2009 until 2017.

There were wetter than average periods from the 1950's to the 1990's which were followed by dryer periods from the 1990's to 2010's. In recent years between 2010 and 2013, there were wetter than average periods which have been followed by dryer periods from 2013 until present.

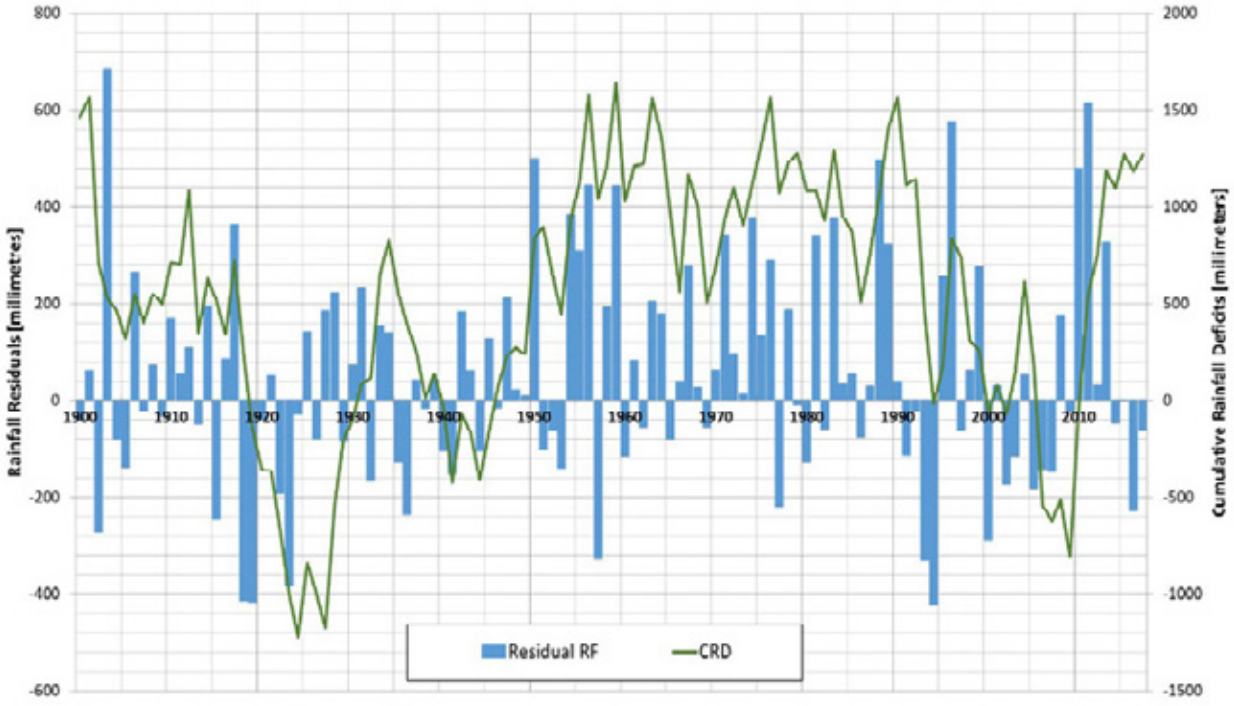


Figure 2: Annual residual rainfall and cumulative residual deficit (cumulative deviation from average) for 'Helidon Post Office' Australian Bureau of Meteorology station number 040096, record period between 1896 and 2018.

3.2 Topography and Drainage

The G2H alignment begins approximately 3.7 km west of Gowrie, adjacent to the QR Western Line at approximately 450 m above sea level. The alignment gradually rises towards the east for approximately 5 km before entering the tunnel and traversing the Toowoomba Range (part of the Great Dividing Range) with approximately 23 km of track at a constant down grade of 1 in 64.7. Of this grade 6.24 km is through the Toowoomba Tunnel which has a maximum depth of 220 m.

The alignment extends over two hydrographic ***basins*** divided by the Toowoomba Range which divides the watershed between coastal flowing rivers and inland flowing rivers:

- West of the Toowoomba Range, the section lies with the Murray-Darling Basin in which Gowrie Creek drains to the west across the Darling Downs, as it is a tributary of the Condamine River.
- East of the Toowoomba Range, the rail alignment lies within the Brisbane Basin predominantly drained by Lockyer Creek, which is a tributary of the much larger Brisbane River.

West of the Toowoomba Range, the section is located within a relatively flat plateau with localised slopes. The alignment then extends to the east across the Toowoomba Range which is the highest point in the area at 650 m above sea level. East of the Toowoomba Range, the area is dominated by steeper terrain, where the alignment crosses several ephemeral creeks (Rocky Creek and Six Mile Creek). Approximately 7 km before Helidon, the area becomes dominated by the alluvial floodplain of Lockyer Creek and its tributaries which is a relatively flat to slightly undulating broad floodplain truncated by a series of meandering watercourses with localised slopes.

The approximate locations of where the Project alignment intersect a watercourse are presented in Table 2.

Table 2: Watercourses intersected by the Project alignment

Watercourse Crossed	Approximate Chainage (km)
Gowrie Creek Tributary	0.900
Gowrie Creek Tributary	3.300
Gowrie Creek (tunnel passes under creek)	7.200
Rocky Creek Tributary	10.400
Rocky Creek Tributary	11.700
Rocky Creek Tributary	12.100
Six Mile Creek	16.500
Lockyer Creek Tributary	20.600
Lockyer Creek Tributary	22.400
Lockyer Creek	24.700

3.3 Land Use and Cover

The G2H rail corridor extends west to east through the north-eastern portion of the Northern Inland Catchments Bioregion (Maranoa-Balonne-Condamine subregion) and the northern portion of the Clarence-Moreton Bioregion (Australian Government, 2018a and 2018b). Land cover in the Maranoa-Balonne-Condamine subregion has undergone significant modification, with approximately 75% of the subregion now used for agriculture, predominantly grazing.

The G2H rail corridor is traversed by a number of ephemeral river systems (e.g. Gowrie Creek, Six Mile Creek and Lockyer Creek). Based on the Department of Science, Information Technology and Innovation (September 2016), the primary land uses within a 5 km corridor of the rail alignment are:

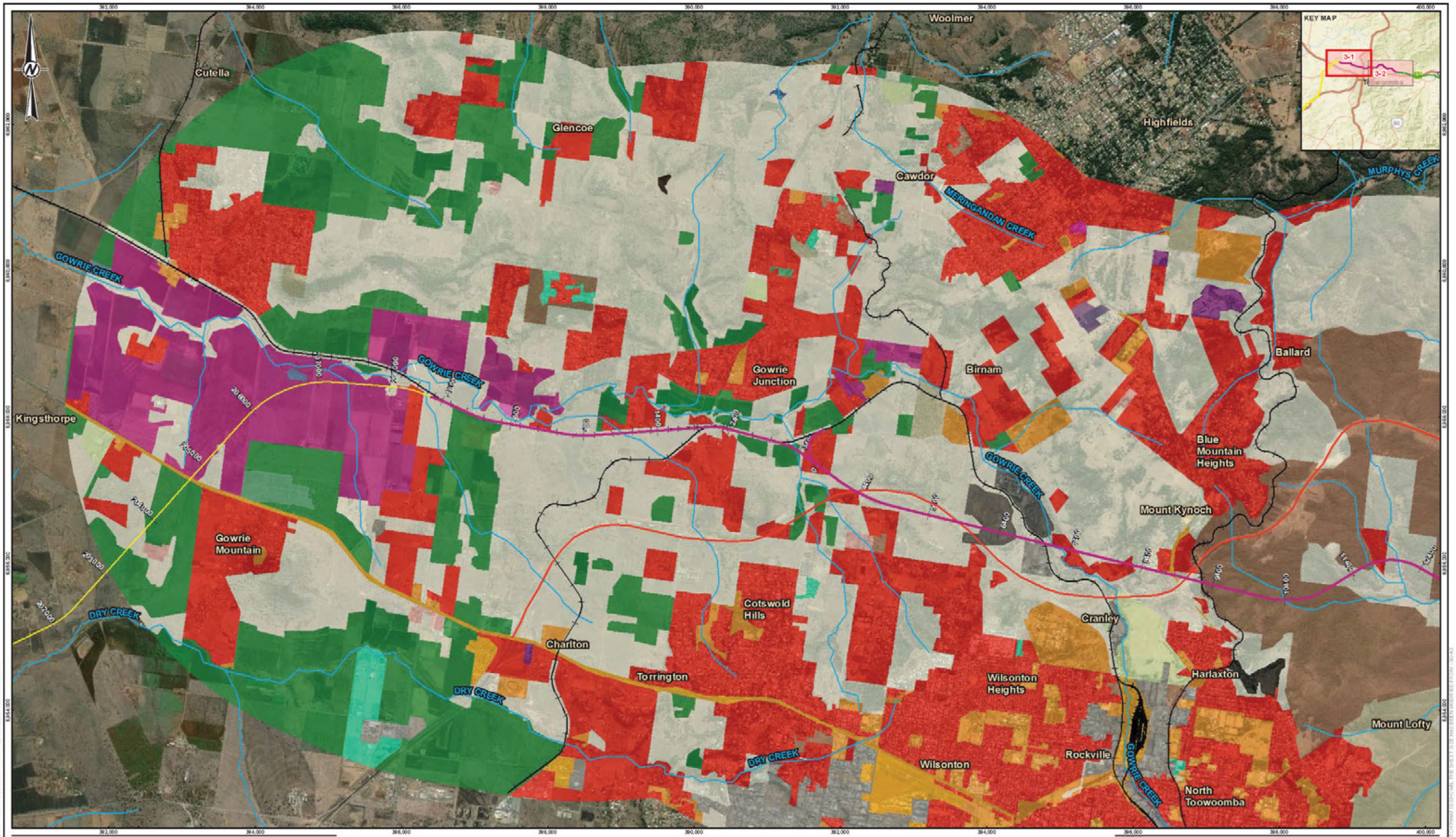
- Grazing native vegetation (44.9% of the total area) predominantly east of the Toowoomba Range in the steeper terrain
- Residential use (22.3%) associated with Toowoomba township.
- Irrigated cropping and modified pastures (seasonal horticulture) occur in close proximity to river systems and comprise approximately 3.6% of the total area. Irrigated areas may contribute to excess ***recharge*** along river systems.

Other land use types within a 5 km corridor are listed in Table 3 and displayed on Figure 3**.**

Table 3: Percent land use by area (within 5-kilometre corridor of G2H alignment)

Land Use Type (Secondary)	Sum Area (Square Metres)	Percent of Total
Grazing native vegetation	158 826 969	44.9%
Residential	78 729 740	22.3%

Land Use Type (Secondary)	Sum Area (Square Metres)	Percent of Total
Other minimal use	38 024 417	10.7%
Cropping	22 774 960	6.4%
Services	11 236 837	3.2%
Irrigated cropping	9 529 354	2.7%
Nature conservation	8 085 938	2.3%
Manufacturing and industrial	6 842 518	1.9%
Transport and communication	3 775 016	1.1%
Irrigated seasonal horticulture	3 114 445	0.9%
Managed resource protection	2 371 378	0.7%
Grazing modified pastures	2 235 358	0.6%
Others (incl. Intensive animal production, Intensive horticulture, irrigated perennial horticulture, land in transition, Mining, perennial horticulture, Reservoir/dam, Waste treatment and disposal)	8 237 297	2.3%



LEGEND

- Watercourse
- Toowoomba second range crossing
- Existing rail network

Inland Rail Alignment

- B2G - Border to Gowrie
- G2H - Gowrie to Helidon

Land use (5km Buffer of Alignment)

- Nature conservation
- Other minimal use
- Grazing native vegetation
- Grazing modified pastures
- Cropping
- Perennial horticulture
- Land in transition
- Irrigated modified pastures
- Irrigated cropping
- Irrigated perennial horticulture
- Irrigated seasonal horticulture
- Intensive horticulture
- Intensive animal husbandry
- Manufacturing and industrial
- Residential
- Services
- Utilities
- Transport and communication
- Mining
- Waste treatment and disposal
- Reservoir/dam

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 500 1,000 1,500 2,000
1:50,000@A3 METRES

NOTE(S)

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Watercourses:** Geoscience Australia
2. **Alignment:** Latest alignment provided by FFJV on 10th Jan 2019.
3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

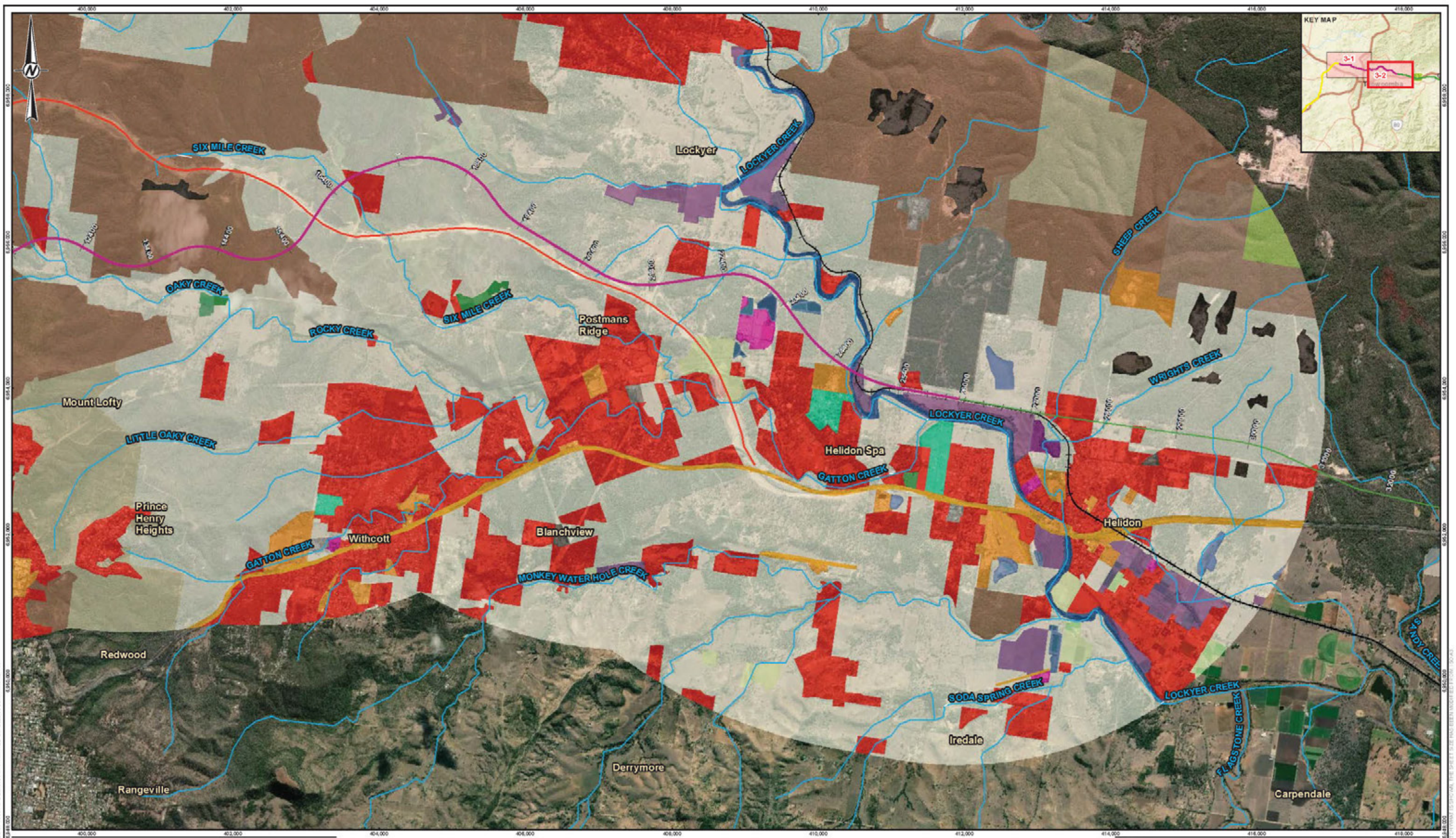
CONSULTANT
GOLDER

DD/MM/YYYY	30/05/2020
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
LAND USE OF THE GOWRIE TO HELIDON RAIL CORRIDOR

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	3-1



LEGEND

- Watercourse
- Toowoomba second range crossing
- Existing rail network

Inland Rail Alignment

- G2H - Gowrie to Helidon
- H2C - Helidon to Calvert

Land use (5km Buffer of Alignment)

- Nature conservation
- Managed resource protection
- Other minimal use
- Grazing native vegetation
- Production forestry
- Grazing modified pastures
- Cropping
- Perennial horticulture
- Land in transition
- Irrigated perennial horticulture
- Irrigated seasonal horticulture
- Intensive horticulture
- Intensive animal husbandry
- Manufacturing and industrial
- Residential
- Services
- Utilities
- Transport and communication
- Mining
- Waste treatment and disposal
- Reservoir/dam
- River

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 500 1,000 1,500 2,000
1:50,000@A3 METRES

NOTE(S)

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Watercourses:** Geoscience Australia
2. **Alignment:** Latest alignment provided by FFJV on 10th Jan 2019.
3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

CONSULTANT
GOLDER

DD/MM/YYYY	30/05/2020
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
LAND USE OF THE GOWRIE TO HELIDON RAIL CORRIDOR

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	3-2

4.0 STRATIGRAPHY AND GEOLOGICAL PROCESSES

The ***stratigraphic units*** encountered within the G2H rail corridor are described below from oldest to youngest.

The G2H alignment is anticipated to encounter the following ***units*** in various areas (Table 4):

- Marburg Subgroup – comprising the Koukandowie Formation (including the Heifer Creek Sandstone Member) and the Gatton Sandstone exposed between Chainage 10.200 and 26.200 km.
- Walloon Coal Measures - not anticipated to be encountered at the surface and is anticipated to be encountered in the subsurface beneath the Main Range Volcanics.
- Main Range Volcanics - The tunnel is anticipated to be within the Main Range Volcanics for a length of 400 m from the western portal.
- Colluvium – may be encountered at the base of the Toowoomba Range between Chainage 9.000 and 26.000 km.
- Quaternary ***alluvium*** – may be located near low lying areas to the west and east of the Toowoomba Range and near all watercourses.

Table 4: Anticipated geological model for the Toowoomba Tunnel

Expected Geological Unit	Preliminary Expected Chainage1 (m)	Expected Material	Comment
Koukandowie Formation	4,500-8,600 and 9,000-10,000	Labile and sub-labile, ***lithic*** and feldspathic sandstones with ***mudstone*** and ***siltstone*** interbeds; minor coal seams	Based on the available information, about 75-80% of the tunnel is likely to be fully located within the upper portion of the Koukandowie Formation.
Walloon Coal Measures	8,400-8,500	Shale, ***siltstone***, sandstone and coal seams	Appears to be present as a discontinuous remnant layer between the Koukandowie Formation and the overlying basalts. Dominated by fine grained and weathered sediments.
Main Range Volcanics	4,100-4,500	Olivine alkali basalt, massive or vesicular and/or amygdaloidal, minor pyroclastics	The tunnel is anticipated to be within the Main Range Volcanics for a length of 400 m from the western portal.
UTS and Tuff	Sporadically within or at the base of basalt	Poorly consolidated lacustrine claystone and tuff within or underlying the basalt. Thick tuffaceous ***sediments*** at lava pools and at eruptive centres	Thin, 2 to 3 m thick layers of UTS, comprising tuff and claystone may be encountered either within the basalt or at the transition from the basalt to the underling Koukandowie Formation, initially appearing below the tunnel invert and gradually migrating through the tunnel and into the crown.

Expected Geological Unit	Preliminary Expected Chainage1 (m)	Expected Material	Comment
Crater Rim	8,600-8,850	***Interbedded*** and mingled basalt, tuff, sandstone and ***siltstone***	Significant lateral variation is expected. Highly weathered and/or altered tuff, potentially with expansive clays. Localised occurrence is anticipated. The proposed tunnel alignment crosses an up to 55 m thick ***sequence*** of mixed tuffaceous, sedimentary and basaltic rocks near CH8,700 m (320-01-BH2102) that has been interpreted as Crater Rim ***sequence*** adjacent to a potential lava pool.
Colluvium	10,000-10,300	Poorly consolidated interbedded ***sediments*** ranging from fine grained clayey material to basalt and sandstone boulders (>1m diameter), potentially bound by landslide surfaces	The eastern approximately 12% of the tunnel alignment is likely to be in colluvium, which appears to form a complex, possibly multi-stage landslide debris cone.

Note: [1] Chainages overlap between the ***units*** where more than one ***unit*** is expected to be encountered. Chainage estimates have been determined using available borehole data and the geological model. As borehole data is limited, these chainages are only approximate.

The geological ***units*** encountered throughout the G2H rail corridor are reported below.

Gatton Sandstone (Marburg Subgroup)

An Early Jurassic age ***unit*** comprises ***lithic*** labile and feldspathic labile sandstone. The Koreelah Conglomerate Member is only found in the western and central part of the Clarence Moreton Basin, but not in the area of the Toowoomba Tunnel.

Gatton Sandstone is the lower ***member*** of the Marburg Subgroup and comprises mainly labile and feldspathic labile sandstone with minor interlaminated shale, ***siltstone*** and ***mudstone*** with clay matrix. Minor beds of granule, pebble and cobble polymictic conglomerate occur. The sandstone is predominantly fine grained, grey in colour and high strength when fresh. The Gatton Sandstone is overlain by the Early to Middle Jurassic age Koukandowie Formation.

Koukandowie Formation (Marburg Subgroup)

An Early to Middle Jurassic age ***unit*** comprising lithofeldspathic labile and sub-labile to quartzose sandstone, ***siltstone***, shale, minor coal and a ferruginous oolite marker. The beds are typically sub-horizontal, dipping less than 15 degrees to the southwest, with very gentle folding on a regional scale.

It should be noted that the Koukandowie Formation rocks have previously been referred to as the Marburg Formation. The Marburg Formation name has since been superseded and the nomenclature described in the above dot points is currently in use. The Koukandowie Formation and the Gatton Sandstone together form the Marburg Subgroup (Figure 4).

- The Undifferentiated Koukandowie Formation,
- The basal Ma Ma Creek Member, and
- The Heifer Creek Sandstone.

The Koukandowie Formation is overlain by the Middle to Late Jurassic age Walloon Coal Measures.

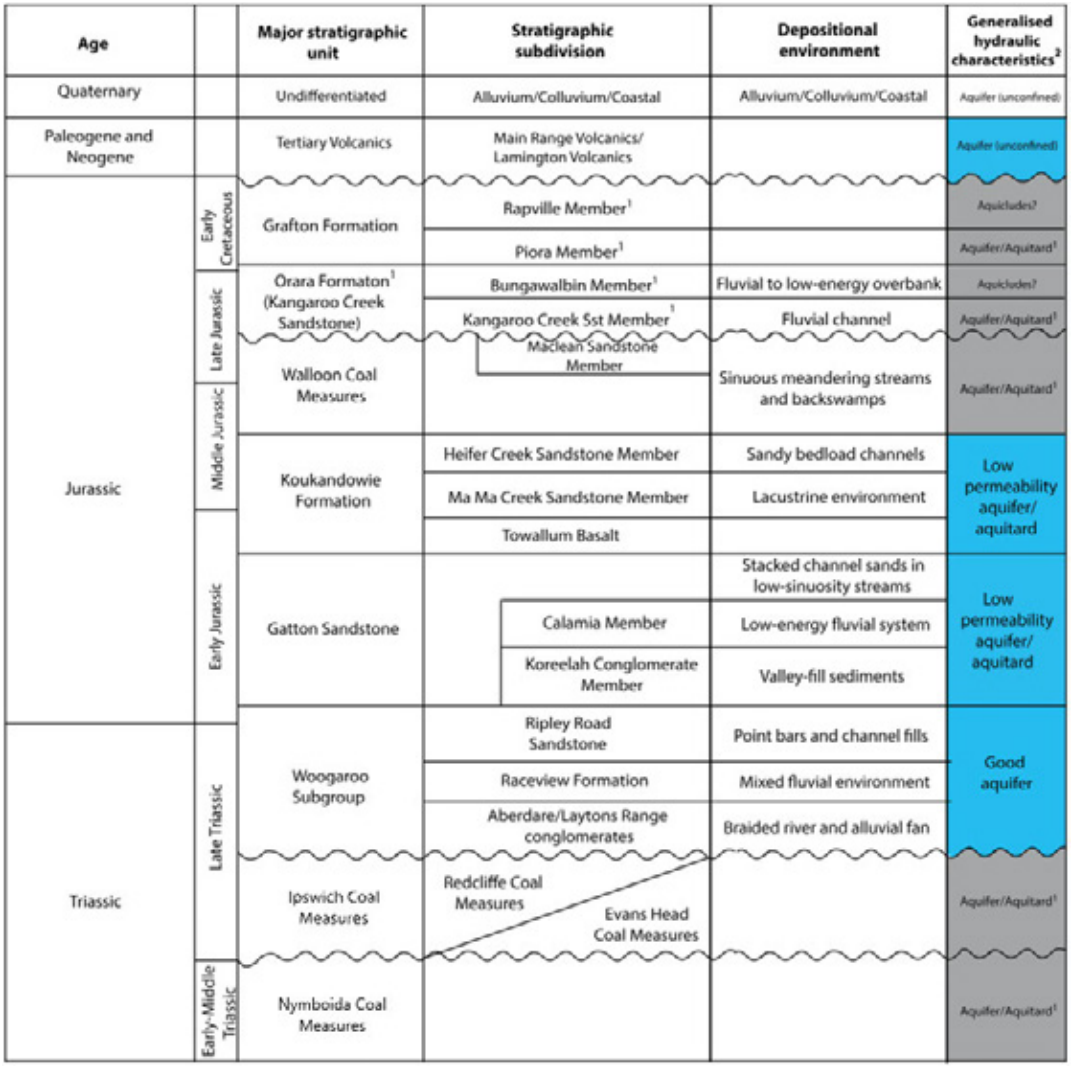


Figure 4: Stratigraphy of the Clarence-Moreton sedimentary basin (Rassam et al 2014)

Walloon Coal Measures

The Walloon Coal Measures (WCM) typically includes sandstone, ***siltstone***, ***mudstone*** and coal in the upper half to two-thirds of the ***unit***, with possible calcareous sandstone, impure limestone and ironstone (Wells and O'Brien 1994). The lower part of the ***unit*** represents stacked overbank deposits within highly sinuous fluviatile systems, with the upper part of the ***unit*** deposited as coal swamps. The WCM rocks, where they ***outcrop*** at the surface, form gently undulating terrain due to their tendency to weather to clayey residual soil to a considerable depth. The WCM is overlain by the Main Range Volcanics.

Due to extensive weathering, the strength of the WCM rocks is typically low compared to the Koukandowie Formation rocks. The extremely weathered to highly weathered sedimentary ***sequence*** of rock underlying the basalts, as encountered in the DH series boreholes is assigned to the WCM.

This ***unit*** is expected to be present only in isolated patches along the alignment, while it is likely to be a continuous layer south of the alignment. The rocks of the Walloon Coal Measures are reported to underlie the

Main Range Volcanics (MRV) just south of the proposed tunnel alignment and are in turn underlain by the Koukandowie Formation.

Undifferentiated Tertiary Sediments

Whilst the geological ***unit*** referred to as “Undifferentiated Tertiary Sediments” (UTS) is not a recognised ***stratigraphic unit*** and has not been officially mapped, it has been encountered and logged in the area during both geotechnical investigations and excavations for infrastructure projects.

The UTS occurs either directly under the MRV basalts or within the basalt. When beneath the basalt, the UTS appears similar to the extremely weathered to highly weathered older sedimentary rocks of the WCM or Koukandowie Formation, except it is commonly represented by claystone rather than ***mudstone***; with the plasticity of the resultant clays significantly higher and further includes the presence of tuff or tuffaceous layers.

The UTS typically comprises high plasticity clay of hard consistency or very low strength claystone, tuff (including lapilli tuff), ***mudstone*** and fine-grained sandstone (Denaro, 1985). The claystone, ***mudstone*** and sandstone often contain volcanic fragments and/or are fissured. In addition, the ***mudstone*** and claystone can have high organic content and the appearance of a poor quality or immature coal.

The thickness of the UTS layers encountered varies greatly between 1 m and 12 m. It is likely that the ***sediments*** were deposited in a relatively low lying or poorly drained swamp or lake environment before or between episodes of volcanic activity. Consequently, the UTS is likely to occur in depressions in the landscape at the time of ***deposition***.

Main Range Volcanics

The rocks of the Tertiary age Main Range Volcanics (MRV) mainly comprise olivine basalt with a variable content of associated pyroclastic rocks. The basalts of the proposed Toowoomba Tunnel area belong to an informal subunit of the MRV, referred to as Toowoomba Volcanics (TV), which is reported to be up to 330 m thick along the escarpment at Toowoomba (Willey, 2012).

Locally, the rock is massive near the base or in the middle of an individual flow, and vesicular and/or amygdaloidal towards the top (referred to as honeycombed or vesicular basalt). The term “massive” is used with reference to lack of abundant and visually identifiable vesicles/amygdales and not related to the presence or absence of discontinuities.

More than 15 individual basalt flows were identified in the area north-east of Toowoomba (Willey, 2012). Buried topsoil, referred to as “paleosol” is commonly present at both the base and top of the Toowoomba Volcanics, as well as between individual flows. The upper paleosol is commonly part of a lateritised, deeply weathered ***sequence***.

The Toowoomba Volcanics are likely to have formed from fissure eruptions with individual lava pools along the feeder dyke system, rather than as a “central volcano”. Lava pools have been identified at both the Harlaxton Quarry and Jubilee Park, south of the proposed eastern portal, with the identified potential lava pools along the escarpment appearing to be located on a north-westerly oriented trend line. A radiometric image indicates the presence of a north-west trending anomaly, which may be related to fissure feeders, dykes or other similar linear structure, crossing the proposed tunnel alignment between approximately CH8,500 and CH9,500 m.

Borehole 320-01-BH2102 drilled at approximate chainage 8,700 m encountered about 56 m of tuffaceous ***sediments*** with basalt and what appears to be Mesozoic age sedimentary rock fragments. A petrographic analysis for a sample from borehole 320-01-BH2102 from a depth of 227.7 m has been identified as dolerite, a medium grained variety of basalt. Since the sample is from a ***sequence*** of inter-mingled basaltic, pyroclastic

and sedimentary rocks, it is likely to have originated from a sub-volcanic structure, such as a dyke, within an extrusive/crater complex.

Colluvium

The slopes and the toe of the escarpment are frequently covered with colluvial deposits of various thicknesses. Depending on the source area and method of emplacement, the following five different types of colluvium can be anticipated around the eastern portal area (APB, 2017):

- Soil colluvium,
- Common colluvium,
- Rocky colluvium,
- Poorly cemented colluvium (often incorrectly referred to as “breccia”), and
- Rock scree.

All five of the above colluvium types are anticipated to have been accumulated by two distinct methods which affects the characteristics and diagnostic features: gradual accumulation of eroded material (up to several metres in thickness), or from a landslide debris cone (up to several tens of meters in thickness) .

Based on the current available data, it is expected that the extent of colluvial deposits are likely to be significantly larger than indicated on the published geological maps.

Alluvium

Alluvial plains exist at the base of the Toowoomba Range within the Lockyer Valley, while alluvial plains of the Murray-Darling Basin exist west of the Toowoomba Range. The alluvial plains overlie incised valleys filled with gravels, sands, loams and clays. The ***alluvium*** is conceptualised to be thicker and contain larger grain sizes such as sand and gravel near the existing watercourses and along palaeochannels. The area surrounding the watercourse which are floodplains of the watercourses are conceptualised to possess ***sediment*** deposits containing smaller particles sizes such as fine-grained sand, silt and clay ***sediments***.

4.1 Geological Structures

The geological structures encountered throughout the G2H rail corridor are reported below.

The presence of a north-west trending anomaly is indicated, which may be related to fissure feeders, dykes or other similar linear structure, crossing the proposed Toowoomba Tunnel alignment (located from c*hainage* 4.200 and 10.250 km) between approximately c*hainage* 8.000 and 9.000 km. The trend line indicated on the radiometric image is sub-parallel with the alignment of the escarpment and with the New England Highway near its current crossing with the Toowoomba Second Range Crossing alignment. Tuffaceous ***sediments***, consistent with the proximal area of an eruptive centre/line, were encountered in boreholes DH02 (DoM, 1985) and BH056 to 059 (DTMR, 2006), between the existing New England Highway and Goombungee Road (approximately Chainage 8.000 to 9.000).

Abundant agglomeratic and tuffaceous layers were similarly encountered in borehole 320-01-BH2101 at around Chainage 5.500, indicating that an eruptive centre and consequently, feeder dyke system, may also be located proximally to this area.

No regional structures are mapped along the proposed tunnel or its vicinity. However, generally north-north-west to east-south-east trending faults and fold axes have been previously mapped to affect the Clarence-Moreton Basin rocks, both to the east and west of the tunnel. It therefore remains a possibility that some regional structures exist along the tunnel alignment below, hidden by the basalt.

The Tertiary age basalts mask the structures in the underlying Mesozoic age sedimentary rocks at the Toowoomba Tunnel. It is possible that the feeder dyke system(s) related to the basaltic eruptive centres have used the pre-existing tectonic weaknesses along the faults to rise to the surface through the underlying sedimentary rocks.

No distinct regional faults or joint trends are reported for the basalts and none were encountered during the excavation of a pilot tunnel adjacent to the proposed Toowoomba Tunnel (Bathurst and Heaton, 2008). It was noted that the basaltic flows and the interbedded UTS layers tend to slope towards the west, which is likely to be indicative of eruptive centres located at or to the east of the Great Escarpment.

Based on the distribution pattern of structures observed in the ***basin***, it is likely that the approximately 6.24 km long tunnel will be intercepted by one to two north-west trending regional structures. This estimate is also supported by the radiometric anomaly, and the increased proportion of tuffaceous material reported in borehole DH2 (TRRT, 1986) and a likely similar, but smaller structure located in the western part of the tunnel, as indicated by identified eruptive centres described in the published literature (Willey, 2012).

5.0 REGIONAL HYDROGEOLOGY

5.1 Hydrostratigraphy

A stratigraphic ***sequence*** of the Clarence-Moreton ***sedimentary basin*** is presented in Figure 4 and identifies general hydraulic characteristics of each ***unit*** (Rassam *et. al.,* 2014). The alignment of the Project is anticipated to encounter the Quaternary, MRV, WCM and the Koukandowie Formation shown on Figure 4. The UTS, colluvium and ***alluvium*** are localised ***stratigraphic units*** encountered along the Project alignment.

There are three conceptualised ***aquifers*** in the Project, these include:

- Quaternary ***aquifer***(s): a shallow unconfined or perched ***aquifer*** in the colluvium or ***alluvium***,
- MRV ***aquifer***: a fractured basalt ***aquifer*** in the MRV which may be unconfined, semi-confined or confined, and
- Sedimentary ***aquifer***(s): a ***confined/semi-confined aquifer*** in the sedimentary rock of the Gatton Sandstone, the Koukandowie Formation and the WCM.

Connectivity between the MRV ***aquifer*** and the underlying sedimentary rock ***aquifers*** are anticipated to be limited due to the presence of the low conductivity UTS layer; however, there may be localised zones where the UTS layer is absent, within the basalt or is disrupted by sub-vertical basaltic feeder dykes (based on non-site-specific data).

5.1.1 Shallow Unconfined or Perched Aquifer in the Colluvium/Alluvium

To the west of the Toowoomba Range the alignment is located within the alluvial plains of the Murray-Darling Basin, and to the east of the Toowoomba Range is located within the alluvial plains of the Lockyer Valley. The alluvial plains have infilled valleys and variable hydraulic conductivity due to grain size variations capable of carrying large supplies of fresh to slightly brackish ***groundwater***. The Quaternary ***aquifers*** are intensely utilised for irrigation and are recharged by surface runoff and creek ***recharge***, subsoil seepage or from adjacent rock ***aquifers***.

The ***alluvium*** is conceptualised to contain large grain sizes, such as sand and gravel in close proximity to existing watercourses and palaeochannels which will be more conductive to ***groundwater*** flow in these areas. The areas surrounding the watercourse which are floodplains are conceptualised to possess alluvial ***sediment*** deposits containing smaller particles sizes such as fine sand, silt and clay ***sediments*** which are less conductive to ***groundwater*** flow within the subsurface.

Colluvium deposit is anticipated at the base of the Toowoomba Range to the east. These deposits are conceptualised to consist of a wide range of grain sizes and is likely to contain high proportion of fine materials due to weathering. Most colluvium is anticipated to be located above the water table. Inflows to cuts which are located in colluvial Quaternary ***aquifers*** may occur intermittently following rainfall.

5.1.2 MRV Aquifer (Fractured Basalt Aquifer)

Groundwater within the MRV ***aquifer*** is anticipated to be highly variable due to the nature of fracture distribution, variable weathering and layering of basalt flows. Individual basalt flows typically have a vesicle/honeycomb structure develop at the top and base of the flow separated by a massive columnar basalt. The honeycombed or vesicular basalts are anticipated to have elevated conductivity whereas the massive basalts have lower conductivity and negligible pore spaces.

A subsurface ***groundwater*** divide is conceptualised to exist in the Toowoomba Range with ***groundwater*** flow directions in the MRV reflecting the location of the surface water catchments. The MRV ***aquifer*** is separated from the underlying Sedimentary rock ***aquifers*** of the WCM and the Koukandowie Formation by the extensive UTS layer, except where the UTS layer is not present due to erosion, basaltic dykes or locally absent due to depositional processes.

Perched ***groundwater*** may exist within the weathering profile of the basalt or at depth where clay impedes downward percolation of pore water to the regional ***groundwater*** table. Perched ***groundwater*** in the MRV may exhibit a wide range in water quality with potentially localised high inflow rates to excavations which will decrease with time as the storage of the perched ***aquifer*** is depleted.

While no major geological structures have been identified in the area surrounding the Toowoomba Tunnel, basalt dykes flow are interpreted to have followed the planes of weakness or preferential flow within ***stratigraphic units*** along foliations, faults, fractures or other structural features. Where basalt ***units*** intersect Sedimentary rock ***aquifers*** or cross ***aquitards***, they may form a conduit for connectivity or hydraulic barrier depending on the fracture network.

5.1.3 Sedimentary Rock Aquifers

The Sedimentary rock ***aquifer*** comprised of the WCMs are not considered a major ***aquifer*** on a regional scale because they dominantly consist of low ***permeability*** sandstone, ***siltstone***, shales, carbonaceous ***mudstones*** with minor sandstones and coal seams. However, coal seams and geological structures such as faulting may locally increase the potential for ***groundwater*** movement and storage.

The WCM are considered a Great Artesian Basin (GAB) ***aquifer*** in the Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017, referred to herein as the GABORA Water Plan. Despite low permeabilities in this formation, there are localised ***groundwater aquifers***. The WCM is part of the Springbok Walloon Groundwater Unit in the GABORA Water Plan. ***Groundwater*** within the Sedimentary rock ***aquifers*** of the WCM beneath the MRV ***aquifer*** is conceptualised as a sub-artesian, ***confined aquifer***. Storage of this Sedimentary rock ***aquifer*** is anticipated to be low and will likely result in low long-term seepage rates.

The Sedimentary rock ***aquifer*** comprised of the Koukandowie Formation are generally described as low ***permeable aquifers*** and ***aquitards***. The Sedimentary rock ***aquifers*** contains various sandstone ***members*** (Figure 4) containing highly variable ***permeability***, though primarily acts as an ***aquifer***. For the purposes of this assessment and due to limited information, the Heifer Sandstone and the Ma Ma Creek Member are considered together and referred to as the Koukandowie Formation. ***Groundwater*** within the Sedimentary rock ***aquifer*** of Koukandowie Formation beneath the Sedimentary rock ***aquifer*** of the WCM and the MRV ***aquifer*** is conceptualised as a sub-artesian, ***confined aquifer***. Where the Koukandowie Formation is exposed at surface, the Sedimentary rock ***aquifer*** is considered unconfined. The Sedimentary rock ***aquifer*** of

the Koukandowie Formation is reportedly the equivalent to the Hutton Sandstone of the Surat Basin west of the Toowoomba Range (IESC, 2014).

The Sedimentary rock ***aquifer*** of the Gatton Sandstone is a relatively poor ***aquifer***; however, the conglomerates and resistant sandstones in the upper Gatton Sandstone may have some hydrogeological significance (McMahon and Cox, 1996; Wilson, 2005; Zahawi, 1975). This Sedimentary rock ***aquifer*** contains water, but overall, is of low to moderate ***permeability*** with poor quality water which is saline water at depth locally. Due to the lack of spatially continuous beds of low ***permeability*** rock or a thick low ***permeability*** soil layer, ***groundwater*** in the Sedimentary rock ***aquifer*** of the Gatton Sandstone is believed to be unconfined below ridges and mostly unconfined elsewhere.

Perched ***groundwater*** may exist along geological contacts, low ***permeability*** faults or intrusive dykes and within zones of weathering.

5.2 Groundwater Level and Flow

There are 39 registered ***groundwater*** bores within 500 m of the Project alignment. These bores only contain one single measurement point. In order to obtain ***groundwater levels*** with long-term monitoring, and excluding bores with insufficient long-term data, the search was expanded to 5 km. This resulted in an additional 9 registered ***groundwater*** bores identified within 5 km of the alignment, resulting in a total of 48 registered ***groundwater*** bores. The number of bores within the various formations are reported in Table 5.

A total of 12 ***groundwater*** monitoring bores were installed during the project site investigations. Pressure transducers (water level data loggers) were installed in the G2H FS SI ***groundwater*** monitoring bores to continuously monitor the ***groundwater levels*** with a barometric pressure correction applied to monitored data hourly.

Locations of registered bores and FFJV SI bores are reported in Figure 8 with the local topography and watercourses. Available hydrographs for bores installed during G2H FS SI investigations are reported in Appendix A. Basic ***groundwater level*** statistics from available ***groundwater*** bores are reported in Table B1 of Appendix B.

Table 5: Registered groundwater monitoring bores by formation for the Project alignment

Monitored Formation	Monitored Aquifer	Number of bores
Alluvium	Quaternary aquifer	2
MRV	MRV aquifer	27
Marburg Subgroup	Sedimentary rock aquifer	6
Koukandowie Formation	Sedimentary rock aquifer	1
Gatton Sandstone	Sedimentary rock aquifer	8
Woogaroo Subgroup	Sedimentary rock aquifer	1
Unknown Formation	Unknown	3

5.2.1 Groundwater Levels in Quaternary Aquifers

There is limited ***groundwater*** data available within Quaternary ***aquifers*** near the Project alignment in the Queensland Government Groundwater Database, with most ***groundwater*** data reported in the registered borehole database reporting only single measurements. A search was conducted to 5 km of the Project alignment and no long-term monitoring bores within the ***alluvium*** were identified. Therefore, only two bores within the ***alluvium*** were identified. RN129229 is installed within the Lockyer Creek Alluvium to the east of the

Toowoomba Range near Helidon Spa and reports a ***groundwater level*** of about 131.1 m AHD (9.5 meters below ground level) in December 2004. RN48325 is installed within the Oakey Creek Alluvium to the west of the Toowoomba Range near Gowrie and reports a ***groundwater level*** of about 464.5 m AHD (9.8 meters below ground level) in February 1976. There are no FFJV 2018 SI reporting ***groundwater levels*** in the Quaternary ***aquifer*** currently available.

5.2.2 Groundwater Levels in the MRV Aquifer

Due to the limited long-term ***groundwater*** observations west of the Toowoomba Range, the search was expanded to include bores within 5 km of the Project alignment. This resulted in identifying 7 registered ***groundwater*** bores containing long-term ***groundwater*** monitoring data in the MRV ***aquifer***. Figure 5 reports these long-term monitoring bores in the MRV ***aquifer*** along with large climatic events reported since 2008 (refer to Figures 6-1 and 6-2 for location of bores):

- All registered bores show a response to the 2011 Floods and increase until Cyclone Oswald and the Bremer River Flooding events in 2014.
- RN42231269 and RN42231662 experienced delayed increases in response to the 2011 floods and peaked in 2014 with increases in ***groundwater levels*** of about 5.5 m and 1.2 m respectively over this monitoring period. This suggests poor connectivity with the surface.
- RN119631 shows a rapid response during the 2011 floods, increasing by about 15.1 m followed by a rapid decrease after the flood event. This suggests increased connectivity with the surface.
- RN42231225 showed a rapid increase of about 4.4 m in response to the 2011 floods followed by a gradual increase to 597.6 m AHD in 2014, resulting in about 13.0 m rise from ***groundwater levels*** after the 2011 floods.
- RN42230955 and RN42231660 contain a great deal of noise which may be instrumentation error or rapid responses to climate events due to fracture connectivity.
- RN42231662 expresses a long-term trend similar to a bore under stressed conditions. Water levels may be decreasing as the bore equilibrates after installation or experiences influences from ***groundwater*** extraction in the ***aquifer***. ***Groundwater*** decreased from 490.7 m AHD in 2008 at the start of monitoring to 471.3 m AHD in 2011 and increased gradually after the 2011 floods until the 2014 Bremer River flooding and Cyclone Ita to about 472.8 m AHD. ***Groundwater*** appears to have generally stabilised from about 2014.

Groundwater levels in the MRV ***aquifer*** are impacted by abstractions for water supply, and the highly variable hydraulic conductivity. It is observed that the variations in hydraulic head in a horizontal direction are influenced by the topography, and measurements of ***groundwater levels*** suggest a marked downward hydraulic gradient in the MRV in the vicinity of the tunnel. This is discussed in the below Figure 5:

- There are two long-term monitoring stations south of the tunnel alignment: RN42231660 and RN42231662. These two bores are screened in the MRV at 30 m bgl and 166 m bgl, respectively. The horizontal distance between these two observation points is just 5 m, while the monitored water level is about 555 m AHD in RN42231660 and about 473 m AHD in RN42231662.
- 320-01-BH2101 is screened between 105 and 117 m bgl. This interval is very close to the interface of the MRV and the underlying sedimentary rocks. The monitored water level is about 475 m AHD.
- There are two VWP`s installed in 320-01-BH2102 at a depth of 184.4 and 204.7 m. Both VWP`s are within the MRV. The monitored water levels are around 489-494 m AHD.

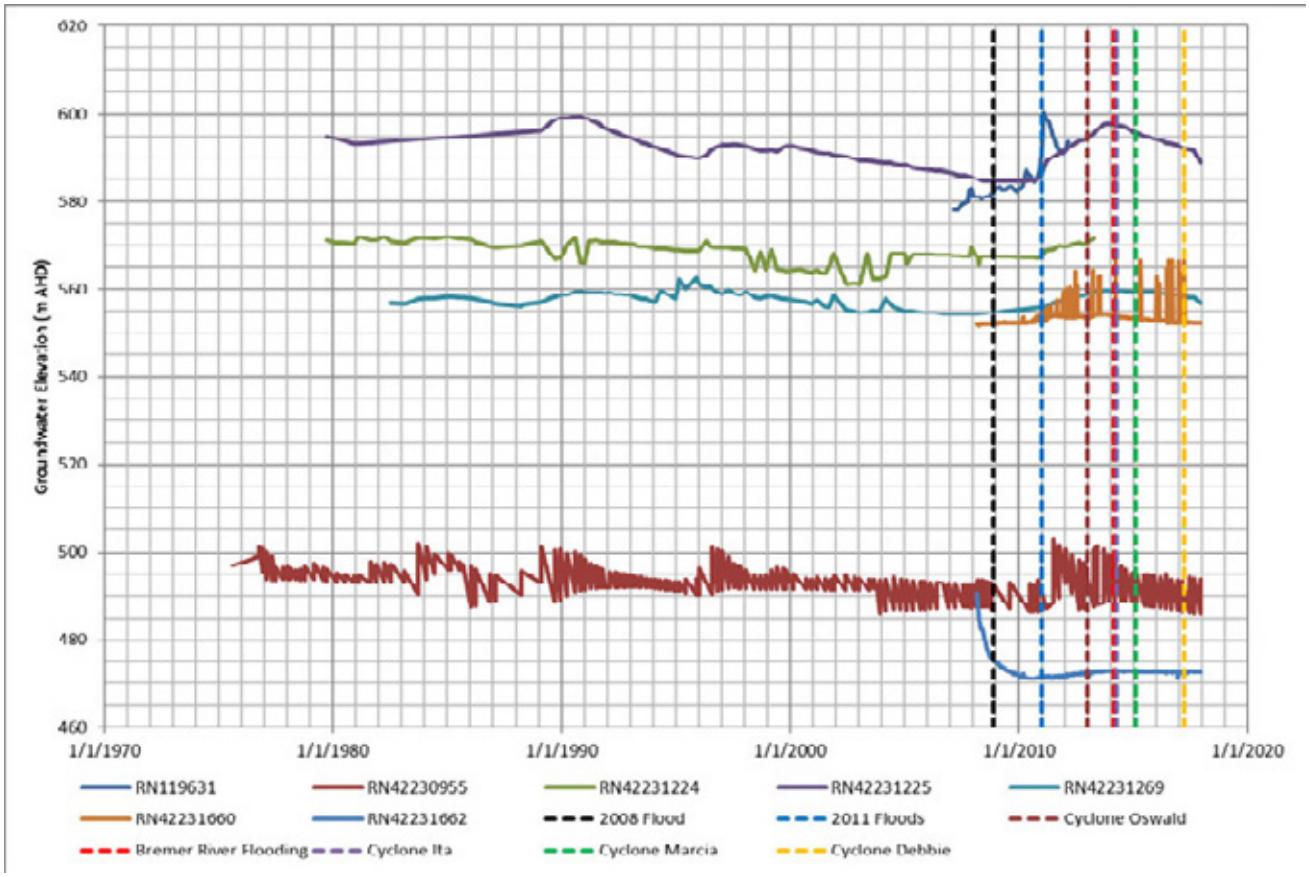


Figure 5: Long-term groundwater monitoring in the Main Range Volcanics west of the Toowoomba Range

5.2.3 Groundwater Levels in the Sedimentary Rock Aquifer

Due to the limited long-term ***groundwater*** observations in the Sedimentary rock ***aquifers*** both to the east and west of the Toowoomba Range, the search was expanded to include bores with long-term monitoring records within 5 km of the Project alignment. This resulted in the identification of 1 registered ***groundwater*** bore east of the Toowoomba Range containing long-term ***groundwater*** monitoring data in the Gatton Sandstone. Figure 6 reports a long-term monitoring bore (RN14320949) which experiences a delayed and limited (compared to the MRV ***aquifer***) influence from the climatic events reported since 2008. RN14320949 shows a delayed response up to about 3.5 m from the 2011 floods while other climatic events reported an increase of about 1 m.

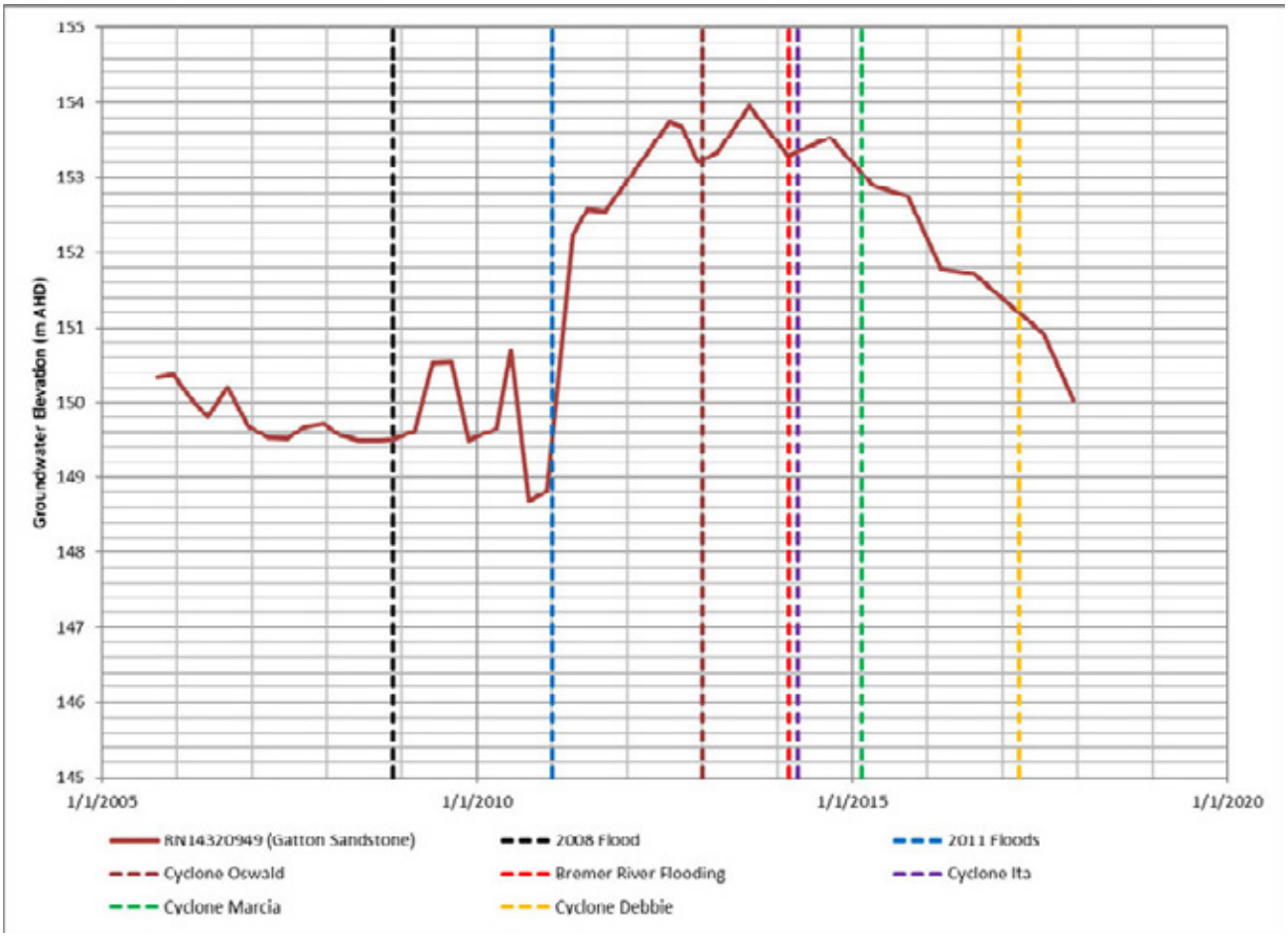
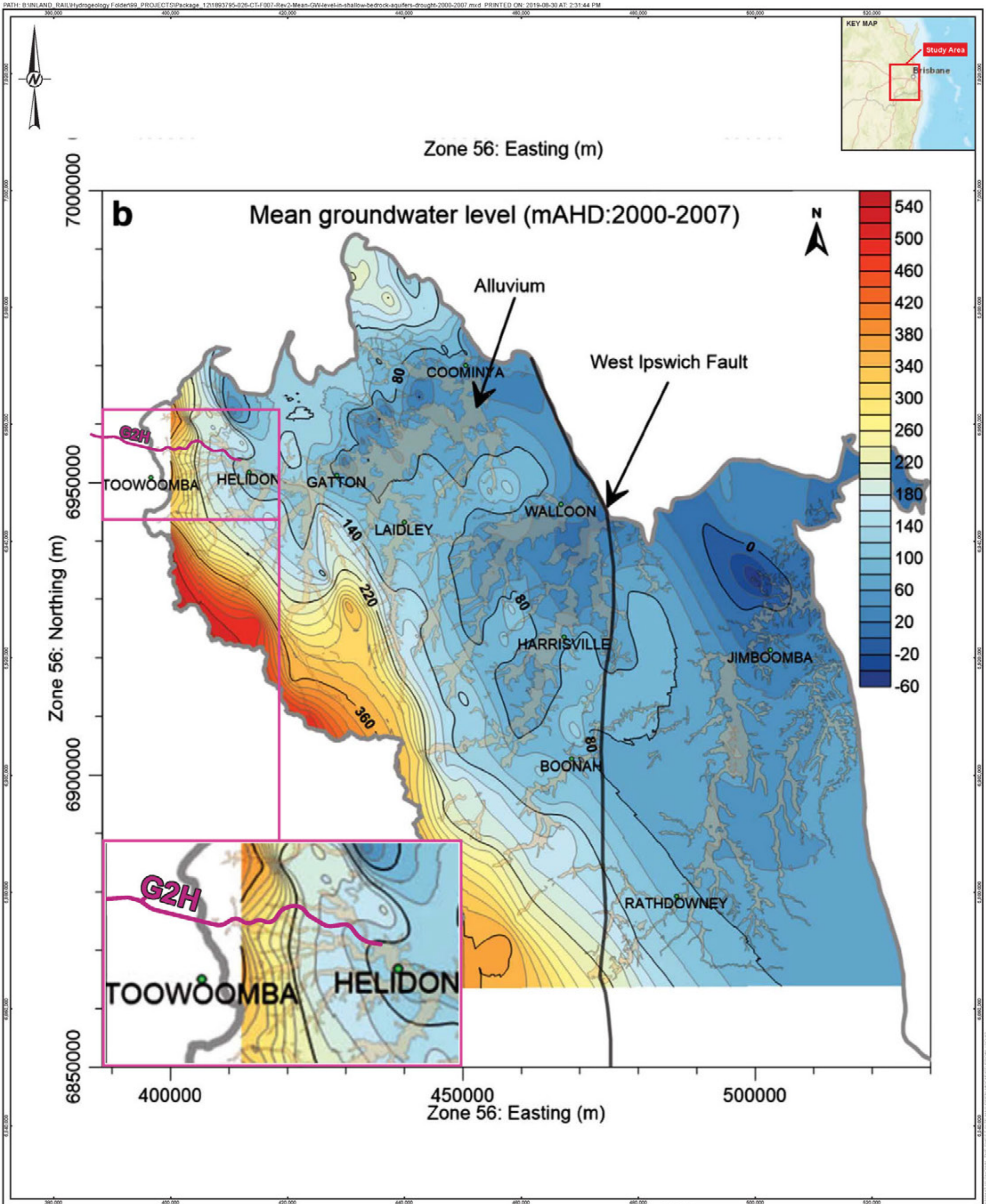


Figure 6: Long-term groundwater monitoring in the Sedimentary rock aquifers east of the Toowoomba Range

Cui *et. al*., 2018 conducted a regional assessment of ***groundwater levels*** in the Lockyer and Bremer River Valley regarding mean ***groundwater level*** in shallow Sedimentary rock ***aquifers*** during the drought period between 2000 to 2007. Results from this study are reported in Figure 7 and illustrate ***groundwater levels*** in shallow Sedimentary rock ***aquifers*** to the east of the ***groundwater*** divide in the Toowoomba Range as discussed in Section 5.2.4.

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LEGEND

Inland Rail Alignment

G2H - Gowrie to Helidon

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 5 10 15 20 Km
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CLIENT
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CONSULTANT
GOLDER

DD/MM/YYYY	30/08/2019
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

NOTE(S)

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Alignment:** Latest alignment provided by FFJV on 10th Jan 2019.
2. **Mean Groundwater Level Image:** Sourced from Cui, T., Raiber, M., Pagendam, D., Gilfedder, M., Rassam, D. (Cui et. al.,), 2018. Response of groundwater level and surface-water/groundwater interaction to climate variability: Clarence-Moreton Basin, Australia. Jounral of Hydrogeology. 2018. Volume 26 pages 593 to 614. DOI 10.1007/s10040-017-1653-6.

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
MEAN GROUNDWATER LEVEL IN SHALLOW BEDROCK AQUIFERS DURING THE DROUGHT PERIOD BETWEEN 2000 TO 2007 (CUI ET. AL, 2018)

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	7

KEY MAP

RN42231269
MERINGANDAN CREEK
RN42231225
RN42231224
MURPHYS CREEK
RN42230855
RN84161
RN83537
RN94340
RN56751
RN83105
RN56783
RN48325
RN48594
RN64388
RN34729
RN66487
RN71234
GOWRIE CREEK
RN107111
RN107110
RN38341
RN119852
320-01-BH2101
RN143273
RN48472
320-01-BH2102
320-01-BH2201
RN106596
320-01-BH2103
RN42231660
RN42231662
RN119831
DRY CREEK
Toowoomba Range

LEGEND

- FFJV 2018 SI Geotechnical Bores
- FFJV 2018 SI Groundwater Bores
- Registered Bores (Water Levels)
- Registered Bores (Water Quality)
- Registered Bores (Longterm Water Levels)
- Watercourse

Inland Rail Alignment

- B2G - Border to Gowrie
- G2H - Gowrie to Helidon

G2H Digitial Elevation Model 1 meter

720 mAHD
420 mAHD
120 mAHD

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

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1:50,000 @A3 METRES

NOTE(S)

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Alignment, 1m DEM:** Latest alignment provided by FFJV on 10th Jan 2019, and derived from LiDAR data provided by FFJV in 2017 respectively.
2. **Registered Bores:** Queensland Groundwater Database (2018)
3. **ARTC Geotech and Groundwater Bores:** Inland Rail G2H - Geotechnical Factual Report (Golder, 2018c).
4. **Watercourse:** Geoscience Australia

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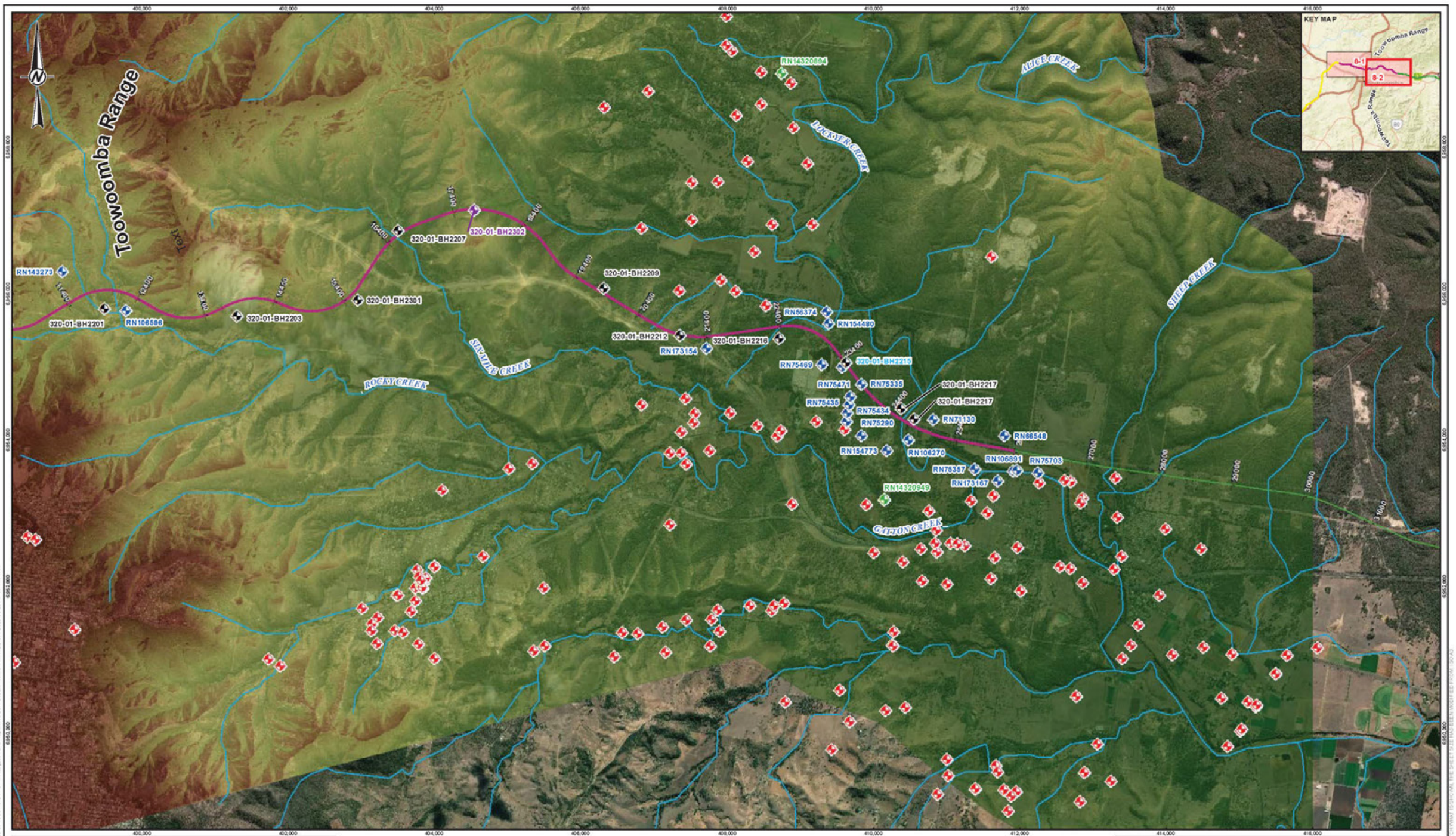
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DD/MM/YYYY	25/05/2020
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	8-1



LEGEND

- FFJV 2018 SI Geotechnical Bores
- FFJV 2018 SI Groundwater Bores
- Registered Bores (Water Levels)
- Registered Bores (Water Quality)
- Registered Bores (Longterm Water Levels)
- Watercourse

Inland Rail Alignment

- G2H - Gowrie to Helidon
- H2C - Helidon to Calvert

G2H Digitial Elevation Model 1 meter

720 mAHD
420 mAHD
120 mAHD

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 500 1,000 1,500 2,000
1:50,000 @A3 METRES

NOTE(S)

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Alignment, 1m DEM:** Latest alignment provided by FFJV on 10th Jan 2019, and derived from LiDAR data provided by FFJV in 2017 respectively.
2. **Registered Bores:** Queensland Groundwater Database (2018)
3. **ARTC Geotech and Groundwater Bores:** Inland Rail G2H - Geotechnical Factual Report (Golder, 2018c).
4. **Watercourse:** Geoscience Australia

CLIENT
FUTURE FREIGHT JOINT VENTURE

CONSULTANT
GOLDER

DD/MM/YYYY	25/05/2020
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	8-2

5.2.4 Groundwater Level Divide

The regional ***groundwater levels*** and flow direction in the Toowoomba region are influenced by the Great Dividing Range. This is supported by single point measurements, taken at unknown dates, from the DH borehole series (DH1 through DH9) which report a ***groundwater*** maximum of 599 m AHD at DH2, about 300 m north of Chainage 8.800. From this location, ***groundwater*** decreases gently to the west and steeply to the east down the escarpment. In lieu of more detailed ***groundwater levels***, the flow direction may be represented by the surface water catchment boundaries which correlate well with the ***groundwater*** divide observed at DH2 (Figure 9).

5.2.5 Wetland Springs

Table 6 summarises 8 registered wetland spring locations within 10 km of the Project alignment, which are typically located near existing water courses, while Figure 9 shows the location of the springs:

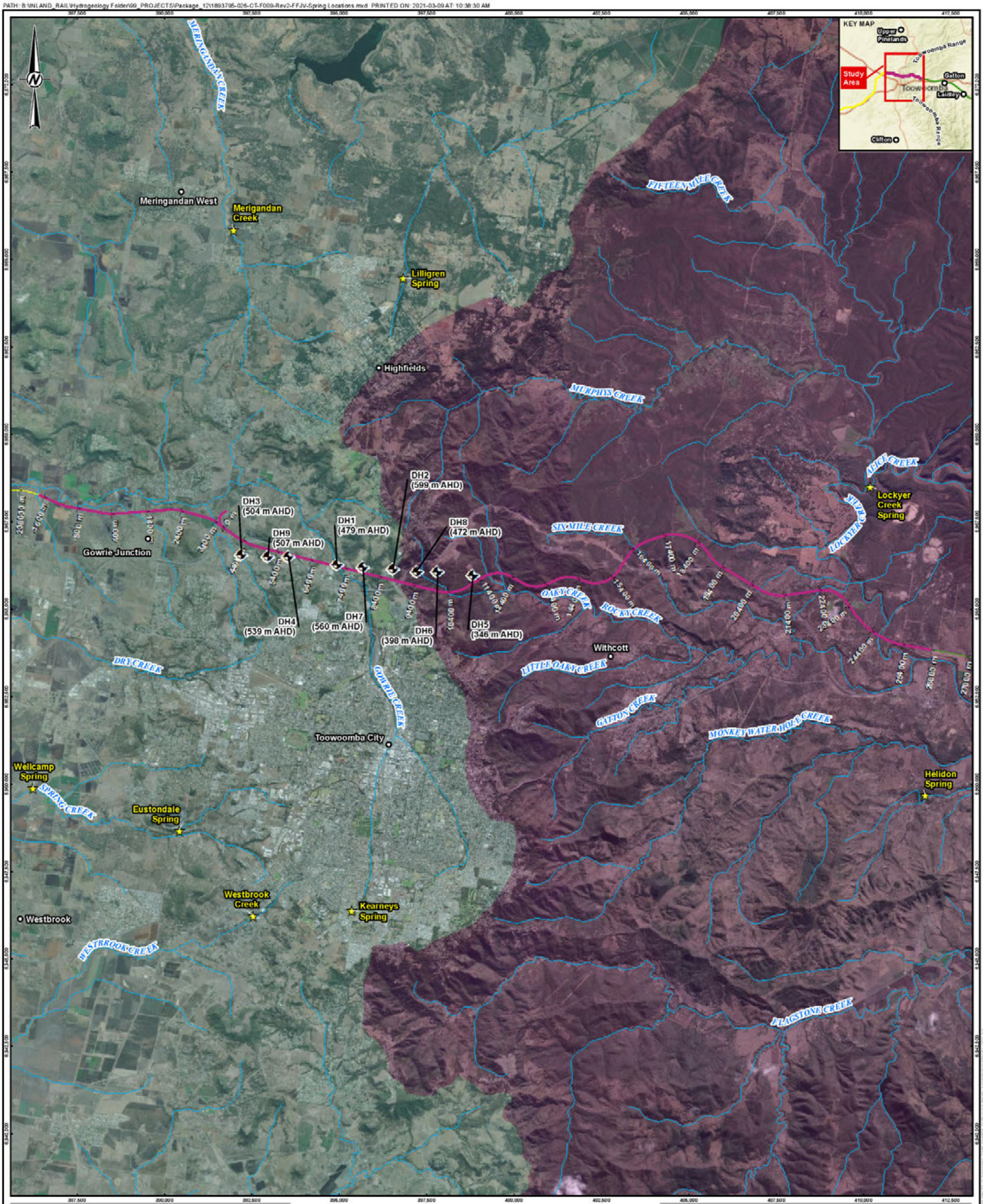
- Wetland springs Merigancan Creek and Lilligren Spring are located about 7.9 km and 8.5 km to the north of the alignment respectively.
- Wellcamp Spring, Eustondale Spring, Westbrook Creek and Kearney's Spring are located to the south of the alignment, approximately 5 km to 10 km to the south and west of Toowoomba.
- Lockyer Creek Spring and Helidon Spring are located about 3.2 km to the north of and 3.8 km to the south of the alignment respectively.

Table 6: Wetland Springs

Wetland Spring ID	Easting	Northing	Surface Elevation (m AHD)	Distance from Alignment (km)
Wellcamp Spring	386238	6949894	483^	8.2
Eustondale Spring	390429	6948666	531^	8.4
Westbrook Creek	392536	6946232	597*	10.3
Lilligren Spring	396829	6964477	598*	8.5
Merigancan Creek	391976	6965848	491*	7.9
Kearneys Spring	395347	6946386	667*	9.5
Lockyer Creek Spring	410156	6958496	176^	3.2
Helidon Spring	411743	6949699	149^	3.8

Note: ^ - Elevation obtained from FFJV Section 320 LiDAR; * - Elevation obtained from Google Earth because outside of FFJV Section 320 LiDAR.

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LEGEND

- DH Series Boreholes
- Wetland Spring Locations
- Watercourse

Inland Rail Alignment

- B2G - Border to Gowrie
- G2H - Gowrie to Helidon
- H2C - Helidon to Calvert

Drainage Sub Basin

- Condamine River
- Lockyer Creek

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

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FUTURE FREIGHT JOINT VENTURE

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GOLDER

DD/MM/YYYY	9/03/2021
DESIGNED	BG
PREPARED	MH
REVIEWED	NMC
APPROVED	DB

NOTE(S)

Service Layer Credits: *Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community*
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Drainage Sub Basin:** © State of Queensland (Department of Natural Resources and Mines) 2012.
2. **Wetland Spring Locations:** © State of Queensland (Department of Environment and Science) 2018.
3. **Alignment:** Latest alignment provided by FFJV on 10th Jan 2019.
4. **Watercourse:** Geoscience Australia.
5. **DH Series Boreholes:** FFJV 7 Nov 2018, Document 2-0001-320-IGE-30-RP-0001.

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
WETLAND SPRING LOCATIONS AND GROUNDWATER DIVIDE

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	9

5.3 Groundwater Recharge

In areas with Quaternary ***aquifer*** (alluvial or colluvial materials), ***recharge*** is anticipated to be supplied by direct infiltration of rainfall, and by seepage from ephemeral streams during periods of flow following rainfall. Sub-cropping Sedimentary rock ***aquifers*** below ***permeable*** Quaternary ***aquifers*** may also act as a source of ***recharge***. ***Recharge*** to the ***groundwater*** table in Sedimentary rock ***aquifers*** along ridgelines is believed to occur via direct infiltration of rainfall across the ridge where the Sedimentary rock ***aquifer***(s) are exposed at the surface, blanketed by a thin layer of topsoil or through fracture networks. Locally perched ***groundwater*** may exist in Quaternary or Sedimentary rock ***aquifers*** where more ***permeable*** weathered rock or soils are underlain by low ***permeable*** material.

There is a net deficit of rainfall on average (annual average evaporation exceeds annual average rainfall), and on average a deficit for each month of the year (Figure 2). Direct infiltration of rainfall to ***groundwater*** is unlikely during dry periods, when light rainfall events will be absorbed by soil moisture only to be subsequently lost to evapotranspiration. ***Recharge*** is likely to only occur in response to higher or more continuous rainfall events, and overall net ***recharge*** rates at the site are expected to be low.

Site-specific assessments of ***recharge*** rates are not available and therefore, ***recharge*** values have been adopted from the Clarence-Moreton Bioregional Assessment (Raiber *et. al.,* 2016). For this Bioregional Assessment, ***groundwater recharge*** to the ***aquifers*** of the Clarence-Moreton Bioregion, including Quaternary ***aquifers*** (alluvial ***units***), the MRV ***aquifer***(s) and Sedimentary rock ***aquifers*** (WCM, Koukandowie Formation and the Gatton Sandstone), was estimated using chloride mass balance. Statistical parameters for measured ***groundwater recharge*** across the broader area considered in the Clarence-Moreton Bioregional Assessment are summarised in Table 7.

There is a large residential space in Toowoomba where the rainfall infiltration and ***recharge*** rates to the MRV ***aquifers*** underlying Toowoomba are much lower due to the catchment associated with Toowoomba, the water collection, the drainage and large concrete surfaces.

Table 7: Clarence-Moreton Bioregion rainfall recharge estimates (Australian Government, 2014)

Formation	Number of Samples/ Tests	Rainfall Recharge (mm/year)		
		25th%ile value	50th%ile value	75th%ile value
Alluvium	2677	3.9	10.6	32.5
Main Range Volcanics	48	11.3	25.5	41.4
WCM	90	1.3	3.5	9.7
Koukandowie Formation (Marburg Subgroup)	21	1.6	2.7	5.9
Gatton Sandstone (Marburg Subgroup)	242	1.1	3.6	10.2

Note: Values are obtained from ranges presented in the Clarence-Moreton Basin Bioregional Assessment (Australian Government, 2014). Actual ***recharge*** values applying in specific areas will vary depending on relief, soil and vegetation cover. Data source: Raiber et al., 2016

5.4 Groundwater Chemistry

Groundwater chemistry is generally discussed in terms of the concentration of total dissolved (soluble) solids which is a key indicator for the suitability of ***groundwater*** to be used as a water source and to assess impacts on the Project and its environment. Total dissolved solids (TDS) expresses the quantity of dissolved material in a sample of water, i.e. total amount of solids that remain when a water sample is evaporated to dryness, reported in either milligrams per Litre (mg/L) or parts per million (ppm). The TDS concentration or electrical conductivity (a proxy measure of TDS) of water is often used to describe its quality.

Water is typically classified based on the TDS concentration as reported in Fetter, 2002:

- Fresh – 0 to 1 000 mg/L;
- Brackish – 1 000 to 10 000 mg/L;
- Saline – 10 000 to 100 000 mg/L; and
- Brine – greater than 100 000 mg/L.

Regional ***groundwater*** chemistry in the Clarence-Moreton Bioregion varies considerably between ***aquifer*** systems due to spatial and temporal separation. ***Groundwater*** in Quaternary ***aquifers*** is generally fresher than ***groundwater*** in Sedimentary rock ***aquifers***. Where discharge of ***groundwater*** from underlying formations into Quaternary ***aquifer***(s) occurs, there are areas in the ***alluvium*** where salinity levels can reach that of the Sedimentary formations. The main control of spatial variability between ***aquifer*** systems is the nature of the connectivity between surface water systems and shallow ***aquifers*** and shallow ***aquifers*** with deep ***aquifer*** systems. For example, near the headwaters of Lockyer Creek, ***groundwater*** in the MRV ***aquifer*** is commonly fresh due to increased ***recharge*** from the Quaternary ***aquifers***. Similarly, a gradual decrease in ***groundwater*** quality (i.e. an increase in electrical conductivity) has been observed downstream from the headwater where connectivity with Quaternary ***aquifers*** is conceptualised to decrease (Rassam et al. 2014).

In bedrock ***aquifers***, such as the MRV ***aquifer*** and the Sedimentary rock ***aquifers*** of the Marburg Subgroup, water quality ranges from fresh to saline, and exhibits larger variability than overlying Quaternary ***aquifers***. Water quality in the MRV ***aquifer*** is generally fresh due to thin soil coverage and rapid ***recharge*** from fractures, whereas ***groundwater*** in the Sedimentary rock ***aquifer*** of the WCM varies between 750 to 19 475 mg/L (Metagsco, 2007).

There is a total of 654 samples from 370 ***groundwater*** monitoring bores within 5 km of the proposed Project rail alignment. Collected samples span a range of 96 years, with the earliest samples collected in 1922 and the most recent collected as part of the G2H Site Investigation. The ***groundwater*** chemistry data has been obtained from the QLD registered bores database and reviewed documents and in the G2H Geotechnical Site Investigation Report (Golder, 2018c). The ***groundwater*** chemistry data is summarised in Appendix C.

Of the 654 samples, 328 contain a complete set of cation and anion analytical records and information about the screened formation; 66 of which are screened in the Quaternary ***aquifer***, 4 in the Sedimentary rock ***aquifer*** of the WCM, 111 in the MRV ***aquifer*** and 141 in the Sedimentary rock ***aquifer*** of the Marburg Subgroup. A summary table of water quality data collected from registered bores is provided in Appendix C (Table C1). A Piper Diagram was generated to determine hydrogeochemical classification of each formation

tested and is shown in Figure 10. The milliequivalents percentage of major cations and anions are shown by separate ternary plots to the lower left and right of the diagram. The apexes of the cation plot are calcium, magnesium and sodium plus potassium cations. The apexes of the anion plot are sulphate, chloride and carbonate plus hydrogen carbonate anions. The two ternary plots are then projected onto the central diamond field, which provides the overall character of the water.

Groundwater sampling data from the G2H FS SI is only available for 320-01-BH2217 (Gatton Sandstone) and 320-01-BH2201 (Koukandowie Formation) at the time of reporting. The ***groundwater*** samples collected from these two bores are also shown in the Piper plot (Figure 10). A summary table of water quality data collected from G2H FS SI boreholes is provided in Appendix C (Table C2).

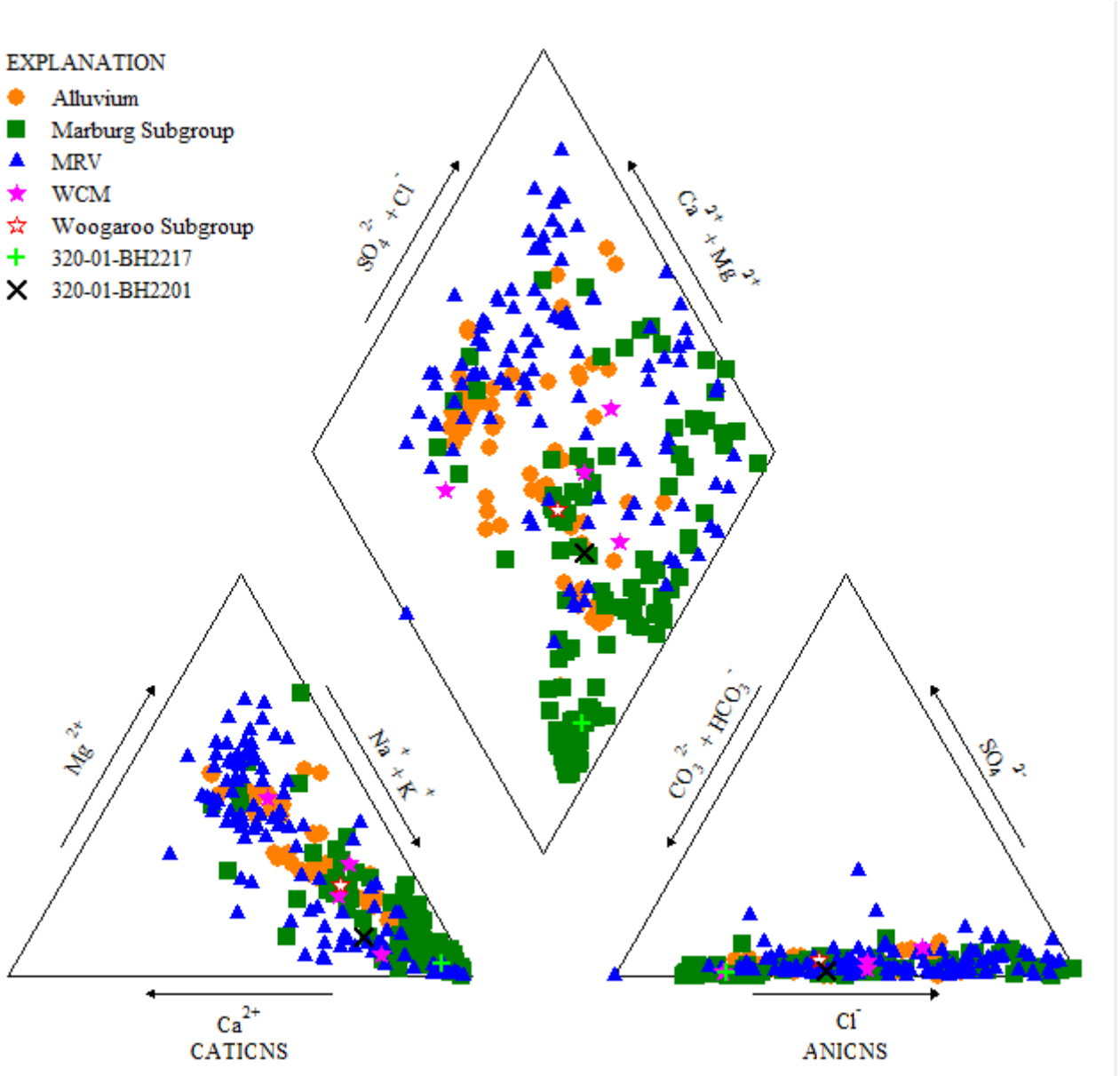


Figure 10: Piper diagram classified by hydrostratigraphic units

The ***groundwater*** in the Quaternary ***aquifer*** is found to be highly variable and does not display a clear trend toward any specific water type. This ***unit*** is anticipated to be influenced by local factors such as agricultural activities, sub-cropping rocks and proximity to roads or topographic highs. ***Groundwater*** in the MRV ***aquifer*** is also variable and does not display a clear trend toward any specific water type. ***Groundwater*** in the

Sedimentary rock ***aquifers*** of the WCM and Marburg Subgroup varies between Na-Cl and Na-CO_3 water types. Variation of water types may be attributed to water bores screened across formations, geological structures separating formations or general variability over time.

The ***groundwater*** sample collected from 320-01-BH2217 and 320-01-BH2201 can both be classified as Na-CO_3 water type with 320-01-BH2201 having a higher relative content in Cl.

Further information on the potential effects of the ***groundwater*** characteristics on durability is provided in Section 8.5.

5.5 Groundwater Use

Groundwater is heavily utilised for supply and irrigation in the Toowoomba area and the Lockyer Valley. Reflecting the land use and cover discussed in Section 3.3 and shown in Figure 3, the ***groundwater*** use in the area is primarily for water supply of Toowoomba City and pastoral and agricultural uses.

Groundwater for Toowoomba City is sourced from the MRV ***aquifer***, abstraction occurs in close proximity to the city limits from multiple locations.

Groundwater for pastoral and agricultural uses is primarily sourced from the Quaternary ***aquifer*** and the Sedimentary rock ***aquifers*** of the Koukandowie Formation and Gatton Sandstone.

There are large areas used for cropping and grazing land along the flatter terrain and near river valleys. Water supply for these activities is generally obtained from shallow alluvial ***aquifers*** in the Lockyer Valley or shallow alluvial and MRV ***aquifers*** to the west of the Toowoomba Range.

Where ***groundwater*** is expressed at the surface, it supplies water to wetlands, marsh areas and springs. Several locations where ***groundwater*** springs are reported within 10 km of the proposed alignment are reported in Figure 9.

Additional information on ***groundwater*** use can be found in the Environmental Impact Assessment for Gowrie to Helidon in the EIS Report Chapter 14 on ***Groundwater*** (2-0001-320-EAP-10-RP-0114).

6.0 CONCEPTUAL HYDROGEOLOGICAL MODELS

Conceptualisations for the proposed Toowoomba Tunnel, portal cuts, slope cuts and embankment locations are presented in this section and form the basis of the ***groundwater*** modelling in Section 7.0.

6.1 Hydrogeological Parameters

Hydraulic conductivity test data have been compiled from various sources including the G2H FS SI along the proposed G2H alignment (Golder, 2018c) and the Clarence-Moreton Bioregional Assessment database (Australian Government, 2018a and 2018b). Hydraulic conductivity values were compared to values adopted for similar sandstone ***units*** (i.e. Hutton Sandstone and Precipice Sandstone) in previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011) and from the New Acland EIS for the Walloon Coal Measures in 2013 (Barnett, 2013). Statistical analysis has been carried out to derive hydraulic conductivity values for the Sedimentary rock ***aquifers*** of the Gatton Sandstone, Koukandowie Formation, Walloon Coal Measures and Quaternary ***aquifers***.

Most hydraulic conductivity records in Clarence-Moreton Bioregional Assessment database were derived from specific capacity (air lift yield) data and information of the geological formation in which the test bore is screened. The records are believed to represent horizontal hydraulic conductivity of the tested formation accurate to within an order of magnitude.

Where not explicitly stated otherwise, hydraulic conductivity refers to the saturated hydraulic conductivity in this report.

6.1.1 Hydraulic Conductivity - Site Specific Testing

Hydraulic parameters are derived from site specific testing from the Geotechnical Factual Report (Golder 2019). Hydraulic Testing Results used for this report are attached in Appendix F, and they are summarised in Table 8.

Slug tests (falling head tests) are scheduled to be conducted in all ***groundwater*** bores installed as part of the G2H FS SI. At the time of this report, slug test results were only available for 320-01-BH2101, 320-01-BH2201, 320-01-BH2209, 320-01-BH2212, 320-01-BH2217, 320-01-BH2218, 320-01-BH2207, 320-01-BH2215, 320-01-BH2216, 320-01-BH2103, 320-01-BH2201. These tests are reported in Geotechnical Factual Report (Golder, 2019).

Two water pressure tests were conducted in borehole 320-01-BH2101 from 94 to 99 m bgl and 103 to 107 m bgl within a competent section of the MRV and the contact between the MRV and the Koukandowie Formation. The result of these tests provides an indication of the hydraulic conductivity of an unaltered section of basalt and the basalt-sandstone contact respectively.

Table 8: Hydraulic test results summary from FFJV 2018 investigations (Golder, 2019)

Bore	Test Interval (m RL)	Test Method	Formation	Analytical Method	Hydraulic Conductivity (m/s)	Lugeon Value (L)
320-01-BH2101	502.0 to 497.0	FHT	MRV	FHT	2.3×10^{-8}	-
	497.0 to 492.0	FHT	MRV	FHT	6.2×10^{-7}	-
	488.0 to 483.0	FHT	MRV	FHT	2.5×10^{-5}	-
	482.0 to 477.0	Lugeon	MRV	Lugeon	1.2×10^{-7}	1.2
	473.0 to 469.0	FHT	MRV and Koukandowie Formation	FHT	2.0×10^{-8}	-
	473.0 to 469.0	Lugeon	MRV and Koukandowie Formation	Lugeon	1.5×10^{-8}	0.1
	466.5 to 426.0	FHT	Koukandowie Formation	FHT	4.0×10^{-8}	-
320-01-BH2103	373.0 to 364.0	FHT	Koukandowie Formation	FHT	2.7×10^{-8}	-
				RHT	1.0×10^{-8}	
320-01-BH2201	312.88 to 306.88	FHT	Koukandowie Formation	FHT	9.0×10^{-8}	-
320-01-BH2207	246.0 to 243.0	FHT	Koukandowie Formation	FHT	2.2×10^{-6}	-

Bore	Test Interval (m RL)	Test Method	Formation	Analytical Method	Hydraulic Conductivity (m/s)	Lugeon Value (L)
320-01-BH2209	208.0 to 202.0	FHT	Gatton Sandstone	FHT	5.7×10^{-7}	-
320-01-BH2212	185.6 to 179.1	FHT	Gatton Sandstone	FHT	3.3×10^{-7}	-
320-01-BH2215	167.0 to 158.0	FHT	Gatton Sandstone	FHT	8.2×10^{-5}	-
320-01-BH2216	160.0 to 154.0	FHT	Gatton Sandstone	FHT	1.7×10^{-8}	-
320-01-BH2217	148.2 to 139.2	FHT	Gatton Sandstone	FHT	3.5×10^{-7}	-
				RHT	1.3×10^{-7}	
320-01-BH2218	141.2 to 135.2	FHT	Gatton Sandstone	FHT	2.7×10^{-8}	-
320-01-BH2301	NR	FHT	Koukandowie Formation	FHT	NR	-

Note: One Lugeon is equal to 1×10^{-7} m/s. NA – Bore not tested with the specified, NR – Not reported at the time of reporting; to be included with 100% Hydrogeological Design Report. FHT – Falling ***Head*** Test, RHT – Rising ***Head*** Test. For K values derived from more than one analysis, an average of the results of the methods was used (see Appendix F)

The results of the seven hydraulic tests conducted in borehole 320-01-BH2101 are presented as a profile of measured hydraulic conductivity with depth in Figure 11. These test results indicate similar hydraulic conductivity for competent MRV at RL 500 and for the underlying Marburg Subgroup. The results also indicate a zone of higher ***permeability*** basalt at the base of the MRV.

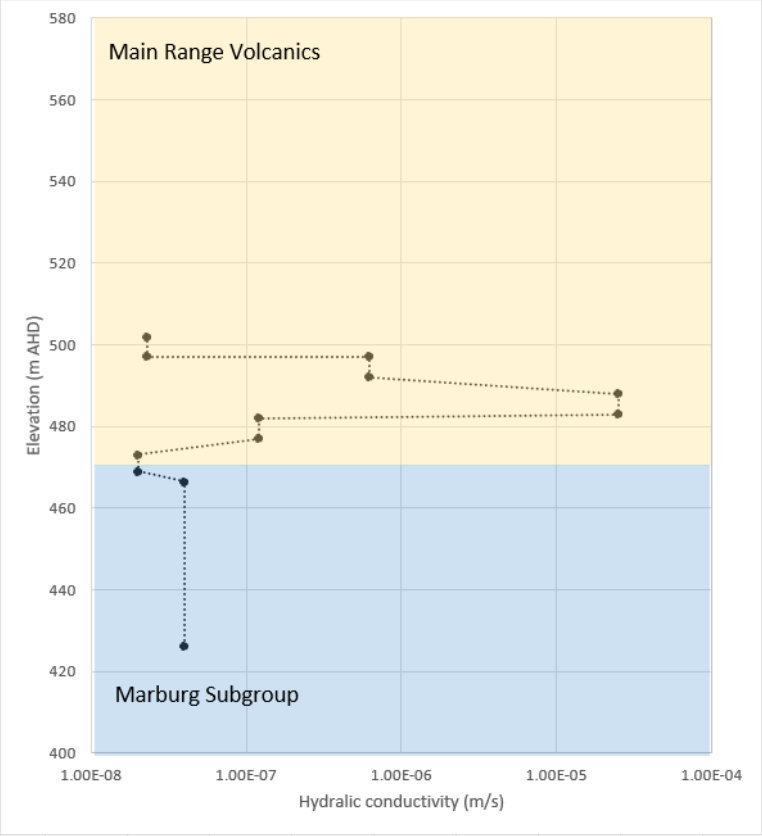


Figure 11 Hydraulic conductivity profile along 320-10-BH2101

6.1.2 Hydraulic Conductivity - Results from other Investigations

In addition to the site-specific testing described above, results have been summarised from the references listed above in Section 6.1.

A statistical distribution of hydraulic conductivity test results for each formation is shown in Figure 12 and statistical parameters for the test records are summarised in Table 9. A discussion about these results for each formation follows.

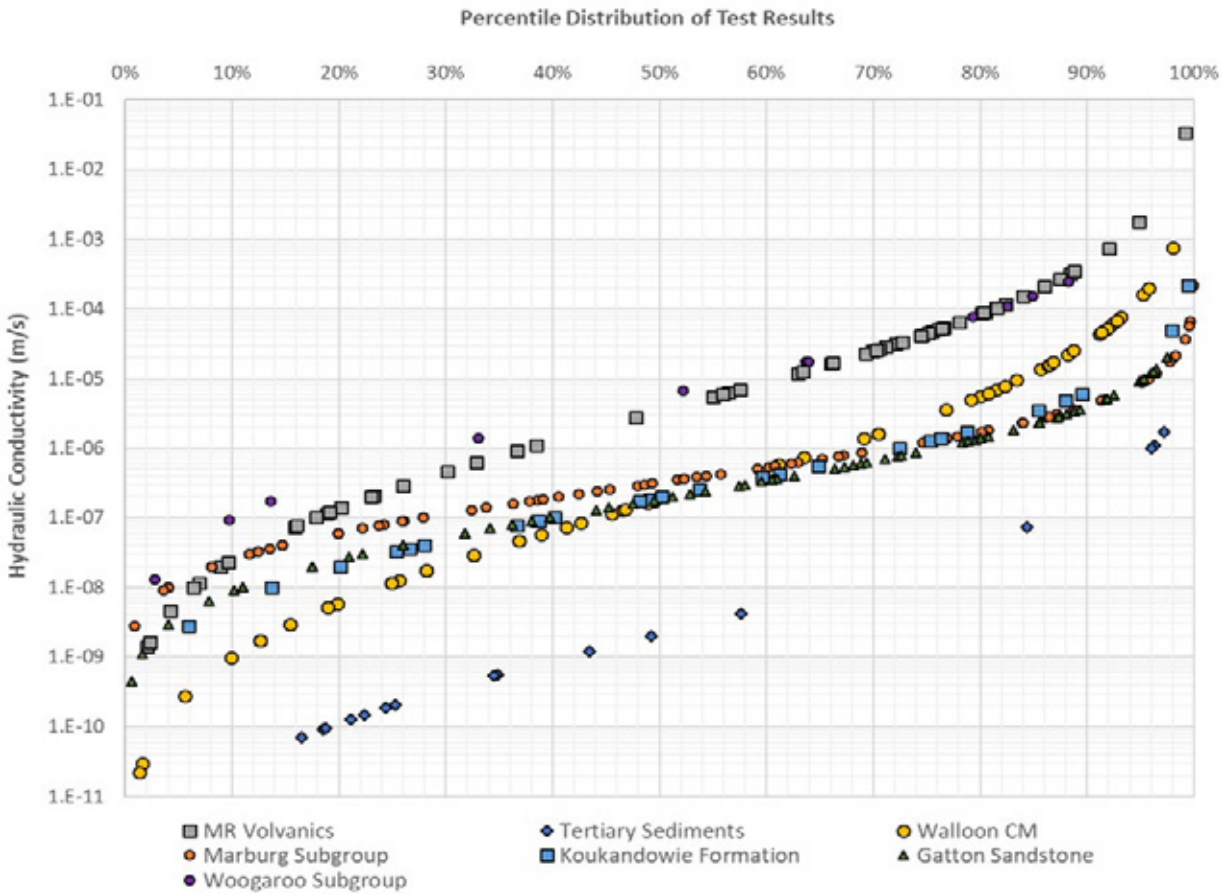


Figure 12: Statistical distribution of permeability test results of the Clarence Moreton Basin and FFJV Investigations (Sections 310, 320, 330 and 340).

Table 9: Summary of hydrogeological conductivity measurements from Clarence Moreton Bioregional Assessment

Formation	Hydraulic Property[A]	Number of Samples/Tests	Lower[B]	Typical[B]	Upper[B]
Marburg Subgroup (Gatton Sandstone)	Hydraulic Conductivity (m/s)	92	2.0×10^{-8}	1.7×10^{-7}	1.3×10^{-6}
Marburg Subgroup (Koukandowie Formation)	Hydraulic Conductivity (m/s)	68	2.9×10^{-8}	1.0×10^{-7}	1.3×10^{-6}
Walloon Coal Measures	Hydraulic Conductivity (m/s)	82	1.2×10^{-9}	1.0×10^{-7}	9.1×10^{-6}
Undifferentiated Tertiary Sediments	Hydraulic Conductivity (m/s)	16	6.0×10^{-11}	1.0×10^{-9}	4.0×10^{-8}

Formation	Hydraulic Property[A]	Number of Samples/Tests	Lower[B]	Typical[B]	Upper[B]
Main Range Volcanics	Hydraulic Conductivity (m/s)	67	1.3×10^{-7}	1.2×10^{-5}	5.3×10^{-5}
Alluvium	Hydraulic Conductivity (m/s)	107	2.6×10^{-4}	6.8×10^{-4}	1.4×10^{-3}

Note: [A] Hydraulic conductivity values represent horizontal hydraulic conductivity

[B] Lower, typical, and upper values are represented by $\mu - \sigma$, μ, $\mu + \sigma$ of hydraulic test records with μ, median, and σ, standard deviation, of the logarithmized test values. Tests were conducted at locations across the Clarence-Moreton Basin.

Sedimentary rock aquifer: Gatton Sandstone

In addition to the four tests carried out in 320-01-BH2209, 320-01-BH2212, 320-01-BH2217 and 320-01-BH2218 as discussed above, a total of 92 test results are available for the Gatton Sandstone for locations across the Clarence-Moreton Basin and FFJV SI, with results ranging between 5×10^{-10} to 2×10^{-5} m/s. Of these 92 ***permeability*** test records, 49 (53%) are above 1×10^{-7} m/s and 25 (27%) are above 1×10^{-6} m/s.

Sedimentary rock aquifer: Koukandowie Formation

In addition to the two tests carried out in 320-01-BH2101 and one test in 320-01-BH2201 as discussed above, a total of 68 test results are available for the Koukandowie Formation for locations across the Clarence-Moreton Basin and FFJV SI, with results ranging between 3×10^{-9} to 2×10^{-4} m/s. Of these 68 ***permeability*** test records, 26 (38%) are above 1×10^{-7} m/s and 14 (21%) are above 1×10^{-6} m/s. The test records indicate that the hydraulic conductivity of the Koukandowie Formation is highly variable, reflecting the fractured nature of the ***aquifer*** and the variability in hydraulic conductivity of the siliciclastic rocks with depth across the weathering profile.

Sedimentary rock aquifer: Walloon Coal Measures

No testing was conducted within ***units*** identified as WCM during FFJV SI. Hydraulic conductivity of the WCM from 82 tests range between 2×10^{-11} and 8×10^{-4} m/s based mostly on specific capacity test records; 39 (48%) are above 1×10^{-7} m/s and 31 (38%) are above 1×10^{-6} m/s. The test records indicate that the hydraulic conductivity of the WCM is highly variable, reflecting the fractured nature of the ***aquifer*** and the variability in hydraulic conductivity of the siliciclastic rocks with depth across the weathering profile.

Undifferentiated Tertiary Sediments

No testing was conducted within ***units*** identified as Tertiary Sediments during the FFJV SI. Hydraulic conductivity of the Tertiary Sediments from the Clarence-Moreton Basin includes 17 tests ranging between 7×10^{-11} and 1×10^{-6} m/s; 7 (41%) are above 1×10^{-9} m/s and 4 (24%) are above 1×10^{-8} m/s. The test records indicate that the hydraulic conductivity of the Tertiary ***Sediment*** is typically low, reflecting the low ***permeability*** of clay and other fine material.

Main Range Volcanic aquifer

In addition to the four tests carried out in 320-01-BH2101 as discussed above, a total of 67 test results are available for the MRV for locations across the Clarence-Moreton Basin and FFJV SI, with results ranging between 1×10^{-9} to 3×10^{-2} m/s. Of these 67 ***permeability*** test records, 52 (78%) are above 1×10^{-7} m/s and 42 (63%) are above 1×10^{-6} m/s. The test records indicate that the hydraulic conductivity of the MRV is highly variable, reflecting the fractured and layered nature of the ***aquifer***.

Quaternary aquifer: Alluvium

A total of 107 test records are available for the ***alluvium*** of the Quaternary ***aquifer*** from locations across the Clarence-Moreton Basin and literature with horizontal hydraulic conductivity values ranging between 1×10^{-6} and 2×10^{-2} m/s. Of these 107 ***permeability*** test records, 88 (82%) are above 1×10^{-4} m/s and 39 (36%) are above 1×10^{-3} m/s.

Test records are considered strongly biased towards the high end of the conductivity range. Tested bores were mostly drilled for irrigation purpose and therefore, targeted the high yielding alluvial gravel and sand Quaternary ***aquifers***. The Quaternary ***aquifers*** are likely transversely isotropic due to interbedding of sandy layers with beds of silt and clay.

Specific yield data were unavailable for the rail corridor. However, a range of specific yield values reported in literature for similar materials has been adopted for design purpose.

This ***unit*** has been used in the assessment of cuts, embankments and bridges. A typical value of 7×10^{-4} m/s has been adopted for the Quaternary ***aquifer units***.

6.1.3 Estimated Vertical Hydraulic Conductivity and Specific Yield

There are no values for vertical hydraulic conductivity or specific yield derived from field testing for the Gatton Sandstone, Koukandowie Formation, WCM, MRV ***aquifer*** or the Quaternary ***aquifers***. A range of specific yield values has been estimated from previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011) for similar sandstones (Hutton Sandstone and Precipice Sandstone), the New Acland EIS for the Walloon Coal Measures in 2013 (Barnett, 2013).

In the absence of measured values, parameter values have been estimated for vertical hydraulic conductivity and specific yield. For vertical hydraulic conductivity, estimates are based on lithological characteristic of the different formations and experience with formations of similar ***lithology***. For specific yield, estimates are based on model calibration results for sandstones in the Surat Basin, and judgement was applied to adjust literature values considering textural features of the different formations.

The range of likely values for these parameters are summarised in Table 10. Values will be spatially variable and at smaller scales could potentially vary between the lowest likely and highest likely values in Table 10 as a result of lithological variations and structural features. At the larger scale represented by the equivalent porous medium model the representative values provided in Table 10 are considered likely to apply. Further discussion about variations in some of these parameters (specifically vertical hydraulic conductivity in the MRV) is discussed in Section 7.

Table 10: Estimated Vertical Hydraulic Conductivity and Specific Yield

Formation	Hydraulic Property	Number of Samples/Tests	Lowest Likely Value	Representative Value	Highest Likely Value
Marburg Subgroup (Gatton Sandstone)	Vertical Hydraulic Conductivity	Estimated - no test data available	4.0×10^{-11}	1.7×10^{-9}	6.5×10^{-8}
	Specific Yield		0.015	0.05	0.10
Marburg Subgroup (Koukandowie Formation)	Vertical Hydraulic Conductivity	Estimated - no test data available	5.8×10^{-11}	1.0×10^{-9}	6.5×10^{-8}
	Specific Yield		0.015	0.05	0.10
Walloon Coal Measures	Vertical Hydraulic Conductivity	Estimated - no test data available	2.4×10^{-12}	1.0×10^{-9}	4.6×10^{-7}
	Specific Yield		0.005	0.035	0.05
Undifferentiated Tertiary Sediments	Vertical Hydraulic Conductivity	Estimated - no test data available	6.0×10^{-11}	1.0×10^{-9}	4.0×10^{-8}
	Specific Yield		0.03	0.07	0.12
Main Range Volcanics	Vertical Hydraulic Conductivity	Estimated - no test data available	2.6×10^{-9}	6.0×10^{-7}	2.7×10^{-6}
	Specific Yield		0.01	0.1	0.15

6.2 Observed and Inferred Groundwater Levels

Groundwater levels along the Toowoomba Tunnel alignment, embankments and cuts locations have been estimated based on the available ***groundwater level*** data within the same rock formation, similar ground relief and land use. Estimates were derived using statistical methods based on the correlation between depth to water table and ground surface elevation. These estimated ***groundwater levels*** in various parts of the alignment are discussed below.

Toowoomba Tunnel

As part of preliminary investigations, DH1 through DH9 were installed near the Project proposed Toowoomba Tunnel alignment. ***Groundwater levels*** reported for those locations and registered bores RN38341, RN107110, RN107111 and RN48472 are reported in Table B1 of Appendix B. While the dates of the ***groundwater levels*** measure in the DH borehole series (DH1 through DH9) are unknown, the maximum reported ***groundwater level*** is 599 m AHD in DH2 located about 300 m north of Chainage 8.800. From this location, ***groundwater level*** decreases gradually to the west and steeply to the east down the escarpment. In lieu of more detailed ***groundwater levels***, the ***groundwater*** flow direction may be represented by the surface water catchment boundaries which correlates well with the ***groundwater*** divide observed at DH2 (Figure 9).

A ***groundwater*** monitoring bore (320-01-BH2101) equipped with a standpipe piezometer has been installed about 50 m to the southwest of Chainage 5.500 km of the proposed G2H tunnel alignment at the top of the ridge. Also, two VWP`s have been installed in 320-01-BH2102 at 460,6 and 439,3 m AHD (Chainage 8.700). Results of monitoring data are presented in Appendix B. Data obtained from monitoring bore 320-01-BH2102 indicates relatively low ***groundwater level*** (489 to 494 mAHD) in the deep MRV ***aquifer***. This is consistent with the ***groundwater levels*** measured in registered bores RN42231660 and RN42231662 (refer to Section 5.2.2). These two bores (located within 5 m of each other) are screened in the MRV at 30 m bgl and 166 m bgl, respectively, with measured ***groundwater levels*** of about 555 m AHD and 473 m AHD in the shallow bore and the deeper bore respectively.

The complex spatial distribution of various basalt types with different hydraulic conductivity will result in a complex pattern of hydraulic connectivity in the MRV. Furthermore, the large topographic variations in combination with the impacts of abstraction for water supply leads to complex spatial variations laterally and vertically in hydraulic head distribution within the MRV.

A simplified conceptualisation of the ***groundwater*** system within the basalt based on the available measurements is as follows:

- Near surface flow regime with ***groundwater levels*** generally well correlated with surface topography;
- Deep flow regime near the base of the MRV with relatively high hydraulic conductivity and ***groundwater*** abstraction for water supply. As a result of the abstraction for water supply, hydraulic heads are significantly lower than in the near surface flow regime. The head difference can be as high as 100m.
- The two flow regimes are likely separated by a low conductivity layer in the MRV.

The horizontal and vertical extent of these subunits is highly uncertain due to the limited information available.

An indicative profile of ***groundwater level*** at the level of the tunnel alignment prior to tunnel construction is shown in Figure 13. Actual ***groundwater levels*** may differ locally due to local variation of ***recharge*** and discharge across the ridge, compartmentalisation of ***groundwater*** in the fractured rock, and abstraction from water supply wells in the Main Range Volcanics.

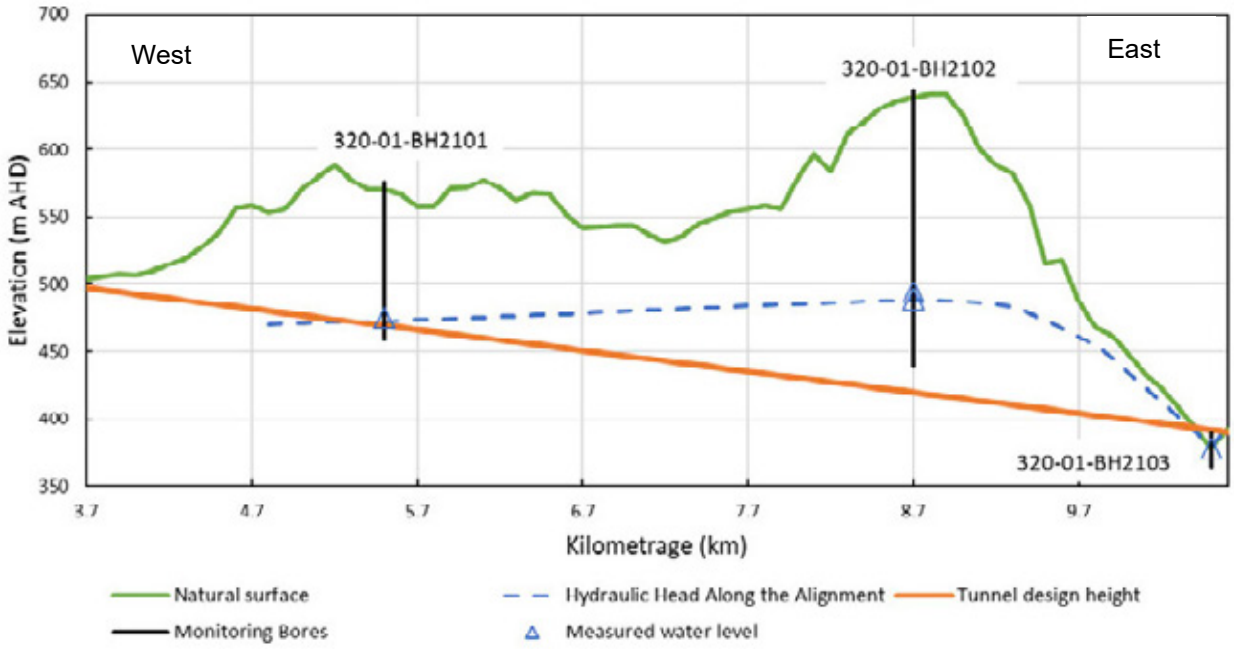


Figure 13: Preliminary estimates of pre-development groundwater level along the alignment between Chainage 3.500 to 10.450 km prior to tunnel construction

The Figure 13 has been revised in this report based on selected borehole data from the PPP Extended Geotech Program work (refer section 2.0)

Cuttings

Registered bores with historical ***groundwater level*** records are typically located in low lying areas near watercourses or gently sloping terrain with limited data available at higher elevations. To account for limitations in the ***groundwater*** monitoring data from spatial distribution and limited data at higher elevations, preliminary ***groundwater levels*** along the alignment were estimated based on a correlation of available ***groundwater level*** data within the same rock formation, similar ground relief and land use. For Cut C4 (located at the eastern portal of the tunnel), the ***groundwater level*** has been measured in borehole 320-02-BH2016 as part of the PPP Extended Geotechnical Investigation Program.

The summary of estimated and measured ***groundwater level*** at deep cuts relative to cut elevations is presented in Table 11. For the cuts where the ***groundwater level*** is assessed to be above the cut elevation, or close to the cut elevation, the ***groundwater level*** and cut elevations for the remaining cuts are provided in Appendix C.

Based on a review of available information, ***groundwater*** is anticipated to be encountered in at least 8 of the 14 deep cut locations. Locally perched ***groundwater*** may exist, which will require further assessment after more detailed site investigations have been conducted for the detailed design.

Table 11: Locations where cuts are anticipated to encounter the groundwater table

Name	Start (km)	End (km)	Length (km)	Median CL Elevation Along Cut (m AHD)	Median GW Level at Cut (m AHD)	Maximum GW Level at Cut (m AHD)	Assumed Geology from Desktop Review and Nearby FFJV Groundwater Bores
C3	3.7	4.10	0.400	492.0	480.4	499.6	Main Range Volcanics
C4	10.24	10.40	0.165	393.6	391.7*	391.8*	Colluvium
C5	10.58	10.88	0.300	387.4	376.6	388.4	Koukandowie Formation
C6	11.17	11.59	0.420	377.3	368.6	388.7	Koukandowie Formation
C9	14.08	14.1	0.020	335.3	331.3	338.1	Koukandowie Formation
C10	14.33	15.72	1.390	321.9	317.2	330.4	Koukandowie Formation
C11	17.52	17.82	0.300	279.7	280.8	301.1	Koukandowie Formation
C12	19.35	19.61	0.260	251.7	245.3	257.3	Gatton Sandstone

Note: CL refers to the rail corridor control line, or the centre of the proposed rail alignment, GW refers to ***groundwater***.

*GW level is based on actual GW level from the PPP Extended Geotech Program work (320-02-BH2016) in the period between August 2019 and November 2019, and thus does not represent long term median and maximum ***groundwater levels***.

7.0 GROUNDWATER LEVEL DRAWDOWN AND INFLOW MODELLING

7.1 100% Feasibility Design Option

The 100% Feasibility Design Option has been provided by FFJV, and it has been summarised in Table 12.

An analysis has been carried out based on the alignment and details for the FFJV 100% Feasibility Design of the Project, on the preliminary hydrogeological parameters listed in Table 13 and on the preliminary ***groundwater levels*** provided in Table 11.

Table 12: Feasibility Design Option

	Chainage (km)		Length (m)	Excavation		Permanent Lining		Permanent Drained Condition
	Start	Finish		From elapsed weeks	To elapsed weeks	From elapsed weeks	To elapsed weeks	
Western Portal	3.700	4.100	400	1	35	N/A		Drained
TBM Tunnel	4.100	9.760	5660	48	125	Progressive lining as the TBM erects.		Limit of 0.3 L/s in total
Mined tunnel	9.760	10.235	475	69	109	109	113	

	Chainage (km)		Length (m)	Excavation		Permanent Lining		Permanent Drained Condition
	Start	Finish		From elapsed weeks	To elapsed weeks	From elapsed weeks	To elapsed weeks	
Cut and cover	10.235	10.340	105	46	69	136	162	Drained
Eastern Portal Cut	10.340	10.400	60	1	35	N/A		Drained
Shaft	6.830	6.830	99	40	62	62	100	Limit of 0.0062 L/s in total

The following assumptions have been made in the simulation of the 100% Feasibility Design option:

- Time discretisation is designed based on the excavation schedule and grid size. To accommodate the different excavation and lining requirements, an increment of 13.39 days was adopted over the first 281 days; after that, an increment of 1.78 days was adopted to allow the simulation of the excavation rates for the tunnel and the shaft.
- The allowable limit on permanent leakage rates through the segmental lining of 0.3 L/s and 0.0062 L/s in total are assumed to be distributed evenly along the tunnel and shaft, respectively.
- The excavation direction for the TBM tunnel is from west to east. The mined tunnel is assumed to be excavated from east to west.
- The TBM excavation rate assumed is 10.5 m per day, and 1.7 m per day for the mined tunnel.

7.1.1 Methodology

A numerical three-dimensional (3D) ***groundwater*** model was developed using the USGS MODFLOW code and GMS 10.4 as graphical user interface. The model was used to estimate the inflows to the tunnel, western portal cut and a shaft and drawdown of the water level in the MRV and potentiometric surface in the Marburg Subgroup due to long-term tunnel and cut drainage.

The ***groundwater*** model was constructed using 11 model layers representing 6 ***hydrostratigraphic units*** of variable thickness. The geological model and spatial distribution were provided by Aurecon (model version of 28 June 2019). The assignment of model layers to the various ***hydrostratigraphic units*** is summarised in Table 13.

The ***model domain*** has a length in the east – west direction of 10.0 km and in the north – south direction of 9.5 km. The base of the ***model domain*** is at 250 m AHD and the top surface is defined by the ground surface elevation. An isometric view of the ***model domain*** is shown in Figure 14, and a plan view with the appropriate water plans is shown in Figure 15.

The model grid used to represent the ***groundwater***-flow system is comprised of 212 rows and 420 columns, aligned in a north-south direction. The model grid spacing is set to approximately 65 m by 65 over the majority of the ***model domain*** and is refined to about 20 m by 20 m along the railway alignment. To assess the inflow and ***groundwater level*** drawdown associated with a mid-tunnel shaft, the model grid was further refined

laterally around the shaft location to allow representation of the shaft and ***recharge*** bores, and to obtain predictive ***groundwater level*** estimates around the shaft and ***recharge*** bore locations. This grid spacing allows for a finer resolution in the area where stresses will be applied (drainage for excavation) while maintaining an adequate number of grid cells across the entire ***model domain*** to reduce computational times.

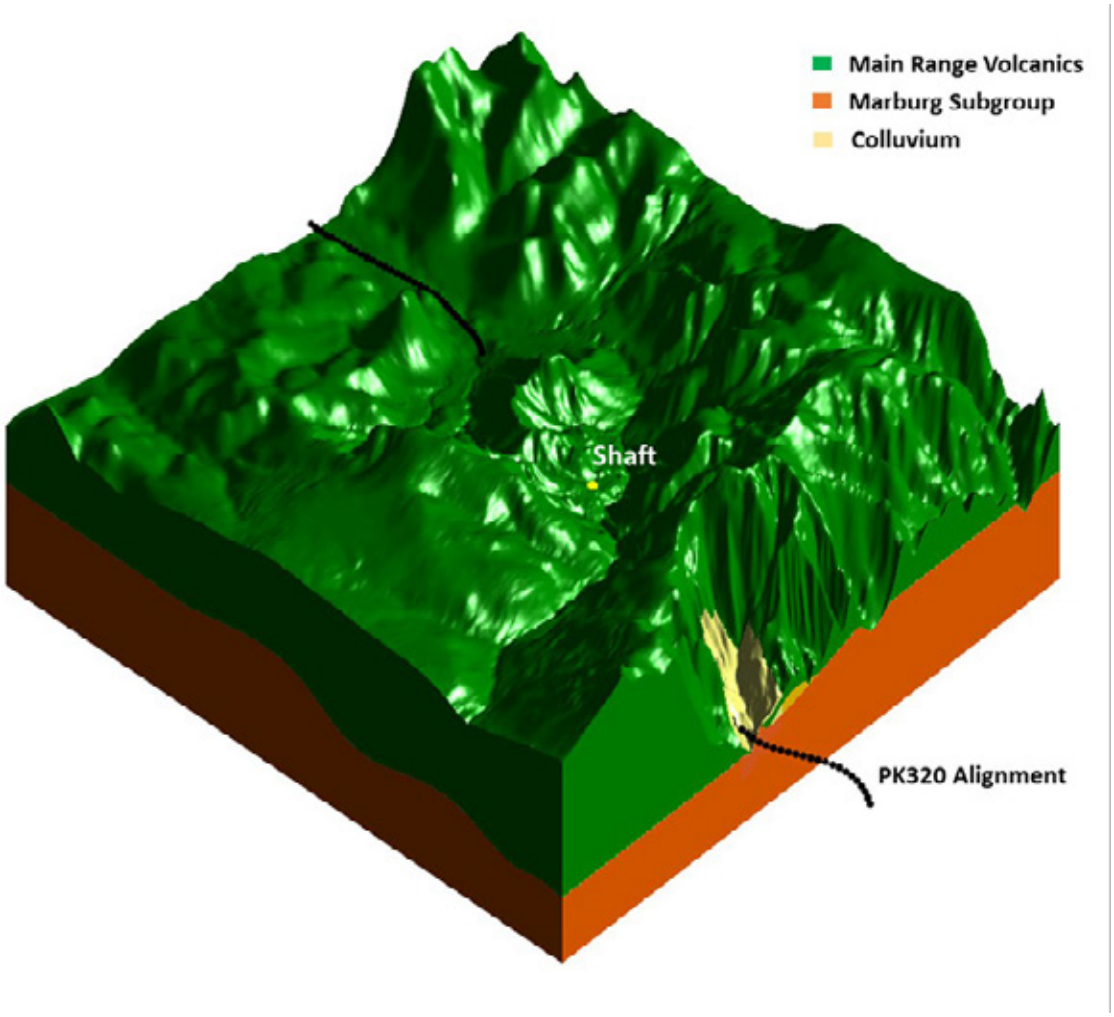
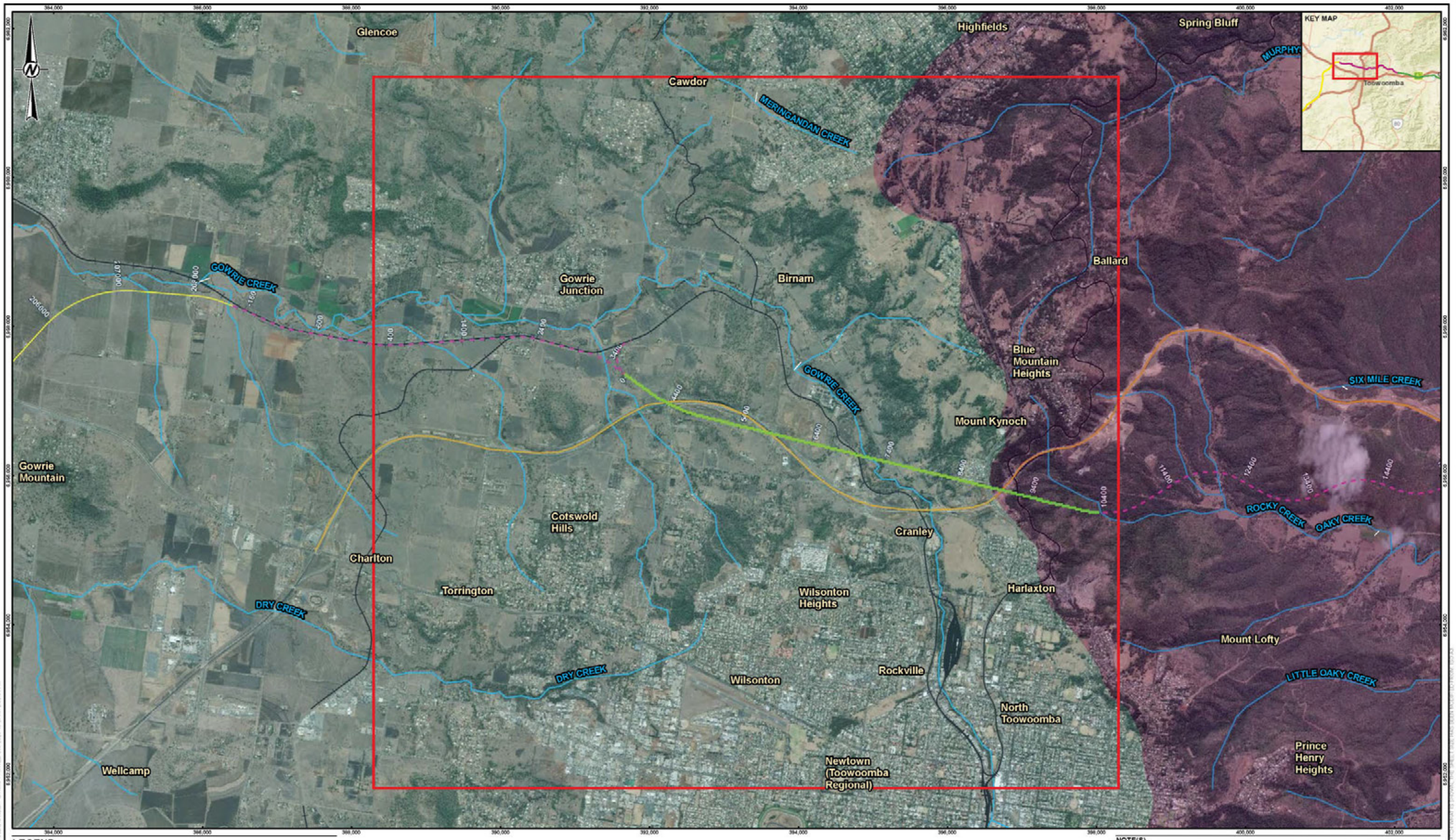


Figure 14: Isometric view of the groundwater model illustrating material layering of the model.



LEGEND

- Watercourse
- Toowoomba second range crossing
- Existing rail network

Inland Rail Alignment

- B2G - Border to Gowrie
- G2H - Gowrie to Helidon
- Model outline
- Tunnel discretization in the model

Drainage Sub Basin

- Condamine River
- Lockyer Creek

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 500 1,000 1,500 2,000
1:49,108@A3 METRES

NOTE(S)

Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)

1. **Watercourses:** Geoscience Australia
2. **Alignment:** Latest alignment provided by FFJV on 10th Jan 2019.
3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

CONSULTANT
GOLDER

DD/MM/YYYY	7/10/2020
DESIGNED	FC
PREPARED	FC
REVIEWED	AT
APPROVED	AT

PROJECT
INLAND RAIL GOWRIE TO HELIDON

TITLE
MODELLED AREA AND WATER PLAN

PROJECT NO.	CONTROL	REV.	FIGURE
1893795	026	9	15

The ***groundwater level*** drawdown and inflow analysis are based on the following assumptions:

- The ***groundwater*** model has been vertically discretised into 11 numerical layers distributed as shown in Figure 16.
- The MRV and Marburg subgroup have been modelled as continuous layers spanning the entire ***model domain***.
- The MRV has been represented in the model across 4 model layers representing a shallow ***aquifer***, a lower ***permeability*** layer, and a deeper ***aquifer***. Layer 4 represent the higher ***permeability*** basalt ***aquifer***.
- The Walloon Coal Measure, Tertiary ***sediment*** deposits, Colluvium and Crater Rim (CR) in the geological model have been combined and retained in the MODFLOW model as localised ***hydrostratigraphic units***.
- The higher conductive basalt ***aquifer*** and the ***hydrostratigraphic units*** of WCM, UTS and CR have been combined in the model Layer 5 in a localised area to the west of the main range. They are assumed to be homogenous and transversely isotropic with respect to hydraulic material characteristics in this area.
- A weathered horizon which overlies the fresh sandstone and underlies the colluvium in the eastern valley has been included in the model. The hydraulic parameters of the weathered sandstone are assumed to be the same as for colluvium.
- The tunnel has been divided into rectangular prisms (cells) with a cell size of approximately 18 m by 21 m and a height of 30 m for the computation.
- An intermediate shaft has been modelled as a rectangular cell with a cell size of approximately 18 m by 21 m and a depth of 93 m at completion.

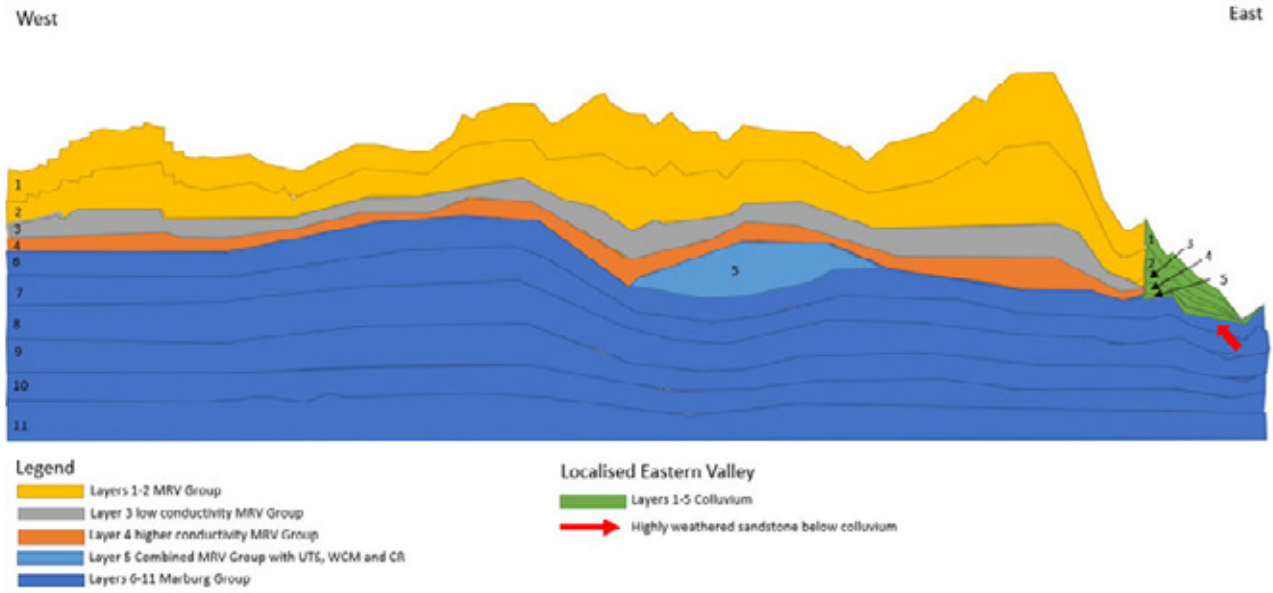


Figure 16: Long Section view of the numerical model illustrating the vertical discretization layering of the model

Boundary conditions in the model have been specified as follow:

- Constant head boundaries have been applied around the perimeter of the shallow layers (Layer 1 and Layer 2) in the MRV. The boundary head used in the model is derived from the correlation between topography and water levels.
- A no-flow boundary has been assigned around the perimeter of layers 3 and 4, with layer 3 representing the MRV (low conductivity layer) and layer 4 representing the base of the MRV (high conductivity layer). These layers are modelled as unconfined aquifers and are conceptualised to receive most inflow from rainfall recharge. The model boundaries are deemed to be sufficiently distant from the tunnel to not require specified head boundaries to stimulate throughflow in response to tunnel-induced drawdown (as would be required if the model layers were set to confined status).
- In the eastern portal, the water table is below the bottom of layer 4, as explained in section 7.2.3. A constant head boundary was applied along the eastern edge of the colluvium with head specified at the base of the colluvium.
- Due to the low hydraulic conductivity of the Marburg Subgroup, it is considered that there will be very limited flow across this boundary, and this assumption will lead to conservative estimates of drawdown.
- A no flow boundary has been applied at the base of the ***model domain***. Below 250 m AHD, the rock is assumed to be practically impermeable and thus very little flow will cross this boundary.
- Initial ***groundwater recharge*** rates used in the model were based on the values presented in Section 5.3. These values were adjusted during initial model calibration.

  The tunnel and shaft excavation have been simulated as time dependent boundary conditions using a combination of the MODFLOW drain package to simulate drainage during excavation and the well package to simulate leakage.
- Surface waters (e.g. Gowrie Creek) identified within the modelling domain are represented as MODFLOW drain cells, for which it is assumed that discharge occurs when the computed water level is higher than the stage elevation of the drain boundary. Stage elevations of the drain boundaries representing surface water were set at ground elevation.
- ***Groundwater*** is heavily utilised for supply in the Toowoomba area. The distribution of the water supply bores has been simplified to assist with convergence by placing 4 ***groundwater*** supply bores as shown in Figure 17, which extract water from the bottom layer in the MRV. The total pumping rate that has been applied was adjusted in the calibration process to improve the match between model calculated hydraulic head and observations of ***groundwater levels*** from long-term monitoring bores.

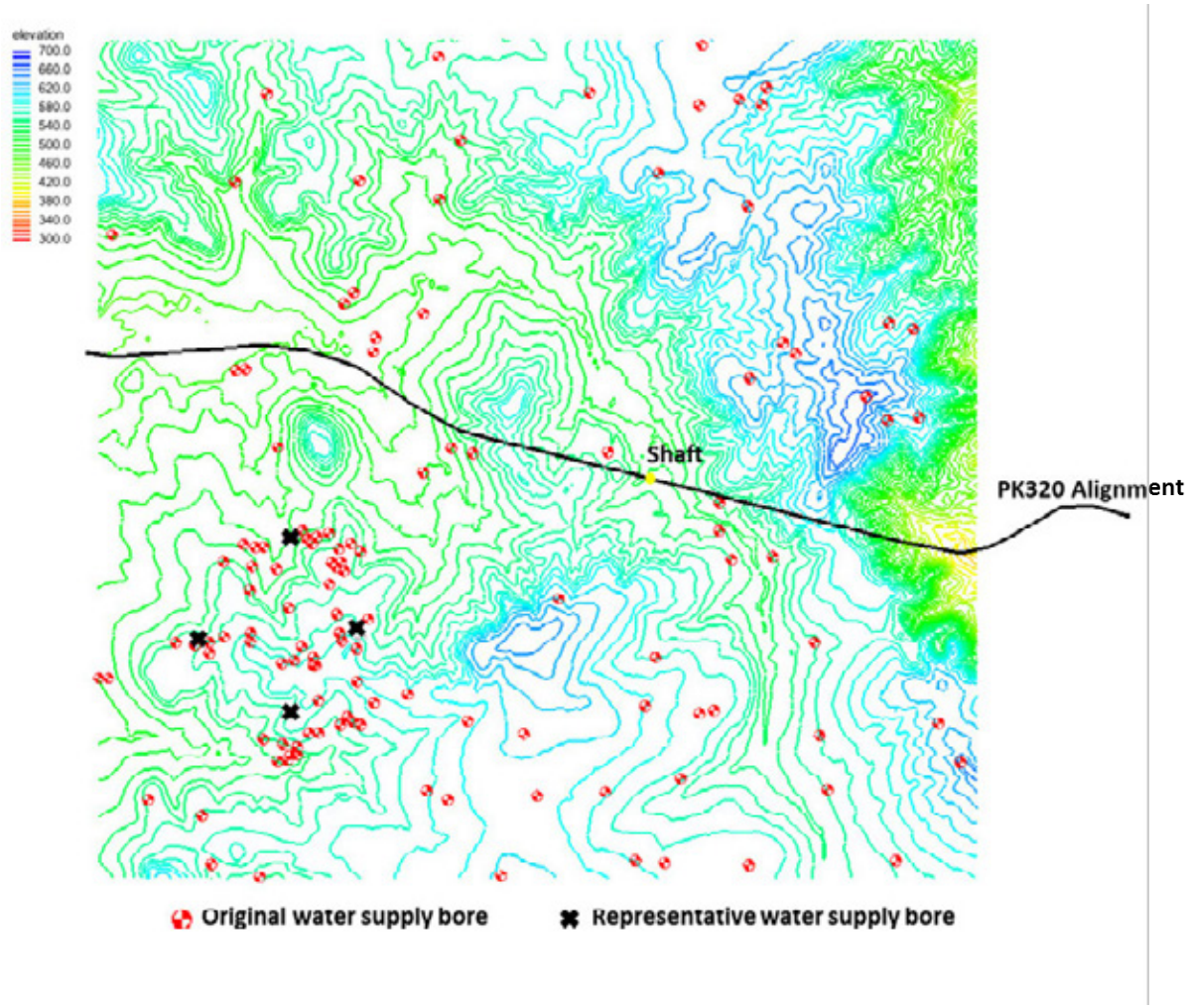


Figure 17: Water supply bores identified within the modelling domain. The red dots show the locations of registered water supply bores. The black crosses show the locations of representative water supply bores.

7.1.2 Model Calibration

The model was calibrated using ***groundwater levels*** from long-term monitoring bores. The observed data was based on the long-term ***groundwater level*** measurement reported in the QLD registered bore database (QLD Globe) and ***groundwater level*** monitoring conducted by Golder (Golder, 2018c).

The initial hydraulic conductivity parameters were based on the "typical" (i.e. 50%ile) values for horizontal hydraulic conductivity as outlined in Table 9, and on the "representative" values estimated for vertical hydraulic conductivity as outlined in Table 10. Since no observations are available to calibrate the model to transient conditions, specific yield parameters were not adjusted in the calibration process and were maintained at the estimated "representative" values as outlined in Table 10.

Recharge rates were also adjusted in the calibration process from the "typical" (i.e. 50%ile) values as outlined in Table 7, resulting in spatially variable ***recharge*** rates applied across the ***model domain*** surface. The mean ***recharge*** rates for the calibrated model are approximately equivalent to the ***recharge*** rates listed in Table 7.

The total ***groundwater*** extraction rate from the four wells used in the model to represent ***groundwater*** extraction from the Toowoomba ***groundwater*** supply system was adjusted as part of the calibration process in order to reproduce the large difference in hydraulic head that has been observed between the shallow MRV and the deeper MRV in some locations as discussed in Section 6.2 The total extraction rate applied in the

calibrated model is 70 L/s (divided equally between the 4 bores), which is consistent with the yields reported in the bore cards of the QLD registered bore database (DNRME, 2018).

Hydraulic conductivity values for each ***hydrostratigraphic unit*** following calibration are shown in Table 13. Adjustments from the initial parameters as described above were mainly required to the 3 layers representing the Main Range Volcanics, in order to reproduce the observed distribution of hydraulic head including the observed vertical gradient in this ***unit***.

Table 13: Hydrogeological parameter used in the model

Hydrostratigraphy	Horizontal Hydraulic Conductivity (m/s)	Vertical Hydraulic Conductivity (m/s)	Specific Yield	Vertical Discretization
Main Range Volcanics	1.2×10^{-5}	6.0×10^{-7}	0.10	Layer 1 - 2
Low conductive layer in MRV	1.2×10^{-8}	5.8×10^{-10}	0.10	Layer 3
High conductive layer in MRV	4.6×10^{-5}	2.3×10^{-6}	0.10	Layer 4
Walloon Coal Measure	1.0×10^{-7}	1.0×10^{-9}	0.04	Layer 5
Undifferentiated Tertiary Sediments	1.0×10^{-7}	1.0×10^{-9}	0.07	Layer 5
Crater Rim	1.2×10^{-5}	6.0×10^{-7}	0.1	Layer 5
Marburg Subgroup	1.0×10^{-7}	1.0×10^{-9}	0.05	Layer 6 - 11
Colluvium	1.2×10^{-5}	6.0×10^{-7}	0.10	Layer 1- 5 Eastern Valley

As reported in Figure 18, there is a good correlation between the observed and calculated heads in the model. As shown in Figure 19, calibrated ***groundwater levels*** have a reasonable match with observed data in most of the monitoring bores.

The hypothesis of multiple layers with variable hydraulic conductivities in the MRV has successfully reproduced the large head differences between RN42231660 and RN42231662 and between RN42231656 and RN42231657. However, ***groundwater levels*** in 320-01-BH2101, 320-01-BH2103 and RN42231662 have been overestimated by 25 m, 13 m and 19 m, respectively while ***groundwater levels*** in RN42231656 and RN42231657 have been underestimated by about 25 m. Further refinement of the predicted ***groundwater level*** at 320-01-BH2101 and 320-01-BH2103 would require more detailed information on ***groundwater*** abstraction from the Main Range Volcanics, and adjustments to geological model and hydraulic conductivity values to allow for spatial variations in hydraulic conductivity, however there is insufficient information available at this stage to support such refinement.

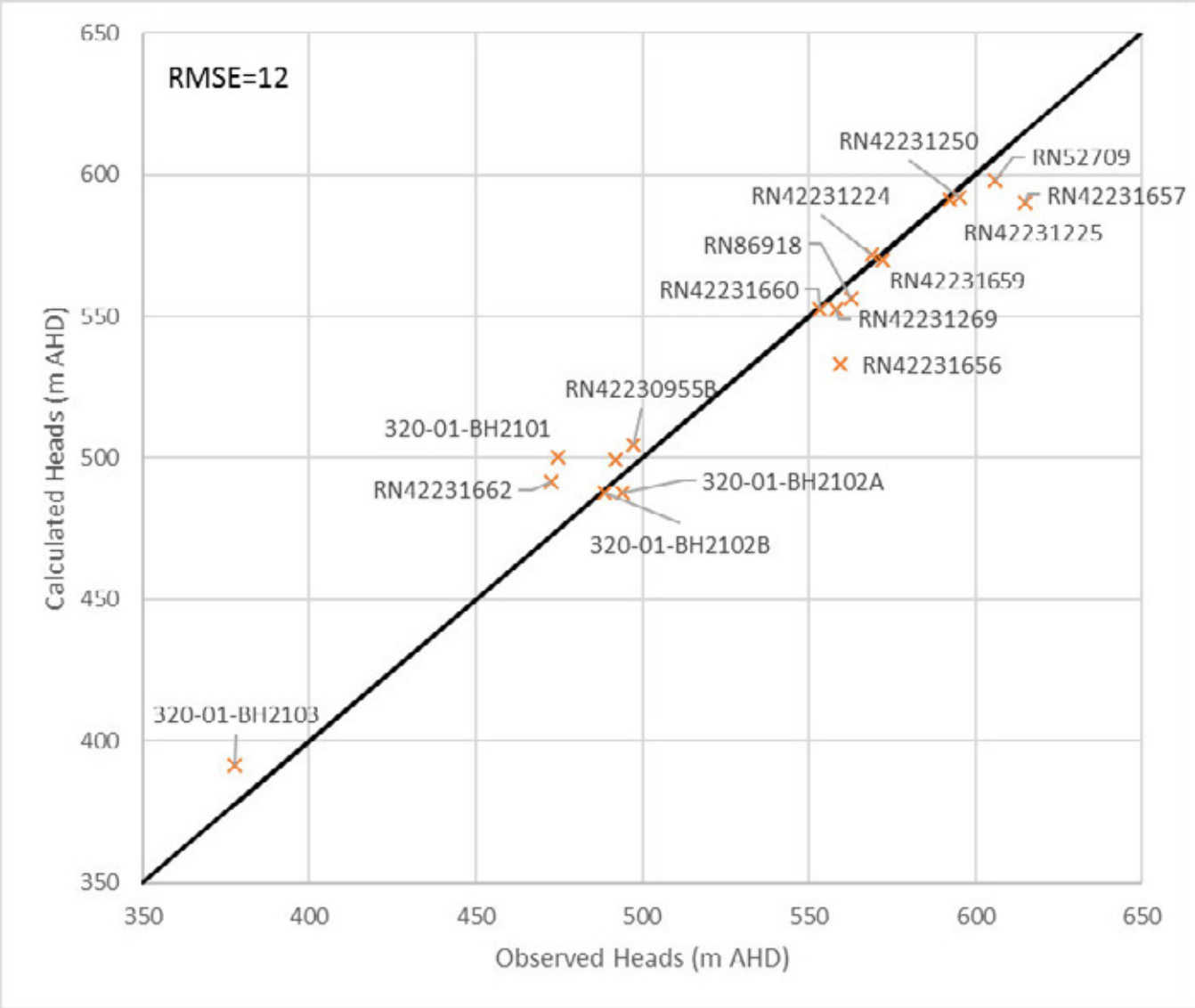


Figure 18: Observed versus calculated heads

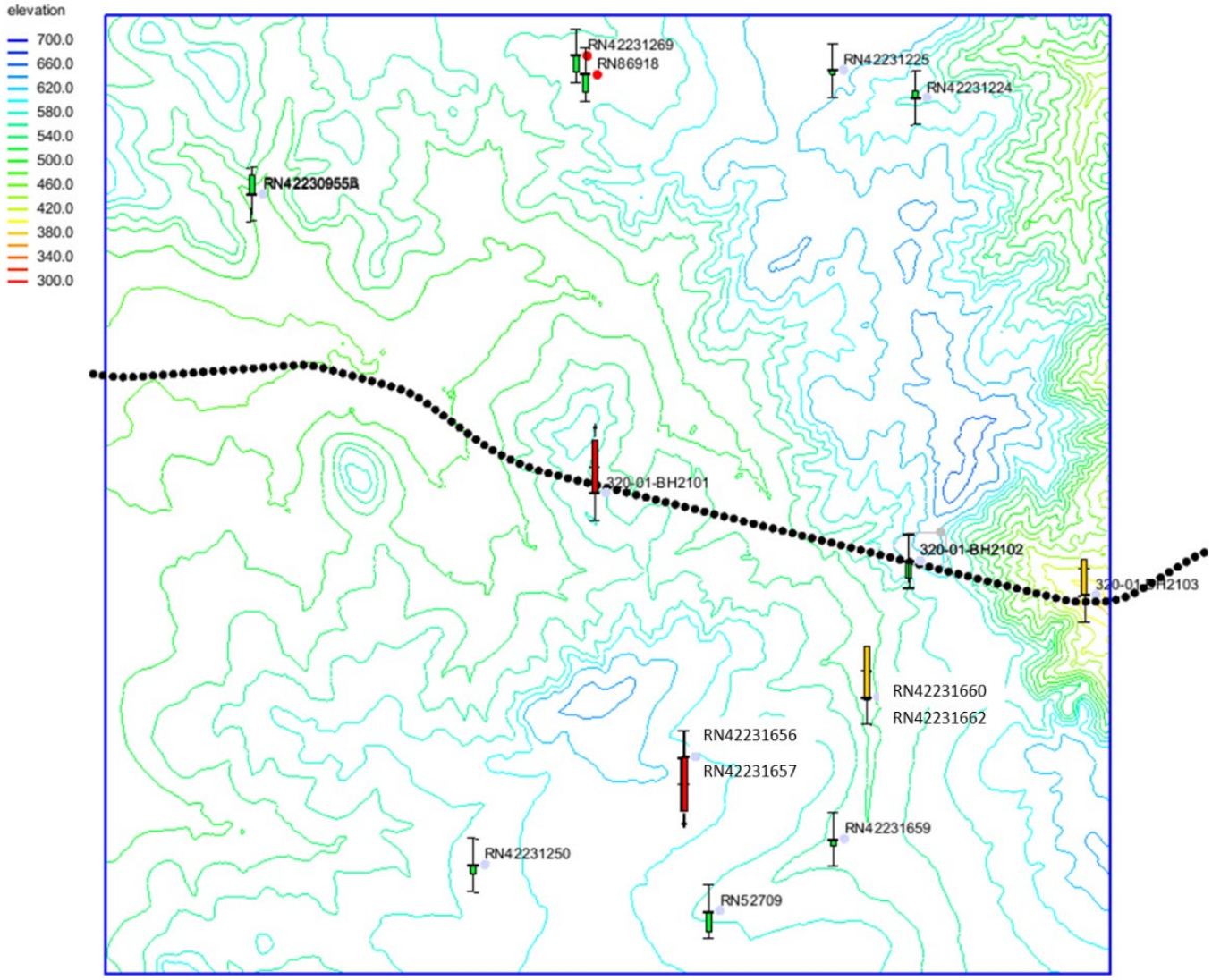


Figure 19: Result of model calibration. The length of the bar shows the head difference between computed water level and simulated water level. The green bar, yellow and red bar represent the head difference from 0 to 10 m, from 10 to 20 m and more than 20m, respectively. Modelled and observed values for each bore are presented in Figure 18.

7.1.3 Groundwater Inflow Estimates

Long-term (20 years) and short-term (construction stage) ***groundwater*** inflows have been estimated for this report.

The long-term ***groundwater*** model for the 100% Feasibility Design indicates that the ***groundwater*** inflows into the western portal are estimated to be 2.6 L/s. Inflows to the tunnel and shaft are equal to the allowable limit on permanent leakage rates, which is applied as a boundary condition in the model.

The variation in simulated inflows to the tunnel over time are shown in Figure 20 and Figure 21.

Based on estimated inflow rates for geology ***units*** (Figure 20), the maximum inflow during construction is expected to be approximately 113.7 L/s at elapsed 107 weeks which is composed of 79.7 L/s due to drainage in the Main Range Volcanics near the advancing face of the TBM tunnel section where permanent segments are not yet in place, and 34 L/s in the colluvium due to drainage of the mined tunnel (in Figure 20).

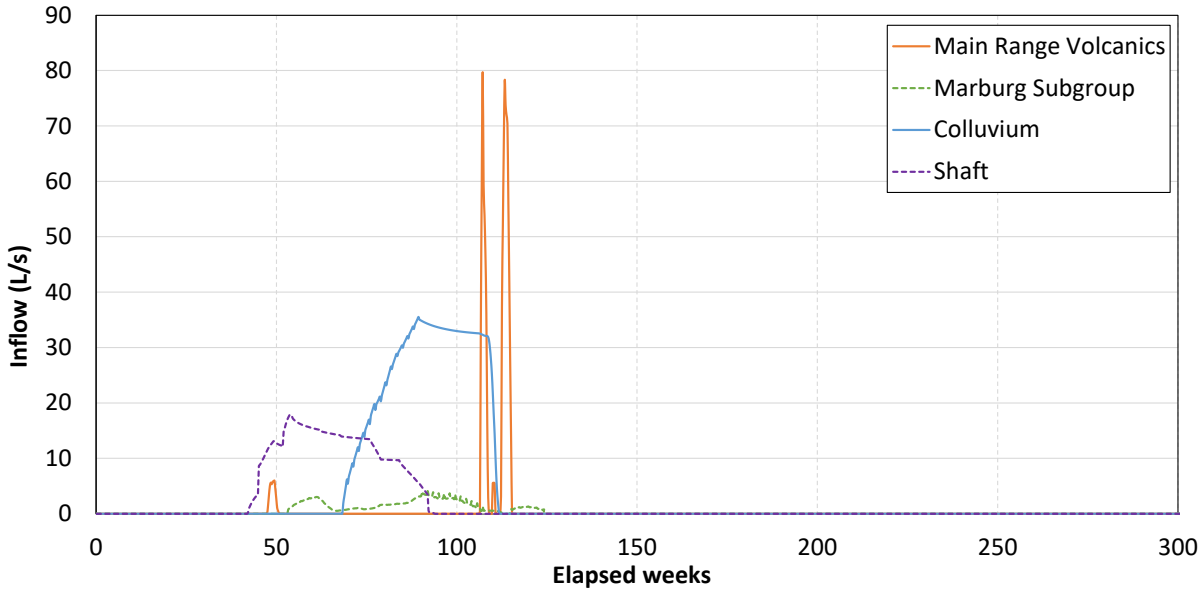


Figure 20: Estimated tunnel inflow rates for the 100% Feasibility Design option for geology units (western/eastern portals not included)

The total predicted inflow volumes from each aquifer area were calculated for the construction and operational phases for each water plan (Condamine River and Lockyer Creek) based on the 100% Feasibility Design Option that has been provided by FFJV, and it has been summarised in Table 14.

The following assumptions were adopted from the 100% Feasibility Design Option:

- Overall Construction phase from elapsed weeks 1 to 224, and operational phase from elapsed weeks 231 to 1205 (refer to Table 12).
- Period of shaft construction:
  - Excavation in the MRV from elapsed weeks 41 to 59 and lining from elapsed weeks 68 to 100.
  - Excavation and lining in the Marburg from elapsed weeks 59 to 68.
- The limit between the Condamine River Basin and Lockyer Creek Basin is located approximately in chainage 8.9 Km (QLD Globe). The TBM Tunnel crosses the limit at elapsed 113 weeks.
- For the construction stage:
  - Total inflow in the MRV considers Western Portal, TBM tunnel, shaft within the MRV and allowable limit on permanent leakage rates for TBM Tunnel and shaft.
  - Total inflow in the Marburg considers TBM tunnel, Mined tunnel, part of shaft excavated within the Marburg and allowable limit on permanent leakage rates for TBM tunnel, Mined tunnel and shaft.
  - Total inflow in the Colluvium considers Mined tunnel and allowable limit on permanent leakage rates for Mined tunnel.
- For the operation phase:
  - Total inflow in the MRV considers Western Portal and allowable limit on permanent leakage rates for TBM tunnel and shaft.

- Total inflow in the Marburg considers the allowable limit on permanent leakage rates for tunnel, and shaft.
- Total inflow in the Colluvium considers allowable limit on permanent leakage rates for Mined tunnel.

- Open cut and Cut & cover are not considered in the calculations, since most part of the water table is below those structures, based on selected borehole data from the PPP Extended Geotech Program work (see Section 7.2.3).
- Length of shaft is 79.3 m within the MRV and 35.4 m within the Marburg.

Table 14: Total predicted inflow volumes

Water Plan	Main Range Volcanics (MRV)	Marburg Subgroup		Colluvium
		Eastern Downs Marburg	Murphys Creek Marburg	
Construction phase				
Condamine River	728.9	152.3	--	0.0
Lockyer Creek	96.8	--	16.8	688.4
Total	825.6	169.1		688.4
Operational phase				
Condamine River	1663.1	136.7	--	0.0
Lockyer Creek	25.6	--	39.1	13.5
Total	1688.7	175.8		13.5

Note: Inflows are presented in megalitres (ML)

The estimated inflow rates for the main tunnel structures during construction are shown in Figure 21. The maximum inflow during construction for the TBM tunnel section is estimated to be approximately 100 L/s at elapsed 107 weeks. The maximum inflow for the mined tunnel is estimated to be approximately 37 L/s at elapsed 89 weeks during the construction works. The maximum estimate inflow in the western portal is expected to be approximately 6.0 L/s at elapsed 35 weeks. The maximum estimate inflow in the shaft is expected to be approximately 17 L/s at elapsed 54 weeks.

The maximum estimated inflows above do not include any water control mitigation measures which may be implemented during construction, such as operating the TBM in closed mode, or probing and grouting ahead of the excavation.

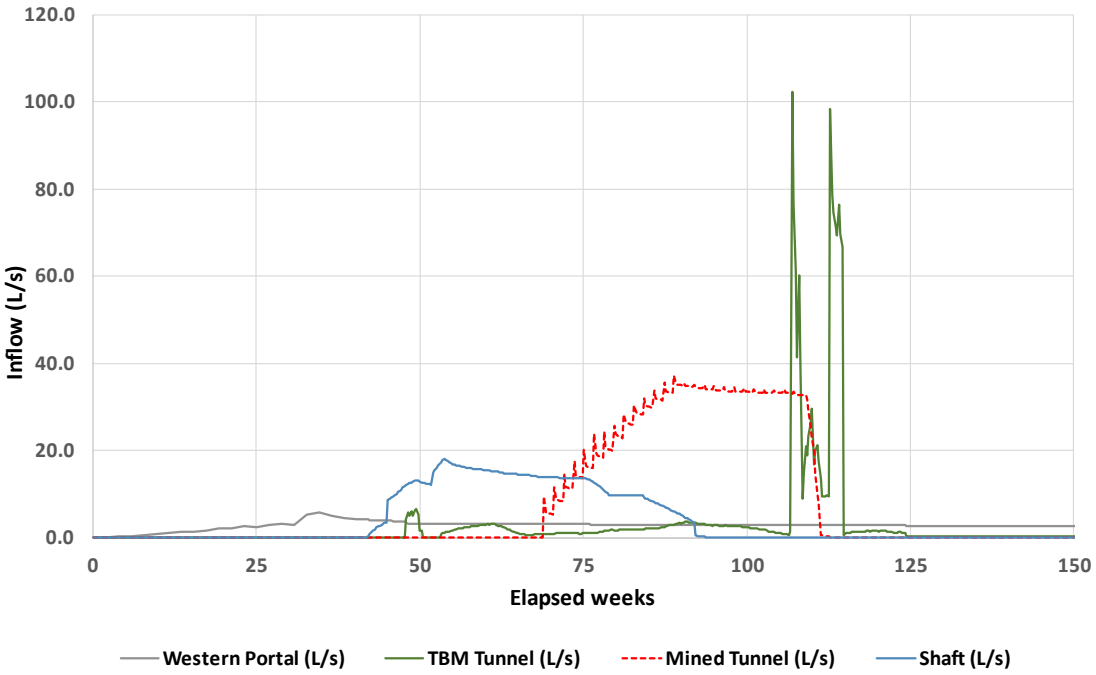


Figure 21: Estimated inflow rates for the 100% Feasibility Design option for the main tunnel structures

7.1.4 Groundwater Level Drawdown Estimates

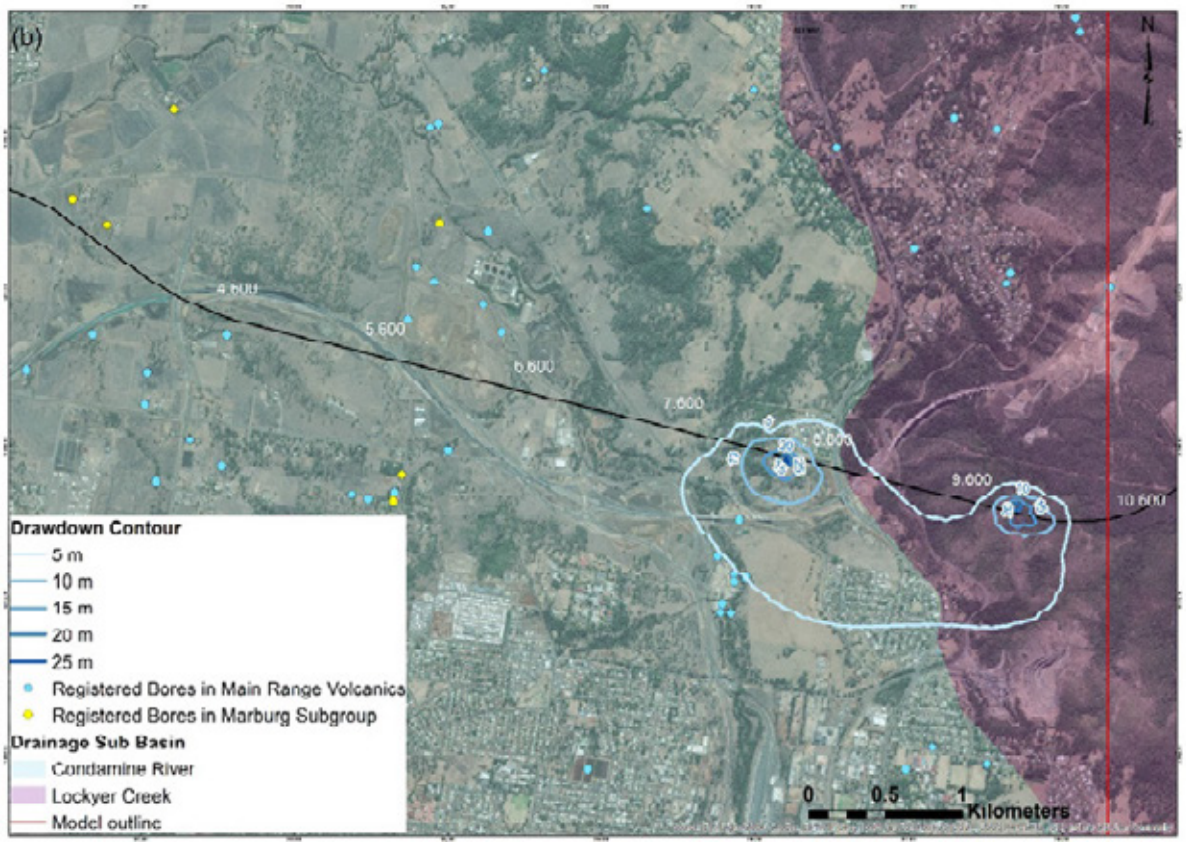
Long-term (20 years) and short-term (construction stage) ***groundwater level*** drawdown has been estimated for the 100% Feasibility Design option.

The approximate extents of the predicted long-term ***groundwater level*** drawdown are illustrated in three ***aquifers***: the shallow MRV ***aquifer*** with typical value of hydraulic conductivity, the deep MRV ***aquifer*** which is a high conductive layer and the Marburg Subgroup ***aquifer***.

Figure 22 shows the estimated ***groundwater level*** drawdown at elapsed 107 weeks when the inflow to the tunnel reaches maximum value. At that time, drawdown is developed as follows:

- Drawdown of up to 15 m develops at the eastern end of the tunnel along the mined tunnel.
- Drawdown is developed over a larger area in the deep MRV, with drawdown in excess of 5 m between Chainage 8.000 and 10.400 km. The highest drawdowns of up to 25 m are present around Chainage 8.500, where the TBM tunnel intersects high ***permeability*** MRV materials (maximum ***groundwater level*** drawdown of up to 25 m at 107 weeks). Drawdown of up to 20 m is also developed along the mined tunnel, centred around Chainage 10.000 km. At this point in time the mined tunnel has been fully excavated.
- More extensive drawdown is developed in the Marburg Subgroup ***aquifer***, with drawdown in excess of 5 m drawdown contour between Chainage 6.400 km and 10.400 km, extending up to about 700 m either side of the tunnel (refer to Figure 22 (c)).


(a)
N
4,600
5,600
6,600
7,600
8,600
9,600
10,600
Drawdown contour
5 m
10 m
15 m
Registered Bores in Main Range Volcanics
Registered Bores in Marburg Subgroup
Drainage Sub Basin
Condamine River
Lockyer Creek
Model outline
0
0.5
1
Kilometers


(b)
N
4,600
5,600
6,600
7,600
8,600
9,600
10,600
Drawdown Contour
5 m
10 m
15 m
20 m
25 m
Registered Bores in Main Range Volcanics
Registered Bores in Marburg Subgroup
Drainage Sub Basin
Condamine River
Lockyer Creek
Model outline
0
0.5
1
Kilometers

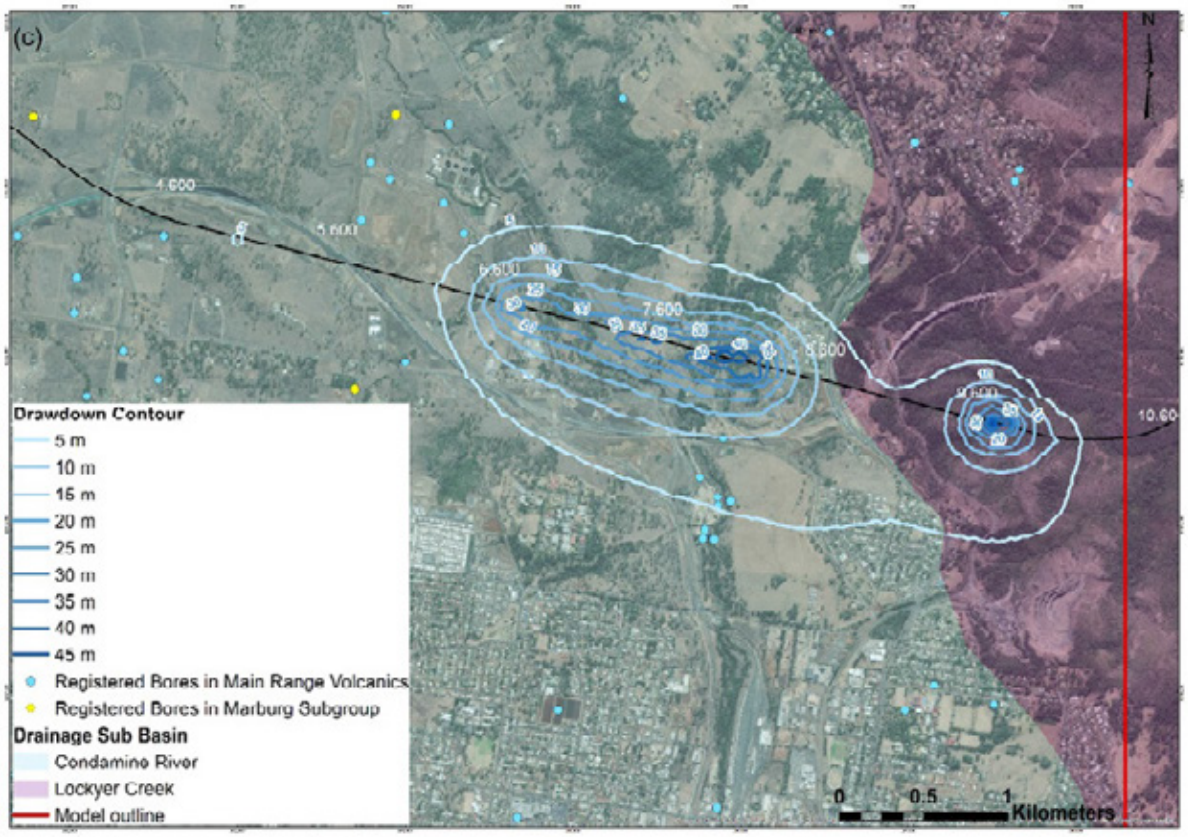


Figure 22: Estimated drawdown contours in (a) shallow MRV, (b) deep MRV and (c) Marburg Subgroup at elapsed time of 107 weeks (i.e. time of maximum inflow rate)

Figure 23 shows the estimated groundwater level drawdown at an elapsed time of 34 weeks (i.e. February 2022) when the inflow to the western portal reaches its maximum value. At that time, drawdown in the shallow MRV of up to 5 m extends a short distance from the western portal cut, as shown in Figure 23.

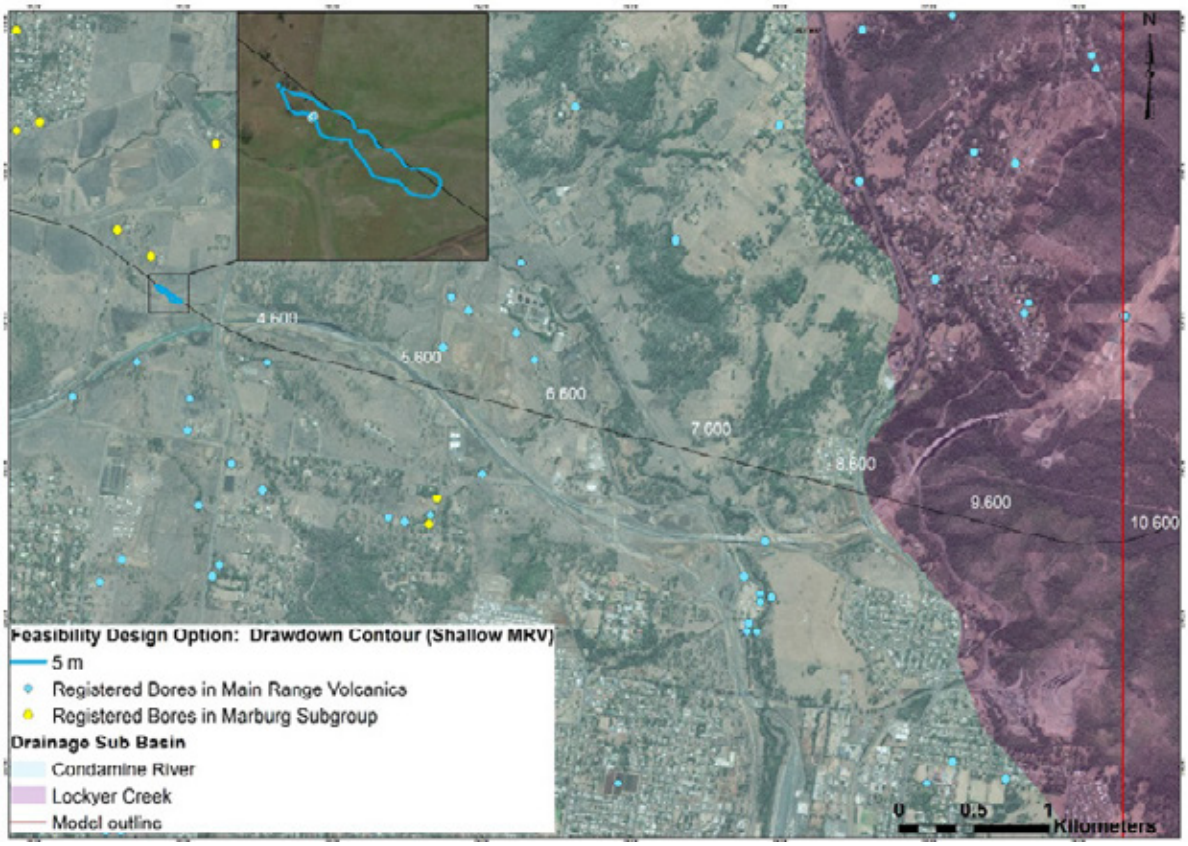


Figure 23: Estimated drawdown contours for the western portal in shallow MRV at elapsed time of 34 weeks (i.e. time of maximum inflow rate)

Figure 24, Figure 25 and Figure 26 show the estimated drawdown contours in the vicinity of the shaft at an elapsed time of 62 weeks (i.e. August 2022), which corresponds to the completion of the shaft excavation. At that time, drawdown is developed as follows:

- Drawdown of up to 10 m is developed in the shallow MRV around the shaft, with drawdown of up to 5 m extending to 100 m from the shaft (refer to Figure 24).
- Drawdown of up to 30 m is developed in the deep MRV in the immediate vicinity of the shaft, with drawdown of up to 5 m extending to 120 m from the shaft (refer to Figure 25).
- Drawdown of up to 40 m is developed in the Marburg Subgroup ***aquifer***, with drawdown of up to 5 m extending to 255 m from the shaft (refer to Figure 26).

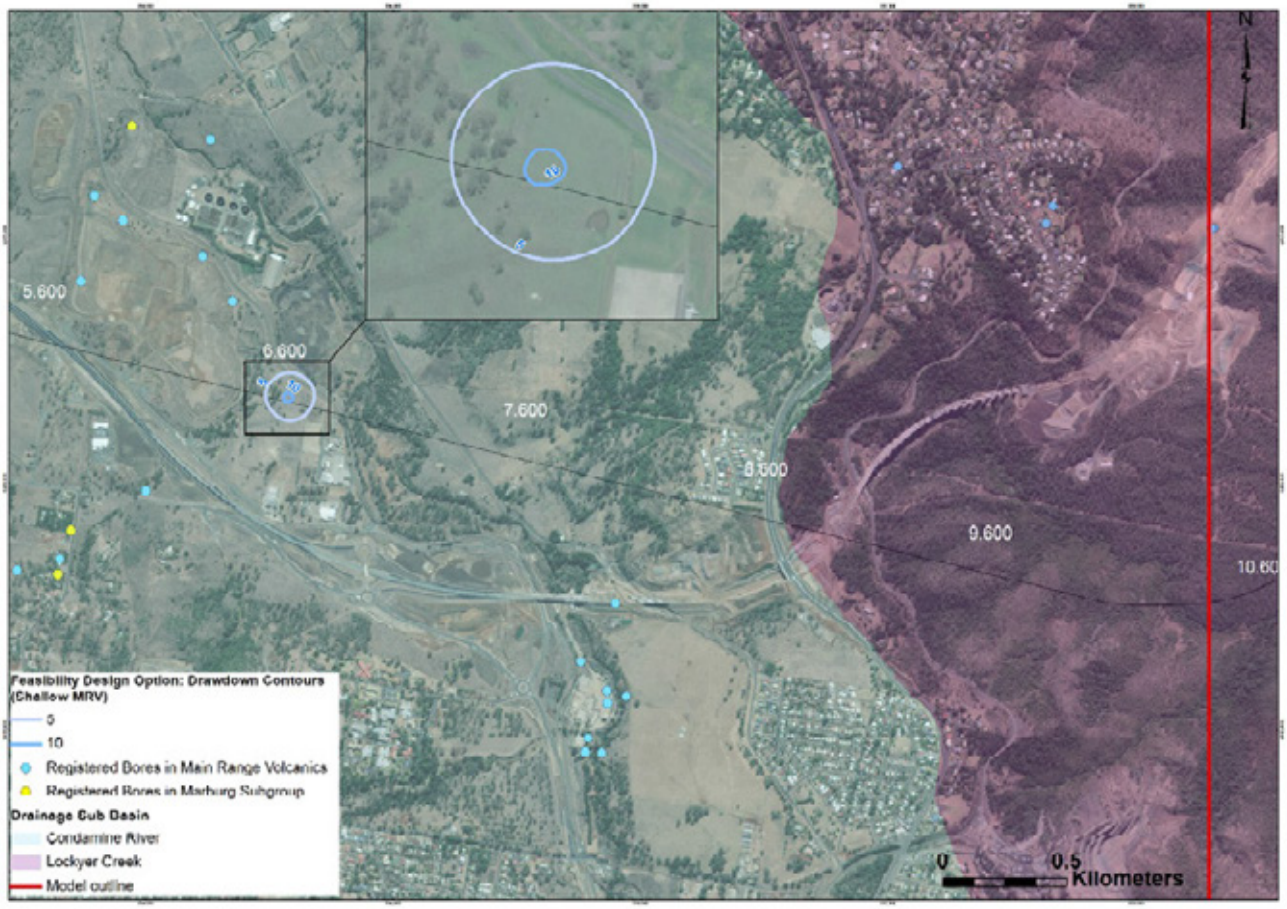


Figure 24: Estimated drawdown contours for the shaft in shallow MRV at elapsed time of 62 weeks (i.e. completion of the shaft excavation)



Figure 25: Estimated drawdown contours for the shaft in deep MRV at elapsed time of 62 weeks (i.e. completion of the shaft excavation)

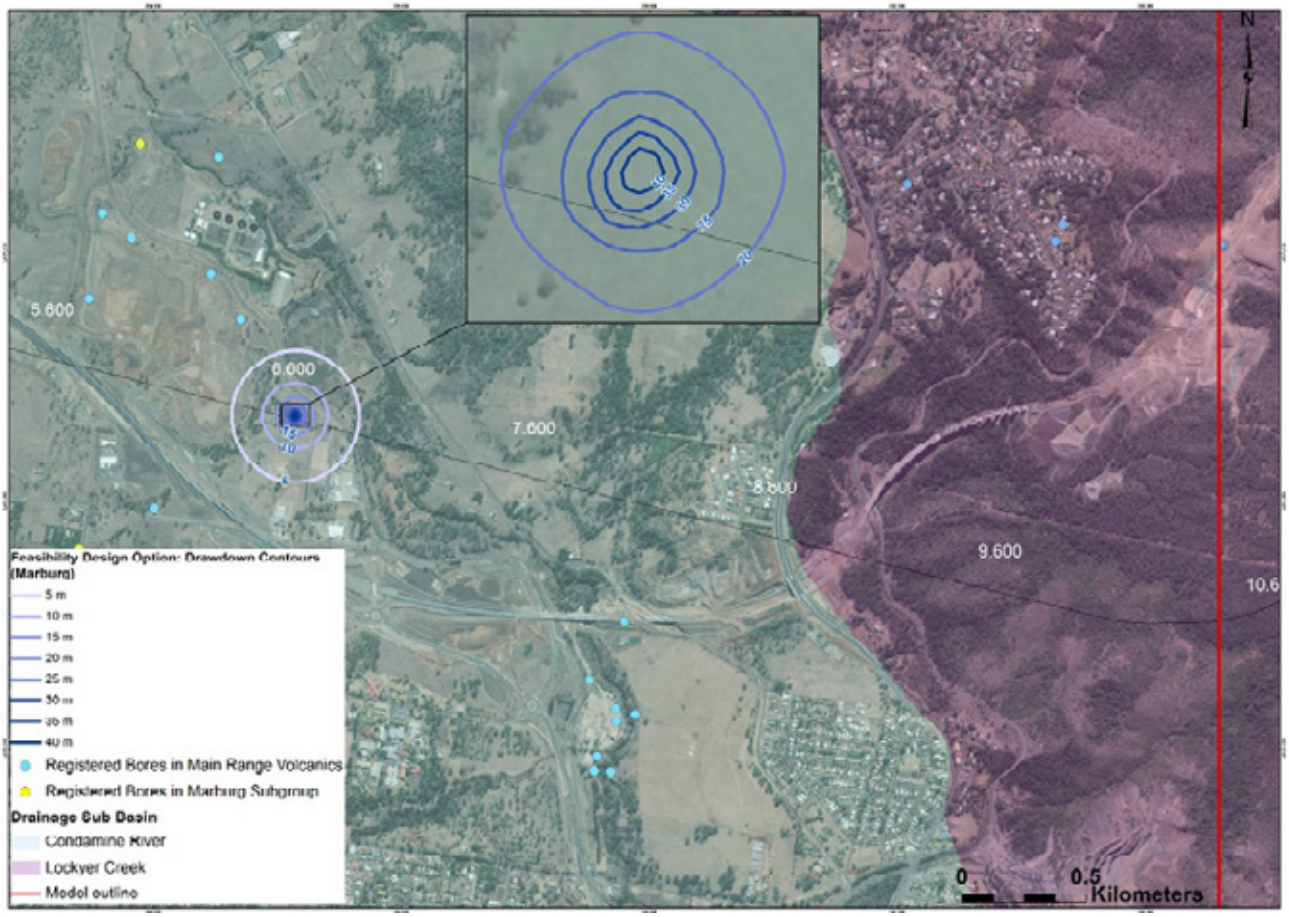


Figure 26: Estimated drawdown contours for the shaft in Marburg Subgroup at elapsed time of 62 weeks (i.e. completion of the shaft excavation)

The predicted long-term drawdown contours for the MRV and Marburg Subgroup are illustrated in Figure 27. The long-term ***groundwater level*** for the deep MRV will recover along the tunnel alignment and no drawdown is anticipated.

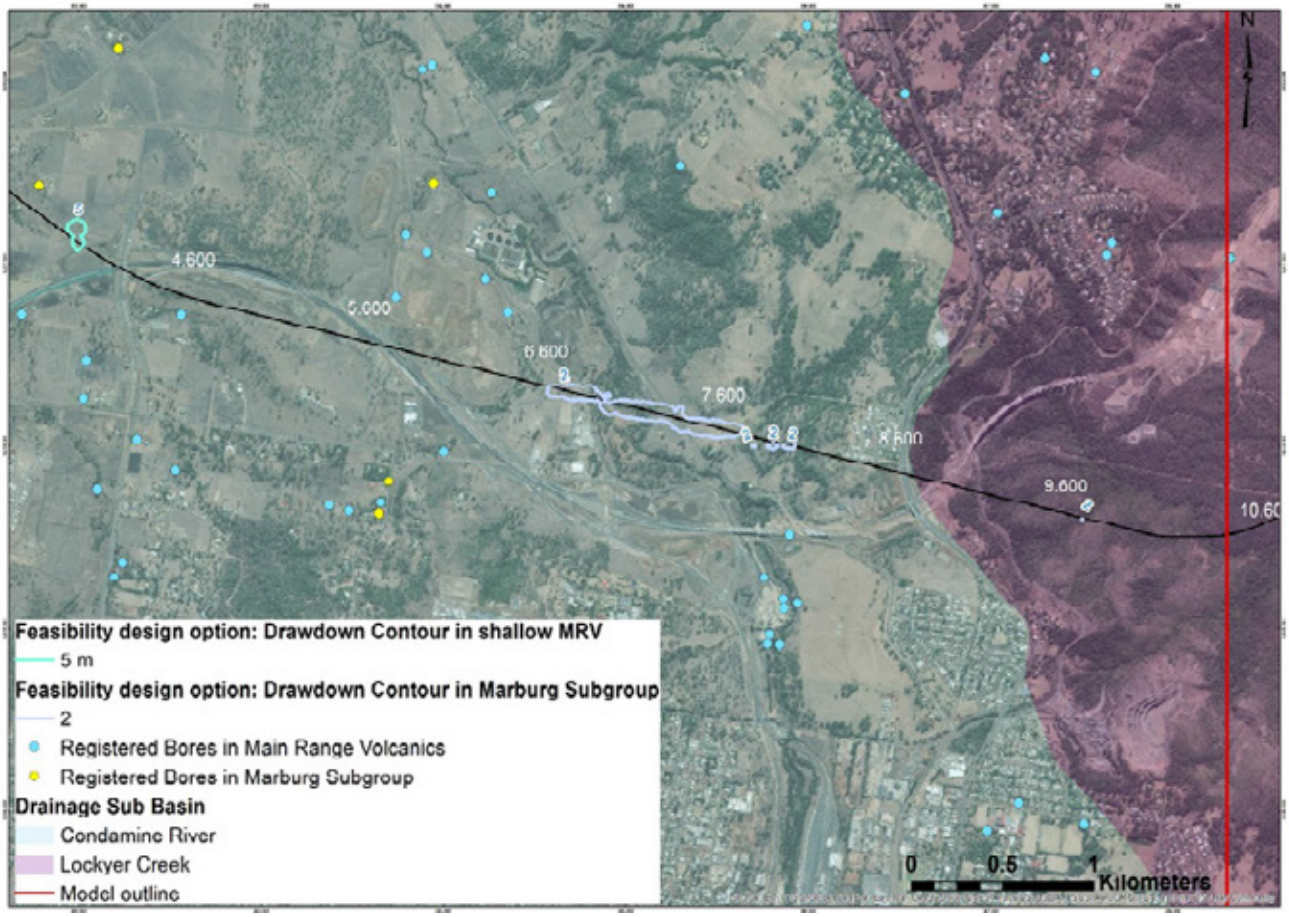


Figure 27: Estimated drawdown contour in shallow MRV (light green) and Marburg Subgroup (light blue) at elapsed 20 years

7.1.5 Sensitivity Analysis

A **sensitivity *analysis*** was carried out to account for the effects of parameter sensitivity on the ***groundwater*** inflow and drawdown. The ***sensitivity analysis*** was undertaken for the 100% Feasibility Design option for the construction stage, and the long term. Two scenarios were simulated:

- Scenario 1-B:
  - The horizontal hydraulic conductivity of low conductive layer in the MRV has been increased by one order of magnitude (i.e. to 1.2 x 10^{-7} m/s).
- Scenario 1-C:
  - When considering an increase in ***permeability*** of the Marburg Subgroup, the upper value of 1.0 x 10^{-6} m/s has been adopted for the top layer of the Marburg Subgroup where the tunnel will be built.

The results are reported in Table 15 and Table 16.

Groundwater Inflow

Results for long term ***groundwater*** inflow estimates for the sensitivity scenarios are summarised in Table 15 and indicate the following:

- When the hydraulic conductivity of the intermediate confining layer in the MRV is increased by one order of magnitude (Scenario 1-B), the long-term inflow to the tunnel is not affected. This because it is

controlled in the model to be equal to the maximum allowable inflow through the tunnel lining. The estimate inflows of the western portal cut are estimated to increase by 77%.

- The assumption of the increased hydraulic conductivity for the shallow layer in the Marburg Subgroup does not impact the computed inflow to the tunnel (Scenario 1-C). This because the tunnel inflows are controlled in the model. The estimated long-term inflow to the western portal cut change slightly (i.e. by less than 1%) because of the change in the hydraulic conductivity of the Marburg Sandstone considered for Scenario 1-C.

Table 15: Inflow estimates under scenarios for sensitivity analysis

Option and Scenario	Groundwater inflow at elapsed time of 20 years					
	Western Portal Cut		Tunnel		Shaft	
	L/s	ML/yr	L/s	ML/yr	L/s	ML/yr
100% Feasibility Design option with preliminary hydrogeological parameters as listed in Table 9	2.6	82.0	0.3	9.5	0.006	0.2
Scenario 1-B with an increased hydraulic conductivity for the low conductivity layer between the upper and lower MRV	4.6	145.1	0.3	9.5	0.006	0.2
Scenario 1-C with an increased hydraulic conductivity for the Marburg Subgroup	2.5	78.8	0.3	9.5	0.006	0.2

Note – inflows to the tunnel and shaft are equal to the allowable limit on permanent leakage rates, which is applied as a boundary condition in the model

Results for construction stage maximum ***groundwater*** inflow estimates for the sensitivity scenarios are summarised in Table 16 and indicate the following:

- When the hydraulic conductivity of the intermediate confining layer in the MRV is increased by one order of magnitude (Scenario 1-B), maximum ***groundwater*** inflow estimates during the construction of the tunnel are significantly increased (since it is controlled by the higher hydraulic conductivity of the excavated materials along the tunnel alignment). The inflows in the shaft are estimated to increase by 124%.
- However, the assumption of increased hydraulic conductivity for the shallow layer in the Marburg Subgroup reduces dramatically the computed inflow to the TBM tunnel 77%, and in the western portal 56% (Scenario 1-C).

Table 16: Maximum inflow estimates under scenarios for sensitivity analysis during construction phase

Option and Scenario	Western Portal		TBM Tunnel		Mined Tunnel		Shaft	
	L/s	ML/yr	L/s	ML/yr	L/s	ML/yr	L/s	ML/yr
100% Feasibility Design option with preliminary hydrogeological parameters as listed in Table 9	5.7	179.8	102.1	3219.8	32.9	1037.5	15.2	479.3

Option and Scenario	Western Portal		TBM Tunnel		Mined Tunnel		Shaft	
	L/s	ML/yr	L/s	ML/yr	L/s	ML/yr	L/s	ML/yr
Scenario 1-B with an increased hydraulic conductivity for the low conductivity layer between the upper and lower MRV	8.5	268.1	121.4	3828.5	42.7	1346.6	34.1	1075.4
Scenario 1-C with an increased hydraulic conductivity for the Marburg Subgroup	2.5	78.8	23.8	750.6	31.9	1006.0	12.3	387.9

Groundwater Level Drawdown

The approximate extents of the predicted long-term ***groundwater level*** drawdown under the sensitivity scenarios are illustrated in Figure 28. These results indicate the following:

- Scenario 1-B: The increased hydraulic conductivity in the low conductivity layer between the upper and lower MRV causes expansion of the 5 m drawdown extent in the MRV ***aquifers***. The extent of estimated 5 m drawdown zone is increased around the western portal in the shallow MRV Figure 28 (a). The maximum drawdown in the Deep MRV and Marburg Subgroup is less than 5 m.
- Scenario 1-C: When the hydraulic conductivity of the Marburg Subgroup is increased by one order of magnitude, the long-term groundwater level will recover along the tunnel alignment. Therefore, there is no groundwater drawdown in the Scenario 1-C.

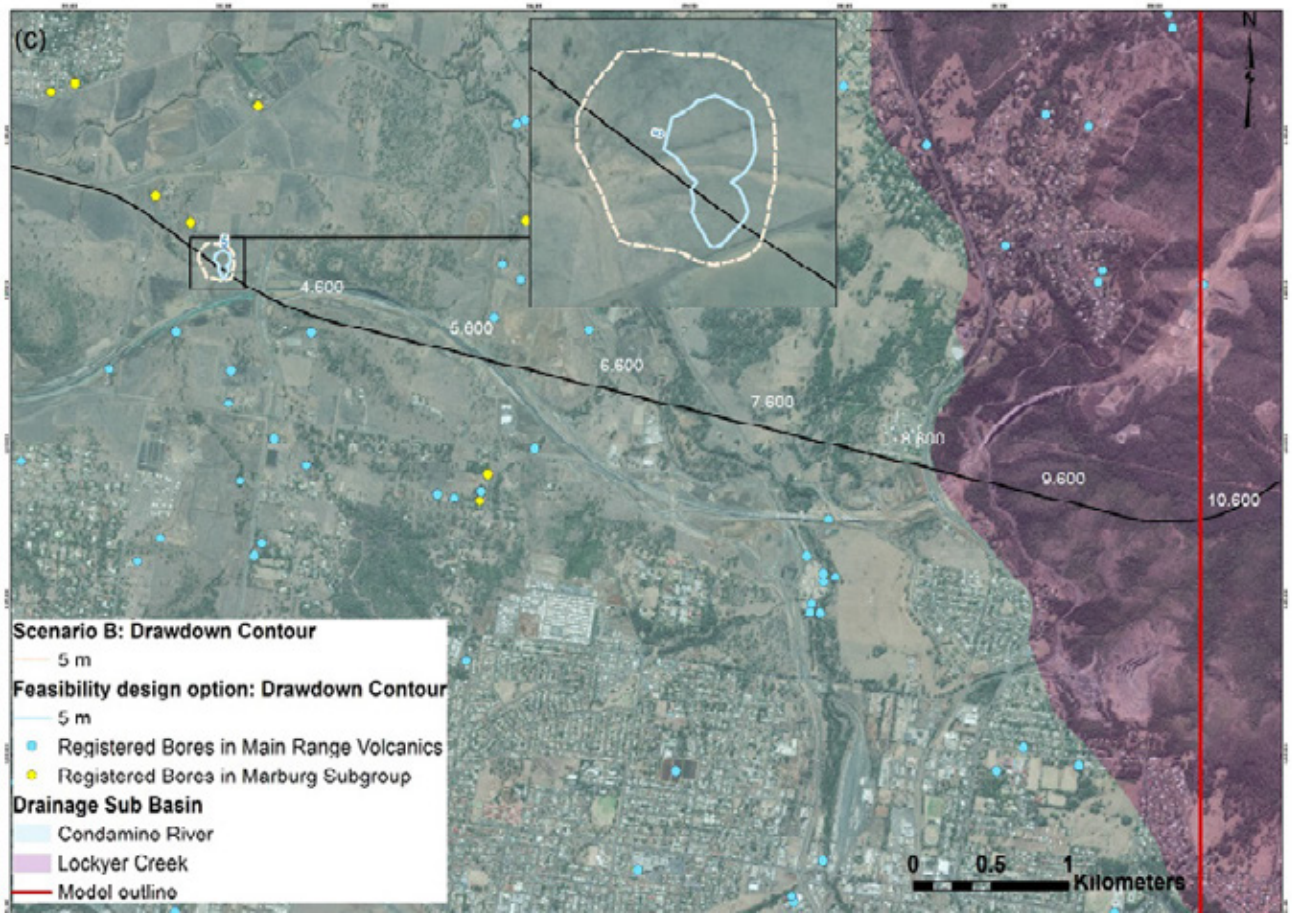


Figure 28: Estimated 5 m drawdown[1] at elapsed 20 years in (a) shallow MRV and (b) deep MRV under Scenario 1-B.

7.1.6 Model Limitations

Some of the limitations of the ***groundwater*** models used for estimating tunnel and portal cut inflows and drawdown of the ***groundwater*** table include:

- The materials have been assumed to be saturated only. The effects of variability in saturation of soil and rock on ***groundwater*** flow and ***recharge*** have been neglected. Nevertheless, this is considered to be a conservative assumption
- The low conductivity confining layer in the MRV that has been interpreted as being laterally extensive in the model may not be present in some areas which could significantly affect the inflow and drawdown due to tunnel drainage.
- The tunnel design indicates the eastern section of tunnel (between Chainage 8.600 km and 8.900 km) is likely to encounter Crater Rim materials (CR). The information about the extent and the hydrogeological properties of CR is very limited.

[1] 5 m drawdown has been selected based on the Water Bore threshold drawdown trigger from the Water Act 2000 (DEHP, 2016).

7.2 Cuts Along the Alignment

7.2.1 Design Assumptions

A total of 14 cuts will be required along the alignment of the Inland Rail project considered in this report. Cuts will range in length from 70 m up to 1 390 m. Locations of deep cuts anticipated to experience ***groundwater*** seepage are summarised in Appendix D.

An analytical solution has been applied to estimate the ***groundwater*** inflow into slope cuts based on the following assumptions:

- Slope cuts are assumed to be permanently drained
- The geological material is assumed to be homogenous and isotropic
- The rock below the bottom of the slope cut is assumed to be practically impermeable
- ***Groundwater recharge*** is not included in this analysis
- The analysis is based on the typical values of hydrogeological design parameters listed in Table 9
- Each cut has been divided into 10 m intervals for calculation

7.2.2 Methodology

Groundwater seepage from the proposed G2H alignment cuts were estimated using the method described by Nguyen and Raudkivi (1983). The approach is based on a Laplace-type formulation based on the Dupuit–Forchheimer assumption and provides estimation of the phreatic surface and the flow rate as a function of time. The Dupuit–Forchheimer assumption holds when ***groundwater*** flows horizontally in an ***unconfined aquifer*** and the ***groundwater*** discharge is proportional to the saturated ***aquifer*** thickness above the toe of the cut. A schematic is shown as Figure 29. Seepage was calculated using inferred ***groundwater levels*** at 10 m intervals along the length of each cut.

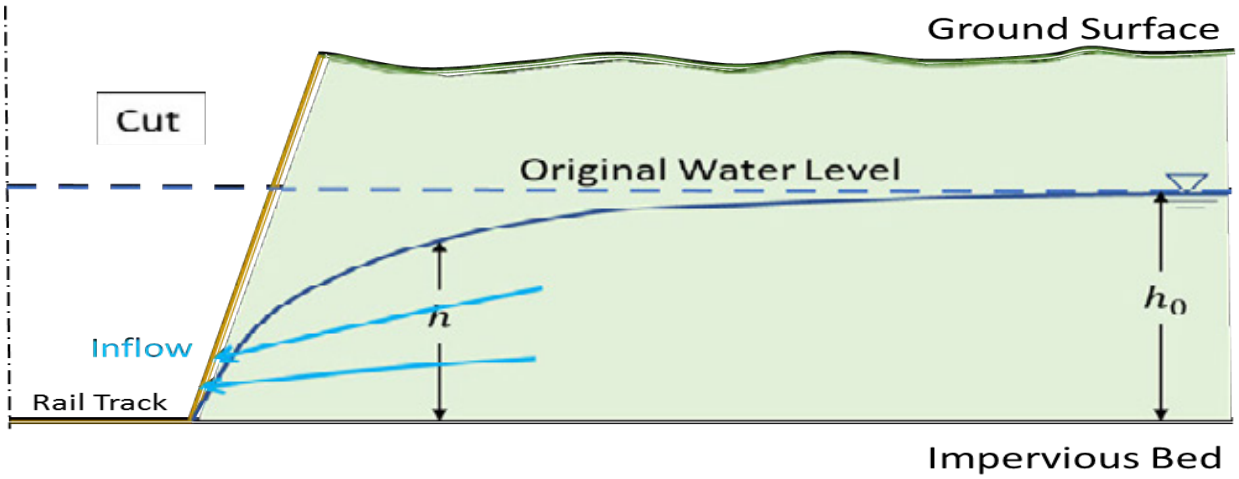


Figure 29: Seepage flow analytical model for cuts along the G2H rail track alignment where h0 is the undisturbed (ambient) piezometric water level and h is the piezometric head

7.2.3 Seepage Rate Estimates

The estimated long-term average seepage rates after the completion of the slope cuts and steady state seepage rates are summarised in Table 17. Estimated inflow rates are less than 0.1 L/s for all cuts. Note that for the purposes of this summary, the cut at the eastern portal (C4) has been combined with the immediately adjacent cut and cover tunnel, since they form in essence a contiguous drainage element in terms of influence on the ***groundwater***.

It is noted that the median estimated ***groundwater levels***, for all cuts is below the base elevation of the cuts (refer to Table 11), with the exception of Cut C12 where the median ***groundwater level*** is estimated to be approximately 1 m above the base of the cut.

At all cuts, regional ***groundwater levels*** may rise temporarily above the base of the cut as a result of ***groundwater level*** fluctuations in response to rainfall patterns (refer to Table 11). In addition, water which infiltrates following larger rainfall events may form temporary perched ***groundwater*** systems adjacent to cuts which result in temporary inflows, particularly through rock joints in relatively more ***permeable*** horizons overlying lower ***permeability*** perching ***units***. For the cuts which are located in the Koukandowie Formation and the Gatton Sandstone, temporary inflows as a result of either an increase in the regional ***groundwater level*** and/or the formation of temporary perched systems are likely to be less than 1 L/s at their peak, with the duration of inflow from these temporary perched systems likely to be less than 1 month.

For the eastern portal and adjacent cut and cover tunnel, the excavation will be located in the colluvium, with the sedimentary Koukandowie Formation and the Gatton Sandstone ***units*** located at the base of the excavation or at shallow depth below the excavation. The colluvium is interpreted to have a significantly higher hydraulic conductivity than the Koukandowie Formation and the Gatton Sandstone, and thus there is

potential for greater inflow as a result of temporary increases in the regional ***groundwater level*** than for the cuts in these less ***permeable*** formations. The ***groundwater level*** observed in the area of the eastern portal in borehole 320-02-BH2016 was approximately 2 m below the base of the excavation between September and December 2019. The ***groundwater level*** during this period is likely to be below the long-term median ***groundwater level***. Based on the local topography and subsurface geology and likely high specific yield of the colluvium, it is assessed that the long-term median ***groundwater level*** is unlikely to be above the base of the excavation. Hence, the long-term inflow is assessed to be low as for other cuts, despite the higher hydraulic conductivity. Temporary inflows following temporarily larger increases in ***groundwater level*** following large rainfall events are estimated to be, at their upper limit, in the range of 2-5 L/s for more significant and thus less frequent increases in ***groundwater level***. These peak inflows would be of relatively short duration (potentially up to a month), however as a result of the likely relatively high specific yield of the colluvium, temporary inflows are likely to continue at decreasing rates over somewhat longer periods than in formations with lower storage capacity.

Table 17: Estimated long-term average seepage rate into slope cuts with groundwater intersection along the proposed G2H alignment

Cut Name	Length (m)	Geology	Total Seepage Rate (L/s)	
			1 year after construction	Long-term
C4 (eastern portal) plus cut and cover tunnel	165	Colluvium	Less than 0.1	Less than 0.1
320-C5	376	Koukandowie Formation	Less than 0.1	Less than 0.1
320-C6	373	Koukandowie Formation	Less than 0.1	Less than 0.1
320-C9	317	Koukandowie Formation	Less than 0.1	Less than 0.1
320-C10	311	Koukandowie Formation	Less than 0.1	Less than 0.1
320-C11	295	Koukandowie Formation	Less than 0.1	Less than 0.1
320-C12	250	Gatton Sandstone	Less than 0.1	Less than 0.1

7.2.4 Limitations

The following limitations of this method are noted:

- The assumption of an impervious bed below the rail track may result in lower flow rate estimates.
- The analytical solution does not account for rainfall effects on seepage rate.
- Structural features have not been included in this analysis.
- Seepage from perched ***groundwater*** has not been included in the analysis.

8.0 HYDROGEOLOGICAL DESIGN CONSIDERATIONS

8.1 Design Groundwater Levels for Toowoomba Tunnel

Groundwater levels for the design of tunnel elements can be based on the results of ***groundwater*** modelling for various configurations of permanent drainage for tunnel and shaft elements. It is noted that the hydrogeological conceptualisation has been revised from that in the previous revisions of this report, based on more recent site data regarding ***groundwater levels***. These changes in conceptualisation lead to changes in predicted ***groundwater level*** for the various design options compared to the predicted ***groundwater levels*** reported in the previous revisions of the report.

The conceptualisation in the previous revisions of the report assumed a single flow regime within the MRV, with a ***groundwater level*** that is correlated with surface topography. As discussed in Section 6.2, data from monitoring bores 320-01-BH2101 and 320-01-BH2102 and from registered bores RN42231660 and RN42231662 suggest that hydraulic head is much lower in the deep sections of the MVR; and that this deep flow regime is hydraulically separated from a near surface flow regime in which ***groundwater levels*** are significantly higher than in the deep flow regime; and are generally well correlated with surface topography.

The data on which the current conceptual model is based is relatively limited, and uncertainties remain regarding:

- the horizontal and vertical extent of deep and shallow flow regimes and spatial variations in the connectivity between the two;
- connectivity between the tunnel alignment and these flow regimes;
- hydraulic properties of the flow regimes; and
- hydraulic head variation within the deep and shallow flow regimes;

Although recent findings suggest relatively low hydraulic head at the elevation of the tunnel, higher ***groundwater levels*** calculated on the basis of the previously adopted conceptual model could be considered as a “worst case scenario” for tunnel support design because of the above uncertainties.

8.2 Groundwater Quality and Durability Considerations for Toowoomba Tunnel

8.2.1 Groundwater quality

To assess the ***groundwater*** quality and durability in the area of the Toowoomba tunnel, Queensland registered bore database has been interrogated for ***groundwater*** chemistry data and records within a 4 km of the proposed alignment between Chainage 2.400 and 11.450 km. Records are available for 85 bores screened in the MRV, 8 in the Marburg Subgroup and one in the WCM. The ***groundwater*** quality results indicate:

- ***Groundwater*** in the MRV is generally fresh to slightly brackish, with TDS measurements ranging from 194 to 2730 mg/L.
- ***Groundwater*** in the Marburg Subgroup is generally fresh with TDS measurements between 474 and 1071 mg/L.
- The pH values measured in the MRV and Marburg Subgroup are generally slightly alkaline with typical values of 7.8 and 8.1 for the formations, respectively.
- Metals concentrations in both the MRV and Marburg Subgroup are typically low.

The classification scheme for water based on the total dissolved solids (TDS) is displayed in Table 18.

Table 18: Classification of water based on concentration in Total Dissolved Solids (TDS). (Fetter, 2002)

Class	TDS (mg/L)
Fresh	0 to 1 000
Brackish	1 000 to 10 000
Saline	10 000 to 100 000
Brine	Greater than 100 000

Site specific data was obtained from 320-01-BH2201 which is a shallow ***groundwater*** monitoring installed in the Koukandowie Formation below an alluvial ***unit***, for which the following results were recorded for a sample collected on 30 October 2018:

- An electrical conductivity of 2640 µS/cm (estimated TDS of about 1700 mg/L).
- A pH of 8.04
- A concentration of ammonia as nitrogen of 0.43 milligrams per litre (mg/L).

Based on published water chemistry data for the MRV and Marburg Subgroup of the Clarence-Moreton Basin, the ***groundwater*** seepage into the tunnel and cut excavations during construction and operation are expected to be fresh to brackish, sodium-chloride dominated and typically neutral to slightly alkaline. Water quality parameter values may vary slightly due to seasonal rainfall infiltration.

The area to the west of the Toowoomba Range (approximately Chainage 8.900 km) is located within the Condamine River Basin (part of Basin No.422), and to the east is located within the Lockyer Creek Basin (Part of Basin No.143). The available ***groundwater*** quality results are found to generally meet the EPP Water 2019 discharge criteria for those particular basins. However, there could potentially be some exceedances of salinity and nutrients (total nitrogen) for discharge to streams. The concentration of ammonia as nitrogen is above the Water Quality Objective (WQO) for upland freshwater ecosystems which has a trigger value of 0.01 mg/L.

8.2.2 Groundwater Aggressivity and Scaling Potential

Groundwater characteristics relevant to durability assessment (i.e. ***groundwater*** salinity; electrical conductivity; pH; chloride, magnesium, and sulphate concentrations; and magnesium/calcium ratio) for the MRV and Marburg Subgroup as well as for monitoring bore 320-01-2201 (Koukandowie Formation) are summarised in Table 19, respectively. Results of current data analysis for the two formations indicate a broad range of ***groundwater*** quality parameters for both the MRV and Marburg Subgroup. In general, higher values of magnesium and EC were reported for the MRV, while a similar range of values for pH were reported for both formations.

Table 19: Estimated characteristics of groundwater in the Main Range Volcanics and Sedimentary rock aquifers to inform durability assessment

Characteristic [A]	Unit	MRV	Marburg Subgroup	320-01-BH2201
Sulphate	mg/L	1 to 481	8 to 25	18
Chloride	mg/L	14 to 1600	86 to 485	403
Carbonate	mg/L	0 to 76	1 to 18	0
Bicarbonate	mg/L	43 to 870	230 to 578	830
Calcium	mg/L	2 to 258	4 to 117	101
Magnesium	mg/L	0 to 440	5 to 110	32
Magnesium/Calcium Ratio	-	0 to 35	<1 to 24	<1
pH	-	6.5 to 9.2	7.7 to 8.8	8.0
Electric Conductivity	µS/cm	233 to 5500	875 to 2330	2640
Langelier Saturation Index (LSI)	-	-2.2 to 1.0	0.3 to 1.0	1.0
Ryznar Stability Index (RSI)	-	5.9 to 11.1	6.0 to 8.2	6.0

Note: [A] Records retrieved from the Queensland registered bore database for an approximately 5 km wide corridor of the tunnel alignment between Chainage 2.400 and 11.450 km.

8.3 Groundwater Quality for Seepage to Cuts

To assess the ***groundwater*** quality in areas of deep cuts where ***groundwater*** seepage could occur a total of 655 records from the Queensland Registered Bores Database (DNRM, 2018) and SI borehole 320-01-BH2201 records were examined. The results indicate that ***groundwater*** seepage could range from being fresh to brackish (about 118 to 12 500 µS/cm).

Borehole 320-01-BH2201, which is located at Chainage 11.900 km between Cut 320-C6 and Cut 320-C7 suggests that the ***groundwater*** quality there is brackish (EC of 2640 µS/cm (estimated TDS of about 1700 mg/L) and slightly alkaline (pH value of 8.04).

The estimated inflow rate for cuts in rock is generally low (less than or equal to 0.1 L/s over the full length of the cuts) and consequently evaporative ***deposition*** of salt could occur on the batters and at the base of cuts. This would be more severe when the salinity is higher at the location of the cut.

8.4 Potential for Groundwater Level Mounding along Embankments

Obstruction of natural drainage pathways due to embankments may cause more frequent inundation of areas upstream of the embankment, with the potential for the temporary development of a ***groundwater*** mound beneath inundated areas. This could have long-term adverse impacts on soil salinity and in extreme cases may affect the stability of the embankment.

Potential for ***groundwater*** mounding at embankments has been calculated using estimated current ***groundwater levels***, and an estimate of the potential increase in ***groundwater level*** based on records of

groundwater variation around the time of historical flood events. Estimated current ***groundwater levels*** at embankments are reported in Appendix D. Based on the available records it is assessed that:

- In the MRV, at embankments overlying rock formations, low effective porosity and variable fracture ***permeability*** may result in a potential ***groundwater*** rise of between 1.2 m and up to about 15.1 m rapidly to delayed depending on connectivity of fractures following large rainfall or flood events (Section 5.2).
- In the sedimentary ***units*** within the Lockyer Valley east of the Toowoomba Range, at embankments overlying rock formations, low effective porosity may result in a potential ***groundwater*** rise of between 1.0 m up to about 3.5 m which may be delayed following large rainfall or flood events (Section 5.2).
- Where embankments are located in flood plains overlying areas with deep ***alluvium***, a potential increase of ***groundwater levels*** by up to 10 m is anticipated. This estimate in level increase is based on historical water level records within the Lockyer Valley reported in Section 330 (Golder, 2018d) which suggest that ***groundwater levels*** in the alluvial flood plain of the Lockyer Valley rose by up to 10 m after a series of flood events between 2008 and 2012.

As the majority of embankments are located overlying rock, most are susceptible to larger potential increases in ***groundwater level*** from the assessed "typical" ***groundwater levels***. Table 20 summarises the embankment locations that could potentially see a rise in ***groundwater levels*** such that the ***groundwater*** would rise to within 2 m of the ground surface.

Table 20: Estimated groundwater level mounding at selected embankment locations

Structure Name	Median Estimated Surface Elevation (m AHD)[1]	Median Estimated GW Level (m AHD)[2]	Median Estimated GW Level (m bgl)	Potential Mounded GW Level (m bgl)	Formation
320-E1	462.6	453.8	8.8	0	MRV
320-E2	476.0	464.9	11.2	0	MRV
320-E3	488.7	477.0	12.2	0	MRV

Note: GW = ***Groundwater***, [1]Estimated surface elevation calculated based on the typical value for elevation along the proposed rail alignment (RL), [2]Estimated ***groundwater level*** based on correlation of ***groundwater***, elevation and formation type.

8.5 Groundwater Aggressivity for Bridge Sub-structures

Observed and inferred ***groundwater*** characteristics for bridge locations along the proposed G2H rail alignment and relevant to durability assessment (i.e. ***groundwater*** salinity; electrical conductivity; pH; chloride, magnesium, and sulphate concentrations; and magnesium/calcium ratio) are summarised in Table 21. ***Groundwater*** quality parameters were calculated based on the typical value for each formation (MRV, Marburg Subgroup and Gatton Sandstone) within 5 km of the proposed alignment. For the purposes of this assessment, the Koukandowie formation has been reported as part of the Marburg Subgroup.

Results of current data analysis across three formations indicate a broad range of ***groundwater*** quality parameters. In general, lower values of Mg and Ca were reported for the Marburg Subgroup, while higher values of TDS, alkalinity and electrical conductivity (EC) were reported for the Gatton Sandstone. More specific information on ***groundwater*** characteristics at proposed bridge locations (320-01-BH2202 to 320-01-BH2207, 320-01-BH2209, and 320-01-BH2211 to 320-01-BH2216) which was not available at the time of preparing this report, are provided in the Groundwater Monitoring report 1899276-232-TM-REV0 (Golder, 2020). Table 21 provides results for bridge locations which are located near a Golder SI bore, while a complete set of results is provided in Appendix E.

Table 21: Estimated characteristics of groundwater at proposed bridge locations along the G2H rail alignment to inform durability assessment

Bridge Location	SO_4[A] [mg/L]	Cl[A] [mg/L]	CO_3[A] [mg/L]	HCO_3[A] [mg/L]	Ca [mg/L]	Mg [mg/L]	Mg/Ca [-]	pH [-]	EC [µS/cm]	T[B, 1] (C°)	LSI [-]	RSI [-]
320-BR07	9.81	403	<1	830	101	32	0.08	8.04	2640	22.4	6.88	0.51
320-BR14	4.5	145	<1	657	13.5	5.5	0.04	7.44	1645	23.2	6.15	0.62

Note: [A] Records retrieved from the Queensland registered bore database for an approximately 5 km wide corridor of the proposed G2H rail alignment. [B] T = Temperature. [1]Recorded field water quality parameters from nearby SI Borehole.

9.0 RISK AND MITIGATION

Groundwater related risks and proposed mitigation measures are summarised in Table 22.

Table 22: Risks Identified and Mitigation

Risk/Issue	Proposed Mitigation at Detailed Design Phase
Groundwater levels in the MRV and Marburg Subgroup are higher than anticipated and consequently pore pressures and ***groundwater*** inflows to the tunnel and portal cuts would be higher than estimated. This may result in risks associated with: ■ excavation instability ■ erosion/scouring and long-term condition of eastern portal cut ■ inflows exceeding design specifications of 1 L/s/km ■ change in construction water management requirements ■ elevated pore water pressures in the tunnel crown ■ increased scaling potential ■ increased volumes of drainage water to be treated during tunnel operation if water treatment is required.	Installation of monitoring bores every 400 m along the tunnel alignment and at every cut identified to intersect the ***groundwater*** table and installation of water level probes prior to final design and construction to establish ***groundwater levels***. Conduct a pumping test(s) within the Tertiary basalt and the Koukandowie Formation to determine connectivity between ***units*** and ***aquifer*** characteristics.
Fault or fracture structures or dykes allowing preferential ***groundwater*** flow and consequently causing localised ***groundwater*** inflow higher than anticipated which may result in risks associated with: ■ inflows exceeding design specifications of 1 L/s/km ■ change in construction water management requirements ■ increased regional or localised drawdown affecting nearby ***groundwater*** users (water supply bores) or ***groundwater*** values ■ change in construction method	Further ground probing using drilling and geophysical investigation methods, installation of piezometers in identified structures and borehole ***permeability*** testing (water pressure or falling head recovery testing) prior to final design and construction to establish location, extent and hydrogeologic characteristics of geological structures along the tunnel alignment. Allowance in cost and design for: ■ change in construction method when tunnelling through structural zones ■ additional ***groundwater*** control (e.g. grouting or tanking of structural zones with high seepage rates).

Risk/Issue	Proposed Mitigation at Detailed Design Phase
■ Requirements for additional ***groundwater*** control	
Hydraulic conductivity of the Marburg Subgroup, Walloon Coal Measures or Colluvium deposits lower or higher than anticipated. Lower values of hydraulic conductivity may result in higher pore pressures in the vicinity of tunnels and portals, and conversely higher values may result in higher ***groundwater*** inflows. This may result in risks associated with: ■ support design for cuts and tunnels ■ over or under designing tunnel and cut drainage ■ over- or under designing treatment facility should ***groundwater*** treatment be required ■ inflows exceeding design specifications of 1 L/s/km ■ increased regional or localised drawdown affecting nearby ***groundwater*** users (water supply bores) or ***groundwater*** values.	***Permeability*** testing (water pressure or falling head recovery testing) of rocks and alluvial ***sediment*** deposits prior to final design and construction of the tunnel and slope cuts to establish hydrogeologic characteristic of the ***aquifer*** systems along the tunnel alignment and at cut locations. At a minimum ***permeability*** testing in open boreholes located at 400 m spacing along the tunnel alignment. Testing to be conducted below ***groundwater*** table in open test intervals of 5 m length or less. At minimum two tests below the tunnel's track elevation, two tests within the tunnel cross section and two tests above the tunnel crown. Two tests below ***groundwater*** table at cut locations anticipated to intersect the ***groundwater*** table. Allowance in cost and design for monitoring ***groundwater*** inflow from seepage locations and ***groundwater level*** drawdown during construction
Groundwater recharge higher or lower than anticipated and consequently ***groundwater*** inflows to the tunnel and portal cuts higher or lower than expected which may result in risks associated with: ■ over or under designing tunnel drainage ■ over or under designing treatment facility should ***groundwater*** treatment be required ■ inflows exceeding design specifications of 1 L/s/km ■ increased regional or localised drawdown affecting nearby ***groundwater*** users (water supply bores) or ***groundwater*** values.	Continuous recording of ***groundwater levels*** in monitoring bores along the tunnel alignment at each cut location anticipated to intersect the ***groundwater*** table prior to final design and construction. Assessment of ***recharge*** from water level records of several larger rainfall events and chloride concentrations in ***groundwater***. Monitoring or water levels at identified structurally affected zones may provide further information about response in highly conducted zones to large rainfall events.
Groundwater quality characteristics exceeding discharge criteria and therefore, a need for water treatment prior to disposal.	Installation of monitoring bores prior to final design and construction and ***groundwater*** sampling for water quality analysis. Installation of standpipe piezometers in

Risk/Issue	Proposed Mitigation at Detailed Design Phase
	boreholes drilled along the tunnel alignment at 400 m spacing and each cut location anticipated to intersect the ***groundwater*** table.
Magnesium concentrations higher than expected and consequently impact of ***groundwater*** on concrete durability larger than expected.	Repeated ***groundwater*** sampling of the Marburg Subgroup along the tunnel alignment and testing for magnesium and calcium concentration. Concrete durability to be designed based on additional testing results as required.
Groundwater aggressivity and scaling potential of tunnel drainage higher than expected.	Repeated ***groundwater*** sampling of the Marburg Subgroup along the tunnel alignment and testing for aggressivity and scaling potential parameters prior to final design and construction.
Drainage during construction and long-term drainage impacting on the Toowoomba City water supply and Condamine and Balonne water management plans and nearby boreholes.	Conduct a pumping test(s) within the Tertiary basalt and the Koukandowie Formation to determine connectivity between ***units*** and ***aquifer*** characteristics. Results would provide information on water treatment plant design, temporary dewatering estimates, grouting requirements, ***groundwater*** control measures, impact on ***groundwater*** values and provide important insights into the design. Monitoring of ***groundwater*** using VWPs where fractured rock has been identified will provide background data collection and identify any impacts from tunnel construction at an early stage.
Perched ***groundwater*** encountered during excavation may result in risks associated with: ■ unexpected inflows requiring management, treatment and disposal, ■ stability of unsupported excavations in unconsolidated material.	Additional allowance for the management of short-term increases in water inflow during excavation of cuttings, tunnel portal cuts and shaft excavation.

10.0 IMPORTANT INFORMATION RELATING TO THIS REPORT

Your attention is drawn to the document - “Important Information Relating to this Report”, which is included as APPENDIX H of this report. The statements presented in this document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks associated with the services provided for this project. The document is not intended to reduce the level of responsibility accepted by Golder Associates, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

11.0 REFERENCES

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12.0 GLOSSARY

Alkalinity: a measure of the capacity of water to resist or buffer changes in pH.

Alluvium: deposits of clay, silt, sand, gravel, or other particulate material that have been deposited by a stream or other body of running water in a streambed, on a flood plain, on a delta, or at the base of a mountain.

Aquifer: a saturated underground geological formation or group of formations, that can store water and yield it to a bore or spring. A saturated formation that will not yield water in usable quantities is not considered an aquifer.

Aquitard: a geological formation that prevents significant flow of water due to its low permeability (e.g., clay layers or tight deposits of shale).

Basin

- Geological: an area in which the rock strata dip from the margins toward a common centre; the site of accumulation of a large thickness of sediments.
- Groundwater or hydrogeological: a groundwater system made up of multiple aquifers; may be equivalent to a geological basin.

Bore trigger thresholds: thresholds used to identify bores that are likely to be impacted and require further bore assessment**.** The Water Act defines bore trigger thresholds as a decline in the water level in the aquifers of five metres for consolidated aquifers (such as sandstone) and two metres for unconsolidated aquifers (such as alluvium).

Conductivity: the degree to which a specific material or substance conducts electricity.

Confined aquifer: a saturated aquifer bounded between low permeability materials such as clay or dense rock.

Consolidated aquifer: a water-bearing aquifer made of consolidated rock such as sandstone, coal, limestone or granite.

Deposition: the laying down/settling of material (clay, sand, rock) carried by wind, water, or ice.

Development profile: a tenure holder's production footprint with associated planned commencement, development sequencing and cessation.

Drawdown: the difference between the groundwater pressure before and after pumping or depressurisation.

Formation (geological): a sediment or rock, or group of sediments or rocks. Geologists often group rocks of similar types and ages into named formations, for example the Hooray Sandstone of the Great Artesian Basin.

Fracture (geological): a minor break in a geological formation with no measurable movement, or

displacement (see also ‘Fault’).

Groundwater: also known as underground water. Water found in the cracks, voids, pores or other spaces between particles of clay, silt, sand, gravel or rock within the saturated zone of a geological formation.

Groundwater level: a level to which groundwater rises in a monitoring bore. This reflects the water pressure in the aquifer tapped by the bore.

Hardness: a measure of the amount of dissolved calcium and magnesium in water.

Head (groundwater): groundwater level or pressure.

Homogenous formation: a geological formation that has identical material properties throughout its entire extent.

Hydraulic parameters: the parameters that describe the material properties that control the flow and storage of water within an aquifer, such as permeability and storativity.

Hydrogeology: the study of how groundwater moves, how it is distributed and how it interacts with rock.

Hydrostratigraphic unit: A definable unit based on its hydrogeological properties.

Hydrostratigraphy: the identification of units on the basis of hydraulic properties.

Interbedded: where beds, or layers, of geological material of different lithology or properties are layered together.

Ion: a charged atom or molecule.

Lithic: geological deposits or sedimentary rocks that contain abundant fragments of previously formed rocks.

Lithology: the physical characteristics of rock, with reference to qualities such as colour, composition and texture.

‘Make good’: the Water Act specifies the circumstances under which petroleum tenure holders need to investigate impairment of water bores and develop ‘make good’ agreements with bore owners about the impairment.

Measures (geological): a series of coal-bearing rocks, such as the Walloon Coal Measures.

Member (geological): a named lithologic subdivision of a formation; for example, the Boxvale Sandstone Member.

Model domain: the areal extent of the regional groundwater flow or associated geological model.

Monitoring installation: an individual borehole equipped to monitor water quality and/or water pressure, potentially at multiple vertical levels.

Mudstone: an extremely fine-grained sedimentary rock consisting of a mixture of clay and silt-sized particles.

Outcrop (noun): a geological formation or rock strata exposed at the ground surface.

Outcrop (verb): to be exposed at the ground surface.

Permeable: capable of transmitting water through porous rock, sediment or soil.

Permeability: a property of a soil, sediment or rock indicating how easily water will be transmitted through it under a hydraulic gradient.

Petroleum: naturally occurring hydrocarbons such as oil, gas and CSG.

Petroleum tenure holder: an entity that holds an authority to prospect and/or a petroleum lease under the Petroleum and Gas (Production and Safety) Act 2004.

Recharge: the process of water flowing into an aquifer.

Sediment: material suspended in water or deposited from suspension. The plural form, sediments, is applied to all kinds of deposits from the waters of streams, lakes and seas.

Sedimentary basin: a geological basin containing a sequence of mainly sedimentary rocks.

Sequence (geological): a sequence of geological events, processes, or rocks, arranged in chronological order.

Sensitivity analysis: In strict mathematical terms, a sensitivity measures how fast one quantity changes when another changes. During trial-and-error calibration in groundwater modelling, sensitivity analysis involves changing a model parameter by a small amount to establish how model predictions are affected by that change.

Siltstone: fine-grained sedimentary rock consisting of consolidated silt.

Strata: a series of layers of rock in the ground (singular: stratum).

Stratigraphic unit: a volume of rock of identifiable origin and relative age range that is defined by the distinctive and dominant, easily mapped and recognizable petrographic, lithologic or paleontologic features (facies) that characterise it.

Turbidity: the measure of relative clarity of a liquid.

Unconfined aquifer: an aquifer with no overlying low permeability layers that restrict water movement into the aquifer. The water level in an unconfined aquifer is known as the water table.

Unit (geological): see ‘Stratigraphic unit’.

Signature Page

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Appendix A
Hydrographs from 2018 FFJV investigations

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



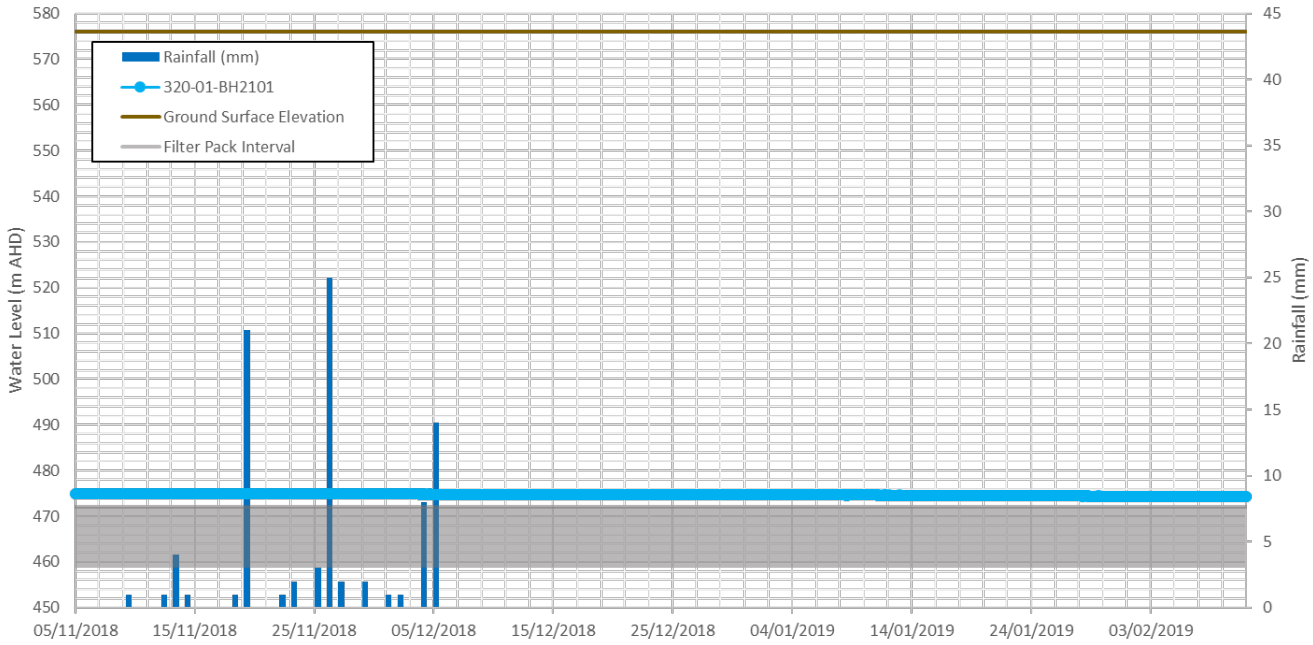


Figure A1: Hydrograph of 320-01-BH2101, rainfall from the Helidon TM weather station (Station 040829)

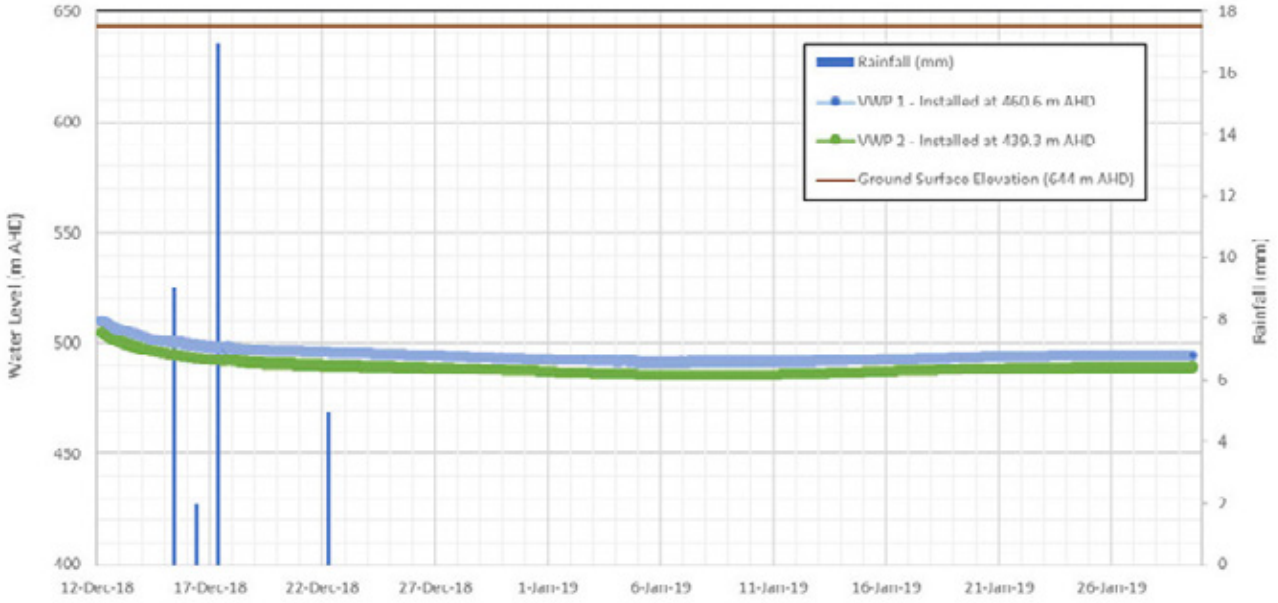


Figure A2: Hydrograph of 320-01-BH2102, rainfall from the Helidon TM weather station (Station 040829)

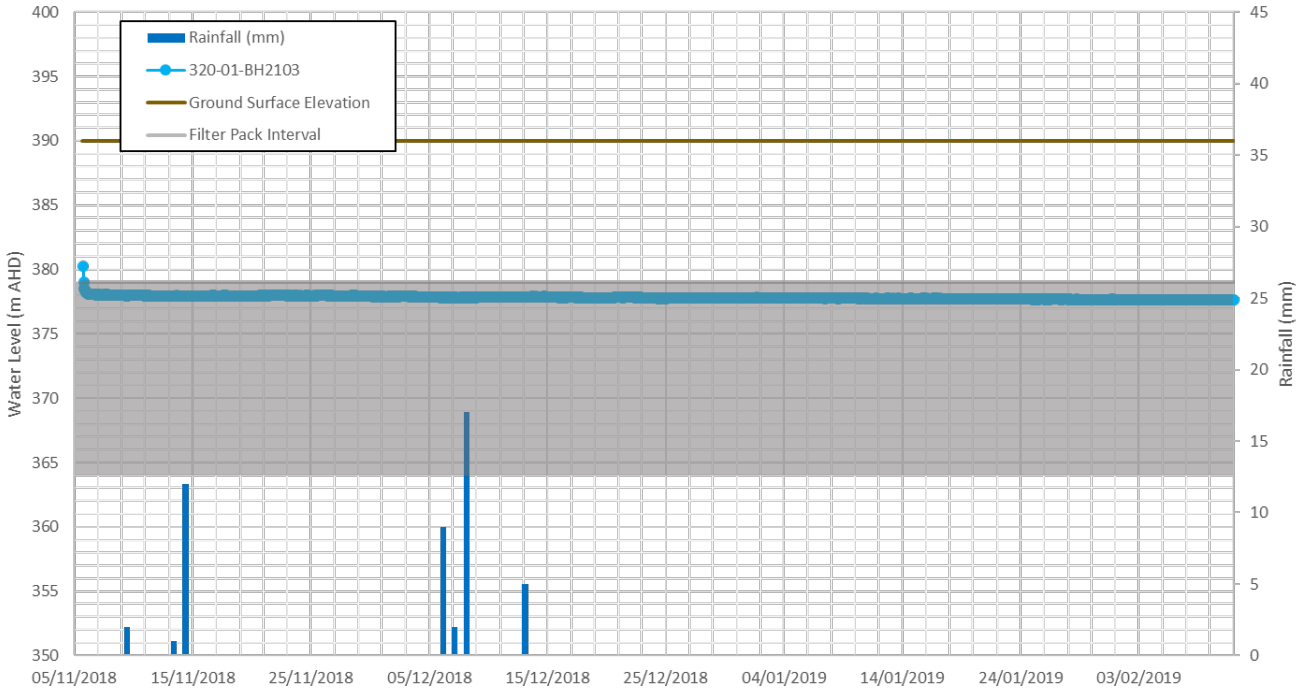


Figure A3: Hydrograph of 320-01-BH2103, rainfall from the Helidon TM weather station (Station 040829)

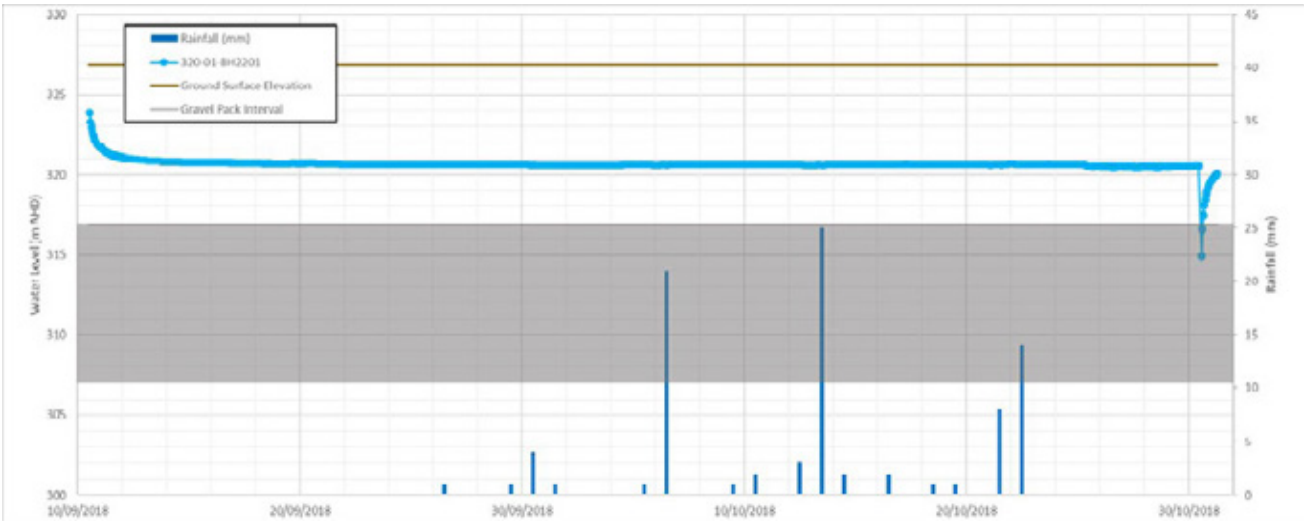


Figure A4: Hydrograph of 320-01-BH2201, rainfall from the Helidon TM weather station (Station 040829)

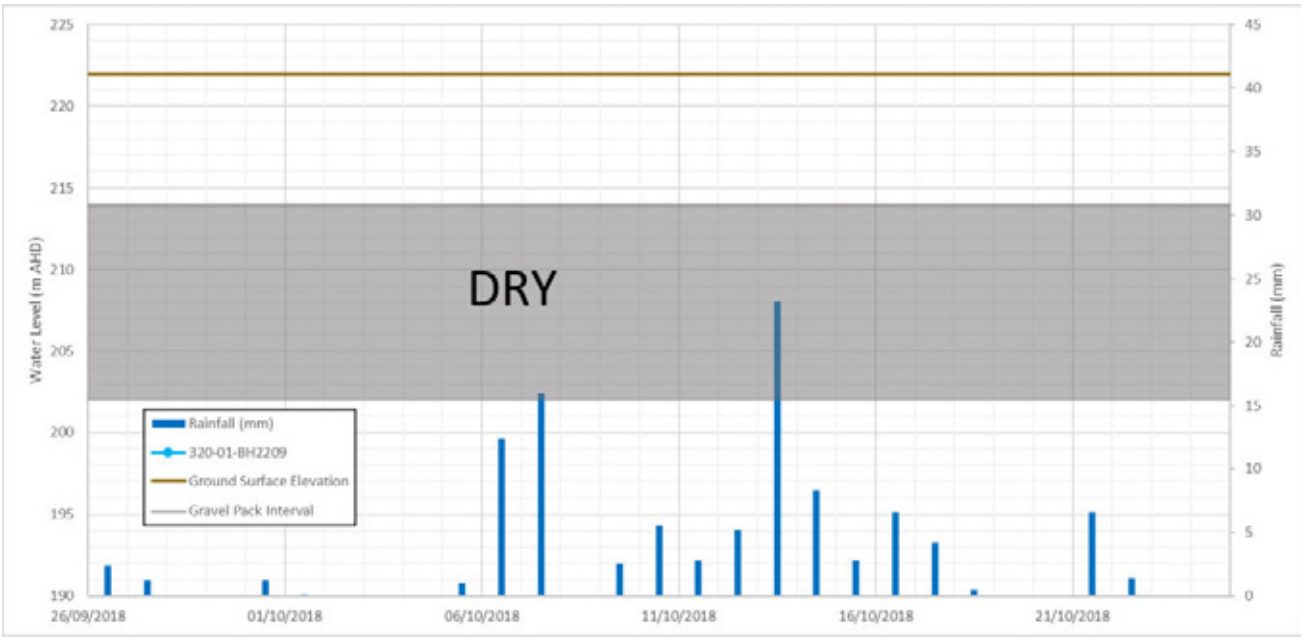


Figure A5: Hydrograph of 320-01-BH2209 (dry), rainfall from the Helidon TM weather station (Station 040829)

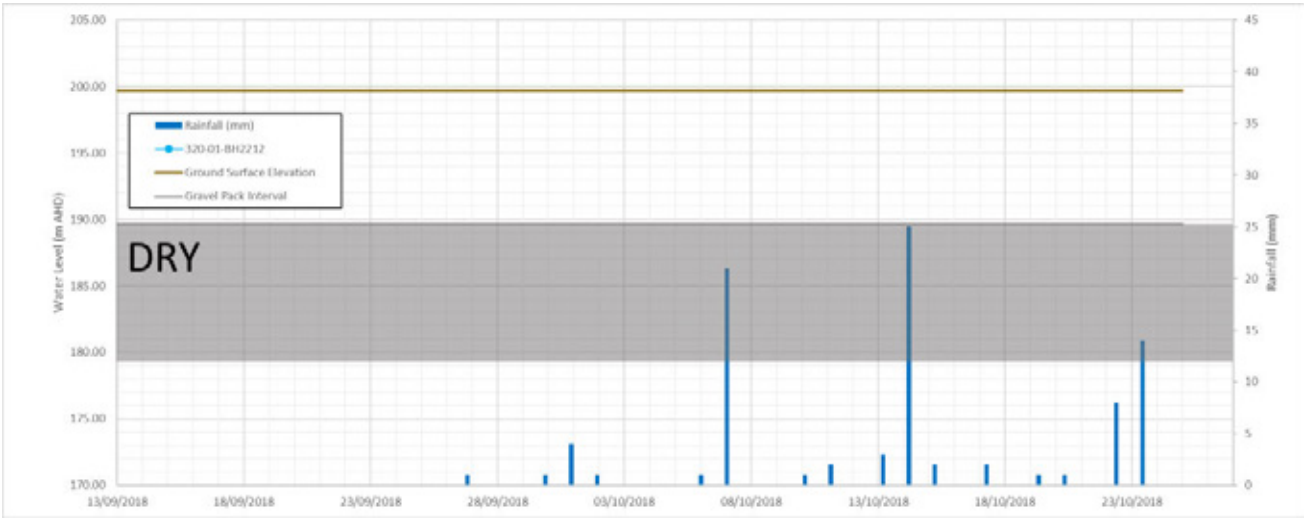


Figure A6: Hydrograph of 320-01-BH2212 (dry), rainfall from the Helidon TM weather station (Station 040829)

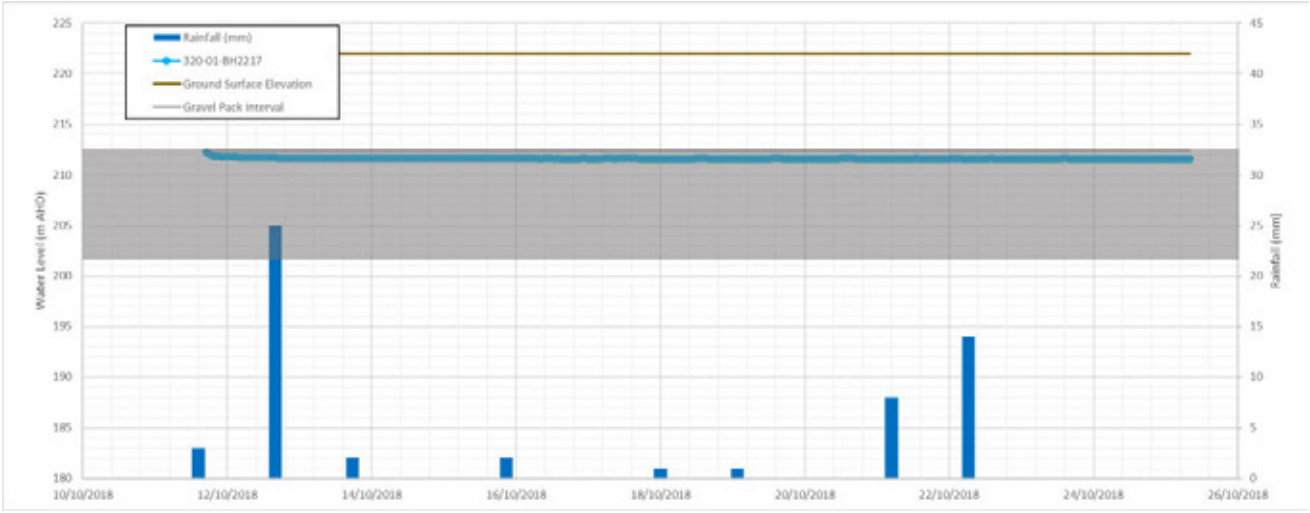


Figure A7: Hydrograph of 320-01-BH2217, rainfall from the Helidon TM weather station (Station 040829)

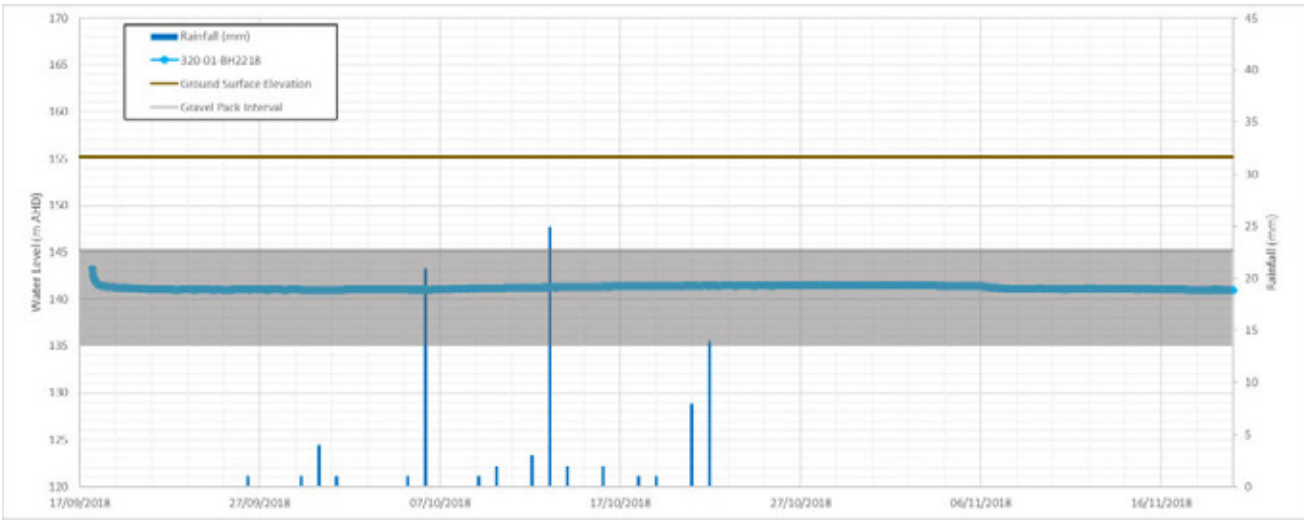


Figure A8: Hydrograph of 320-01-BH2218, rainfall from the Helidon TM weather station (Station 040829)

Appendix B
Groundwater level summary

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



Table B1: ***Groundwater levels*** statistics for 2018 investigation bores and registered ***groundwater*** bores (DNRME, 2018) within 500 m of the Project alignment

Bore ID	Formation	Groundwater Level (m AHD)						
		Date From	Date To	Min	Max	Median	Mean	Number of Measurements
320-01-BH2101	Koukandowie Formation	13/09/2018	11/02/2019	474.3	475	474.8	474.7	3619
320-01-BH2102	Main Range Volcanics	12/12/2018	01/29/2019	491.4	510.2	494.2	494.6	1159
320-01-BH2102	Main Range Volcanics	12/12/2018	01/29/2019	485.7	504.8	488.5	489.0	1159
320-01-BH2103	Koukandowie Formation	05/11/2018	11/20/2019	377.6	383.0	377.8	377.8	2347
320-01-BH2201	Koukandowie Formation	9/10/2018	10/31/2018	314.9	323.8	320.6	320.6	1217
320-01-BH2207	Koukandowie Formation	-	-	-	-	-	-	-
320-01-BH2209	Gatton Sandstone	9/27/2018	10/24/2018	DRY	DRY	DRY	DRY	976
320-01-BH2212[2]	Gatton Sandstone	9/13/2018	10/25/2018	DRY	DRY	DRY	DRY	1000
320-01-BH2215	Gatton Sandstone	10/31/2018	-	DRY	DRY	DRY	DRY	-
320-01-BH2216	Gatton Sandstone	-	-	-	-	-	-	-
320-01-BH2217	Gatton Sandstone	10/11/2018	10/25/2018	211.6	212.3	211.6	211.7	328
320-01-BH2218	Gatton Sandstone	9/17/2018	11/20/2018	140.9	143.2	141.1	141.2	1528
320-01-BH2301	Koukandowie Formation	-	-	-	-	-	-	-
DH1[3]	Walloon Coal Measures	Unknown	Unknown	479.3		-	-	1
DH2[3]	Main Range Volcanics	Unknown	Unknown	599.3		-	-	1

Bore ID	Formation	Groundwater Level (m AHD)						
		Date From	Date To	Min	Max	Median	Mean	Number of Measurements
DH3[3]	Main Range Volcanics	Unknown	Unknown	503.5		-	-	1
DH4[3]	Main Range Volcanics	Unknown	Unknown	539.0		-	-	1
DH5[3]	Koukandowie Formation	Unknown	Unknown	346.3		-	-	1
DH6[3]	Koukandowie Formation	Unknown	Unknown	397.5		-	-	1
DH7[3]	Main Range Volcanics	Unknown	Unknown	560.1		-	-	1
DH8[3]	Main Range Volcanics	Unknown	Unknown	471.6		-	-	1
DH9[3]	Main Range Volcanics	Unknown	Unknown	507.2		-	-	1
BH54[4]	Main Range Volcanics	Unknown	Unknown	539.0	549.0	-	-	Unknown
BH55[4]	Main Range Volcanics	Unknown	Unknown	568.0	589.0	-	-	Unknown
BH56[4]	Main Range Volcanics	Unknown	Unknown	547.0	559.0	-	-	Unknown
BH57[4]	Main Range Volcanics	Unknown	Unknown	602.0	631.0	-	-	Unknown
BH58[4]	Main Range Volcanics	Unknown	Unknown	582.0	585.0	-	-	Unknown
BH59[4]	Main Range Volcanics	Unknown	Unknown	570.0		-	-	1
BH101[4]	Main Range Volcanics	Unknown	Unknown	605.0	608.0	-	-	Unknown
BH103[4]	Main Range Volcanics	Unknown	Unknown	568.5		-	-	1
BH104A[4]	Main Range Volcanics	Unknown	Unknown	581.0	616.0	-	-	Unknown

Bore ID	Formation	Groundwater Level (m AHD)						
		Date From	Date To	Min	Max	Median	Mean	Number of Measurements
BH104B[4]	Main Range Volcanics	Unknown	Unknown	593.0		-	-	1
BH135[4]	Main Range Volcanics	Unknown	Unknown	585.0	590.0	-	-	Unknown
RN129229	Alluvium	12/17/2004	-	131.1		-	-	1
RN48325	Alluvium	2/9/1976	-	464.5		-	-	1
RN75178	Gatton Sandstone	3/1/1991	-	125.3		-	-	1
RN154480	Gatton Sandstone	8/15/2012	-	151.2		-	-	1
RN154773	Gatton Sandstone	12/10/2014	-	151.5		-	-	1
RN173167	Gatton Sandstone	6/9/2016	-	132.4		-	-	1
RN75357	Gatton Sandstone	7/27/1992	-	137.3		-	-	1
RN106891	Gatton Sandstone	11/1/2004	-	128.7		-	-	1
RN143273	Koukandowie Formation	1/11/2008	-	368.6		-	-	1
RN66497	Marburg Subgroup	5/23/1982	-	489.6		-	-	1
RN71234	Marburg Subgroup	5/29/1984	-	481.3		-	-	1
RN83537	Marburg Subgroup	11/8/1988	-	445.6		-	-	1
RN94001	Marburg Subgroup	5/11/1994	-	438.7		-	-	1
RN94161	Marburg Subgroup	8/25/1995	-	410.9		-	-	1

Bore ID	Formation	Groundwater Level (m AHD)						
		Date From	Date To	Min	Max	Median	Mean	Number of Measurements
RN106596	Marburg Subgroup	3/31/2004	-	310.9		-	-	1
RN31938	Main Range Volcanics	10/4/1970	-	445.6		-	-	1
RN34729	Main Range Volcanics	1/24/1970	-	480.9		-	-	1
RN38341	Main Range Volcanics	7/12/1972	-	510.7		-	-	1
RN48472	Main Range Volcanics	3/29/1976	-	514.2		-	-	1
RN48594	Main Range Volcanics	11/19/1976	-	466.7		-	-	1
RN56783	Main Range Volcanics	1/16/1980	-	469.5		-	-	1
RN64092	Main Range Volcanics	7/17/1982	-	446.5		-	-	1
RN64283	Main Range Volcanics	4/22/1983	-	436.0		-	-	1
RN64398	Main Range Volcanics	5/23/1982	-	473.2		-	-	1
RN83105	Main Range Volcanics	4/4/1987	-	469.5		-	-	1
RN94340	Main Range Volcanics	10/15/1996	-	455.2		-	-	1
RN107110	Main Range Volcanics	1/23/1998	-	524.8		-	-	1
RN107111	Main Range Volcanics	1/21/1998	-	522.1		-	-	1
RN55868	Unknown	1/1/1977	-	132.9		-	-	1
RN56363	Unknown	3/1/1979	-	129.7		-	-	1

Bore ID	Formation	Groundwater Level (m AHD)						
		Date From	Date To	Min	Max	Median	Mean	Number of Measurements
RN56751	Unknown	5/2/1980	-	463.6		-	-	1
RN14320949	Gatton Sandstone	9/28/2005	12/13/2017	148.7	151.0	150.4	151.0	38
RN119631	Main Range Volcanics	3/7/2007	2/29/2012	578.1	600.3	583.1	585.6	59
RN42230955	Main Range Volcanics	8/22/1975	12/7/2017	486.0	502.9	493.3	493.1	318
RN42231224	Main Range Volcanics	9/27/1979	4/8/2013	561.1	572.1	569.0	568.5	133
RN42231225	Main Range Volcanics	9/27/1979	12/7/2017	584.6	599.4	592.3	592.0	126
RN42231269	Main Range Volcanics	7/7/1982	12/7/2017	554.2	562.5	558.1	557.7	136
RN42231660	Main Range Volcanics	3/4/2008	12/11/2017	551.8	566.5	553.3	553.4	2935
RN42231662	Main Range Volcanics	3/4/2008	12/11/2017	471.1	490.7	472.6	472.4	3051

Note:

1 Surface elevations were used from LiDAR because survey data was not available at the time of reporting. ***Groundwater levels*** will be updated when this information is available. These bores are fitted with a data logger and the hydrographs will be updated during the 100% Hydrogeological Design Report.

2 Logger was installed above the water level at the base of the bore and therefore, statistics and a hydrograph cannot be created for this bore.

3 Data was obtained from 2019.

4 Data was obtained from 2019; however, no coordinates were available and therefore, these locations do not show up on Figure 8.

NR: No information was available from these bores during the preparation of this report. Data will be included in the 100% Hydrogeological Design Report.

Appendix C
Groundwater chemistry

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



RN	Easting	Northing	Latitude	Longitude	Sampled Date	DEPTH	Conductivity (uS/cm)	PH (pH Units)	Turbidity (NTU)	SIO2 (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	SAR	Total Ions (mg/L)	TDS (mg/L)	NA (mg/L)	K (mg/L)	CA (mg/L)	MG (mg/L)	FE (mg/L)	MN (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	CL (mg/L)	F (mg/L)	NO3 (mg/L)	SO4 (mg/L)	ZN (mg/L)	AL (mg/L)	B (mg/L)	CU (mg/L)	PO4 (mg/L)	Formation
14320189	4E+05	6950054	-27.57072316	152.13925	06-11-2001	19.88	1840	7.8	9999.9	22	307	485	7.3	1337.11	1061.21	292.1	6.9	51.1	43.6	0	0.01	586.3	2.9	316.8	0.64	1.8	35.1	0.12	0	0.08	0.01	N/A	ALLUVIUM
14320188	4E+05	6950381	-27.56778033	152.141313	06-11-2001	21.75	1051	7.4	1056	9	89	152	1.8	660.03	575.31	191.1	4.3	12.1	14.3	0	0.07	185.2	0.3	250.2	0.79	0.8	0.9	1.69	0	0.08	0.01	N/A	ALLUVIUM
106852	4E+05	6951895	-27.55340503	152.022379	17-03-1993	275	2010	7.1	133	N/A	54	1071	29.3	1974.63	1312.32	490	19	13	5	7.5	0.03	1303	1	135	N/A	0.1	1	N/A	N/A	N/A	N/A	N/A	HELIDON SANDSTONE
42230955	4E+05	6959566	-27.48304313	151.885247	21-10-2003	18	2880	7.2	56.7	42	877	455	3.2	1744.87	1505.83	216.2	13.2	87.6	160.1	0.01	0.53	553.1	0.8	708.6	0.13	0	5	0.01	0.01	0.01	0	N/A	MAIN RANGE VOLCANICS
14320850	4E+05	6951050	-27.56165489	152.1455	25-01-2002	N/A	361	7.1	9466	51	104	127	1.6	270.75	243.24	36.4	0.7	20.2	13.1	0	0	154.7	0.1	38.7	0.17	2.2	4.5	0.03	0.02	0.05	0.01	N/A	LOCKYER CREEK ALLUVIUM
14320851	4E+05	6950802	-27.5638827	152.143961	25-01-2002	N/A	1503	8	4814	44	445	299	3.1	989.75	851.3	149	2	84.2	57.2	0	0	359.3	2.6	296.7	0.32	15.9	22.5	0	0.01	0.04	0.01	N/A	LOCKYER CREEK ALLUVIUM
14320852	4E+05	6950363	-27.56794183	152.141177	25-01-2002	N/A	1317	8.4	1140	36	206	431	6.9	1002.14	779.86	226.4	4	28.5	32.9	0	0.01	508.7	8.4	177.8	0.7	0	14.7	0.01	0.01	0.09	0.03	N/A	LOCKYER CREEK ALLUVIUM
14320853	4E+05	6950031	-27.57092642	152.139071	28-01-2002	N/A	1619	8.3	5.8	46	291	449	6.4	1165.14	940.34	250.9	9.3	31.6	51.6	0	0	532.4	7.4	259	0.27	0	22.6	0	0.02	0.11	0.05	N/A	LOCKYER CREEK ALLUVIUM
14320854	4E+05	6949823	-27.57280451	152.137219	07-03-2002	N/A	2643	7.6	9999	22	339	510	10.6	1784.8	1492.7	449.8	18	52.8	50.4	0	0	617.8	2.1	581.2	0.52	0	12.3	0.01	0	0.19	0.01	N/A	LOCKYER CREEK ALLUVIUM
42230955	4E+05	6959566	-27.48304313	151.885247	29-10-2007	N/A	2010	7.7	4	35	879	549	1.7	1450	1140	114	1.7	113	145	0.01	0.05	666	1.8	355	0.12	13	36	0.01	0.05	0.03	0.03	N/A	MAIN RANGE VOLCANICS
106551	4E+05	6951174	-27.5605785	152.133995	11-12-2006	N/A	1020	7.2	332	29	235	122	3.1	591	545	109	2.7	36	35	0.01	0.01	149	0.1	237	0.16	2.8	19.1	0.02	0.05	0.05	0.03	N/A	HELIDON SANDSTONE
14320948	4E+05	6950354	-27.5677181	152.092686	28-07-2005	10.5	2850	8.1	N/A	N/A	323	1257	15	2707.39	1929.69	620	5	50.2	47.8	N/A	N/A	1530	1	311	0.89	1	140	N/A	N/A	N/A	0.5	N/A	GATTON SANDSTONE
14320949	4E+05	6953186	-27.5421352	152.08997	28-07-2005	13.8	2450	8.7	N/A	N/A	111	1024	23.7	2090.74	1501.11	572	15	7.8	22	N/A	N/A	1160	43	261	2.04	0.4	7	N/A	N/A	N/A	0.5	N/A	GATTON SANDSTONE
42230955	4E+05	6959566	-27.48304313	151.885247	31-10-2005	13	2160	7.6	1	38	929	534	1.6	1490	1200	111	1.7	122	152	0.01	0.08	646	2.4	396	0.1	14	43	0.01	0.05	0.04	0.03	N/A	MAIN RANGE VOLCANICS
14320950	4E+05	6952517	-27.5484539	152.133711	29-07-2005	22.2	1000	7.2	N/A	N/A	163	50	4.1	513.02	483.54	119	6	20.8	26.9	N/A	N/A	58	1	253	0.02	0.1	27.7	N/A	N/A	N/A	0.5	GATTON SANDSTONE
42230955	4E+05	6959566	-27.48304313	151.885247	06-09-2006	N/A	443	8.3	1	18	7	59	14	258	241	85	0.4	2.3	0.3	0.01	0.03	69	1.2	89	0.1	0.5	11.7	0.01	0.05	0	0.03	N/A	MAIN RANGE VOLCANICS
42230955	4E+05	6959566	-27.48304313	151.885247	06-09-2006	15	2140	7.9	1	37	898	539	1.6	1470	1170	110	1.8	116	148	0.01	0.07	653	2.5	380	0.2	13	42	0.04	0.05	0.02	0.03	N/A	MAIN RANGE VOLCANICS
42230955	4E+05	6959566	-27.48304313	151.885247	02-11-2004	15	2720	7.7	2	40	1151	600	1.9	1832.57	1503.54	147	2.2	136	197	0.01	0.06	726	2.4	572	0.1	2.7	47	0.01	0.05	0.01	0.03	N/A	MAIN RANGE VOLCANICS
129870	4E+05	6951669	-27.555729	152.074262	03-05-2007	N/A	2470	7.4	5	13	72	1140	29	2170	1490	563	24	20	5.7	0.01	0.01	1380	1.7	176	1.5	2.5	10	1.9	0.05	0.38	0.03	N/A	GATTON SANDSTONE
61258	4E+05	6959547	-27.48340916	151.909394	23-10-2008	N/A	1070	8.3	1	41	256	345	3.9	804	636	144	1.5	48	33	0.01	0.01	411	4.9	131	0.08	0.5	30	0.01	0.05	0.06	0.03	N/A	MAIN RANGE VOLCANICS
83111	4E+05	6953893	-27.53465128	151.935772	15-05-1993	51	445	7.7	N/A	67	109	96	1.7	278.89	286.42	40.7	3	17.9	15.7	0	0.01	116.8	0.4	75.9	0.01	7.4	1.1	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
87818	4E+05	6958386	-27.49317739	151.886965	01-07-1994	74	875	8.1	N/A	17	286	321	1.7	653.08	474.88	64.4	9.1	69	27.7	0	0.01	384.8	3.2	85.7	0.12	0.8	8.3	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
14320894	4E+05	6959013	-27.48943805	152.076189	05-07-2011	N/A	958	7.1	1	13	188	252	4	661	518	127	7.8	32	26	0.01	0.16	307	0.3	140	0.16	0.5	17.5	0.01	0.05	0.04	0.03	N/A	WOOGAROO SUBGROUP
42231225	4E+05	6960801	-27.47235745	151.943778	24-05-2012	70	1120	6.3	3	77	147	44	5.1	538	589	141	6.4	17	25	0.01	0.34	53	0	290	0.08	1	4	0.07	0.05	0.03	0.03	N/A	MAIN RANGE VOLCANICS
48481	4E+05	6952893	-27.54174535	151.899975	18-02-1976	38	1050	8.4	N/A	N/A	164	230	5.4	706.3	0	158	1.6	46	12	N/A	N/A	271	4.5	180	0.2	0	33	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48491	4E+05	6959146	-27.48674264	151.873029	23-03-1976	60	1750	7.4	N/A	8	483	245	3.6	1081.8	938.33	180	3	63	79	N/A	N/A	298	0.5	360	0.3	49	49	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48505	4E+05	6960146	-27.47790289	151.896291	30-11-1976	181	2010	7.7	N/A	34	733	285	2.1	1213.3	1071.94	133	6	117	107	N/A	N/A	345	1.3	485	0	4	15	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56783	4E+05	6957937	-27.49776844	151.88739	19-01-1980	24	1200	8	N/A	N/A	446	440	1.8	906.1	0	88	3.5	55	75	N/A	N/A	529	3.5	132	0.1	12	8	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
64806	4E+05	6954909	-27.5255556	151.945278	11-03-1983	75	1150	7.8	N/A	67	453	153	1.2	721.5	694.46	61	3.5	81	61	N/A	N/A	185	0.8	290	0.2	37	2	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
64815	4E+05	6961347	-27.46711847	151.903851	22-04-1983	41	2150	7.6	N/A	50	908	717	1.9	1616.6	1224.38	130	3	100	160	N/A	N/A	870	2.3	335	0.3	4	12	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
64815	4E+05	6961347	-27.46711847	151.903851	22-08-1988	51	2200	7.9	N/A	52	970	710	1.7	1650	1270	125	2.2	100	175	0.05	0.01	850	6.3	375	0.4	5.1	7.6	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
83213	4E+05	6959829	-27.47924546	151.914141	22-02-1922	0	850	7.7	N/A	5	145	66	3.8	480	440	105	8.9	40	11	0	0	80	0.2	215	0.1	0	17	N/A	N/A	N/A	N/A	0	MAIN RANGE VOLCANICS
83213	4E+05	6959829	-27.47924546	151.914141	22-05-1987	N/A	850	7.7	N/A	5	145	66	3.8	477.72	442.06	105	8.9	40	11	0.01	0.01	80	0.2	215	0.1	0.5	17	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
83266	4E+05	6959765	-27.48106475	151.861834	15-07-1987	160	1600	7.9	N/A	14	156	100	9.2	900.6	853.6	265	3.3	51	7	0	0	120	0.7	450	0.1	0.2	3.3	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
52658	4E+05	6952549	-27.54652759	151.902898	01-03-1977	52	425	7.5	N/A	N/A	18	118	80	1.3	260.6	229.29	33	0.4	29	11	N/A	N/A	97	0.1	70	0.1	10	10	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52661	4E+05	6952244	-27.54021507	151.897793	01-03-1977	31	1250	7.8	N/A	N/A	60	491	240	1.1	760.2	672.79	58	3	86	67	N/A	N/A	290	1.1	244	0.1	11	0	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52665	4E+05	6953677	-27.5363296	151.901057	02-03-1977	67	1040	8.3	N/A	N/A	12	37	40	12.8	510	497.6	178	0.8	14	0.4	N/A	N/A	48	0.6	268	0.2	0	0	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52673	4E+05	6958977	-27.48792145	151.830712	27-02-1978	N/A	920	7.5	N/A	N/A	20	112	298	6.5	693.5	529.5	158	1.5	30	9	N/A	N/A	362	0.7	120	0.2	2.1	10	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
83298	4E+05	6959174	-27.48622137	151.840852	20-03-1991	38	4110	8	N/A	N/A	21	1655	304	2.4	2367.62	2203.82	224	3.6	116	332	0	0	363.8	3.5	1226	0.17	0	98.6	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52715	4E+05	6959868	-27.47813504	151.822476	06-08-1976	50	1950	8.2	N/A	N/A	64	570	187	3.3	1161	1112.16	182	7	167	37	N/A	N/A	222	2.8	480	0.2	8	55	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52778	4E+05	6953355	-27.53921411	151.897858	31-07-1977	50	2250	7.7	N/A	N/A	N/A	789	330	2.1	1298.6	0	138	2	138	108	N/A	N/A	399	1.6	490	N/A	17	5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
83445	4E+05	6958809	-27.48992864	151.891459	04-12-1987	51	740	8.4	N/A	N/A	12	158	229	3.1	521.12	395.88	89	12	7.2	34	0.01	0.01	270	4.8	99	0.1	0.5	4.5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
83494	4E+05	6955192	-27.52063466	151.857475	29-09-1988	N/A	440	7	N/A	N/A	30	49	81	4.4	274.97	254.65	71	0.7	7.2	7.6	0.07	0.1	99	0.1	86	0.2	0.5	2.5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61232	4E+05	6961172	-27.46832549	151.857543	05-11-1980	N/A	1550	8.2	N/A	N/A	12	174	155	8.1	904.1	822.06	244	3	53	10	N/A	N/A	185	2	375	0.1	5	27	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61232	4E+05	6961172	-27.46832549	151.857543	05-11-1980	N/A	2000	8.2	N/A	N/A	12	266	150	8	1165.7	1086.71	300	4.5	80	16	N/A	N/A	179	2.1	535	0.1	7	42	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61232	4E+05	6961172	-27.46832549	151.857543	01-11-1982	N/A	3800	7.5	N/A	N/A	13	703	44	8.4	2149.3	2135.36	510	6	245	22	N/A	N/A	53	0.2	1250	0.1	2	61	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61232	4E+05	6961172	-27.46832549	151.857543	17-10-1986	170	2500	8	N/A	N/A	13	399	96	7.7	1393.93	1348.48	355	4.2	140	12	0.03	1.7	115	1	710	0	0	55	N/A	N/A	N/A	N/A	0	MAIN RANGE VOLCANICS
61232	4E+05	6961172	-27.46832549	151.857543	16-03-1988	181	3100	7.6	N/A	N/A	13	487	63	8.4	1687.76	1662.13	425	4.8	170	15	0.04	0.02	76	0.3	950	0.1	0.5	46	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61258	4E+05	6959547	-27.48340916	151.909394	18-12-1980	N/A	4650	7.9	N/A	N/A	44	1949	362	2.4	2761.1	2580.94	246	4	174	368	N/A	N/A	441	0	1420	0.1	8	100	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
66497	4E+05	6957600	-27.5009282	151.90213	24-11-1983	N/A	1550	8	N/A	N/A	39	612	412	1.4	1050.24	837.63	81	2.4	110	82	0.03	0.01	495	3.7	235	0.1	21	20	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66540	4E+05	6950721	-27.56174486	151.95053	18-07-1985	26	N/A	7.1	N/A	N/A	0	209	151	1.4	427	333.43	48	2.5	40.8	26.1	0	0	184.1	0	108	0	17.5	0	N/A	N/A	N/A	0	N/A	MAIN RANGE VOLCANICS
83696	4E+05	6960291	-27.47660724	151.897978	22-01-1989	33	1400	8	N/A	N/A	58	660	500	0.9	1070	820	56	1.6	83	110	0.05	0.17	600	4.9	185	0.2	19.5	9.6	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
83740	4E+05	6955391	-27.52086828	151.902249	23-04-1989	N/A	2750	7.9	N/A	N/A	N/A	1050	350	2	1740	1530	150	5.1	105	195	0.02	0.08	420	2.7	640	0.1	145	79	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
86569	4E+05	6956708	-27.51756285	151.894179	06-10-1989	N/A	1350	8.2	N/A	N/A	25	649	496	1.1	1101.12	826.22	62	1.1	87	105	0.01	0.01	590	7.3	175	0.2	39.5	34	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61411	4E+05	6955676	-27.51843788	151.920358	19-12-1980	N/A	790	7.6	N/A	N/A	12	225	110	1.7	451.4	395.8	60	3	34	34	N/A	N/A	133	0.3	182	0.1	0	5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61456	4E+05	6955929	-27.51567318	151.859521	30-03-1981	73	7520	7.6	N/A	N/A	40	745	219	21.4	4431.3	4338.13	1340	15	150	90	N/A	N/A	262	2.3	2520	0	1	51	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61456	4E+05	6955929	-27.51567318	151.859521	08-03-1984	27	1300	8	N/A	N/A	31	553	507	1.4	1018.43	739.37	78	1	70	92	0.02	0.01	610	4.3	140	0.2	1.9	21	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61456	4E+05	6955929	-27.51567318	151.859521	08-03-1984	27	1300	8	N/A	N/A	31	553	507	1.5	1017.57	738.51	79	1	70	92	0.01	0.26	610	4.3	140	0.2	1.8	19	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61504	4E+05	6958222	-27.49341239	151.874697	06-05-1981	77	1060	7.9	N/A	N/A	17	404	444	1.5	841.5	586.05	68	7.5	76	52	N/A	N/A	536	2.7	90	0.3	0	9	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
55004	4E+05	6953625	-27.53674184	151.893198	11-05-1982	69	2200	7.9	N/A	N/A	750	564	3.2	1595.7	0	200	1.5	86	130	N/A	N/A	N/A	680	4	450	0.2	4	40	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
55026	4E+05	6962333	-27.45785141	151.858417	04-04-1978	N/A	1750	7.9	N/A	N/A	14	318	245	5.1	1020.7	0	211	6	40	53	N/A	N/A	295	1.6	360	0.1	N/A	54	N/A	N/A	N/A	N/A	N/A	WALLOON COAL MEASURES
66613	4E+05	6958911	-27.4890106	151.891011	28-03-1984	49	1150	8.8	N/A	N/A	32	463	374	1.7	858.94	677.46	82	2.7	4.1	110	0.03	0.01	420	18	185	0.1	12	25	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
86819	4E+05	6956740	-27.50822392	151.843776	01-06-1990	76	902	8.3	N/A	N/A	41	376	328	1.6	730.05	573.24	70	0.3	42	66	0	0	389.2	5.4	80	0.31	0.9	76	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
66723	4E+05	6952917	-27.54350138	151.940326	27-07-1984	40	700	7.1	N/A	N/A	24	208	86	1.4	454.81	425.44	45	11	35.5	29	0.1	0.01	105	0.1	87	0.1	125	17	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
66749	4E+05	6955632	-27.51886071	151.923104	02-05-1986	1360	930	8.5	N/A	N/A	18	162	197	4.6	612.41	513.5	135	2.5	35	18	0.01	0	230	5	175	0.1	0.8	11	N/A	N/A	N/A	N/A	0	MARBURG SUBGROUP
86912	4E+05	6959416	-27.48412746	151.851913	04-06-1991	N/A	791	8.1	N/A	N/A	11	41	157	10.8	533.03	448.22	159	2.6	9.7	4	0.01	0	188.5	1.5	159	0.12	0	8.6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61677	4E+05	6959156	-27.48639711	151.865061	31-11-1981	35	1670	8.4	N/A	N/A	32	352	478	5.1	1175.3	921.64	218	1.1	29	68	N/A	N/A	562	10	250	0.3	0	37	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
61690	4E+05	6960875	-27.46980102	151.919141	01-02-1983	28	3400	7.8	N/A	N/A	71	1376	344	2.2	2074.4	1934.46	190	3	205	210	N/A	N/A	415	2.3	980	0.1	13	56	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
71039	4E+05	6959405	-27.4825792	151.86053	27-07-1984	57	1500	7.8	N/A	N/A	131	31	8.9	789.22	0	235	2.5	45	4.5	0.01	0.01	37.5	0.2	435	0.5	0.5	28.5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
71039	4E+05	6959405	-27.4825792	151.86053	28-02-1986	59	1500	7.8	N/A	5	130	31	8.9	790	770	235	2.5	45	4.5	0	0	37.5	0.2	435	0.5	0	28.5	N/A	N/A	N/A	N/A	0	MAIN RANGE VOLCANICS
71045	4E+05	6951125	-27.5597962	151.956051	04-02-1986	23	770	8.3	N/A	52	256	139	0.9	447.32	415.45	32	2.7	45	35	0.02	0	165	2	110	0	50	5.6	N/A	N/A	N/A	N/A	0	MAIN RANGE VOLCANICS
87063	4E+05	6958509	-27.49245387	151.879047	06-04-1994	32	720	8	N/A	N/A	17	105	108	4.2	440.27	391.19	100	3.9	33	5.5	0.02	0.05	130	0.7	150	0.1	0.5	16.5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
64075	4E+05	6958271	-27.49481552	151.895362	04-10-1983	39	1450	7.8	N/A	N/A	22	584	472	1.6	1032.52	764.79	88	2	69	100	0.11	0.01	570	2.9	190	0.2	0.5	9.8	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
64098	4E+05	6955278	-27.5222222	151.944444	29-03-1982	82	1800	7.6	N/A	N/A	55	1025	466	2.5	2207.42	1982.86	215	1.6	200	220	0.1	0.02	550	9	990	0.2	1	20.5	N/A	N/A	N/A	N/A	N/A	BASALT DETRITUS
71129	4E+05	6960875	-27.47105993	151.864068	13-11-1985	158	1000	8.3	N/A	N/A	12	105	220	7	670	550	165	6	32	6	0	0	260	3.6	185	0.1	0	8.5	N/A	N/A	N/A	N/A	0	WALLOON COAL MEASURES
87550	4E+05	6959151	-27.48079539	151.908574	14-08-1992	53	3750	8.3	N/A	N/A	N/A	1405	466	2.5	2207.42	1982.86	215	1.6	200	220	0.1	0.02	550	9	990	0.2	1	20.5	N/A	N/A	N/A	N/A	N/A	BASALT DETRITUS
64157	4E+05	6957665	-27.49978465	151.833842	03-05-1982	49	1100	8.1	N/A	N/A	9	27	69	18.4	648.7	615.52	220	1.5	10	0.5	N/A	N/A	83	0.6	250	0.1	38	45	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
87642	4E+05	6954596	-27.52758145	151.844766	12-04-1994	N/A	870	8.1	N/A	N/A	41	33	150	13.7	585.44	534.95	180	1	11.5	1	0.02	0.02	180	1.3	145	0.1	0.5	65	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
87767	4E+05	6959881	-27.47988841	151.846434	15-05-1993	163	820	8.4	N/A	N/A	11	20	182	16.1	548.07	449.79	165	1.8	6.5	0.9	0.02	0.05	215	3.6	150	0.2	0.5	4.5	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
71372	4E+05	6961918	-27.46155521	151.853293	20-12-1985	220	1500	8.4	N/A	N/A	10	137	149	9.1	874.82	795.87	245	4.2	39	9.6	0.02	0	175	3	385	0.1	1.9	12	N/A	N/A	N/A	N/A	0	MARBURG SUBGROUP
64283	4E+05	6958577	-27.49157902	151.836726	04-08-1982	56	810	7.8	N/A	N/A	24	94	223	6.3	565.8	452.56	140	1.8	13	15	N/A	N/A	270	1.1	115	0.1	6.1	3.7	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
64286	4E+05	6952757	-27.54438067	151.869122	16-09-1982	N/A	1700	7.8	N/A	N/A	27	102	215	13.1	1026.4	921.25	305	2	36	3	N/A	N/A	260	1.3	395	0.1	0	24	N/A	N/A	N/A	N/A	N/

RN	Easting	Northing	Latitude	Longitude	Sampled Date	DEPTH	Conductivity (uS/cm)	PH (pH Units)	Turbidity (NTU)	SIO2 (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	SAR	Total Ions (mg/L)	TDS (mg/L)	NA (mg/L)	K (mg/L)	CA (mg/L)	MG (mg/L)	FE (mg/L)	MN (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	CL (mg/L)	F (mg/L)	NO3 (mg/L)	SO4 (mg/L)	ZN (mg/L)	AL (mg/L)	B (mg/L)	CU (mg/L)	PO4 (mg/L)	Formation
56370	4E+05	6954246	-27.53245871	152.080594	20-02-1979	N/A	2060	8.2	N/A	11	94	1039	22.6	1949.1	1329.81	505	18	18	12	N/A	N/A	1240	13	140	1.4	1.7	0	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56370	4E+05	6954246	-27.53245871	152.080594	18-09-1980	14	2200	7.9	N/A	13	80	980	24.4	1868.6	1281.81	501	18	17	9	N/A	N/A	1180	7.2	124	1.4	1	10	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56370	4E+05	6954246	-27.53245871	152.080594	09-06-1982	13	2200	7.7	N/A	14	99	1033	21.8	1967.1	1345.73	500	17	20	12	N/A	N/A	1250	4.6	135	1.5	2	25	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56371	4E+05	6954058	-27.53419345	152.075234	20-02-1979	N/A	2150	8.2	N/A	8	84	1047	24.5	1977	1349.63	516	19	17	10	N/A	N/A	1250	13	148	0.8	1.2	2	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56371	4E+05	6954058	-27.53419345	152.075214	18-09-1980	74	2300	8.1	N/A	15	133	1053	18.6	1984.8	1359.34	495	19	32	13	N/A	N/A	1260	12	144	0.8	1	8	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56373	4E+05	6954361	-27.53127476	152.068669	22-10-1980	24	4000	7.3	N/A	10	282	1078	21.1	2963	2307.13	814	36	60	32	N/A	N/A	1310	2.3	698	0.7	2	8	N/A	N/A	N/A	N/A	N/A	HEUDON SST FORM
56373	4E+05	6954361	-27.53127476	152.068669	21-02-1979	18	2080	8.6	N/A	14	61	949	28.8	1857.9	1312.77	518	13	8	10	N/A	N/A	1100	28	175	0.3	0.6	5	N/A	N/A	N/A	N/A	N/A	HEUDON SST FORM
56373	4E+05	6954361	-27.53127476	152.068669	09-06-1982	24	2300	7.8	N/A	18	124	993	19.9	1999.1	1407.14	510	15	30	12	N/A	N/A	1200	5.6	190	0.5	2	34	N/A	N/A	N/A	N/A	N/A	HEUDON SST FORM
56374	4E+05	6955755	-27.5189014	152.08215	15-10-1980	11	2260	8.2	N/A	14	85	1017	24.5	1970	1368.96	520	19	21	8	N/A	N/A	1210	15	165	1	4	7	N/A	N/A	N/A	N/A	N/A	
56374	4E+05	6955755	-27.5189014	152.08215	15-06-1982	18	2350	8.1	N/A	16	109	1002	21.6	1996.2	1402.24	520	20	24	12	N/A	N/A	1200	11	170	1.2	6	32	N/A	N/A	N/A	N/A	N/A	
56376	4E+05	6956950	-27.50805556	152.074722	22-02-1979	N/A	3850	7.5	N/A	8	233	997	22.9	2900.6	2293.56	804	33	44	30	N/A	N/A	1210	2.8	750	0.7	1.1	25	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56376	4E+05	6956950	-27.50805556	152.074722	09-10-1980	N/A	4000	7.5	N/A	9	252	1072	22.8	2962.2	2310.41	832	34	48	32	N/A	N/A	1300	3.5	700	0.7	3	9	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56376	4E+05	6956950	-27.50805556	152.074722	09-06-1982	N/A	3800	8.2	N/A	14	160	1053	28.2	2872.2	2250.83	820	31	18	28	N/A	N/A	1250	16.5	700	0.7	2	6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
56379	4E+05	6957529	-27.50277778	152.067222	22-02-1979	N/A	3690	7.7	N/A	10	222	1000	24	2855.6	2250.56	820	36	36	32	N/A	N/A	1210	4.4	710	0.7	3.5	3	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56379	4E+05	6957529	-27.50277778	152.067222	09-10-1980	N/A	2400	7.9	N/A	19	114	996	20.7	1981.7	1390.74	507	12	29	10	N/A	N/A	1200	7.4	205	0.3	1	10	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56379	4E+05	6957529	-27.50277778	152.067222	10-06-1981	64	4150	7	N/A	13	400	1224	17.8	3186.9	2442.53	816	34	104	34	N/A	N/A	1490	1.2	700	0.7	0	7	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56379	4E+05	6957529	-27.50277778	152.067222	09-06-1982	N/A	4000	7.4	N/A	15	378	1236	17.9	3172.9	2425.45	800	36	105	28	N/A	N/A	1500	3.3	690	0.6	5	5	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56382	4E+05	6957075	-27.50841145	152.056599	22-02-1979	N/A	2000	7.7	N/A	15	414	445	5.7	1362	1103.03	265	6	80	52	N/A	N/A	539	1.7	408	0.1	0.2	10	N/A	N/A	N/A	N/A	N/A	HEUDON SANDSTONE
56382	4E+05	6957075	-27.50841145	152.056599	11-06-1981	N/A	1900	7.9	N/A	25	327	437	6.5	1261.5	1018.63	270	5.5	60	43	N/A	N/A	527	2.8	343	0.2	0	10	N/A	N/A	N/A	N/A	N/A	HEUDON SANDSTONE
56382	4E+05	6957075	-27.50841145	152.056599	09-06-1982	N/A	2100	7.6	N/A	26	506	553	5	1518.3	1203.74	260	4	120	50	N/A	N/A	670	1.9	380	0.4	2	30	N/A	N/A	N/A	N/A	N/A	HEUDON SANDSTONE
56383	4E+05	6958442	-27.49621015	152.077747	22-02-1979	24	980	8.1	N/A	10	217	280	3.9	728.2	567.41	133	8.5	39	29	N/A	N/A	336	2.5	160	0.2	0	20	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56383	4E+05	6958442	-27.49621015	152.077747	25-09-1980	9	1010	7.5	N/A	12	206	268	4	691.4	538.2	133	8.5	38	27	N/A	N/A	325	0.7	141	0.2	0	18	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56383	4E+05	6958442	-27.49621015	152.077747	09-06-1982	9	1050	7.5	N/A	13	213	284	4	729.5	567.14	135	7.5	36	30	N/A	N/A	345	0.7	160	0.3	1	14	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
56386	4E+05	6954179	-27.53293422	152.07249	23-02-1979	8	1680	7.9	N/A	12	576	205	2.2	980.9	866.84	119	1.5	79	92	N/A	N/A	248	1.1	430	0.1	4.2	6	N/A	N/A	N/A	N/A	N/A	ROCKY CREEK ALLUVIUM
56386	4E+05	6954179	-27.53293422	152.07249	25-09-1980	61	2300	8.1	N/A	15	207	886	13.8	1817.9	1294.1	456	17	35	29	N/A	N/A	1060	10	202	0.9	2	6	N/A	N/A	N/A	N/A	N/A	ROCKY CREEK ALLUVIUM
56386	4E+05	6954179	-27.53293422	152.07249	09-06-1982	61	1500	7.9	N/A	28	471	369	2.8	1021.7	823.51	140	1	65	75	N/A	N/A	445	2.4	280	0.3	2	11	N/A	N/A	N/A	N/A	N/A	ROCKY CREEK ALLUVIUM
61001	4E+05	6951461	-27.55758809	152.059125	30-11-1982	14	3200	7.9	N/A	34	816	458	5.7	2009	1763.44	375	1.1	96	140	N/A	N/A	550	4	750	0.4	0.5	92	N/A	N/A	N/A	N/A	N/A	MONKEY WATER HOLES CREEK ALLUVIUM
61002	4E+05	6951556	-27.55679514	152.062431	24-03-1980	17	3150	7.9	N/A	35	863	530	5.5	2077.6	1787.29	369	2	110	143	N/A	N/A	640	3.3	710	0.3	0	100	N/A	N/A	N/A	N/A	N/A	MONKEY WATER HOLES CREEK ALLUVIUM
61002	4E+05	6951556	-27.55679514	152.062431	25-03-1980	17	3100	7.8	N/A	36	833	530	5.5	2056.2	1766.89	367	2	106	138	N/A	N/A	640	2.9	700	0.3	0	100	N/A	N/A	N/A	N/A	N/A	MONKEY WATER HOLES CREEK ALLUVIUM
61002	4E+05	6951556	-27.55679514	152.062431	13-05-1980	17	3400	7.3	N/A	47	1153	505	3.8	2216.3	1951.2	300	1	152	188	N/A	N/A	614	0.9	860	0.3	0.1	100	N/A	N/A	N/A	N/A	N/A	MONKEY WATER HOLES CREEK ALLUVIUM
61203	4E+05	6951492	-27.55694241	152.018882	30-09-1980	21	1700	7.7	N/A	30	103	517	14.9	1262.4	974.2	348	4	15	16	N/A	N/A	626	2.2	225	0.2	0	26	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61314	4E+05	6958683	-27.49162381	151.968547	05-12-1980	N/A	1050	7.6	N/A	49	347	314	1.9	741	596.34	81	4	55	51	N/A	N/A	381	0.9	155	0.1	0	13	N/A	N/A	N/A	N/A	N/A	BASALT
61390	4E+05	6949853	-27.57240859	152.119247	09-09-1980	46	9600	7.7	N/A	26	961	1033	29.3	6408.9	5794.44	2090	8.5	80	185	N/A	N/A	1260	0	2680	0.4	20	85	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
61390	4E+05	6949853	-27.57240859	152.119247	11-06-1982	46	8500	7.7	N/A	30	842	1285	25.5	5988.9	5231.04	1700	25	90	150	N/A	N/A	1550	8.3	2350	0.6	25	90	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
61391	4E+05	6949062	-27.57952897	152.116767	09-09-1980	N/A	7100	7.4	N/A	37	1572	476	10	4170.3	3912.49	915	20	135	300	N/A	N/A	580	0	1970	0.3	70	180	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
61391	4E+05	6949062	-27.57952897	152.116767	21-08-1982	N/A	7200	7.4	N/A	40	1759	767	10.2	4812.9	4380.18	980	15	210	300	N/A	N/A	930	2.5	2100	0.4	65	210	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61409	4E+05	6958948	-27.49150611	152.05774	10-01-1991	9	1450	8.3	N/A	33	601	600	1.8	1170.1	842.21	100	3.1	89	92	N/A	N/A	710	10.5	160	0.2	1.2	4.1	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61399	4E+05	6952072	-27.55219341	152.095067	24-09-1980	27	2800	8	N/A	12	114	1166	25.2	2313.6	1613.98	620	26	26	12	N/A	N/A	1400	11	209	1.6	1	7	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61399	4E+05	6952072	-27.55219341	152.095067	09-06-1982	27	2600	7.6	N/A	12	104	1196	26.1	2368.1	1643.07	610	25	25	10	N/A	N/A	1450	4.4	205	1.7	2	35	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61400	4E+05	6952044	-27.55259882	152.098503	09-10-1980	N/A	2800	7.7	N/A	12	108	1257	28.1	2481.7	1721.08	672	28	30	8	N/A	N/A	1520	6.2	204	1.5	0	12	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
6208	4E+05	6952474	-27.54861249	152.097224	17-09-1980	8	2500	8.6	N/A	12	49	1151	39.1	2223.4	1564.44	627	28	8	7	N/A	N/A	1320	41	179	1.4	1	11	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
6208	4E+05	6952474	-27.54861249	152.097224	11-06-1982	42	2550	7.6	N/A	12	250	1238	16	2423.2	1672.76	580	23	90	6	N/A	N/A	1500	4.6	180	1.6	2	36	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
14483	4E+05	6952597	-27.54791263	152.097749	11-06-1982	44	3050	7.4	N/A	14	146	1400	25.2	2706.6	1856.49	700	28	42	10	N/A	N/A	1700	3.4	200	1.2	2	20	N/A	N/A	N/A	N/A	N/A	HEUDON SST FORM
14483	4E+05	6952597	-27.54791263	152.097749	06-05-1983	57	2950	7.8	N/A	12	174	1449	24.1	2822.7	1945.17	730	31	50	12	N/A	N/A	1750	8.6	200	1	3.1	37	N/A	N/A	N/A	N/A	N/A	HEUDON SST FORM
61400	4E+05	6952044	-27.55259882	152.098503	09-06-1982	21	2750	7.5	N/A	14	98	1319	29	2538.3	1739.02	660	26	26	8	N/A	N/A	1600	3.9	205	1.4	2	6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61401	4E+05	6952847	-27.54495504	152.060263	24-10-1977	N/A	9000	7.1	N/A	7	596	392	29.8	5190.2	4954.23	1670	64	120	72	N/A	N/A	478	0	2690	0.2	N/A	96	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61401	4E+05	6952847	-27.54495504	152.060263	24-10-1977	N/A	9000	7.2	N/A	6	570	360	31.4	5199.2	4982.06	1720	64	116	68	N/A	N/A	439	0	2700	0.2	N/A	92	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61401	4E+05	6952847	-27.54495504	152.060263	25-10-1977	N/A	11800	7.7	N/A	17	669	612	40	7148.8	6786.61	2380	30	70	120	N/A	N/A	746	0	3600	0.3	2.5	200	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61403	4E+05	6953027	-27.54349818	152.091627	16-03-1987	15	3200	7.4	N/A	14	116	1194	27.4	2529.4	1806.37	678	20	16	N/A	N/A	N/A	1450	2.8	327	1.6	0	14	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
61404	4E+05	6954234	-27.53245557	152.063618	22-10-1980	73	7520	7.6	N/A	7	745	215	21.4	4378	4251.83	1340	15	150	90	N/A	N/A	262	0	2520	0	1	0	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
75283	4E+05	6954475	-27.53021876	152.056484	27-10-1980	N/A	2340	7.9	N/A	23	156	1063	17.9	2044.9	1417.28	513	17	31	19	N/A	N/A	1280	7.9	168	1	0	8	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
75283	4E+05	6954475	-27.53021876	152.056484	09-06-1982	104	2200	7.6	N/A	12	83	990	24.8	1937.1	1339.14	520	20	20	8	N/A	N/A	1200	3.5	130	1.6	4	30	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61406	4E+05	6956182	-27.51493807	152.067519	22-10-1980	12	2700	8.1	N/A	13	109	1063	26.5	2275.5	1642.96	636	20	24	12	N/A	N/A	1270	13	289	0.5	1	10	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61406	4E+05	6956182	-27.51493807	152.067519	09-06-1982	12	2600	7.7	N/A	14	119	1115	22.8	2237.7	1565.5	570	18	31	10	N/A	N/A	1350	5	215	0.7	2	36	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61410	4E+05	6959974	-27.48231948	152.068569	15-10-1980	N/A	1200	7.4	N/A	11	233	269	4.7	829.2	673.99	164	8.5	44	30	N/A	N/A	327	0.6	250	0.1	0	5	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61410	4E+05	6959974	-27.48231948	152.068569	09-06-1982	N/A	1100	8.4	N/A	19	208	271	4.5	757.2	613.54	150	7	37	28	N/A	N/A	320	5	195	0.2	1	14	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61489	4E+05	6951140	-27.56040405	152.041261	18-03-1982	29	9500	7.8	N/A	20	999	698	26.2	6378.9	5971.93	1900	43	120	170	N/A	N/A	840	5.6	3000	0.3	10	290	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
61506	4E+05	6951366	-27.55841842	152.055686	16-03-1981	18	2700	8	N/A	29	771	257	3.5	1489.5	1361.94	224	2	68	146	N/A	N/A	308	2.4	665	0.1	2	72	N/A	N/A	N/A	N/A	N/A	GATTON SANDSTONE
64123	4E+05	6952543	-27.54813288	152.108304	21-06-1982	24	2050	7.8	N/A	18	260	828	10.8	1747.4	1257.1	400	6	30	45	N/A	N/A	1000	4.6	230	0.8	1	30	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
33089	4E+05	6952788	-27.54597691	152.128859	23-07-1976	N/A	690	8.2	N/A	12	66	277	6.7	545.2	388.44	125	7.6	14	7.6	N/A	N/A	332	2.9	53	1.1	N/A	2	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
44557	4E+05	6951972	-27.55267716	152.042673	19-11-1975	260	2650	8.9	N/A	N/A	41	947	41	2020.7	1499.18	600	16	8	5	N/A	N/A	1026	63	300	1.5	N/A	1.2	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
48290	4E+05	6954120	-27.53352871	152.075689	20-02-1979	74	2150	8.2	N/A	8	67	1047	27.7	1963.6	1336.23	522	21	17	6	N/A	N/A	1250	13	130	1.6	1	2	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
48290	4E+05	6954120	-27.53352871	152.075689	09-10-1980	75	2200	8.2	N/A	15	60	1042	30.1	1972.5	1357.21	535	21	14	6	N/A	N/A	1240	15	133	1.5	1	6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
48290	4E+05	6954120	-27.53352871	152.075689	09-06-1982	70	2200	7.7	N/A	14	104	991	22.2	1938.1	1342.14	520	20	25	10	N/A	N/A	1200	4.4	130	1.7	2	25	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
64126	4E+05	6953476	-27.5396608	152.122001	15-10-1980	N/A	205	6.1	N/A	9	31	34	1.9	120.7	108.86	24	2.9	5.7	4	N/A	N/A	41	0	35	0.1	0	8	N/A	N/A	N/A	N/A	N/A	HEUDON SDST FORM
64470	4E+05	6952585	-27.54752333	152.099734	06-05-1983	N/A	3500	7.4	N/A	36	223	1647	23.3	3169.3	2188.7	800	35	66	14	N/A	N/A	2000	4.1	230	0.9	2.3	17	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
64470	4E+05	6952585	-27.54752333	152.099734	22-05-1983	N/A	3900	7.3	N/A	13	223	1933	27.4	3692.8	2511.3	940	40	66	14	N/A	N/A	2350	3.5	265	0.6	2.7	11	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
64470	4E+05	6952585	-27.54752333	152.099734	17-02-1984	61	4000	7.6	N/A	14	173	1982	34.7	3861.14	2655.22	1050	42	38	19	0.13	0.01	2400	8.4	300	0.5	1.1	2	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
64470	4E+05	6952585	-27.54752333	152.099734	06-03-1984	61	3800	7.7	N/A	11	139	1860	33.9	3553.12	2420.44	920	40	26	18	0.01	0.01	2250	8.9	275	0.6	2.6	12	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
64470	4E+05	6952585	-27.54752333	152.099734	05-03-1987	0	4050	7.5	N/A	11	191	1938	31.5	3775.9	2592.4	1000	43	55	13	0.05	0.05	2350	6.8	295	0.5	2.5	10	N/A	N/A	N/A	N/A	0	MARBURG SUBGROUP
64904	4E+05	6957951	-27.50065743	152.079695	12-02-1986	44	1200	8.4	N/A	11	232	326	4.4	833.51	648.81	155	11	45	29	0.01	0	385	6.3	190	0.2	0	12	N/A	N/A	N/A	N/A	0	HEUDON SST FORM
64955	4E+05	6958055	-27.49067644	152.077433	16-03-1983	50	970	7.9	N/A	12	195	261	3.9	664.1	515.99	125	4.8	32	28	N/A	N/A	315	1.6	140	0.1	0.6	17	N/A	N/A	N/A	N/A	N/A	HEUDON SANDSTONE
66272	4E+05	6951371	-27.55805812	152.02322	22-08-1983	28	1800	8.3	N/A	10	27	402	32	1228.62	997.18	385	1.8	5.5	3.3	0.01	0.01	475	7.3	340	0.3	1.1	9.3	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66272	4E+05	6951371	-27.55805812	152.02322	22-08-1984	28	1750	8.4	N/A	2	30	382	30.2	1198.02	971.28	380	1.8	6.1	3.6	0.01	0.01	450	7.6	340	0.3	1.2	7.4	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66478	4E+05	6952347	-27.54980222	152.092461	22-12-1983	77	2950	8	N/A	10	63	1336	38.5	2604.62	1801.34	700	30	12	7.9	0.01	0.01	1600	14.5	225	1.2	10	4	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66479	4E+05	6952505	-27.54817863	152.094993	22-12-1983	50	2450	7.8	N/A	10	97	1119	23.9	2131.52	1455.32	540	24	28	6.5	0.01	0.01	1350	7.1	170	1.6	1.8	2.5	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66479	4E+05	6952505	-27.54817863	152.094993	20-02-1984	73	2400	8	N/A	10	102	1081	24.2	2099.22	1448.43	560	12	29	7.1	0.01	0.01	1300	9.1	175	1.5	2.3	3.2	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66479	4E+05	6952505	-27.54817863	152.094993	05-03-1987	N/A	2350	7.8	N/A	12	98	1160	24.2	2188.44	1488.82	550	24.5	28	6.8	0.02	0.02	1400	7.3	165	1.8	1	4	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66525	4E+05	6952564	-27.54781826	152.101085	24-03-1983	27	3500	7.8	N/A	50	215	1533	24.9	3116	2225.64	840	26	30	34	N/A	N/A	1850	9.6	310	0.9	1.5	14	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66525	4E+05	6952564	-27.54781826	152.101085	28-03-1983	64	4350	7.8	N/A	14	146	2117	37.9	4035.4	2753.23	1050	44	22	22	N/A	N/A	2550	15.5	310	0.4	0.5	21	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66525	4E+05	6952564	-27.54781826	152.101085	25-05-1983	28	4300	7.9	N/A	22	166	2161	37.2	4132.7	2833.12	1100	43	30	22	N/A	N/A	2600	17.5	305	0.4	4.8	10	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66526	4E+05	6959210	-27.48924465	152.073303	23-06-1982	N/A	1050	7.9	N/A	13	184	269	4.5	708.8	556.6	140	7.5	31	26	N/A	N/A	325	1.6	155	0.2	0.5	22	N/A	N/A	N/A	N/A	N/A	HEUDON SANDSTONE
66526	4E+05	6959210	-27.48924465	152.073303	06-03-1984	58	900	7.6	N/A	10	175	260	4.1	654.97	504.86	125	6.9	29	25	0.04	0.08	315	0.8	135	0.1	0	18	N/A	N/A	N/A	N/A	N/A	HEUDON SANDSTONE
48290	4E+05	6954120	-27.53352871	152.075689	21-08-1986	74	9	9	N/A	9	56	0	27.9	520	530	480	19	14.5	4.8	0.26	0	0	0	1	0	0	0	N/A	N/A	N/A	N/A	0	MARBURG SUBGROUP
48298	4E+05	6953145	-27.54026254	152.082372	04-10-1976	44	2100	7.8	N/A	23	363	654	7.4	1562	1182.93	325	4	40	64	N/A	N/A	791	3.5	310	0.5	N/A	24	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
48322	4E+05	6955841	-27.51808832	152.073738	16-09-1975	N/A	2300	8.1	N/A	N/A	81	1034	25.6	2001.3	1373.04	530	22	11	13	N/A	N/A	1236

RN	Easting	Northing	Latitude	Longitude	Sampled Date	DEPTH	Conductivity (uS/cm)	PH (pH Units)	Turbidity (NTU)	SIO2 (mg/L)	Hardness (mg/L)	Alkalinity (mg/L)	SAR	Total Ions (mg/L)	TDS (mg/L)	NA (mg/L)	K (mg/L)	CA (mg/L)	MG (mg/L)	FE (mg/L)	MN (mg/L)	HCO3 (mg/L)	CO3 (mg/L)	CL (mg/L)	F (mg/L)	NO3 (mg/L)	SO4 (mg/L)	ZN (mg/L)	AL (mg/L)	B (mg/L)	CU (mg/L)	PO4 (mg/L)	Formation
52514	4E+05	6955696	-27.51768013	151.847819	13-01-1977	44	1150	7.8	N/A	52	463	385	1.4	886	701.13	69	1	65	73	N/A	N/A	466	1.7	120	0.3	40	50	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
37830	4E+05	6958854	-27.48939842	151.876043	21-03-1991	N/A	835	7.4	N/A	4	144	74	4.2	507.2	465.33	115.6	4.3	44.9	7.7	0.85	0.06	90.2	0	197.2	N/A	N/A	46.4	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52611	4E+05	6959410	-27.48313422	151.928863	03-06-1978	N/A	2720	7.2	N/A	67	930	250	2.1	1485	1397.48	145	11	125	150	N/A	N/A	304	0.4	735	0.1	4.5	10	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52629	4E+05	6953768	-27.53546941	151.896045	01-03-1977	37	3200	7.3	N/A	42	1206	650	2.4	2079.3	1719.74	190	2	186	180	N/A	N/A	790	1.2	700	0.1	0	30	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52631	4E+05	6952532	-27.54668158	151.902595	01-03-1977	49	1140	7.7	N/A	66	417	185	1.2	689.4	641.54	58	1.6	78	54	N/A	N/A	224	0.7	224	0.1	49	0	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52634	4E+05	6953812	-27.53341206	151.898864	27-02-1985	79	2000	8.3	N/A	26	220	359	9.7	1291.4	1101.37	330	1.7	65	14	0	0	425	6.5	395	0	0.2	54	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
52635	4E+05	6953817	-27.533412	151.905253	21-01-1976	56	1200	8	N/A	34	134	355	8.1	864.49	681.45	214	1.4	37	10	N/A	N/A	427	2.8	160	0.29	0	12	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48066	4E+05	6956905	-27.5067708	151.848813	18-02-1975	77	880	7.7	N/A	N/A	71	154	8.1	607.1	512.05	156	1.6	20	5	N/A	N/A	187	0.5	125	0	0	112	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48082	4E+05	6957331	-27.50222081	151.884955	28-05-1975	32	1980	7.6	N/A	N/A	726	505	1.7	1312.02	0	104	0.8	88	123	N/A	N/A	612	1.6	345	0.22	17.4	20	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48205	4E+05	6958756	-27.4902006	151.865925	29-03-1975	41	3020	7.8	N/A	N/A	605	162	6.7	1701.3	1601.67	380	6.5	145	59	N/A	N/A	196	0.8	790	N/A	N/A	124	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48213	4E+05	6953217	-27.54030535	151.878498	08-03-1977	62	1630	7.8	N/A	37	520	325	2.4	1026.7	864.45	127	1	93	70	N/A	N/A	392	2.2	328	0.1	3.4	10	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
26029	4E+05	6950783	-27.56118925	151.958585	12-05-1982	N/A	600	7.8	N/A	78	203	132	1.2	400.2	396.88	39	2.5	35	28	N/A	N/A	160	0.6	110	0.1	15	10	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48249	4E+05	6953083	-27.54153294	151.880461	16-07-1975	17	1100	7.7	N/A	N/A	116	114	6.9	609.8	0	170	1	25	13	N/A	N/A	138	0.5	255	0.1	N/A	7.2	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48249	4E+05	6953083	-27.54153294	151.880461	25-07-1984	56	1050	7.9	N/A	21	145	162	5.8	654.53	576.42	160	1	25	20	0.02	0.01	195	1	235	0.1	1.4	16	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48253	4E+05	6955887	-27.51632574	151.8932	21-07-1975	43	1150	8	N/A	N/A	504	436	1	850.44	0	52	0.4	60	86	N/A	N/A	525	3.4	113	0.14	1.5	9	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
48325	4E+05	6958050	-27.49666356	151.87611	12-09-1980	18	1640	7.6	N/A	N/A	671	429	1.2	1090.5	0	72	1	102	101	N/A	N/A	520	1.3	277	0.2	0	16	N/A	N/A	N/A	N/A	N/A	OAKEY CREEK ALLUVIUM
48325	4E+05	6958050	-27.49666356	151.87611	13-09-1980	N/A	1720	7.5	N/A	34	710	450	1.2	1146.5	902.97	73	1	108	107	N/A	N/A	546	1.3	294	0.2	0	16	N/A	N/A	N/A	N/A	N/A	OAKEY CREEK ALLUVIUM
37306	4E+05	6961707	-27.46347989	151.854888	30-11-1989	146	750	7.9	N/A	11	44	170	9.8	537.02	443.82	150	2.1	12.5	3.1	0.01	0.01	205	1	155	0.2	0.8	7.3	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
48461	4E+05	6953896	-27.53257877	151.894142	18-02-1976	164	555	9.2	N/A	N/A	11	60	14.1	315	0	106	1	3.6	0.4	N/A	N/A	61.5	5.5	136	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
75540	4E+05	6956949	-27.50809794	152.080284	18-01-1994	N/A	3250	8.1	N/A	14	349	923	14.9	2443.74	1898.61	640	27	86	32.5	0.02	0.02	1100	12.5	540	0.7	1	4	N/A	N/A	N/A	N/A	N/A	HEUIDON SANDSTONE
83150	4E+05	6954357	-27.53133331	152.063826	09-03-1987	80	4000	7.7	N/A	5	201	116	24	2373.6	2307.44	780	22	49	19	0.05	0.05	140	0.6	1350	0.4	2.5	10	N/A	N/A	N/A	N/A	N/A	HEUIDON SST
83150	4E+05	6954357	-27.53133331	152.063826	10-03-1987	157	2150	8.4	N/A	11	51	1065	32.8	1997.24	1372.87	540	20	10	6.4	0.02	0.02	1250	24	140	0.2	2.6	4	N/A	N/A	N/A	N/A	N/A	HEUIDON SST
75290	4E+05	6954067	-27.5341875	152.086846	19-08-1991	37	2150	8.1	N/A	11	66	1043	27.9	1968.84	1344.47	520	24	16	6.3	0.02	0.02	1250	11	135	1.5	1	4	N/A	N/A	N/A	N/A	N/A	HEUIDON SANDSTONE
75335	4E+05	6954774	-27.5278526	152.086873	19-08-1991	37	2200	8.9	N/A	11	41	980	35.9	1858.34	1335.63	530	24	4.7	7.2	0.02	0.02	1050	71	165	1.4	1	4	N/A	N/A	N/A	N/A	N/A	HEUIDON SANDSTONE
75289	4E+05	6954988	-27.52571746	152.084221	19-08-1991	42	2250	8	N/A	12	75	999	27.1	2003.64	1405.68	540	24	16	8.6	0.02	0.02	1200	8.7	200	1.3	1	4	N/A	N/A	N/A	N/A	N/A	HEUIDON SANDSTONE
61404	4E+05	6954234	-27.53245557	152.063618	03-09-1979	N/A	5050	8.2	N/A	32	597	475	14.9	3015.9	2753.59	836	2	38	122	N/A	N/A	579	0	1400	0.4	3.5	35	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
71448	4E+05	6960145	-27.47845136	151.950089	26-02-1986	40	1000	7.9	N/A	64	278	137	2.2	585.33	565.46	83	4.8	42	42	0.02	0.11	165	0.8	245	0.1	0.5	2	N/A	N/A	N/A	N/A	N/A	MAIN RANGE VOLCANICS
14320386	4E+05	6952228	-27.55034812	152.025242	05-10-1982	N/A	1150	8	N/A	34	402	350	2.3	831.6	652.12	105	1	57	63	N/A	N/A	420	3.2	170	0.4	0	12	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320386	4E+05	6952228	-27.55034812	152.025242	18-10-1983	8	1050	8.1	N/A	30	340	308	2.1	735.34	577.27	88	0.5	44	56	0.04	0	370	2.9	155	0.2	1.7	17	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320386	4E+05	6952228	-27.55034812	152.025242	15-03-1985	8	1300	7.9	N/A	30	451	340	1.9	859.25	680.85	95	0.6	67	69	0.04	0.01	410	2.3	205	0.2	1	9.1	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320387	4E+05	6952134	-27.55119345	152.025466	04-10-1982	N/A	1050	7.8	N/A	35	353	335	2.3	768.2	597.34	100	1	44	59	N/A	N/A	405	1.9	145	0.3	0	12	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320387	4E+05	6952134	-27.55119345	152.025466	18-10-1983	8	1150	8.2	N/A	29	418	356	1.8	834.2	647.18	83	0.7	65	62	0.1	0	425	4.2	165	0.2	0	29	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320387	4E+05	6952134	-27.55119345	152.025466	15-03-1985	7	1150	8.1	N/A	31	375	321	1.9	771.22	606.52	85	0.7	48	62	0.01	0.01	385	3.4	180	0.2	0.7	6.2	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320388	4E+05	6952070	-27.55176918	152.025667	04-10-1982	N/A	1000	8	N/A	38	375	337	1.6	739.2	571.34	72	1	53	59	N/A	N/A	405	3	135	0.2	1	10	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320388	4E+05	6952070	-27.55176918	152.025667	18-10-1983	8	1150	8.1	N/A	34	439	351	1.6	818.7	639.22	75	0.8	62	69	N/A	N/A	420	3.7	150	0.2	18	20	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320388	4E+05	6952070	-27.55176918	152.025667	15-03-1985	8	1050	8.3	N/A	31	365	329	1.6	727.84	560.6	71	0.7	54	56	0.03	0.01	390	5.5	145	0.2	0.5	4.9	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320390	4E+05	6952032	-27.55211645	152.025745	05-10-1982	N/A	1050	7.9	N/A	41	406	390	1.7	822.1	624.2	78	1	57	64	N/A	N/A	470	2.8	130	0.3	4	15	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320390	4E+05	6952032	-27.55211645	152.025745	18-10-1983	5	1250	7.5	N/A	36	457	395	1.6	886.06	678.08	79	0.7	71	68	0.06	0	480	1	165	0.3	0	21	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320391	4E+05	6951997	-27.55243173	152.025868	05-10-1982	N/A	1200	7.7	N/A	39	470	438	1.6	913.3	682.9	81	1	68	73	N/A	N/A	530	2	140	0.3	0	18	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320391	4E+05	6951997	-27.55243173	152.025868	19-10-1983	8	1250	7.9	N/A	33	477	386	1.4	891.18	687.83	72	1.3	74	71	0.08	0	465	2.6	170	0.2	12	23	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320392	4E+05	6951976	-27.55262367	152.025943	06-10-1982	N/A	1200	7.7	N/A	32	446	397	1.4	852.8	640.82	69	1.8	68	67	N/A	N/A	480	1.8	145	0.2	6	14	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320392	4E+05	6951976	-27.55262367	152.025943	18-10-1983	7	820	7.5	N/A	30	308	280	1.5	636	493.18	60	1.8	49	45	N/A	N/A	340	0.7	85	0.2	45	9.3	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320396	4E+05	6951710	-27.554968	152.017556	06-12-1983	4	1050	8.1	N/A	28	409	321	1.2	732.65	564.96	54	1.5	68	58	0.05	0	385	3	150	0.1	0	13	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320185	4E+05	6951064	-27.56163978	152.145507	08-09-1981	11	230	7.1	N/A	45	51	73	1.2	149.3	149.06	19	1	9	7	N/A	N/A	89	0.1	20	0.2	0	4	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320185	4E+05	6951064	-27.56163978	152.145507	08-10-1982	N/A	265	7.2	N/A	53	62	80	1.6	174	172.69	28	1	12	7.7	N/A	N/A	97	0.1	22	0.2	1	5	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320185	4E+05	6951064	-27.56163978	152.145507	19-10-1983	11	210	7.4	N/A	58	59	72	1.4	152.83	166.1	24	0.5	11	7.6	0.02	0.01	88	0.1	17	0.1	0.5	4	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320186	4E+05	6950809	-27.5639338	152.143977	06-10-1982	N/A	790	7.4	N/A	40	167	124	3	495.7	459.46	88	23	29	23	N/A	N/A	150	0.3	150	0.4	10	22	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320186	4E+05	6950809	-27.5639338	152.143977	19-10-1983	14	830	7.6	N/A	34	167	91	3	464.1	442.19	89	2.6	29	23	N/A	N/A	110	0.3	165	0.2	17	28	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320188	4E+05	6950381	-27.56778033	152.141313	08-10-1980	21	1600	8	N/A	27	156	506	10.9	1219	936.95	313	5	26	22	N/A	N/A	608	4.3	227	0.7	2	11	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320188	4E+05	6950381	-27.56778033	152.141313	03-09-1981	22	1540	8	N/A	24	125	464	11.4	1129	868.86	293	6	17	20	N/A	N/A	559	3.2	218	0.8	0	12	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320188	4E+05	6950381	-27.56778033	152.141313	06-10-1982	N/A	1500	8.1	N/A	23	120	451	11.7	1121	869.52	295	6	15	20	N/A	N/A	540	5.2	230	0.8	0	9	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320188	4E+05	6950381	-27.56778033	152.141313	19-10-1983	22	1450	8.1	N/A	29	141	434	9.7	1065	829.68	265	5.6	22	21	N/A	N/A	520	4.6	215	0.8	0	11	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320188	4E+05	6950381	-27.56778033	152.141313	19-03-1985	22	1400	8.3	N/A	19	115	413	10.8	1022.77	792.7	265	5.4	18	17	0.06	0.01	490	6.8	210	0.8	0.5	9.2	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	06-02-1980	N/A	1350	8.3	N/A	39	172	435	7.7	1014.7	791.42	233	4.5	31	23	N/A	N/A	516	7.2	185	0.6	0.4	14	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	03-09-1981	20	1330	8.3	N/A	37	155	425	8.1	992	771.8	233	5	29	20	N/A	N/A	506	6.3	176	0.7	0	16	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	05-10-1982	N/A	1350	8.3	N/A	39	170	431	8	1012.5	792.27	240	6	30	23	N/A	N/A	510	7.8	180	0.7	0	15	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	19-10-1983	20	1300	8.2	N/A	25	161	411	7.9	994.9	770.83	230	4.9	30	21	N/A	N/A	490	5.4	180	0.8	0.8	32	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	19-03-1985	20	1400	8.5	N/A	34	172	437	7.8	1022.69	797.46	235	6.1	31	23	0.07	0.02	510	11.5	185	0.5	0.5	20	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320195	4E+05	6951224	-27.56027386	152.123897	09-09-1981	13	1620	7.9	N/A	46	379	379	4.3	1074.6	888.31	191	2	66	52	N/A	N/A	457	2.4	292	0.2	0	12	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320195	4E+05	6951224	-27.56027386	152.123897	05-10-1982	N/A	1550	8	N/A	40	303	325	4.8	977.1	818.87	190	1.9	47	45	N/A	N/A	390	2.9	290	0.3	0	10	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320195	4E+05	6951224	-27.56027386	152.123897	09-02-1984	13	1500	8	N/A	40	336	354	4.5	1015.82	839.8	190	1.7	62	44	0.01	0.01	425	3.3	270	0.3	0.5	19	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320196	4E+05	6951022	-27.561877	152.12275	10-03-1980	N/A	1320	8	N/A	30	301	365	4.1	928.6	735.46	165	4	48	44	N/A	N/A	439	2.8	225	0.2	0.6	0	N/A	N/A	N/A	N/A	N/A	LOCKYER CREEK ALLUVIUM
14320196	4E+05	6951022	-27.561877	152.12275	10-06-1981	12	1340	8.3	N/A	31	299	370	4.2	932	739.86	166	4	44	46	N/A	N/A	439	5.8	221	0.2	1	5	N/A	N/A	N/A	N/A	N/A	LOCKYER CREEK ALLUVIUM
14320196	4E+05	6951022	-27.561877	152.12275	05-10-1982	N/A	1350	8	N/A	34	314	396	4.3	984	776.56	175	4	50	46	N/A	N/A	475	3.7	230	0.3	0	0	N/A	N/A	N/A	N/A	N/A	LOCKYER CREEK ALLUVIUM
14320196	4E+05	6951022	-27.561877	152.12275	18-10-1983	12	1350	8.1	N/A	23	304	379	4.1	949.32	741.04	165	4.1	51	43	0.12	0	455	3.6	220	0.2	2.3	5	N/A	N/A	N/A	N/A	N/A	LOCKYER CREEK ALLUVIUM
14320196	4E+05	6951022	-27.561877	152.12275	18-03-1985	12	1350	7.8	N/A	29	299	385	4.3	955.92	748.56	170	4	49	43	0.01	0.01	465	2.1	220	0.3	0.5	2	N/A	N/A	N/A	N/A	N/A	LOCKYER CREEK ALLUVIUM
56387	4E+05	6953833	-27.53623059	152.061916	30-01-1987	N/A	1250	8	N/A	45	423	308	2.1	863.75	720.68	99	1.6	67	62	0.03	0.02	370	2.8	240	0.3	11	10	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320388	4E+05	6952070	-27.55176918	152.025667	14-03-1991	4	1050	8.3	N/A	32	449	409	1.8	881.12	666.59	88	1.8	66	69	0.01	0.01	485	6.9	150	0.3	3.6	10.5	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
75074	4E+05	6951190	-27.56016157	152.090994	26-06-1990	120	2550	8.3	N/A	12	55	1187	37.5	2321.22	1621.6	640	27	7.7	8.7	0.01	0.01	1400	23.5	205	1.6	3.7	4	N/A	N/A	N/A	N/A	N/A	
14320391	4E+05	6951997	-27.55243173	152.025868	14-03-1991	4	1050	8.2	N/A	37	441	390	1.6	831.82	632.46	75	1.2	63	69	0.01	0.01	465	5.3	140	0.3	0.5	12.5	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320387	4E+05	6952134	-27.55119345	152.025466	14-03-1991	5	1150	8.3	N/A	32	442	363	1.8	853.32	666.75	89	0.8	65	68	0.01	0.01	430	6.2	175	0.2	0.6	18.5	N/A	N/A	N/A	N/A	N/A	GATTON CREEK ALLUVIUM
14320186	4E+05	6950809	-27.5639338	152.143977	18-09-1992	10	582	8.8	N/A	61	130	160	2.5	387.7	356.96	65.1	1.8	24.6	16.7	0.03	0.14	179.5	7.3	79.9	0.19	5.2	7.3	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	18-09-1992	20	1973	8.2	N/A	35	307	538	8	1426.15	1135.4	324	7	54.5	41.6	0.06	0.23	640.3	7.9	316	0.69	4.5	29.7	N/A	N/A	N/A	N/A	N/A	ALLUVIUM
73599	4E+05	6952430	-27.54924738	152.122747	01-02-1989	15	960	8	N/A	26	241	274	3.1	679.88	538.14	110	3.6	45.5	31	0.07	0.01	330	2.1	155	0.1	0.5	2	N/A	N/A	N/A	N/A	N/A	LOCKYER CREEK ALLUVIUM
83273	4E+05	6952082	-27.55165105	152.025757	10-12-1986	N/A	1950	8.2	N/A	19	278	690	9.3	1554.36	1156.55	355	3.3	34	47	0.05	0.01	820	10.5	260	1	0.5	23	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66296	4E+05	6951211	-27.55952392	152.025337	22-02-1983	54	1950	8.1	N/A	15	51	397	25.5	1352.7	1126.26	420	2	9	7	N/A	N/A	475	4.3	410	0.4	1	24	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66272	4E+05	6951371	-27.55805812	152.02322	01-08-1983	N/A	1750	8.3	N/A	11	24	402	33.9	1180.37	949.93	380	1.8	5.1	2.7	0.16	0.01	475	7.2	300	0.3	0.5	7.6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66272	4E+05	6951371	-27.55805812	152.02322	03-08-1983	18	2600	8.6	N/A	8	103	369	23.2	1647.9	1439.87	540	10	18	14	N/A	N/A	425	12	610	0.4	0.5	18	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66272	4E+05	6951371	-27.55805812	152.02322	06-08-1983	42	1700	8.4	N/A	10	46	400	24.6	1216	987.1	385	3	12	4	N/A	N/A	470	8.5	325	0.3	2.2	6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66272	4E+05	6951371	-27.55805812	152.02322	05-08-1983	24	1800	8.4	N/A	10	41	406	27.7	1272.9	1038.92	405	3.5	8	5	N/A	N/A	480	7.7	355	0.3	2.4	6	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
66272	4E+05	6951371	-27.55805812	152.02322	04-08-1983	23	1800	8.3	N/A	10	48	395	24.8	1259.6	1030.7	395	3	11	5	N/A	N/A	470	6	355	0.8	5	8.8	N/A	N/A	N/A	N/A	N/A	MARBURG SUBGROUP
14320188	4E+05	6950381	-27.56778033	152.141313	12-11-1996	N/A	1158	7.7	5	18	124	288	8.4	828.58	669.49	215.5	4.5	17.4	19.5	0.02	0.06	348.4	1.3	216.6	0.73	1	2.3	1.11	0.01	0.1	0.05	N/A	ALLUVIUM
14320189	4E+05	6950054	-27.57072316	152.13925	14-11-1996	N/A	2200	7.6	27	37	400	589	7.6	1604.97	1279.6	347.8	6.8	68.8	55.2	0.02	0.2	712.9	2.2	372.2	0.57	13.3	24.5	0.35	0.02	0.1	0.01	N/A	ALLUVIUM

NOTE: N/A (not available) - this water chemistry parameter is not available for this sample

		Heavy Metals																	
		Arsenic	Arsenic (Filtered)	Barium	Barium (Filtered)	Beryllium	Beryllium (Filtered)	Boron	Boron (Filtered)	Cadmium	Cadmium (Filtered)	Chromium	Chromium (Filtered)	Cobalt	Cobalt (Filtered)	Copper	Copper (Filtered)	Iron	Iron (Filtered)
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
EQL		0.001		0.001		0.001		0.05		0.0001		0.001		0.001		0.001		0.05	
Borehole ID	**Sampled Date**																		
310-01-BH2201	30/10/2018	0.007	0.005	0.314	0.238	<0.001	<0.001	0.22	0.22	<0.0001	<0.0001	0.005	<0.001	0.005	<0.001	0.008	<0.001	6.72	0.76
310-01-BH2217	30/10/2018	0.036	0.035	0.383	0.309	<0.001	<0.001	0.42	0.42	<0.0001	<0.0001	0.005	<0.001	0.028	0.017	0.043	<0.001	2.24	0.34
320-01-BH2218	22/11/2018	0.028	0.004	0.611	0.182	0.009	0.002	0.39	0.4	0.0005	<0.0001	0.113	0.008	0.126	0.005	0.288	0.004	-	-

		Heavy Metals														Other
		Lead	Lead (Filtered)	Manganese	Manganese (Filtered)	Mercury	Mercury (Filtered)	Nickel	Nickel (Filtered)	Selenium	Selenium (Filtered)	Vanadium	Vanadium (Filtered)	Zinc	Zinc (Filtered)	Sodium Absorption Ratio (Filtered)
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	-
EQL		0.001		0.001		0.0001		0.001		0.01		0.01		0.005		
Borehole ID	**Sampled Date**															
310-01-BH2201	30/10/2018	0.005	<0.001	0.101	0.029	<0.0001	<0.0001	0.015	0.009	<0.01	<0.01	<0.01	<0.01	0.023	<0.005	9.81
310-01-BH2217	30/10/2018	0.012	<0.001	0.077	0.054	<0.0001	<0.0001	0.029	0.018	<0.01	<0.01	0.01	<0.01	0.044	0.01	21.7
320-01-BH2218	22/11/2018	0.172	0.007	0.458	0.04	<0.0001	<0.0001	0.169	0.008	<0.01	<0.01	0.28	0.02	0.423	0.054	21.4

		Sample Quality Parameters																											
		Electrical Conductivity @ 25°C	pH (Lab)	Total Dissolved Solids @180°C	Sodium (Filtered)	Potassium (Filtered)	Calcium (Filtered)	Magnesium (Filtered)	Chloride	Sulphate (as SO4) (Filtered)	Bicarbonate Alkalinity (as CaCO3)	Carbonate Alkalinity (as CaCO3)	Hydroxide Alkalinity (as CaCO3)	Total Alkalinity (as CaCO3)	Nitrate (as N)	Nitrite (as N)	Nitrogen (Total Oxidised)	Ammonia (as N)	Total Kjeldahl Nitrogen (as N)	Nitrogen (Total)	Fluoride	Reactive Phosphorus (as P)	Total Phosphorus (as P)	Total Anions	Total Cations	Ionic Balance (Lab)	Hardness (as CaCO3) (Filtered)
		uS/cm	pH_Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	meq/L	meq/L	%	mg/L
EQL		1	0.01	10					1		1	1	1	1	0.01	0.01	0.01	0.01	0.1	0.1	0.1	0.01	0.01	0.01	0.01	0.01	
Borehole ID	**Sampled Date**																												
310-01-BH2201	30/10/2018	2640	8.04	1570	442	7	101	32	403	18	830	<1	<1	830	<0.01	<0.01	<0.01	0.43	1.1	1.1	0.4	<0.01	0.09	28.3	27.1	2.25	384
310-01-BH2217	30/10/2018	2080	7.72	1300	461	19	21	8	164	7	893	<1	<1	893	<0.01	<0.01	<0.01	0.06	0.2	0.2	1.8	0.01	0.17	22.6	22.2	0.82	85
320-01-BH2218	22/11/2018	1210	7.17	1160	257	12	6	3	126	2	421	<1	<1	421	0.16	<0.01	0.16	0.24	3	3.2	0.8	<0.01	2.41	12	12	0.1	27

Appendix D
Groundwater levels with relation to earthworks and cut locations

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT

Name	Start (km)	End (km)	Length (km)	Median CL Elevation Along Cut (m AHD)	Median GW Level at Cut (m AHD)	Maximum GW Level at Cut (m AHD)	Groundwater Seepage Expected? *	Assumed Geology from Desktop Review and Nearby FFJV Groundwater Bores
C1	-480	-340	0.14	468.2	461.3	461.9	No	Main Range Volcanics
C2	2.26	2.33	0.07	484.4	475.6	477.7	No	Main Range Volcanics
C3	3.61	4.2	0.59	492	480.4	499.6	Yes	Main Range Volcanics
C4	10.25	10.4	0.15	393.6	403.9	410.7	Yes	Colluvium/Scree over Main Range Volcanics and Koukandowie.
C5	10.58	10.88	0.3	387.4	376.6	388.4	Yes	Koukandowie Formation
C6	11.17	11.59	0.42	377.3	368.6	388.7	Yes	Koukandowie Formation
C7	12.37	12.8	0.43	358.5	350.7	357.9	No	Koukandowie Formation
C8	13.15	14.04	0.89	345.7	333.2	346.2	Yes	Koukandowie Formation
C9	14.08	14.1	0.02	335.3	331.3	338.1	Yes	Koukandowie Formation
C10	14.33	15.72	1.39	321.9	317.2	330.4	Yes	Koukandowie Formation
C11	17.52	17.82	0.3	279.7	280.8	301.1	Yes	Koukandowie Formation
C12	19.35	19.61	0.26	251.7	245.3	257.3	Yes	Gatton Sandstone
C13	20.3	20.45	0.15	237.8	228.4	234.1	No	Gatton Sandstone
C14	20.49	20.6	0.11	235.2	225.7	228.1	No	Gatton Sandstone

Note: Groundwater levels have been calculated based on correlation values except for C3 and C4 where water levels have been extracted from the groundwater model. * Based on maximum GWL Level at Cut

Structure Name	Median Estimated Surface Elevation (m AHD)[1]	Median Estimated GW Level (m AHD)[2]	Median Estimated GW Level (m bgl)	Median Potential Mounded GW Level (m bgl)	Formation
320-E1	462.6	453.8	8.8	-6.3	Main Range Volcanics
320-E2	476.0	464.9	11.2	-3.9	Main Range Volcanics
320-E3	488.7	477.0	12.2	-2.9	Main Range Volcanics
320-E4	391.1	358.7	32.0	28.5	Koukandowie Formation
320-E5	382.8	354.6	29.1	25.6	Koukandowie Formation
320-E6	362.2	339.0	25.4	21.9	Alluvium, Koukandowie Formation
320-E7	350.4	325.6	24.7	21.2	Koukandowie Formation
320-E8	335.7	302.5	33.2	29.7	Koukandowie Formation
320-E9	331.8	305.3	28.1	24.6	Koukandowie Formation
320-E10	288.2	251.5	35.3	31.8	Alluvium, Koukandowie Formation
320-E11	270.6	233.6	34.7	31.2	Gatton Sandstone
320-E12	244.3	205.5	38.4	34.9	Gatton Sandstone
320-E13	236.3	213.8	22.6	19.1	Gatton Sandstone
320-E14	180.0	156.3	23.5	20.0	Alluvium, Gatton Sandstone

Note: GW = Groundwater, [1]Estimated surface elevation calculated based on the typical value for elevation along the proposed rail alignment (RL), [2]Estimated groundwater level based on correlation of groundwater, elevation and formation type.

Appendix E
Inferred groundwater chemistry at proposed bridge locations

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT

Structure Name	SO4	TDS	ALK	Cl	CO3	HCO3	Ca	Mg	Mg/Cl	pH	EC	T	LSI	RSI	Formation	Nearby SI Boreholes and Formation Depth
320-BR01	10	616	187	226	1.1	224	48	34	0.15	7.75	1145	20.0	7.69	0.03	Main Range Volcanics	Estimated from QLD Surface Geology
320-BR02	10	616	187	226	1.1	224	48	34	0.15	7.75	1145	20.0	7.69	0.03	Main Range Volcanics	Estimated from QLD Surface Geology
320-BR03	10	616	187	226	1.1	224	48	34	0.15	7.75	1145	20.0	7.69	0.03	Main Range Volcanics	Estimated from QLD Surface Geology
320-BR04	11	1333	692	275	6.4	830	30	13	0.05	7.90	2300	20.0	6.88	0.51	Koukandowie Formation	Estimated from QLD Surface Geology
320-BR05	11	1333	692	275	6.4	830	30	13	0.05	7.90	2300	20.0	6.88	0.51	Koukandowie Formation	Estimated from QLD Surface Geology
320-BR06	11	1333	692	275	6.4	830	30	13	0.05	7.90	2300	20.0	6.88	0.51	Koukandowie Formation	Estimated from QLD Surface Geology
320-BR07*	10	1570	830	403	<1	830	101	32	0.08	8.04	2640	22.4	6.88	0.51	Alluvium and Koukandowie Formation	320-01-BH2201 (rock (SST/SLST) at 7.2) and 320-01-BH2202 (no data)
320-BR08	11	1333	692	275	6.4	830	30	13	0.05	7.90	2300	20.0	6.88	0.51	Alluvium and Koukandowie	320-01-BH2203 (rock (SLST) at 6.7), 320-01-BH2204 (no data), 320-01-
320-BR09	11	1333	692	275	6.4	830	30	13	0.05	7.90	2300	20.0	5.43	1.30	Koukandowie Formation	320-01-BH2301 (rock (SST) at 8.1)
320-BR10	11	1333	692	275	6.4	830	30	13	0.05	7.90	2300	20.0	6.88	0.51	Alluvium and Koukandowie Formation	320-01-BH2206 (No data) and 320-01-BH2207 (Rock (SST) at 10.7)
320-BR11	25	2620	1869	393	7.2	2270	48	16	0.04	7.40	5130	20.0	6.88	0.51	Gatton Sandstone	320-01-BH2209 - about 800m away (Rock (SST) at 5.5)
320-BR12	25	2620	1869	393	7.2	2270	48	16	0.04	7.40	5130	20.0	6.88	0.51	Gatton Sandstone	320-01-BH2209 (Rock (SST) at 5.5)
320-BR13	25	2620	1869	393	7.2	2270	48	16	0.04	7.40	5130	20.0	6.15	0.62	Gatton Sandstone	320-01-BH2211 (no data), 320-01-BH2212 (6.5), 320-01-BH2213 (no data)
320-BR14	5	1230	657	145	<1	657	14	5.5	0.04	7.45	1645	23.2	6.15	0.62	Gatton Sandstone and Alluvium	320-01-BH2214 (no data), 320-01-BH2215 (rock (SST) at 7.3), 320-01-BH2216 (rock (SST) at 1.6), 320-01-BH2217 (rock (SST) 2.1), 320-01-BH2218

*Based on samples from registered bores within 5 km of alignment

Formation	Number of Samples
MRV	167
Gatton	27
Marburg (Koukand	131

Appendix F
Hydraulic testing results

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



WATER PRESSURE TEST (5 Stage)

Golder Associates

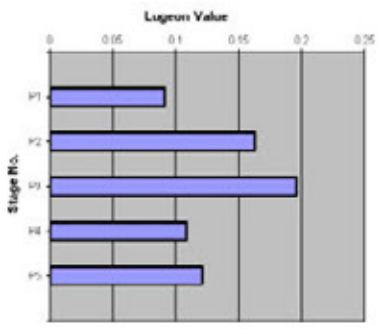
						Revision N° :	18
Client :	FFJV	Hole N° :	BH2101	Drilling Method :	HQ	Vertical depth to Groundwater	Immediately prior to test (m bgl) : 63.44
Project :	Inland Rail	Dip (Deg) :	-90	Hole Diameter (m) :	0.096		Used in analysis (m bgl) : 63.44
Location :	320-01-BH2101	DH Interval Top (m) :	94.00	Downhole Tested Length (m):	5.00		Pressure Gauge Height (m agl) : 0.00
Tested By :	SK	DH Interval Base (m) :	99.00	Packer Type:	Pneumatic - Wireline - Double		Presumed Water Temperature : 26
Date :	20/08/2018	Computed By :	SK	Rock tested :			Casing Inner Diameter (mm) : 77.80
		Date :	26/08/2018	Water Meter Reading in	Litres	Checked By :	Date :

Pressure Stage	Gauge Pressure kPa	No	Actual Time (h:m:s)	Time Intervals (min)	Water Meter Readings Reading (Litres)		Volume (L)	Discharge (L/min)	Discharge/m (L/min/m)	Remarks
										c : 1
P1	200	0	8:48:00	0	10792.0		0.00	0.00	0.00	
		1	8:49:00	01:00	10795.0		3.00	3.00	0.60	
		2	8:50:00	01:00	10798.0		3.00	3.00	0.60	
		3	8:51:00	01:00	10801.0		3.00	3.00	0.60	
		4	8:52:00	01:00	10803.0		2.00	2.00	0.40	
		5	8:53:00	01:00	10805.0		2.00	2.00	0.40	
		6	8:54:00	01:00	10808.0		3.00	3.00	0.60	
		7	8:55:00	01:00	10810.0		2.00	2.00	0.40	
		8	8:56:00	01:00	10814.0		4.00	4.00	0.80	
		9	8:57:00	01:00	10818.0		4.00	4.00	0.80	
		10	8:58:00	01:00	10823.0		5.00	5.00	1.00	
							Total :	31.00	6.20	Start Date & Time :
							Average:	3.100	0.620	
P2	300	0	8:58:00	0	10823.0		0.00	0.00	0.00	c : 1
		1	8:59:00	01:00	10829.0		6.00	6.00	1.20	
		2	9:00:00	01:00	10835.0		6.00	6.00	1.20	
		3	9:01:00	01:00	10841.0		6.00	6.00	1.20	
		4	9:02:00	01:00	10846.0		5.00	5.00	1.00	
		5	9:03:00	01:00	10855.0		9.00	9.00	1.80	
		6	9:04:00	01:00	10858.0		3.00	3.00	0.60	
		7	9:05:00	01:00	10862.0		4.00	4.00	0.80	
		8	9:06:00	01:00	10869.0		7.00	7.00	1.40	
		9	9:07:00	01:00	10875.0		6.00	6.00	1.20	
		10	9:08:00	01:00	10882.0		7.00	7.00	1.40	
							Total :	59.00	11.80	
							Average:	5.900	1.180	
P3	400	0	9:08:00	0	10882.0		0.00	0.00	0.00	c : 1
		1	9:09:00	01:00	10889.0		7.00	7.00	1.40	
		2	9:10:00	01:00	10895.0		6.00	6.00	1.20	
		3	9:11:00	01:00	10902.0		7.00	7.00	1.40	
		4	9:12:00	01:00	10909.0		7.00	7.00	1.40	
		5	9:13:00	01:00	10916.0		7.00	7.00	1.40	
		6	9:14:00	01:00	10923.0		7.00	7.00	1.40	
		7	9:15:00	01:00	10929.0		6.00	6.00	1.20	
		8	9:16:00	01:00	10936.0		7.00	7.00	1.40	
		9	9:17:00	01:00	10944.0		8.00	8.00	1.60	
		10	9:18:00	01:00	10952.0		8.00	8.00	1.60	
							Total :	70.00	14.00	
							Average:	7.000	1.400	
P4	300	0	9:18:00	0	10952.0		0.00	0.00	0.00	c : 1
		1	9:19:00	01:00	10961.0		9.00	9.00	1.80	
		2	9:20:00	01:00	10966.0		5.00	5.00	1.00	
		3	9:21:00	01:00	10973.0		7.00	7.00	1.40	
		4	9:22:00	01:00	10979.0		6.00	6.00	1.20	
		5	9:23:00	01:00	10986.0		7.00	7.00	1.40	
		6	9:24:00	01:00	10992.0		6.00	6.00	1.20	
		7	9:25:00	01:00	10998.0		6.00	6.00	1.20	
		8	9:26:00	01:00	11004.0		6.00	6.00	1.20	
		9	9:27:00	01:00	11010.0		6.00	6.00	1.20	
		10	9:28:00	01:00	11016.0		6.00	6.00	1.20	
							Total :	64.00	12.80	
							Average:	6.400	1.280	
P5		0	9:28:00	0	11016.0		0.00	0.00	0.00	c : 1
		1	9:29:00	01:00	11020.0		4.00	4.00	0.80	
		2	9:30:00	01:00	11025.0		5.00	5.00	1.00	
		3	9:31:00	01:00	11030.0		5.00	5.00	1.00	
		4	9:32:00	01:00	11035.0		5.00	5.00	1.00	
		5	9:33:00	01:00	11040.0		5.00	5.00	1.00	
		6	9:34:00	01:00	11045.0		5.00	5.00	1.00	
		7	9:35:00	01:00	11049.0		4.00	4.00	0.80	
		8	9:36:00	01:00	11053.0		4.00	4.00	0.80	
		9	9:37:00	01:00	11057.0		4.00	4.00	0.80	
		10	9:38:00	01:00	11061.0		4.00	4.00	0.80	
							Total :	45.00	9.00	Finish Date & Time :
							Average:	4.500	0.900	

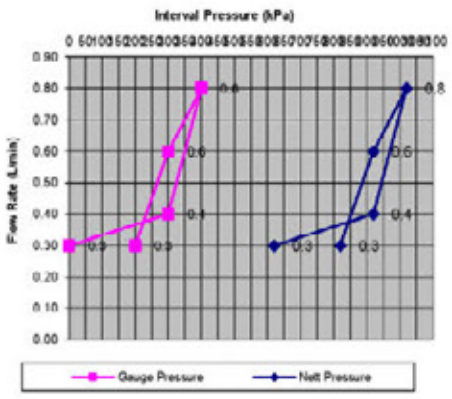
TEST RESULTS

Stage No.	Lugeon (1933) Value	Nett Pressures
P1	0.8	822.1
P2	1.3	921.9
P3	1.4	1021.7
P4	1.4	921.8
P5	1.4	622.0

Lugeon Value Curve



Pressure Vs Flow



Lugeon (1933) method includes nett pressure in calculation that is Hp (gauge pressure) + Hg (height gauges above watertable) - Hf (head losses)

Interpreted Result & Hydraulic Conductivity

H_{LOSS}	0.08	kPa
Stage No.	P1	
Gauge Pressure	200	kPa
Q	3.10	L/min
H	83.8	m
Interpreted Result	0.8	uL

Reported k at Stage P1

Analytical Method 1: (ref = Golder geotechnical field notes draft 1997) k = Q/H x 6.10889 x 10^{-8}x((log(2L/D))/L)

k = 9.1E-08 m/s

Analytical Method 2: (ref = Sharp, J.C 1976 Pit Slope Manual, CANMET report) k = 1/(2Lx3.14) x (Q/H) ln(R/r) m/s (convert L/min to m/s). Assume R = radius of influence of 100m & r = radius of borehole.

k = 1.5E-07 m/s

Flow Type

COMMENTS

WATER PRESSURE TEST (5 Stage)

Golder Associates

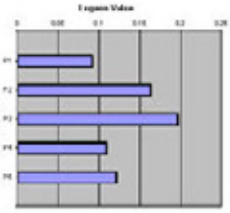
Job N° :	1093795	Hole N° :	DH2101	Drilling Method :	HQ	Vertical depth to Groundwater	
Client :	FFJV	Dip (Deg) :	90	Hole Diameter (m) :	0.096	Revision N° :	18
Project :	Inland Rail	DH Interval Top (m) :	103.00	Downhole Tested Length (m):	4.00	Immediately prior to test (m bgl) :	65.10
Location :	320-01-BH2101	DH Interval Base (m) :	107.00	Packer Type:	Pneumatic - Wireline - Double	Used in analysis (m bgl) :	63.18
Tested By :	SK	Computed By :	SK	Rock tested :		Pressure Gauge Height (m agl) :	0.00
Date :	17/08/2018	Date :	26/08/2018	Water Meter Reading in Litres	Checked By :	Presumed Water Temperature :	26
					Date :	Casing Inner Diameter (mm) :	77.80

Pressure Stage	Gauge Pressure kPa	No	Actual Time (h:m:s)	Time Intervals (min)	Water Meter Readings Reading (Litres)	Volume (L)	Discharge (L/min)	Discharge/m (L/min/m)	Remarks
		0	10:08:00	0	7190.0	0.00	0.00	0.00	e : 1
		1	10:09:00	01:00	7190.0	0.00	0.00	0.00	
		2	10:10:00	01:00	7192.0	2.00	2.00	0.50	
		3	10:11:00	01:00	7192.0	0.00	0.00	0.00	
		4	10:12:00	01:00	7192.0	0.00	0.00	0.00	
P1	200	5	10:13:00	01:00	7192.0	0.00	0.00	0.00	
		6	10:14:00	01:00	7192.0	0.00	0.00	0.00	
		7	10:15:00	01:00	7192.0	0.00	0.00	0.00	
		8	10:16:00	01:00	7193.0	1.00	1.00	0.25	
		9	10:17:00	01:00	7193.0	0.00	0.00	0.00	
		10	10:18:00	01:00	7193.0	0.00	0.00	0.00	
						Total :	3.00	0.75	Start Date & Time :
						Average:	0.300	0.075	
		0	10:18:00	0	7193.0	0.00	0.00	0.00	e : 1
		1	10:19:00	01:00	7194.0	1.00	1.00	0.25	
		2	10:20:00	01:00	7195.0	1.00	1.00	0.25	
		3	10:21:00	01:00	7195.0	0.00	0.00	0.00	
		4	10:22:00	01:00	7195.0	0.00	0.00	0.00	
P2	300	5	10:23:00	01:00	7196.0	1.00	1.00	0.25	
		6	10:24:00	01:00	7197.0	1.00	1.00	0.25	
		7	10:25:00	01:00	7197.0	0.00	0.00	0.00	
		8	10:26:00	01:00	7197.0	0.00	0.00	0.00	
		9	10:27:00	01:00	7198.0	1.00	1.00	0.25	
		10	10:28:00	01:00	7199.0	1.00	1.00	0.25	
						Total :	6.00	1.50	
						Average:	0.600	0.150	
		0	10:28:00	0	7199.0	0.00	0.00	0.00	e : 1
		1	10:30:00	01:00	7200.0	1.00	1.00	0.25	
		2	10:31:00	01:00	7201.0	1.00	1.00	0.25	
		3	10:32:00	01:00	7201.0	0.00	0.00	0.00	
		4	10:33:00	01:00	7202.0	1.00	1.00	0.25	
P3	400	5	10:34:00	01:00	7202.0	0.00	0.00	0.00	
		6	10:35:00	01:00	7203.0	1.00	1.00	0.25	
		7	10:36:00	01:00	7204.0	1.00	1.00	0.25	
		8	10:37:00	01:00	7205.0	1.00	1.00	0.25	
		9	10:38:00	01:00	7206.0	1.00	1.00	0.25	
		10	10:39:00	01:00	7207.0	1.00	1.00	0.25	
						Total :	8.00	2.00	
						Average:	0.800	0.200	
		0	10:39:00	0	7207.0	0.00	0.00	0.00	e : 1
		1	10:40:00	01:00	7207.0	0.00	0.00	0.00	
		2	10:41:00	01:00	7207.0	0.00	0.00	0.00	
		3	10:42:00	01:00	7207.0	0.00	0.00	0.00	
		4	10:43:00	01:00	7208.0	1.00	1.00	0.25	
P4	300	5	10:44:00	01:00	7208.0	0.00	0.00	0.00	
		6	10:45:00	01:00	7209.0	1.00	1.00	0.25	
		7	10:46:00	01:00	7209.0	0.00	0.00	0.00	
		8	10:47:00	01:00	7210.0	1.00	1.00	0.25	
		9	10:48:00	01:00	7210.0	0.00	0.00	0.00	
		10	10:49:00	01:00	7211.0	1.00	1.00	0.25	
						Total :	4.00	1.00	
						Average:	0.400	0.100	
		0	10:49:00	0	7211.0	0.00	0.00	0.00	e : 1
		1	10:50:00	01:00	7211.0	0.00	0.00	0.00	
		2	10:51:00	01:00	7211.0	0.00	0.00	0.00	
		3	10:52:00	01:00	7211.0	0.00	0.00	0.00	
		4	10:53:00	01:00	7212.0	1.00	1.00	0.25	
P5		5	10:54:00	01:00	7212.0	0.00	0.00	0.00	
		6	10:55:00	01:00	7212.0	0.00	0.00	0.00	
		7	10:56:00	01:00	7213.0	1.00	1.00	0.25	
		8	10:57:00	01:00	7213.0	0.00	0.00	0.00	
		9	10:58:00	01:00	7214.0	1.00	1.00	0.25	
		10	10:59:00	01:00	7214.0	0.00	0.00	0.00	
						Total :	3.00	0.75	Finish Date & Time :
						Average:	0.300	0.075	

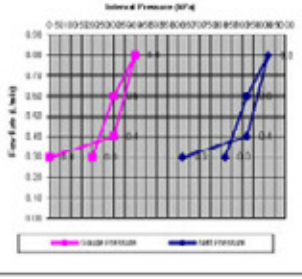
TEST RESULTS

Stage No.	Lugeon (1933) Value	Net Pressure
P1	0.1	819.6
P2	0.2	919.6
P3	0.2	1019.6
P4	0.1	819.6
P5	0.1	819.6

Lugeon Value Curve



Pressure Vs Flow



Lugeon (1933) method includes nett pressure in calculation that is Hp (gauge pressure) + Hg (height gauges above watertable) - Hf (head losses).

Interpreted Result & Hydraulic Conductivity

H LOSS	0.00	kPa
Stage No.	P1	
Gauge Pressure	200	kPa
Q	0.50	l/min
H	83.6	m
Interpreted Result	0.1	Lu

Reported k at Stage P1

Analytical Method 1: (ref = Golder geotechnical field notes draft 1997) $k = Q/H \times 6.10889 \times 10^{-5} x/(log(2L/D)L)$

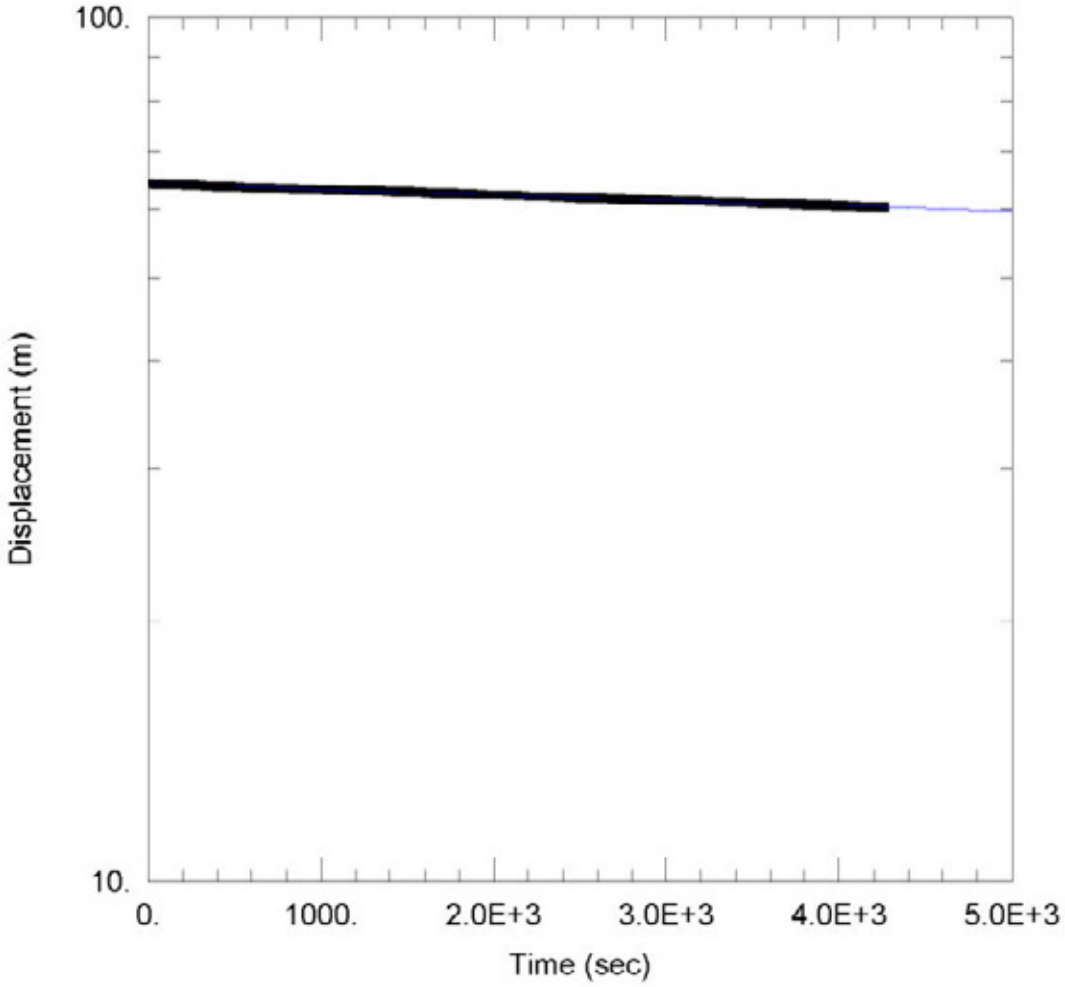
k = 1.1E-06 m/s

Analytical Method 2: (ref = Sharp, J.C. 1975 Pit Slope Manual, CANMET, report 9 - 16, ch3.14) $x(Q/H) \ln(R/r)$ units (current Litres or m3). Assume R = radius of influence of 100m & r = radius of borehole

k = 1.8E-08 m/s

Flow Type

COMMENTS



320-01-BH2101 (FHT 74.0 M TO 79.0 M)

Data Set: V:\...\320-01-BH2101-Test6_Hvor.aqt
Date: 12/13/18 Time: 15:41:04

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 20/08/2018

AQUIFER DATA

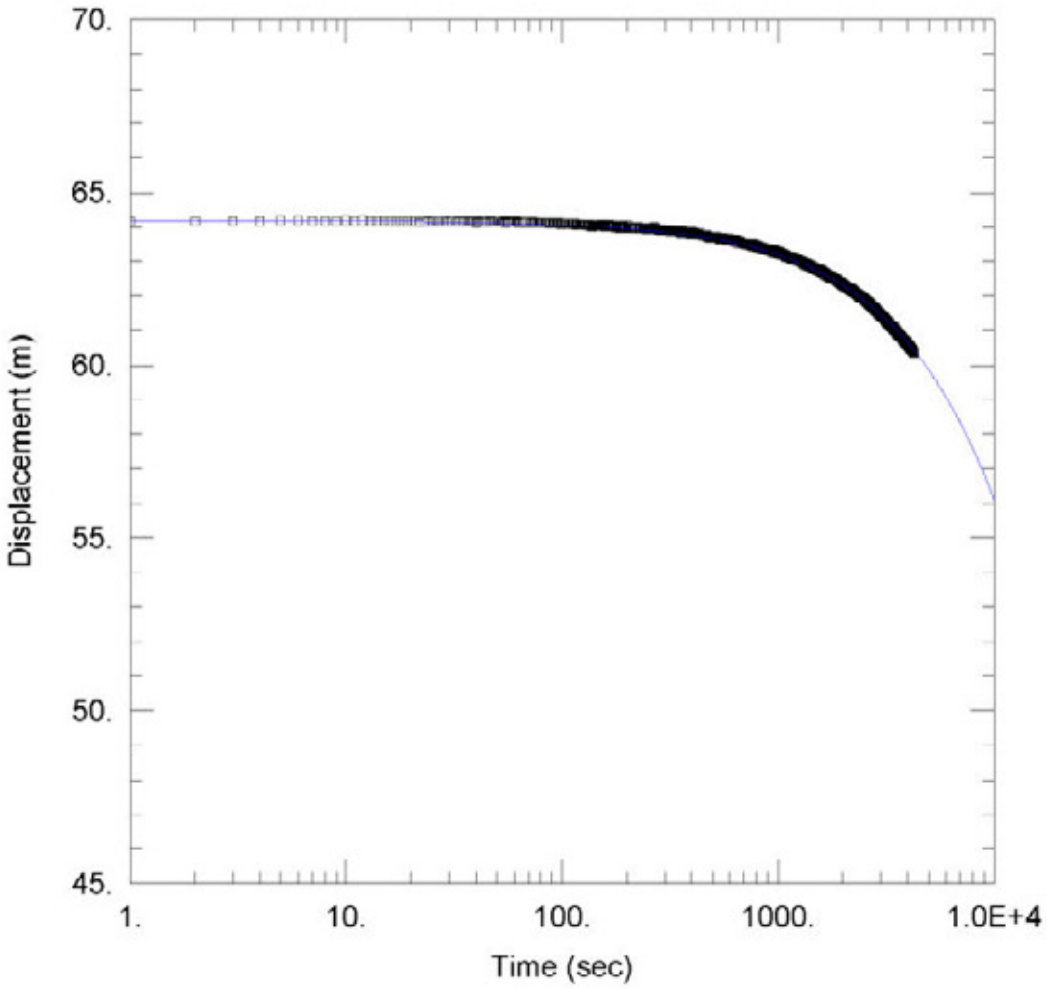
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test6)

Initial Displacement: 64.17 m Static Water Column Height: 14.83 m
Total Well Penetration Depth: 14.83 m Screen Length: 5. m
Casing Radius: 0.048 m Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 1.762E-8 m/sec y0 = 64.17 m



320-01-BH2101 (FHT 74.0 M TO 79.0 M)

Data Set: V:\...\320-01-BH2101-Test6_KGS.aqt
Date: 12/13/18 Time: 15:41:34

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 20/08/2018

AQUIFER DATA

Saturated Thickness: 5. m

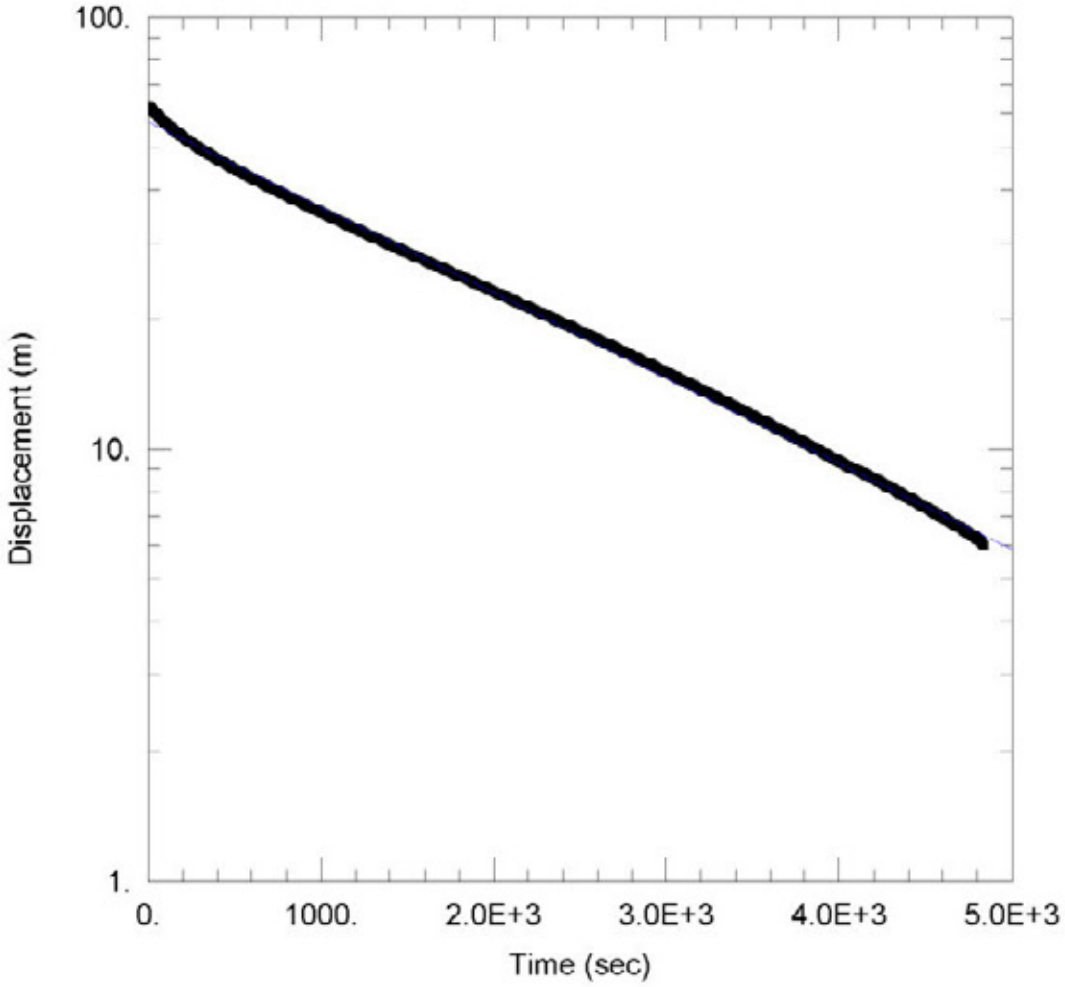
WELL DATA (BH2101-Test6)

Initial Displacement: 64.17 m
Total Well Penetration Depth: 14.83 m
Casing Radius: 0.048 m
Static Water Column Height: 14.83 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 2.823E-8 m/sec
Kz/Kr = 1.
Ss = 1.673E-9 m^{-1}



320-01-BH2101 (FHT 79.0 M TO 84.0 M)

Data Set: V:\...\320-01-BH2101-Test4_Hvor.aqt
Date: 12/13/18 Time: 15:39:25

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

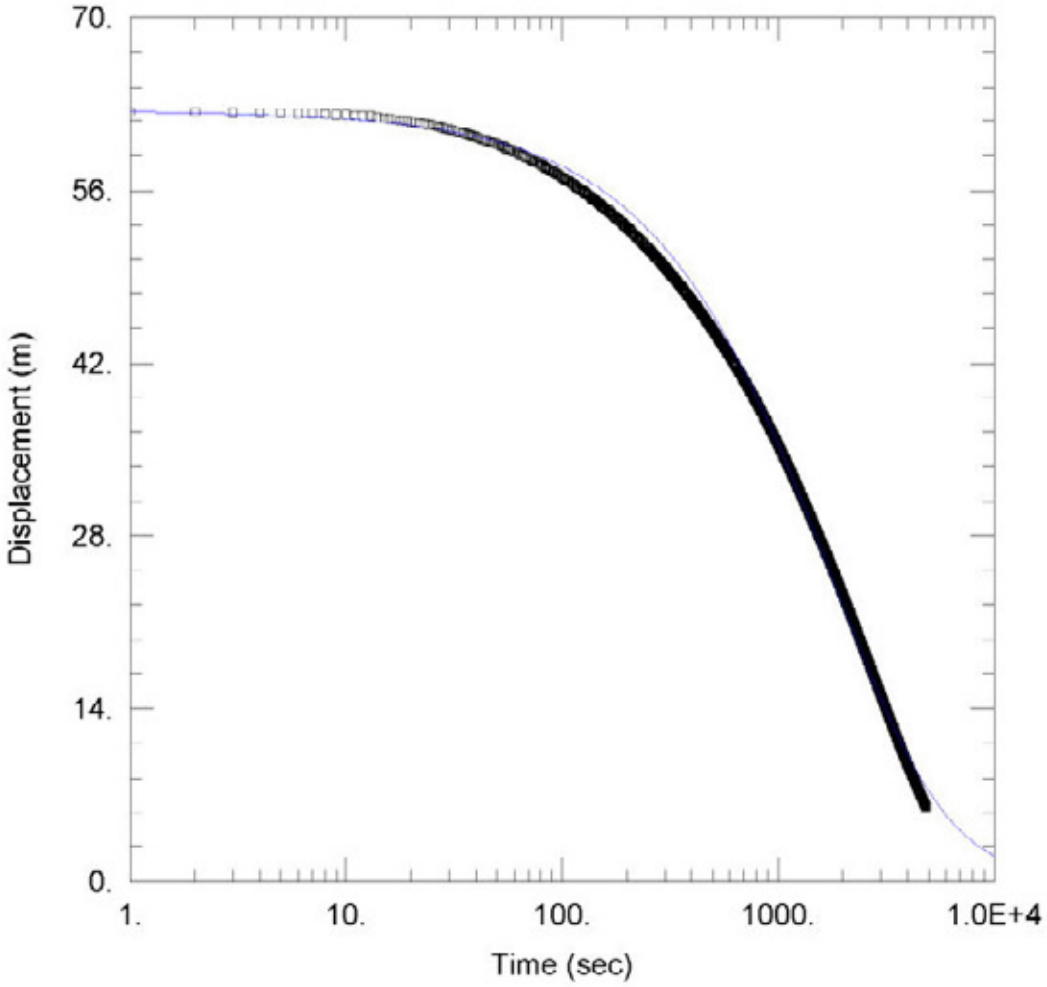
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test4)

Initial Displacement: 62.44 m
Total Well Penetration Depth: 25.16 m
Casing Radius: 0.048 m
Static Water Column Height: 20.16 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
K = 5.563E-7 m/sec
Solution Method: Hvorslev
y0 = 57.33 m



320-01-BH2101 (FHT 79.0 M TO 84.0 M)

Data Set: V:\...\320-01-BH2101-Test4_KGS.aqt
Date: 12/13/18 Time: 15:40:00

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

Saturated Thickness: 5. m

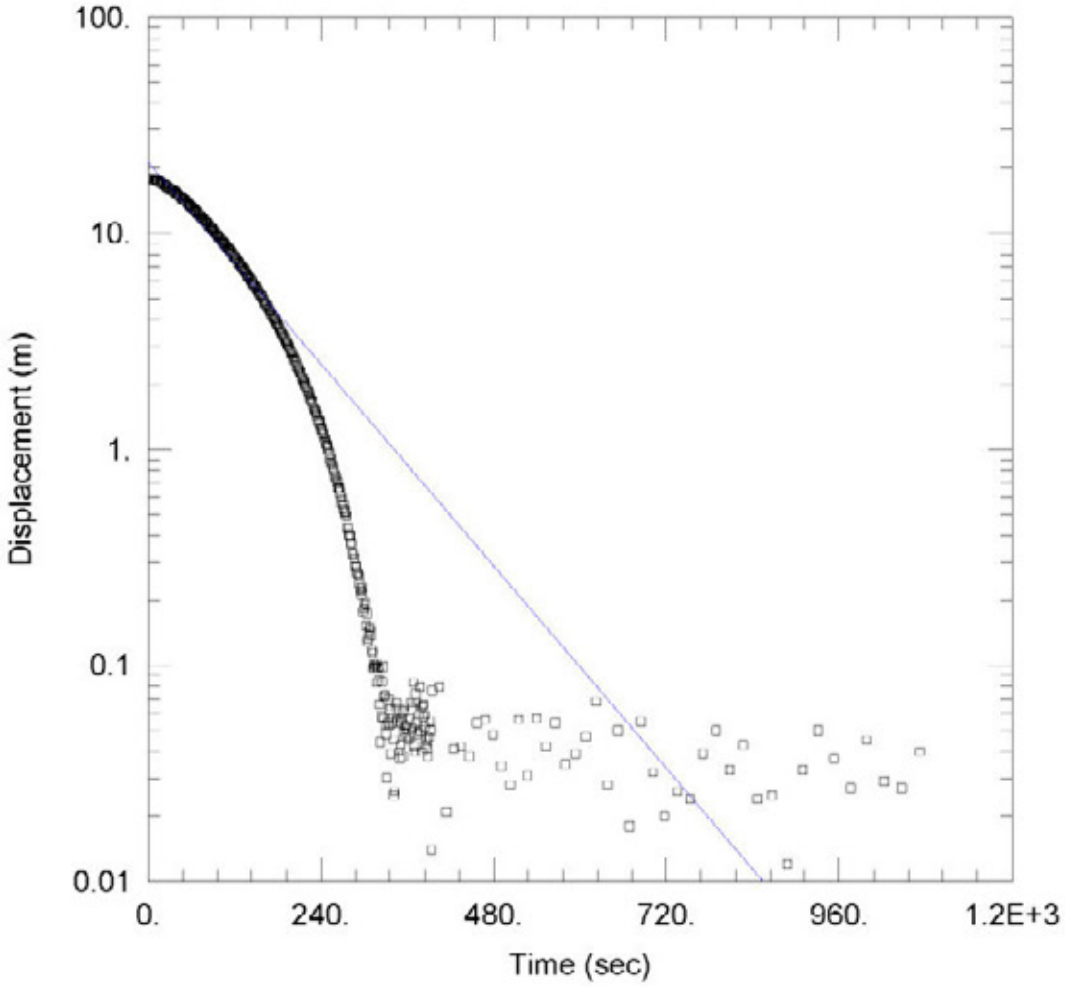
WELL DATA (BH2101-Test4)

Initial Displacement: 62.44 m
Total Well Penetration Depth: 25.16 m
Casing Radius: 0.048 m
Static Water Column Height: 20.16 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 6.801E-7 m/sec
Kz/Kr = 1.
Ss = 1.352E-5 m^{-1}



320-01-BH2101 (FHT 88.0 M TO 93.0 M)

Data Set: V:\...\320-01-BH2101-Test3A_Hvor_early.aqt
Date: 12/13/18 Time: 15:34:06

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

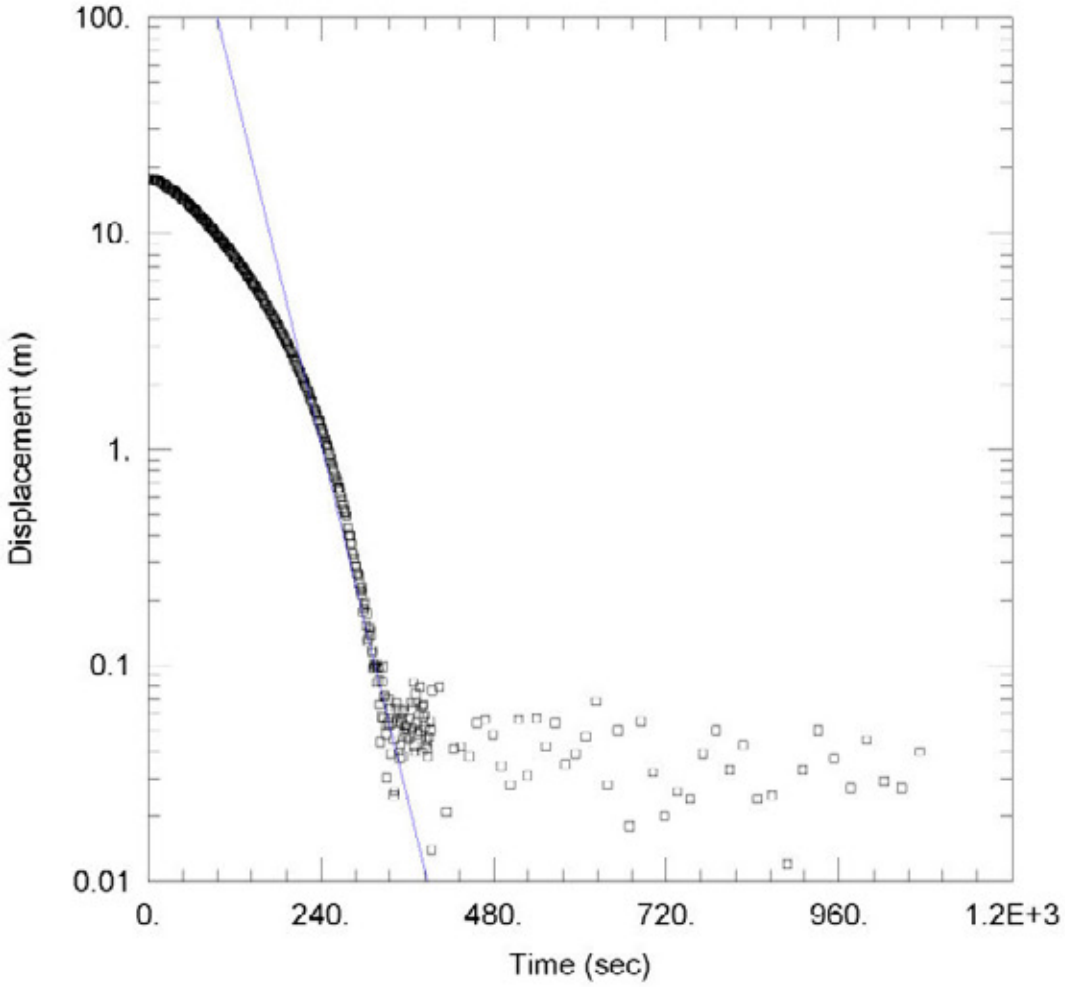
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test3A)

Initial Displacement: 18.05 m Static Water Column Height: 28.95 m
Total Well Penetration Depth: 28.95 m Screen Length: 5. m
Casing Radius: 0.048 m Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 1.097E-5 m/sec y0 = 21.55 m



320-01-BH2101 (FHT 88.0 M TO 93.0 M)

Data Set: V:\...\320-01-BH2101-Test3A_Hvor_Late.aqt
Date: 12/13/18 Time: 15:34:50

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

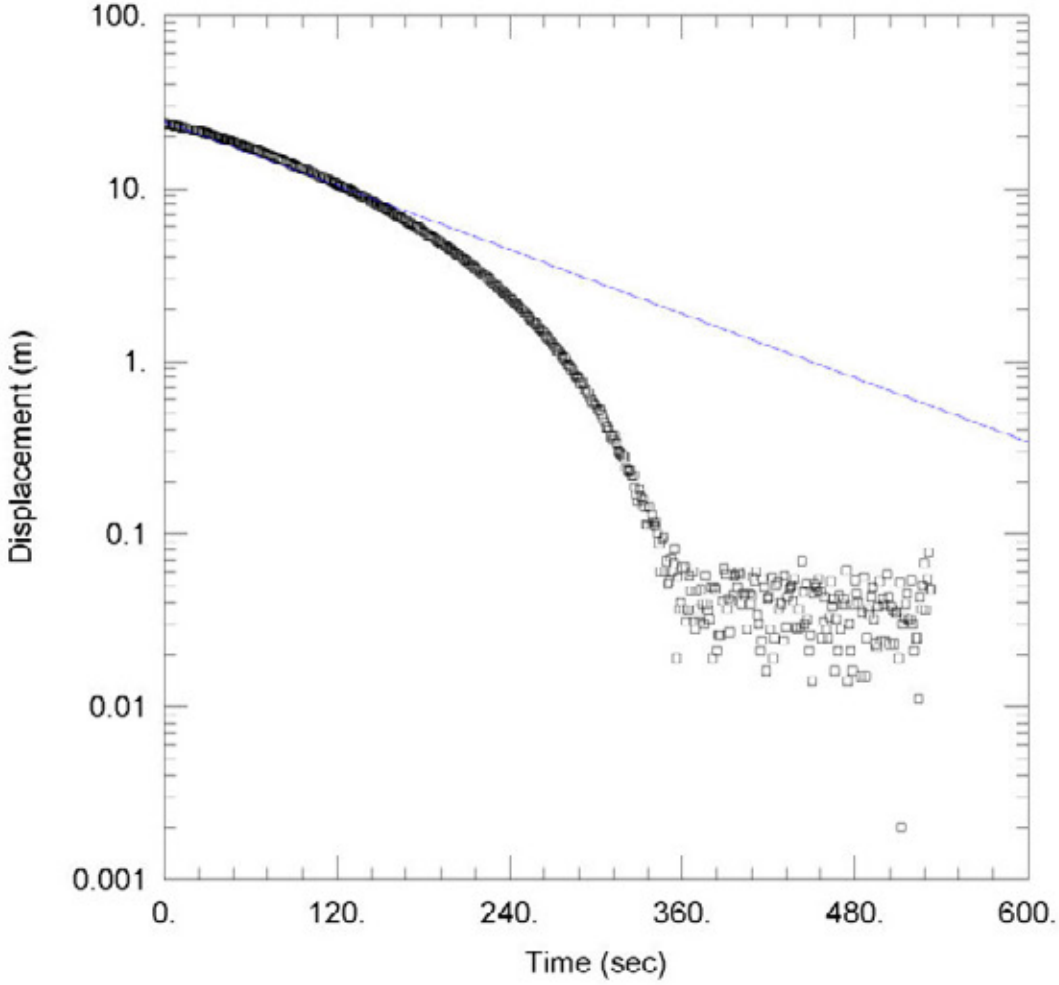
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test3A)

Initial Displacement: 18.05 m Static Water Column Height: 28.95 m
Total Well Penetration Depth: 28.95 m Screen Length: 5. m
Casing Radius: 0.048 m Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 3.845E-5 m/sec y0 = 2054.5 m



320-01-BH2101 (FALLING HEAD TEST 3B)

Data Set: V:\...\320-01-BH2101-Test3B_Hvor_early.aqt
Date: 12/13/18 Time: 15:14:10

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

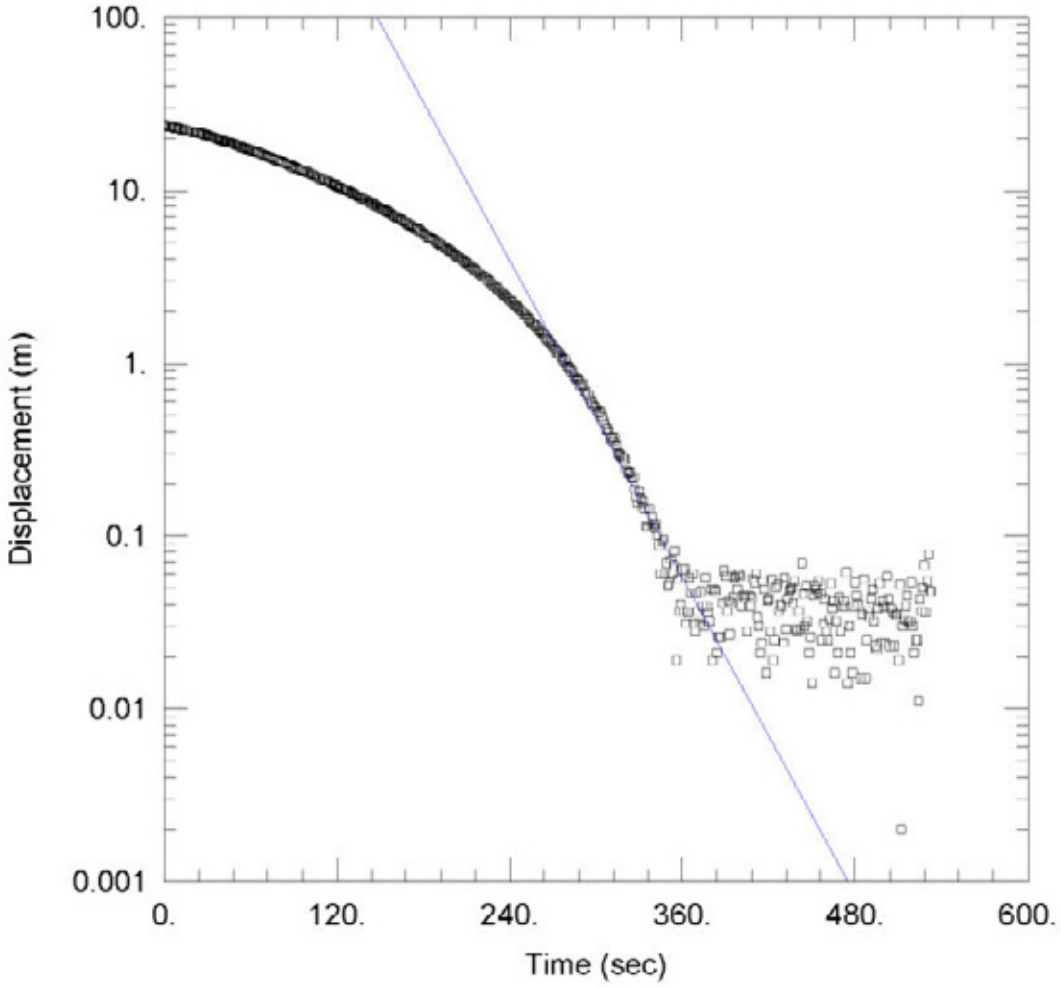
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test3A)

Initial Displacement: 24. m
Total Well Penetration Depth: 28.95 m
Casing Radius: 0.048 m
Static Water Column Height: 28.95 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
K = 8.677E-6 m/sec
Solution Method: Hvorslev
y0 = 24.28 m



320-01-BH2101 (FALLING HEAD TEST3B)

Data Set: V:\...\320-01-BH2101-Test3B_Hvor_Late.aqt
Date: 12/13/18 Time: 15:15:12

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

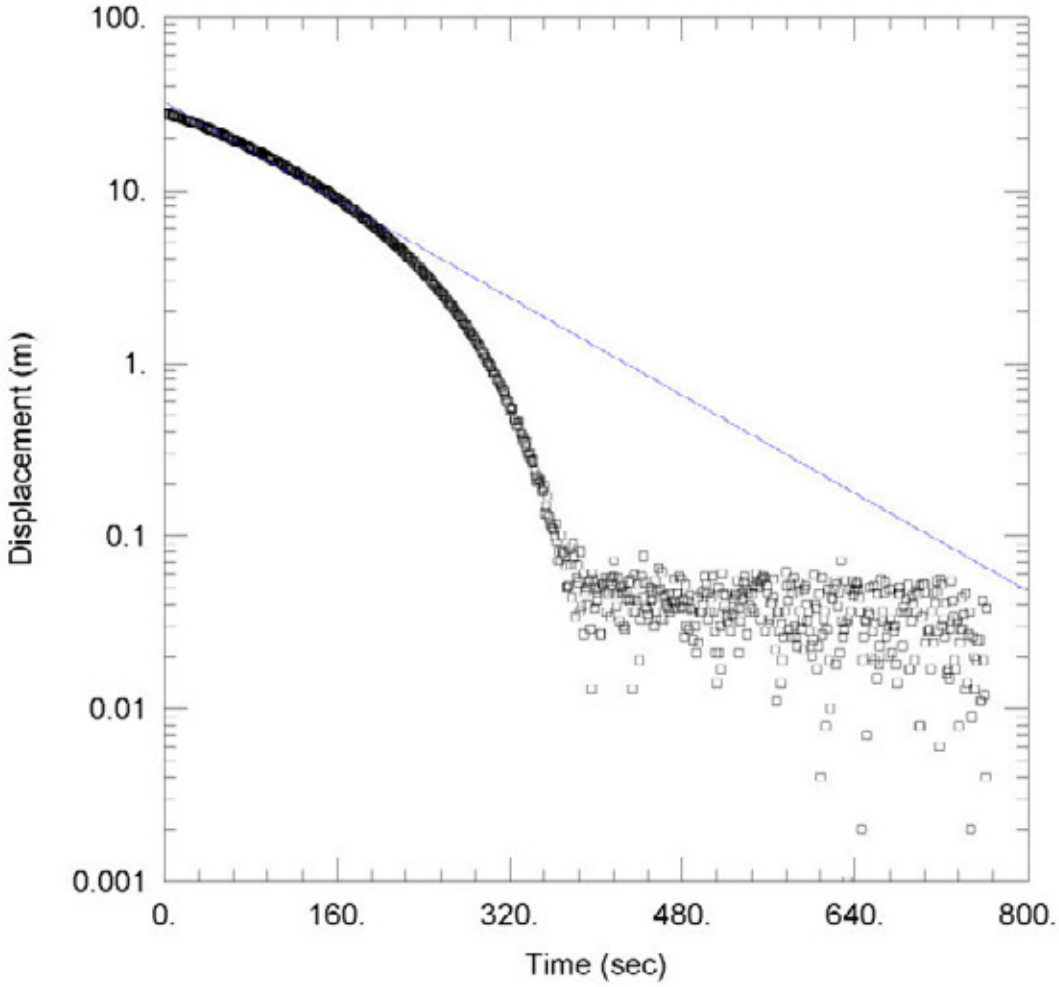
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test3A)

Initial Displacement: 24. m
Total Well Penetration Depth: 28.95 m
Casing Radius: 0.048 m
Static Water Column Height: 28.95 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
K = 4.299E-5 m/sec
Solution Method: Hvorslev
y0 = 1.834E+4 m



320-01-BH2101 (FHT 88.0 M TO 93.0 M)

Data Set: V:\...\320-01-BH2101-Test3C_Hvor_early.aqt
Date: 12/13/18 Time: 15:37:13

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

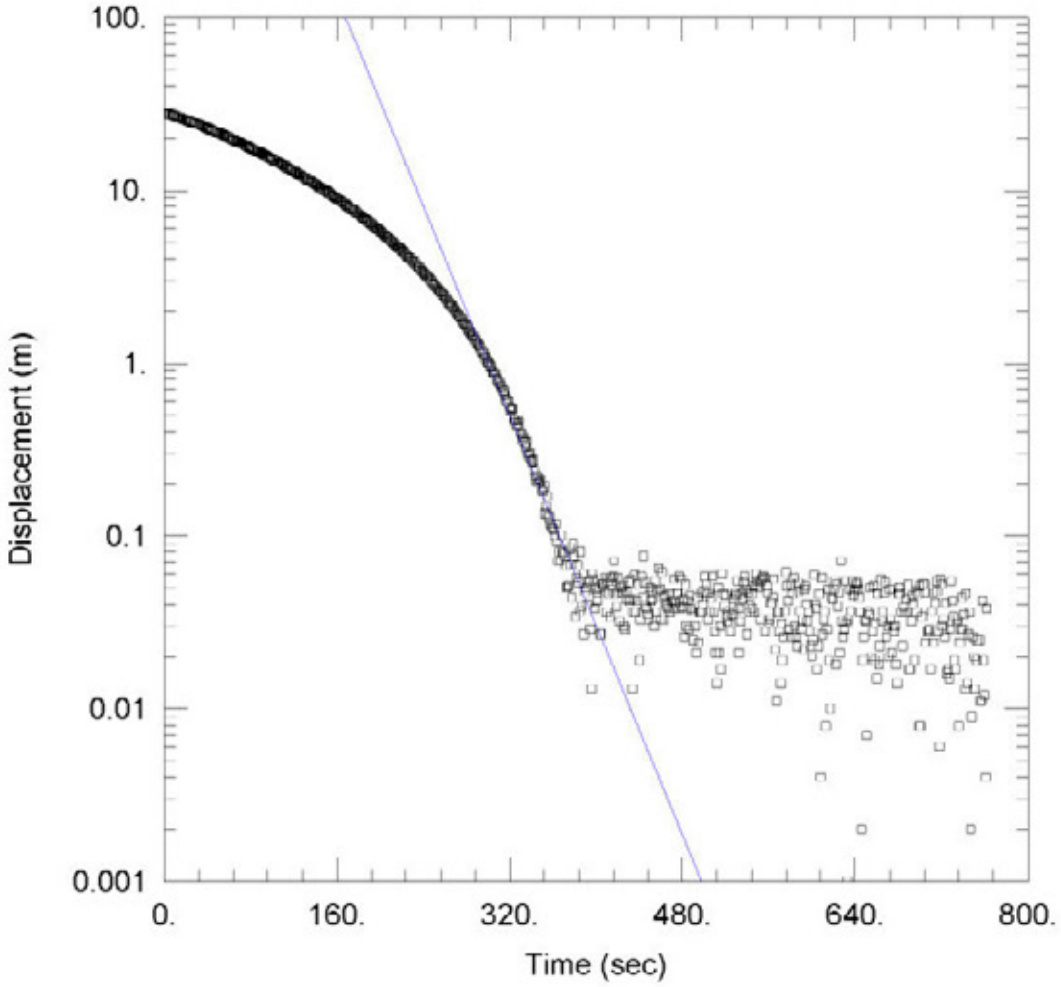
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test3C)

Initial Displacement: 27.9 m
Total Well Penetration Depth: 28.95 m
Casing Radius: 0.048 m
Static Water Column Height: 28.95 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
K = 9.946E-6 m/sec
Solution Method: Hvorslev
y0 = 32.42 m



320-01-BH2101 (FHT 88.0 M TO 93.0 M)

Data Set: V:\...\320-01-BH2101-Test3C_Hvor_late.aqt
Date: 12/13/18 Time: 15:37:48

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

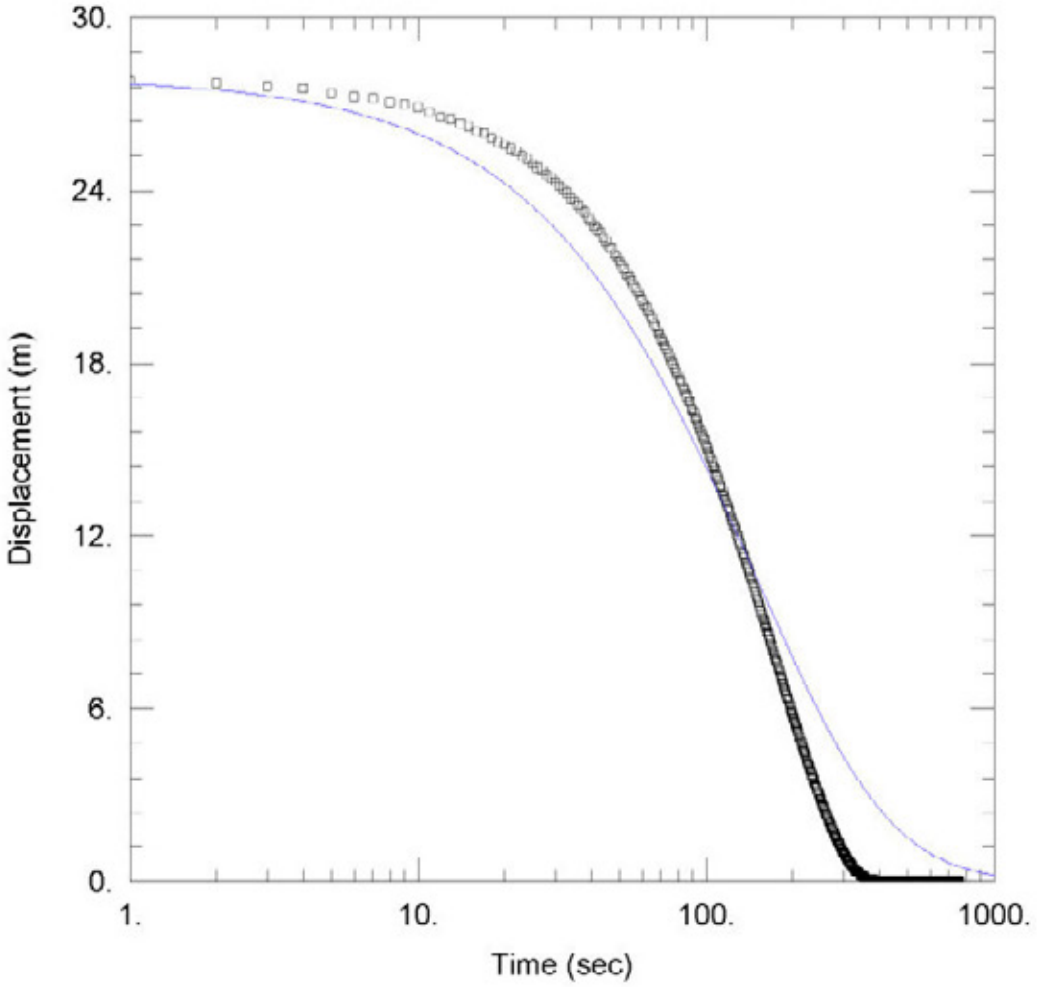
Saturated Thickness: 5. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test3C)

Initial Displacement: 27.9 m
Total Well Penetration Depth: 28.95 m
Casing Radius: 0.048 m
Static Water Column Height: 28.95 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
K = 4.262E-5 m/sec
Solution Method: Hvorslev
y0 = 3.532E+4 m



320-01-BH2101 (FHT 88.0 M TO 93.0 M)

Data Set: V:\...\320-01-BH2101-Test3C_KGS.aqt
Date: 12/13/18 Time: 15:38:25

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

Saturated Thickness: 5. m

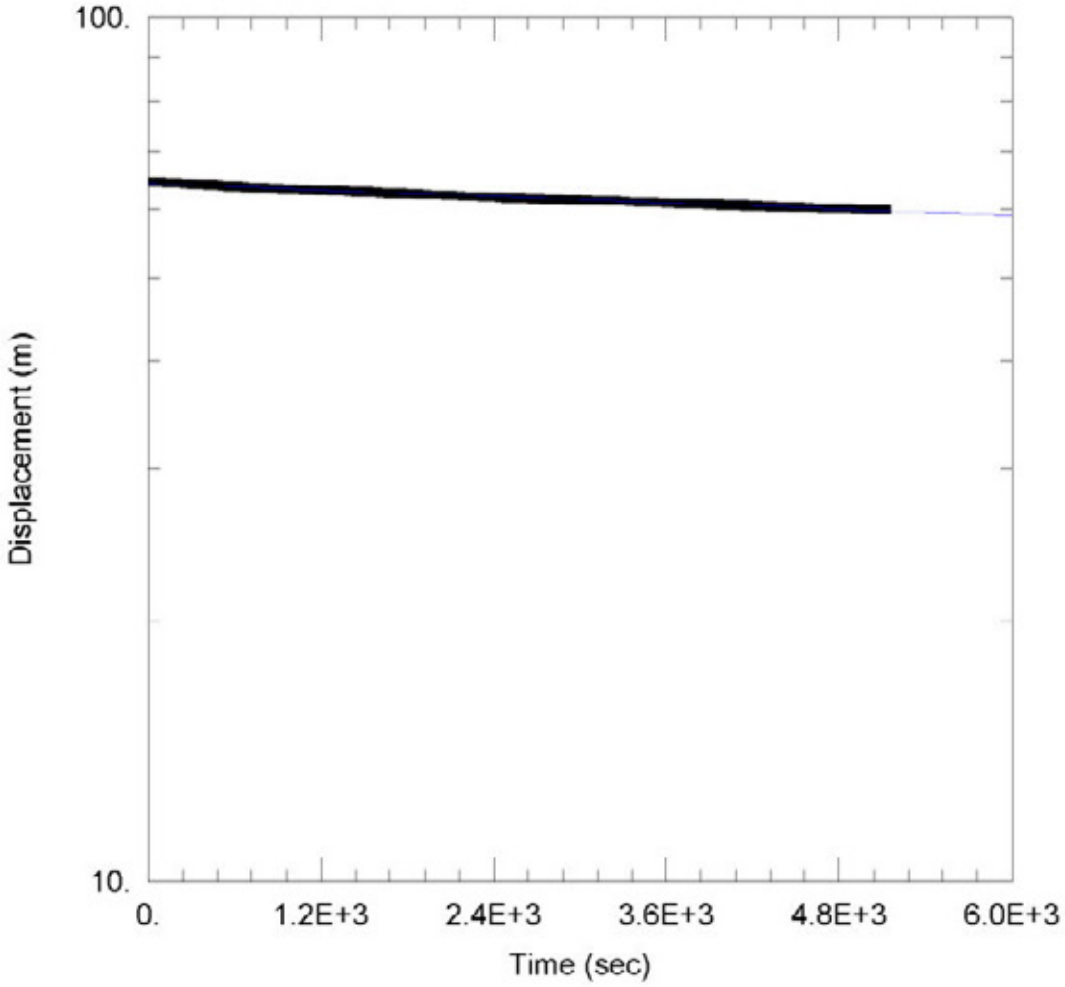
WELL DATA (BH2101-Test3C)

Initial Displacement: 27.9 m
Total Well Penetration Depth: 28.95 m
Casing Radius: 0.048 m
Static Water Column Height: 28.95 m
Screen Length: 5. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 2.414E-5 m/sec
Kz/Kr = 0.001
Ss = 5.929E-12 m^{-1}



320-01-BH2101 (FHT 103 M TO 107 M)

Data Set: V:\...\320-01-BH2101-Test2A_Hvor.aqt
Date: 12/13/18 Time: 15:30:46

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

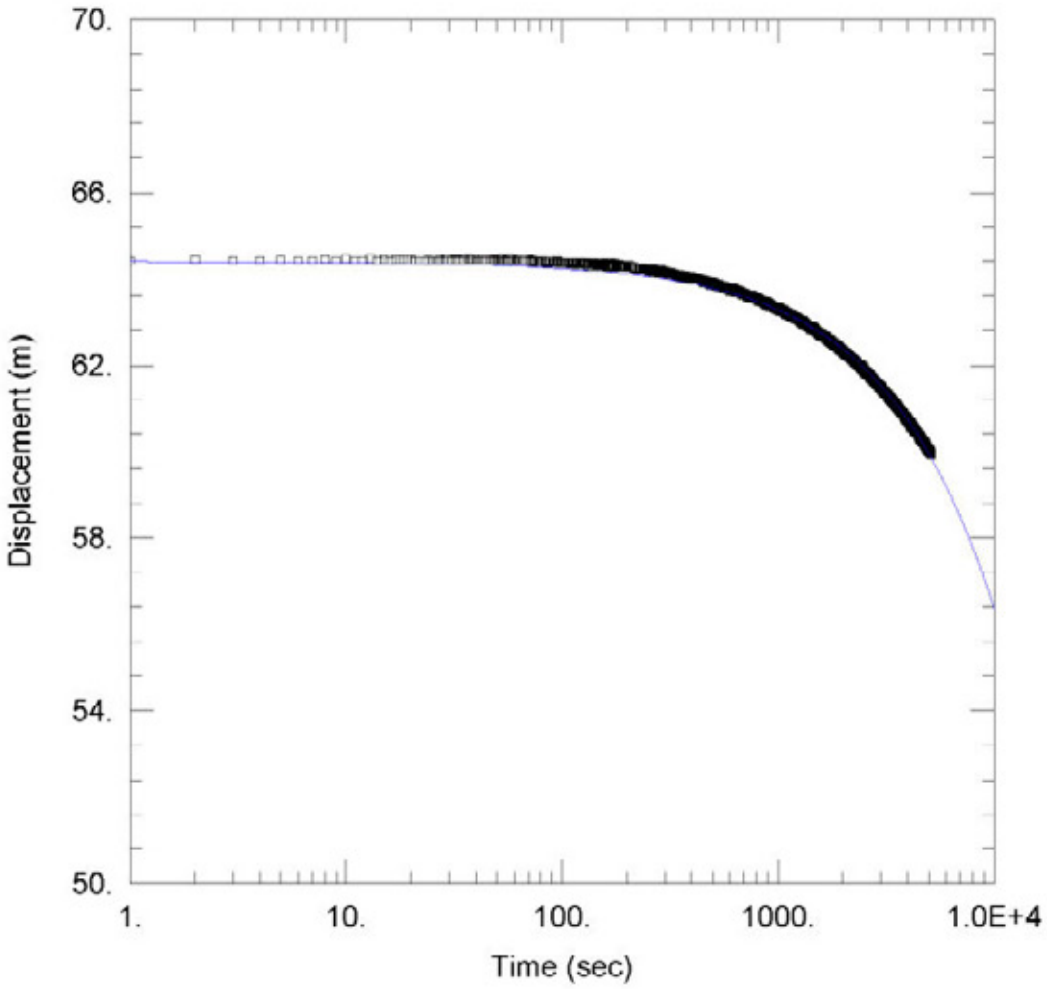
Saturated Thickness: 4. m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test2A)

Initial Displacement: 64.4 m
Total Well Penetration Depth: 68.4 m
Casing Radius: 0.048 m
Static Water Column Height: 38.56 m
Screen Length: 4. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
K = 2.148E-8 m/sec
Solution Method: Hvorslev
y0 = 64.22 m



320-01-BH2101 (FHT 103 M TO 107 M)

Data Set: V:\...\320-01-BH2101-Test2A_KGS.aqt
Date: 12/13/18 Time: 15:31:26

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 17/08/2018

AQUIFER DATA

Saturated Thickness: 4. m

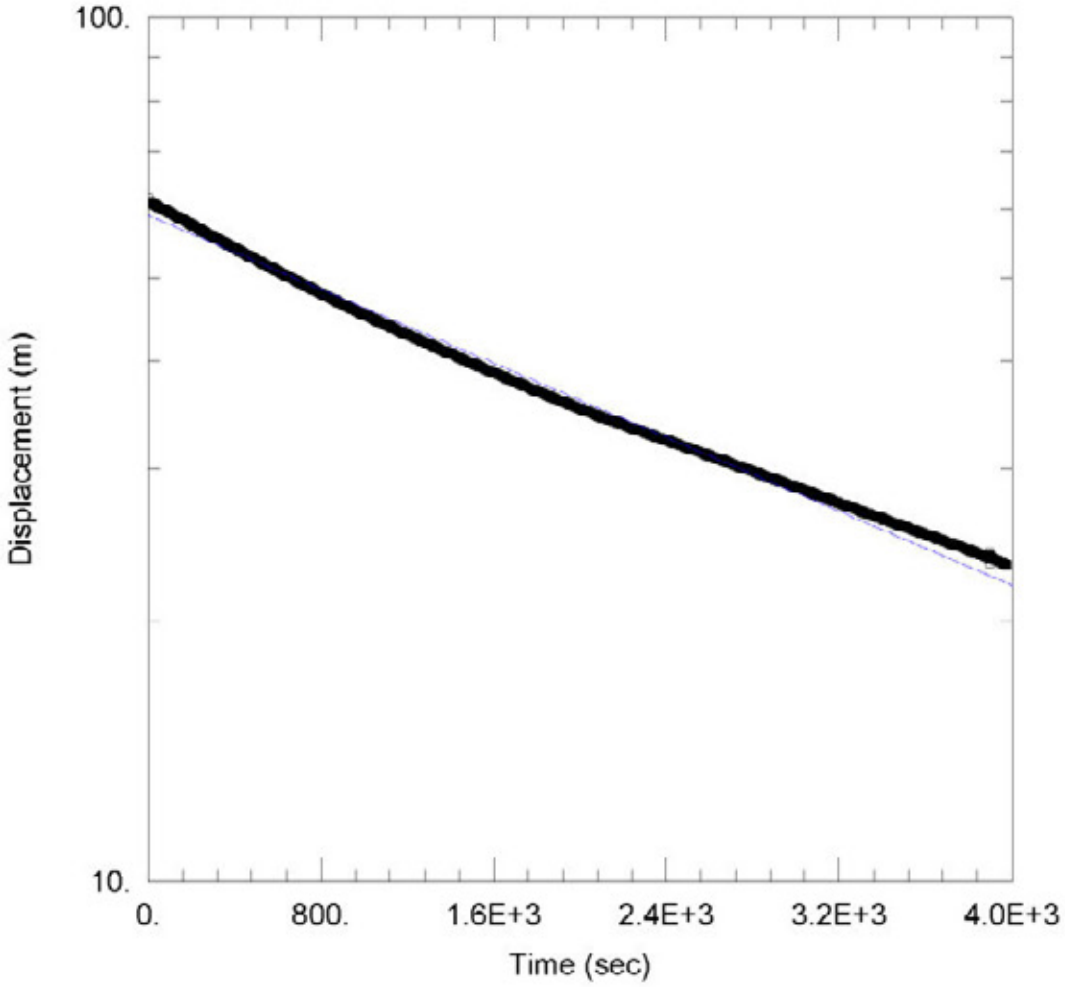
WELL DATA (BH2101-Test2A)

Initial Displacement: 64.4 m
Total Well Penetration Depth: 68.4 m
Casing Radius: 0.048 m
Static Water Column Height: 38.56 m
Screen Length: 4. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 1.862E-8 m/sec
Kz/Kr = 1.
Ss = 1.221E-5 m^{-1}



320-01-BH2101 (FHT 109.5 M TO 150 M)

Data Set: V:\...\320-01-BH2101-Test1_Hvor.aqt
Date: 12/13/18 Time: 15:28:14

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 16/08/2018

AQUIFER DATA

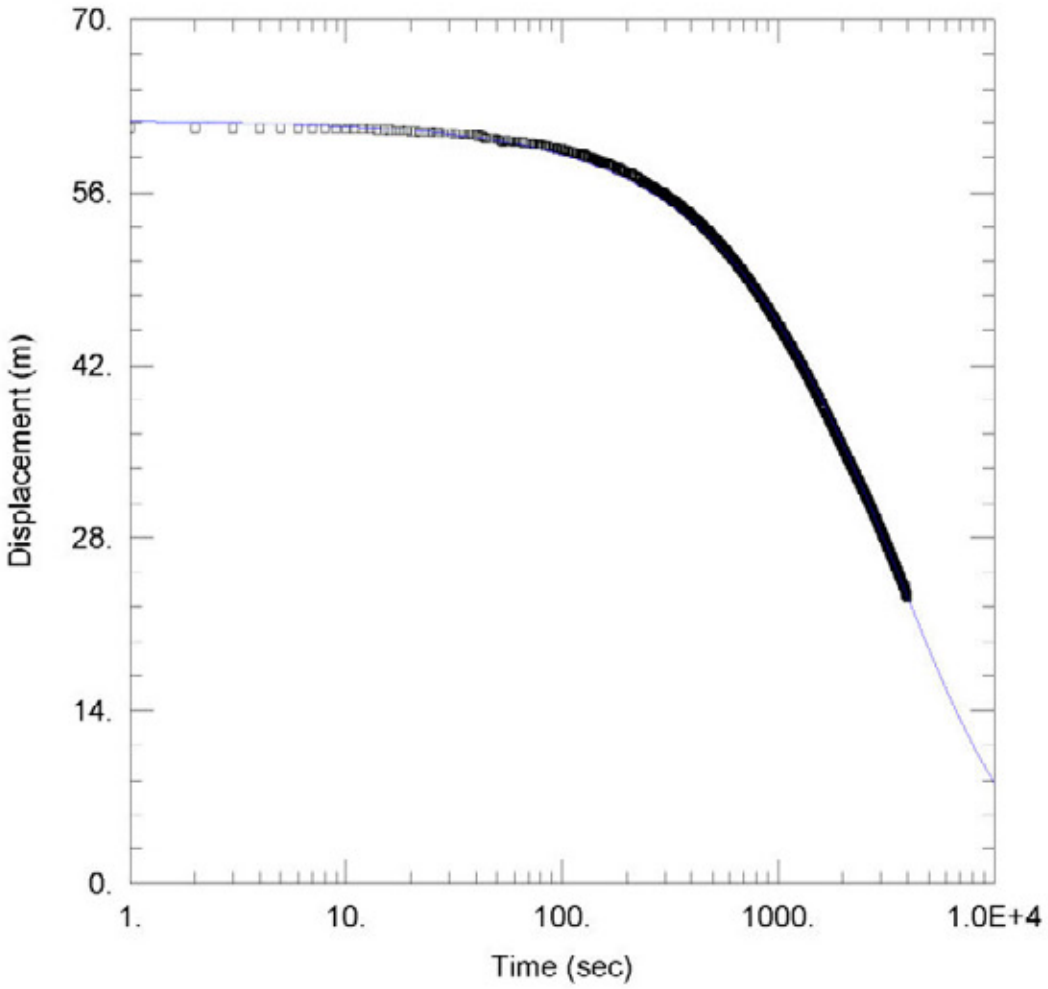
Saturated Thickness: 40.5 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (BH2101-Test1)

Initial Displacement: 61.8 m Static Water Column Height: 88.84 m
Total Well Penetration Depth: 88.4 m Screen Length: 40.5 m
Casing Radius: 0.048 m Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined Solution Method: Hvorslev
K = 3.717E-8 m/sec y0 = 59.05 m



320-01-BH2101 (FHT 109.5 M TO 150 M)

Data Set: V:\...\320-01-BH2101-Test1_KGS.aqt
Date: 12/13/18 Time: 15:29:15

PROJECT INFORMATION

Company: Golder Associates Pty Ltd
Client: FFJV
Project: 1893795
Location: G to H
Test Well: 320-01-BH2101
Test Date: 16/08/2018

AQUIFER DATA

Saturated Thickness: 40.5 m

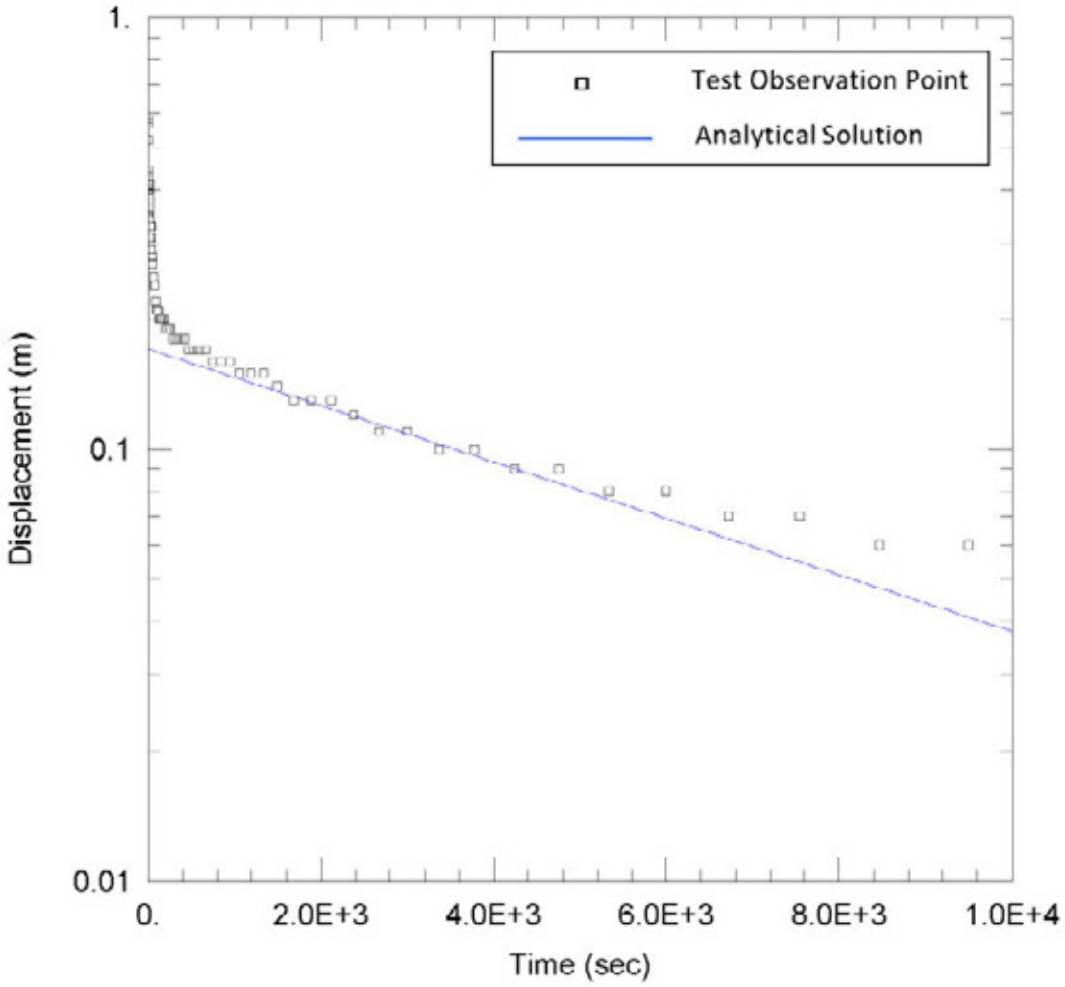
WELL DATA (BH2101-Test1)

Initial Displacement: 61.8 m
Total Well Penetration Depth: 88.4 m
Casing Radius: 0.048 m
Static Water Column Height: 88.84 m
Screen Length: 40.5 m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 4.253E-8 m/sec
Kz/Kr = 1.
Ss = 1.556E-5 m^{-1}



320-01-BH2103 (FALLING HEAD TEST)

Data Set: V:\...\320-01-BH2103 FHT_HVOR.aqt
Date: 03/12/19 Time: 10:32:58

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2103
Test Date: 20/11/2018

AQUIFER DATA

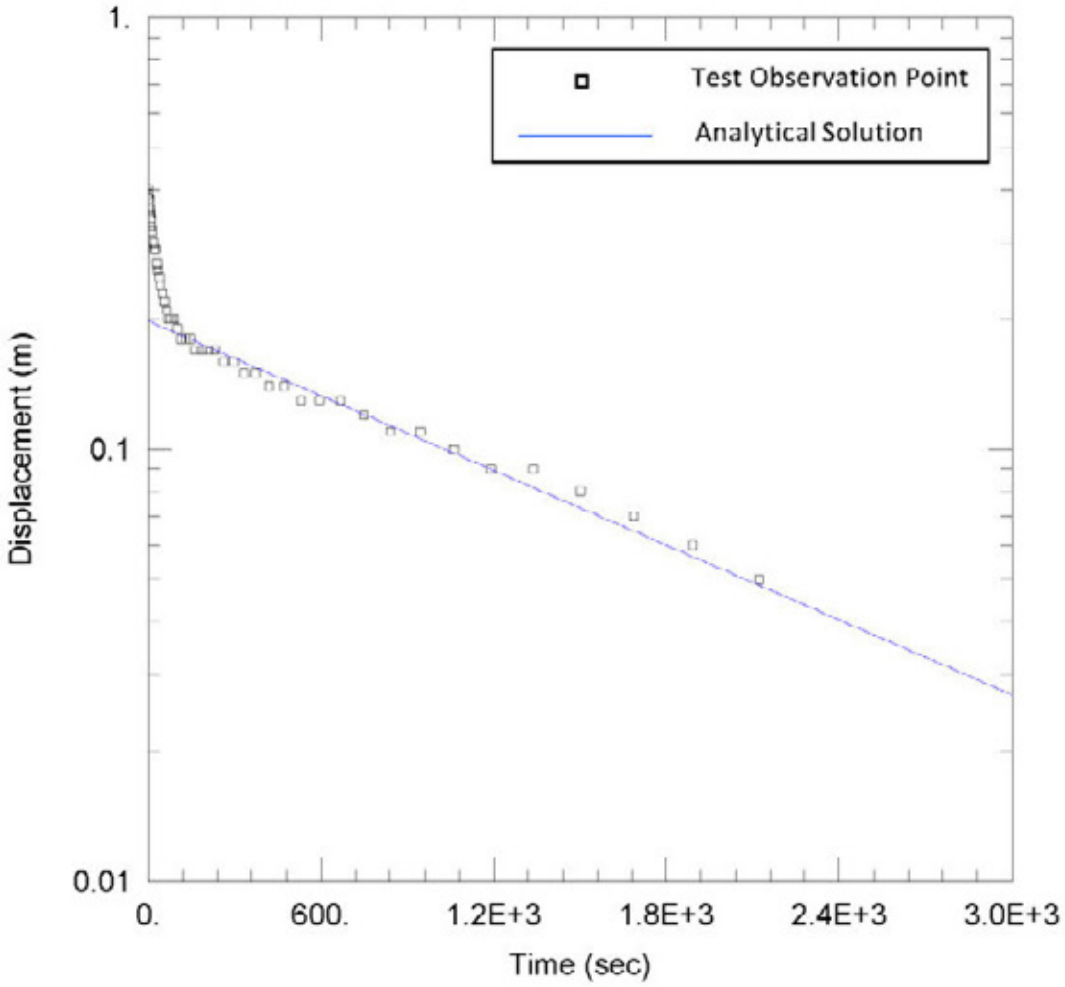
Saturated Thickness: 13.06 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2103)

Initial Displacement: 0.57 m
Total Well Penetration Depth: 13.06 m
Casing Radius: 0.025 m
Static Water Column Height: 13.06 m
Screen Length: 9. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 2.736E-8 m/sec
y0 = 0.1709 m



320-01-BH2103 (RISING HEAD TEST)

Data Set: V:\...\320-01-BH2103 RHT_HVOR.aqt
Date: 03/12/19 Time: 10:34:42

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2103
Test Date: 20/11/2018

AQUIFER DATA

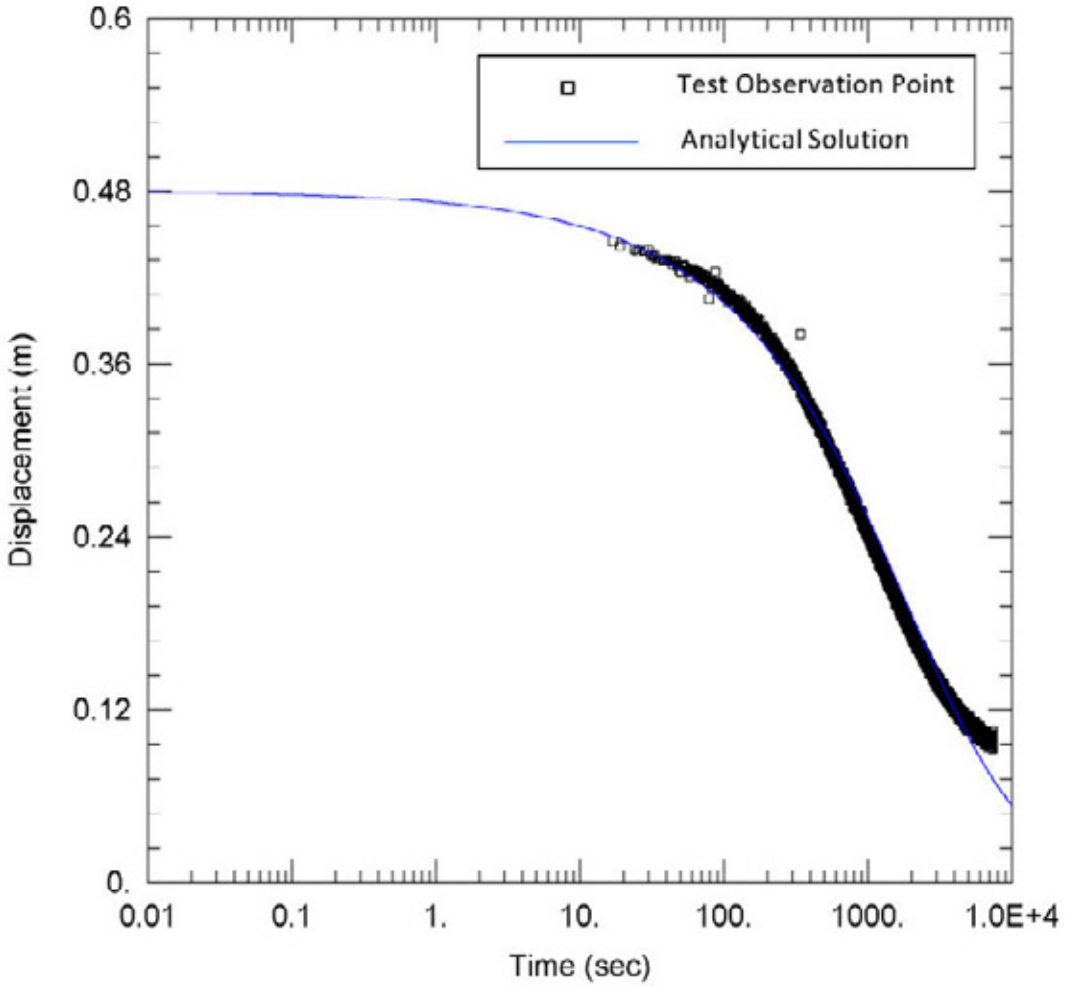
Saturated Thickness: 13.06 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2103)

Initial Displacement: 0.4 m
Total Well Penetration Depth: 13.06 m
Casing Radius: 0.025 m
Static Water Column Height: 13.06 m
Screen Length: 9. m
Well Radius: 10.05 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.001E-8 m/sec
y0 = 0.1985 m



320-01-BH2201 FHT

Data Set: \...\320-01-BH2201 FHT _KGS_SK.aqt
Date: 11/15/18 Time: 15:30:23

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2201

AQUIFER DATA

Saturated Thickness: 13.32 m

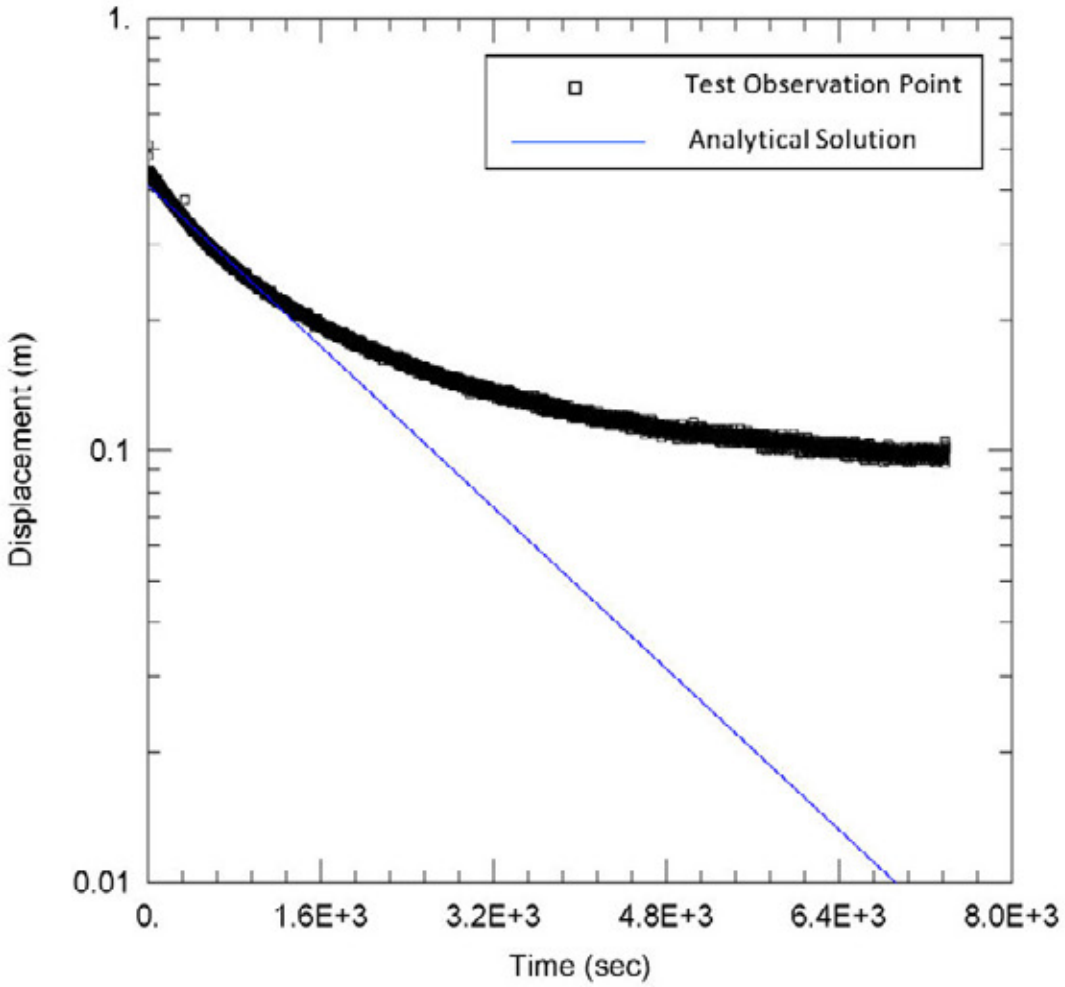
WELL DATA (302-01-BH2201_FHT)

Initial Displacement: 0.48 m
Total Well Penetration Depth: 13.32 m
Casing Radius: 0.025 m
Static Water Column Height: 13.32 m
Screen Length: 6. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 2.987E-8 m/sec
Kz/Kr = 1.
Ss = 0.007508 m^{-1}



320-01-BH2201 FHT

Data Set: \...\320-01-BH2201 Slug in _HVOR.aqt
Date: 11/15/18 Time: 13:54:26

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2201

AQUIFER DATA

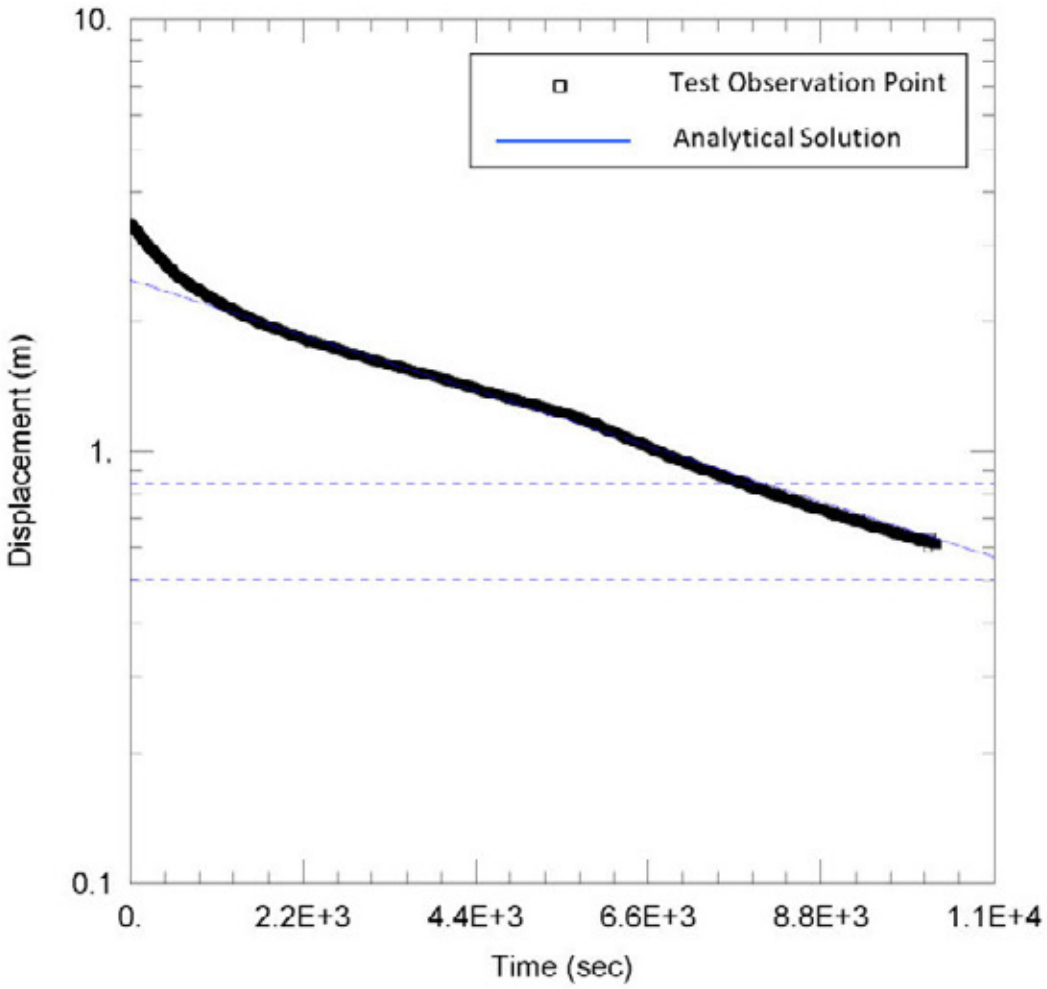
Saturated Thickness: 13.32 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (302-01-BH2201_FHT)

Initial Displacement: 0.48 m
Total Well Penetration Depth: 13.32 m
Casing Radius: 0.025 m
Static Water Column Height: 13.32 m
Screen Length: 6. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.544E-7 m/sec
y0 = 0.411 m



320-01-BH2207 (FALLING HEAD TEST)

Data Set: V:\...\320-01-BH2207 FHT_HVOR.aqt
Date: 04/10/19 Time: 13:08:55

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2207
Test Date: 11/02/2019

AQUIFER DATA

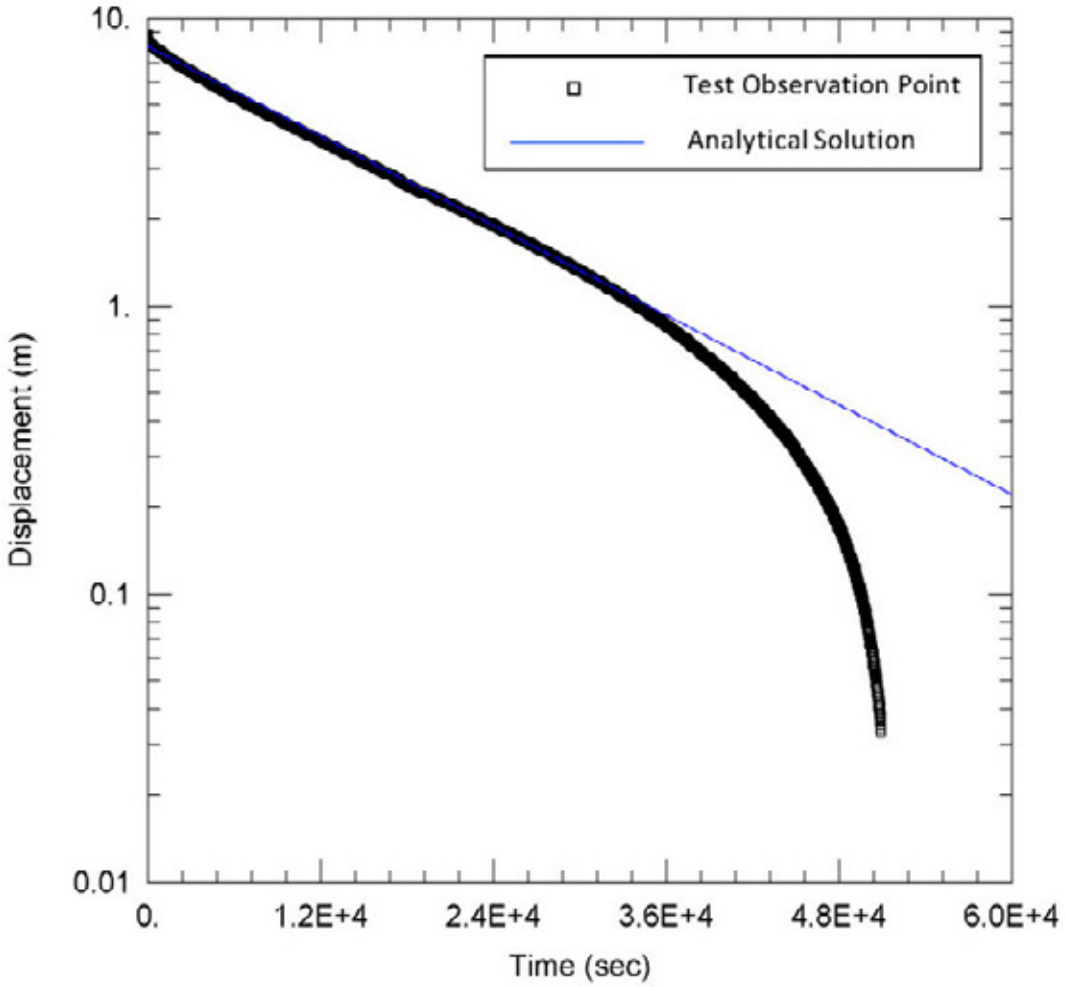
Saturated Thickness: 0.1 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2207)

Initial Displacement: 3.373 m
Total Well Penetration Depth: 0.1 m
Casing Radius: 0.025 m
Static Water Column Height: 0.1 m
Screen Length: 0.1 m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 2.225E-6 m/sec
y0 = 2.497 m



320-01-BH2209 FHT

Data Set: \...\320-01-BH2209 FHT_HVOR.aqt
Date: 11/15/18 Time: 14:10:08

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2209

AQUIFER DATA

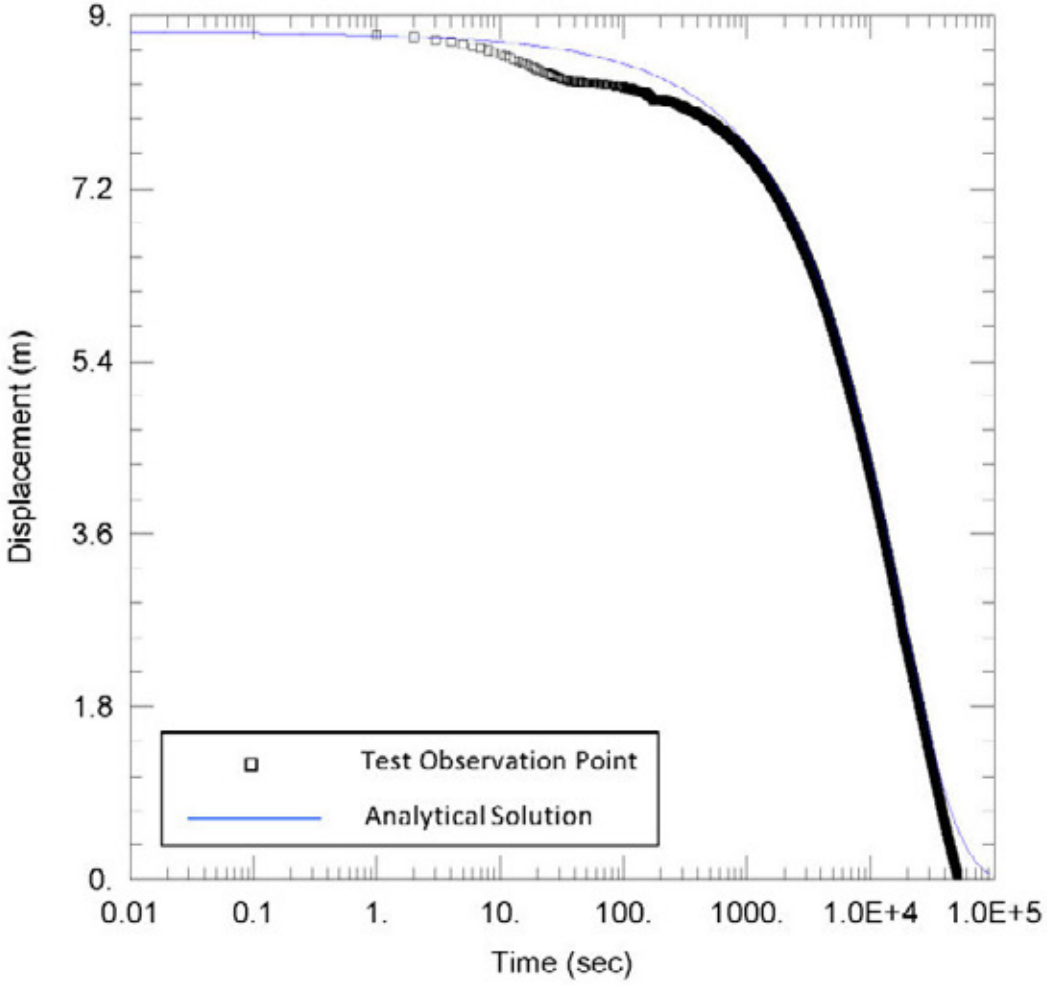
Saturated Thickness: 0.1 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2209)

Initial Displacement: 8.821 m
Total Well Penetration Depth: 1. m
Casing Radius: 0.025 m
Static Water Column Height: 0. m
Screen Length: 1. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
K = 9.877E-7 m/sec
Solution Method: Hvorslev
y0 = 7.985 m



WELL TEST ANALYSIS

Data Set: V:\...\320-01-BH2209 FHT_KGS.aqt
Date: 11/27/18 Time: 14:16:10

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2209

AQUIFER DATA

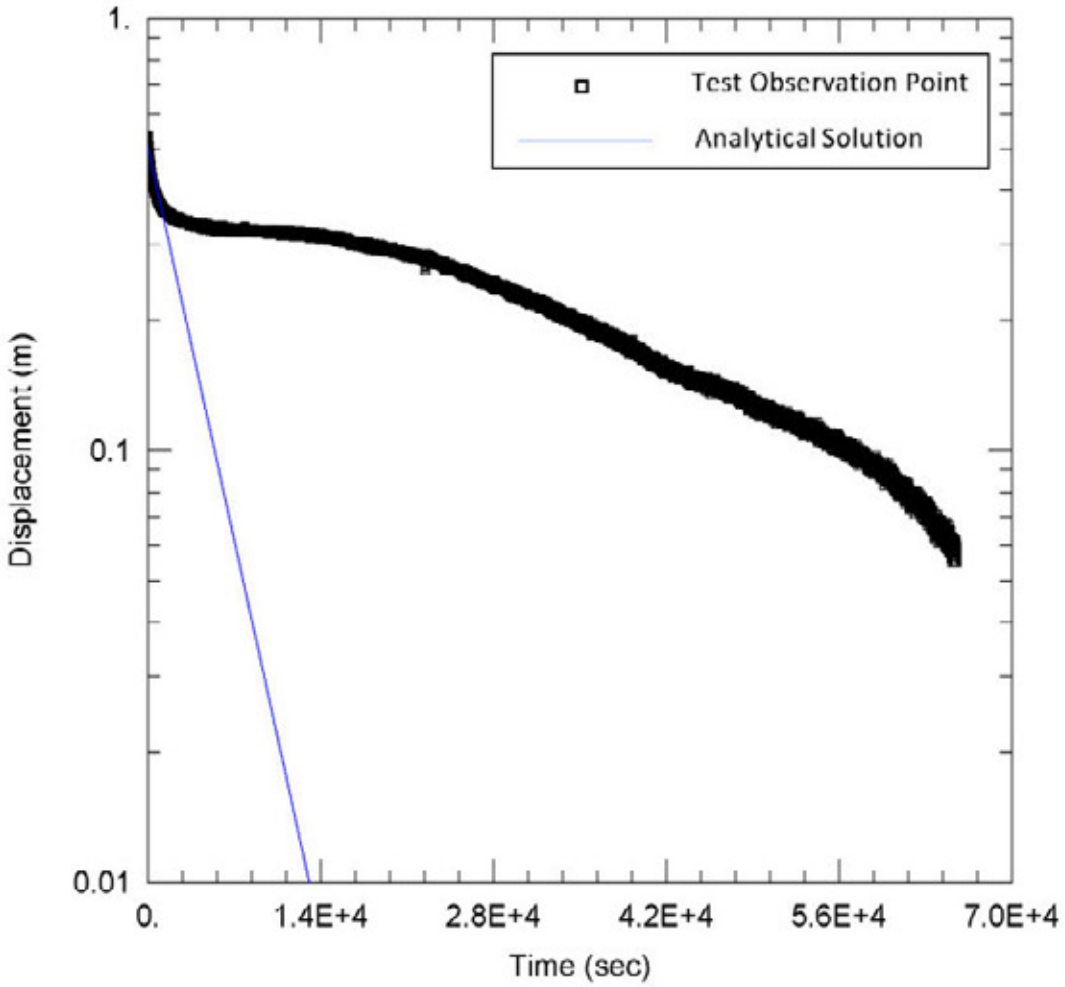
Saturated Thickness: 0.1 m

WELL DATA (320-01BH2209)

Initial Displacement: 8.821 m
Total Well Penetration Depth: 1. m
Casing Radius: 0.025 m
Static Water Column Height: 0. m
Screen Length: 1. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model
Kr = 1.431E-7 m/sec
Ss = 0.2735 m^{-1}
Kz/Kr = 1.



320-01-BH2212

Data Set: \...\320-01-BH2212 FHT_Hvor - SK.aqt
Date: 11/15/18 Time: 14:13:27

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2212

AQUIFER DATA

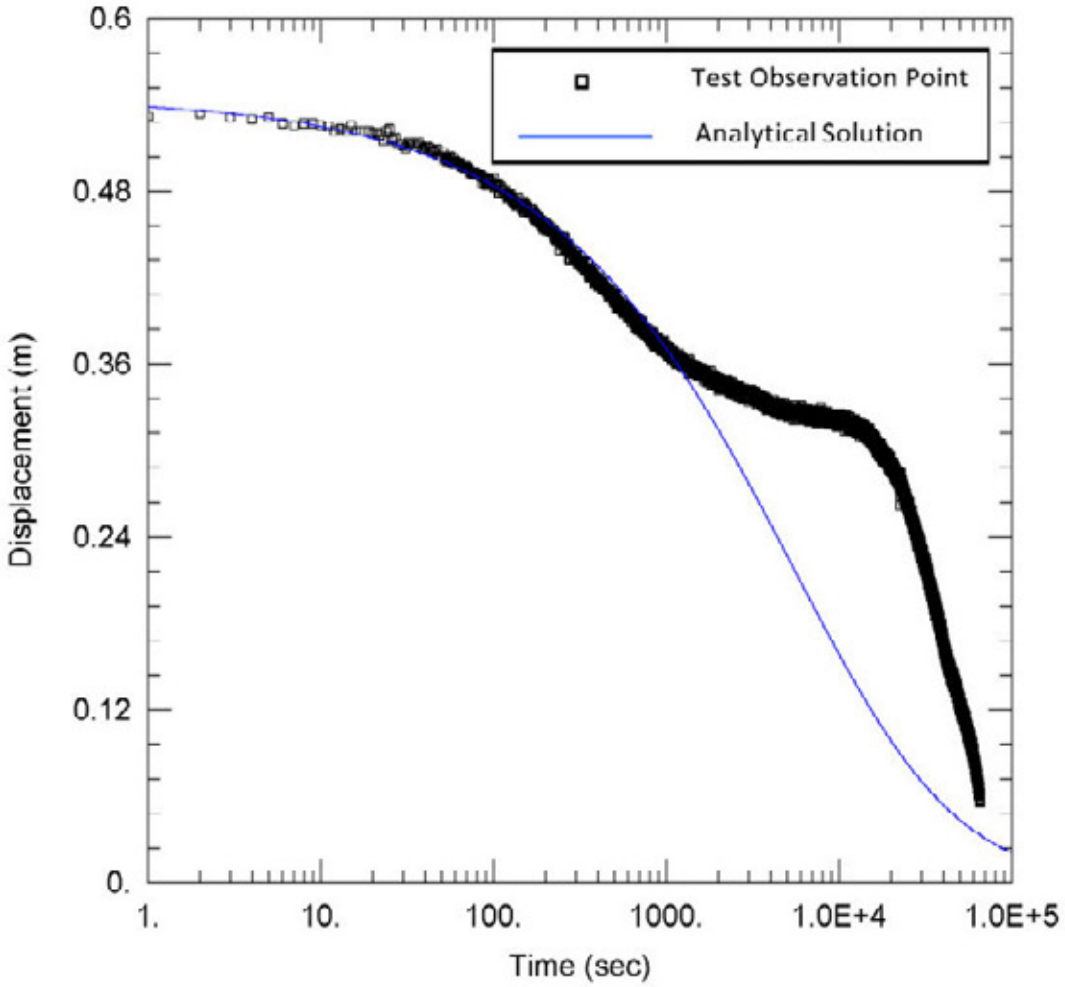
Saturated Thickness: 1. m
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2212)

Initial Displacement: 0.535 m
Total Well Penetration Depth: 1. m
Casing Radius: 0.028 m
Static Water Column Height: 1. m
Screen Length: 1. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 6.226E-7 m/sec
y0 = 0.5041 m



320-01-BH2212

Data Set: \...\320-01-BH2212 FHT_KGS - SK.aqt
Date: 11/15/18 Time: 14:17:22

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2212

AQUIFER DATA

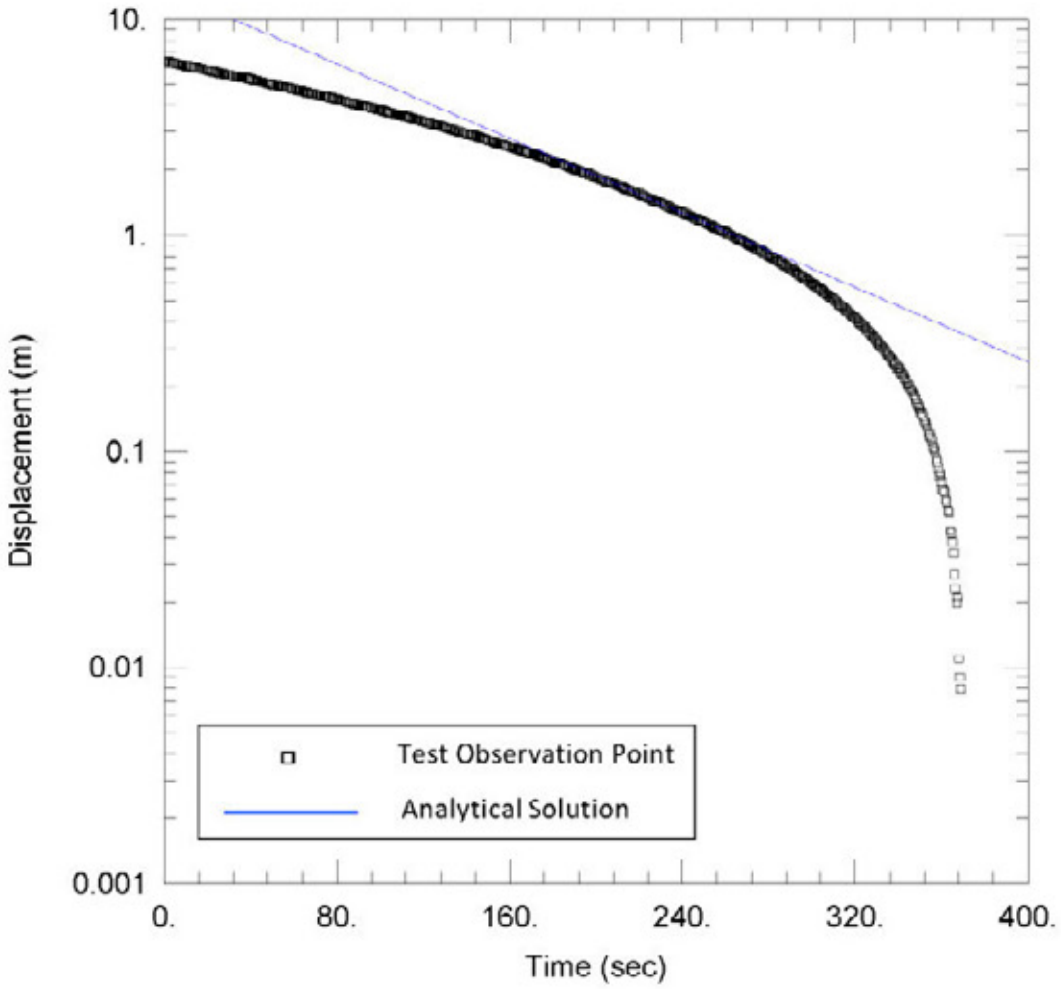
Saturated Thickness: 1. m

WELL DATA (320-01-BH2212)

Initial Displacement: 0.545 m
Total Well Penetration Depth: 1. m
Casing Radius: 0.028 m
Static Water Column Height: 1. m
Screen Length: 1. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Kr = 4.509E-8 m/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 0.1578 m^{-1}



320-01-BH2215 (FALLING HEAD TEST)

Data Set: V:\...\320-01-BH2215 FHT_HVOR.aqt
Date: 04/10/19 Time: 13:09:55

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2215
Test Date: 25/02/2019

AQUIFER DATA

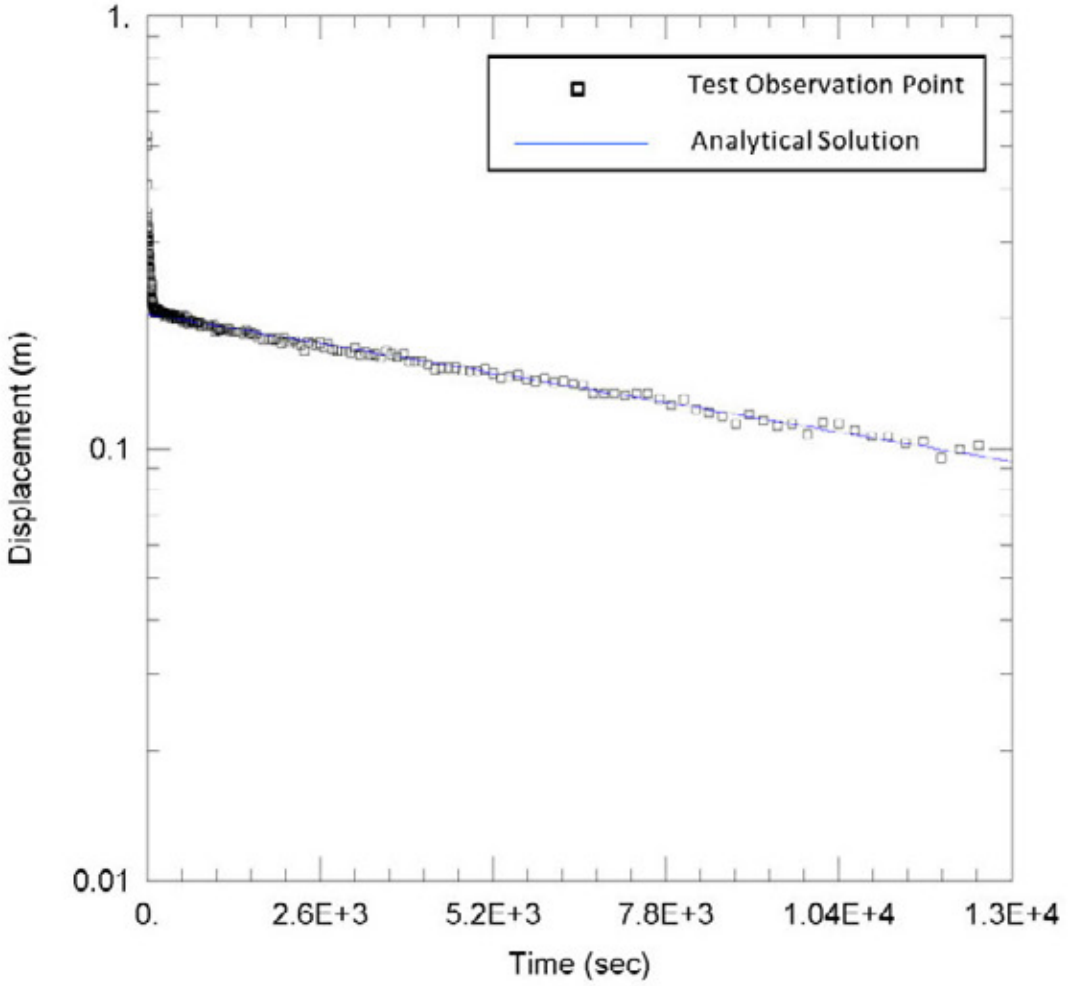
Saturated Thickness: 0.2 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2215)

Initial Displacement: 6.41 m
Total Well Penetration Depth: 0.2 m
Casing Radius: 0.025 m
Static Water Column Height: 0.2 m
Screen Length: 0.2 m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 8.218E-5 m/sec
y0 = 13.77 m



320-01-BH2216 (SLUG IN)

Data Set: V:\...\320-01-BH2216 FHT _HVOR.aqt
Date: 03/14/19 Time: 11:49:35

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2216
Test Date: 07/03/2019

AQUIFER DATA

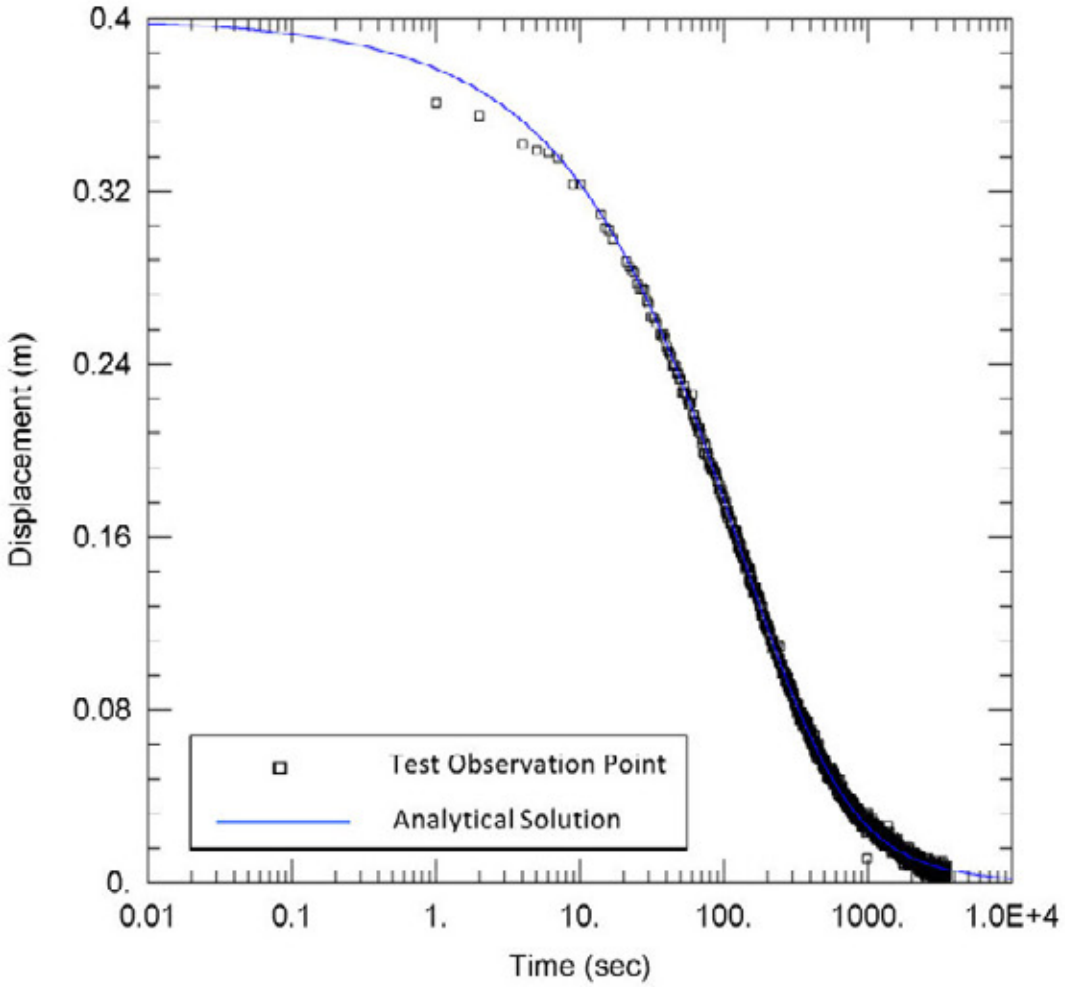
Saturated Thickness: 6.6 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2216)

Initial Displacement: 0.532 m
Total Well Penetration Depth: 6.6 m
Casing Radius: 0.025 m
Static Water Column Height: 6.6 m
Screen Length: 6. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
K = 1.742E-8 m/sec
Solution Method: Hvorslev
y0 = 0.2049 m



320-01-BH2217

Data Set: \...\320-01-BH2217 Slug in _KGS.aqt
Date: 11/15/18 Time: 14:22:48

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2217

AQUIFER DATA

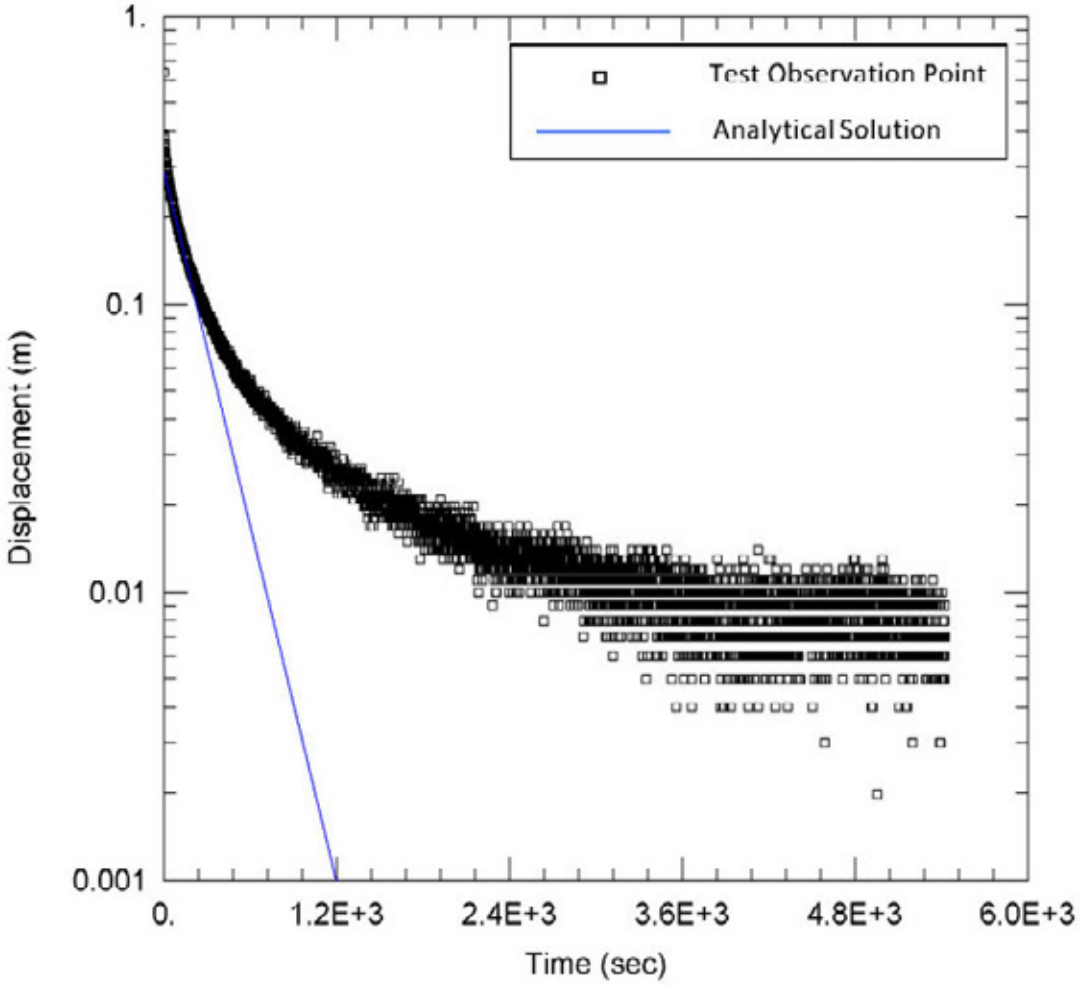
Saturated Thickness: 10.14 m

WELL DATA (320-01-BH2217)

Initial Displacement: 0.4 m
Total Well Penetration Depth: 10.14 m
Casing Radius: 0.025 m
Static Water Column Height: 10.14 m
Screen Length: 9. m
Well Radius: 0.048 m

SOLUTION

Aquifer Model: Unconfined
Kr = 3.513E-7 m/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 0.00363 m^{-1}



320-01-BH2217

Data Set: \...\320-01-BH2217 Slug out_HVOR.aqt
Date: 11/15/18 Time: 14:24:17

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2217

AQUIFER DATA

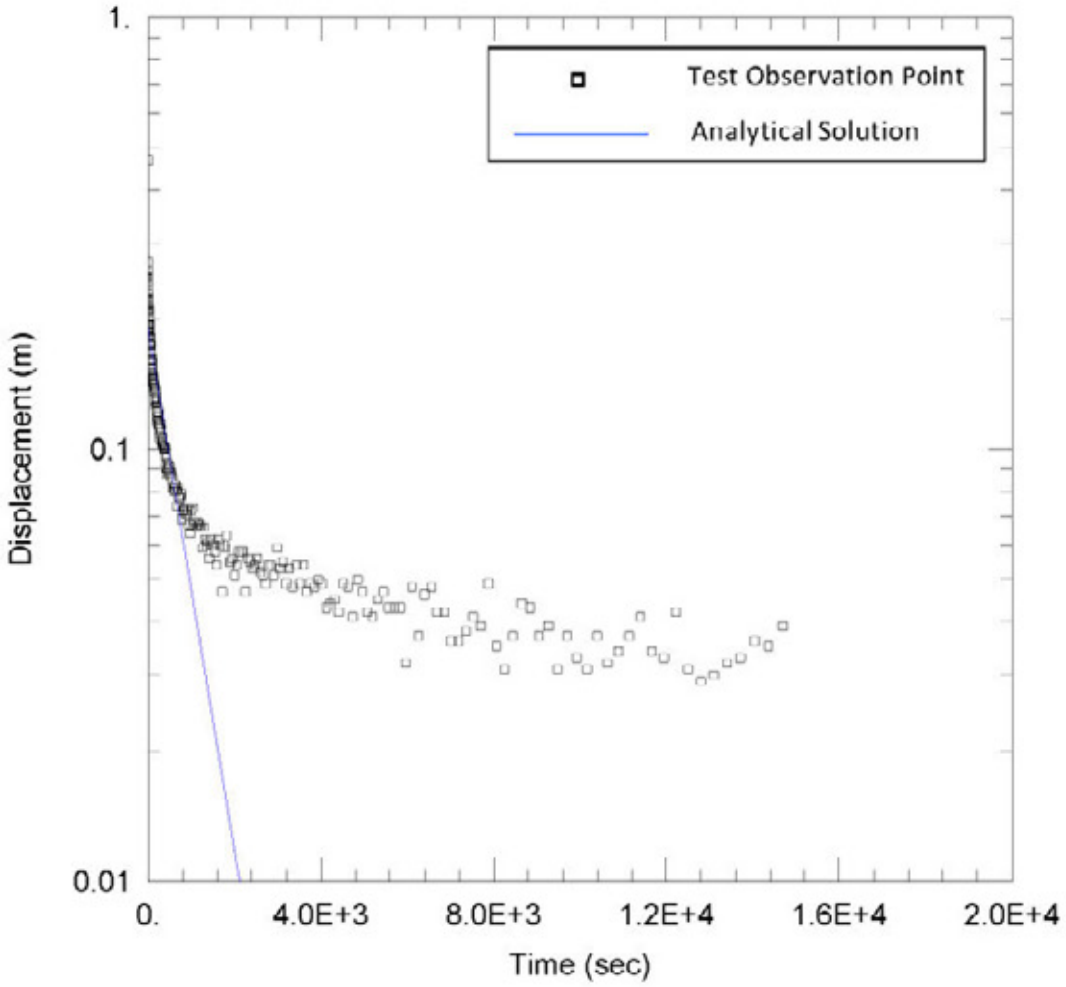
Saturated Thickness: 10.14 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2217)

Initial Displacement: 0.64 m
Total Well Penetration Depth: 10.14 m
Casing Radius: 0.025 m
Static Water Column Height: 10.14 m
Screen Length: 9. m
Well Radius: 10.05 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 1.324E-7 m/sec
y0 = 0.2901 m



320-01-BH2218 (FALLING HEAD TEST)

Data Set: V:\...\320-01-BH2218 FHT_HVOR.aqt
Date: 11/27/18 Time: 14:23:56

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2218
Test Date: 20/11/2018

AQUIFER DATA

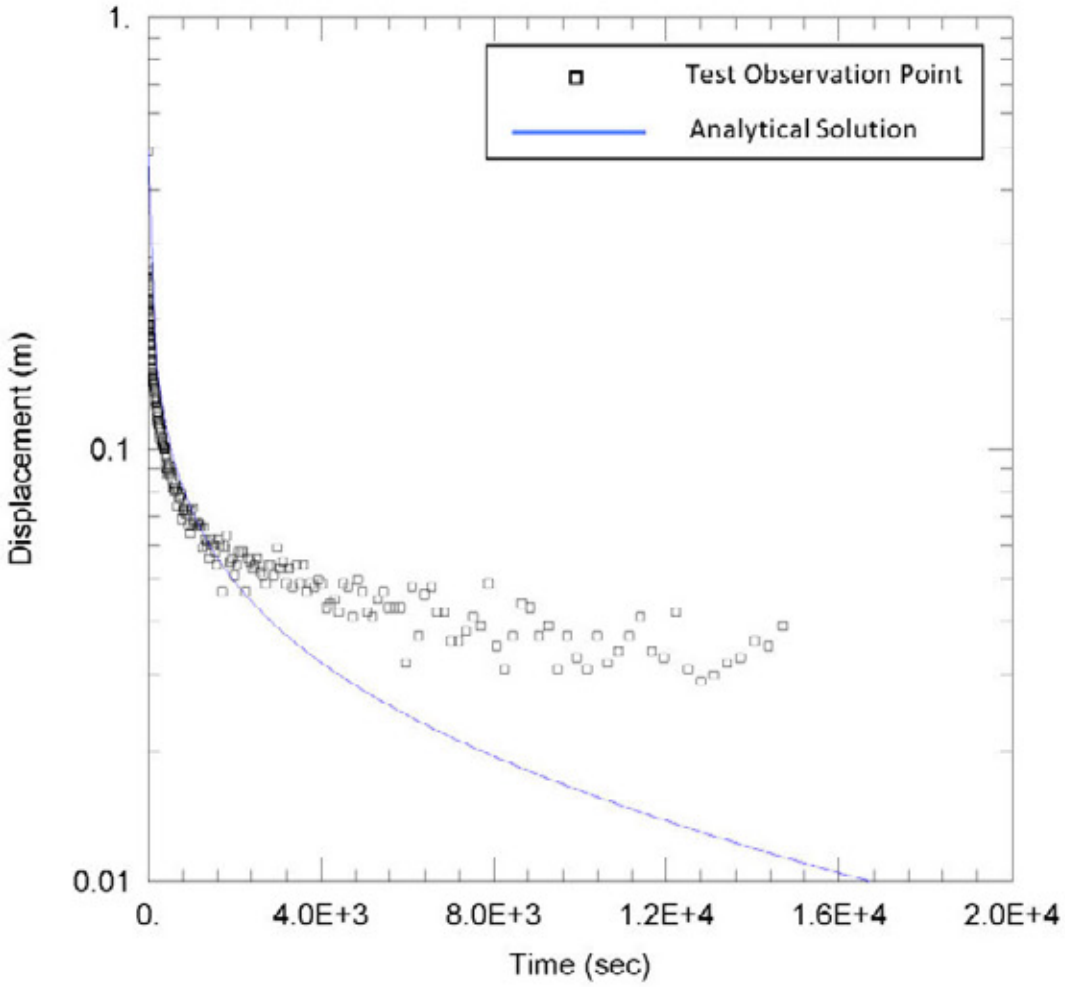
Saturated Thickness: 7.5 m Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (320-01-BH2218)

Initial Displacement: 0.468 m
Total Well Penetration Depth: 7.5 m
Casing Radius: 0.025 m
Static Water Column Height: 7.5 m
Screen Length: 6. m
Well Radius: 10.05 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 4.102E-8 m/sec
y0 = 0.1908 m



320-01-BH2218 (FALLING HEAD TEST)

Data Set: V:\...\320-01-BH2218 FHT_KGS.aqt
Date: 11/27/18 Time: 14:26:44

PROJECT INFORMATION

Company: Golder Associates
Client: FFJV
Project: 1893802
Test Well: 320-01-BH2218
Test Date: 20/11/2018

AQUIFER DATA

Saturated Thickness: 7.5 m

WELL DATA (320-01-BH2218)

Initial Displacement: 0.49 m
Total Well Penetration Depth: 7.5 m
Casing Radius: 0.025 m
Static Water Column Height: 7.5 m
Screen Length: 6. m
Well Radius: 10.05 m

SOLUTION

Aquifer Model: Unconfined
Solution Method: KGS Model

Kr = 1.334E-8 m/sec
Kz/Kr = 1.
Ss = 2.162E-5 m^{-1}

Appendix G
PPP extended geotech program data

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



GOLDER

EXPLANATION OF NOTES, ABBREVIATIONS & TERMS USED ON BOREHOLE AND TEST PIT REPORTS

DRILLING/EXCAVATION METHOD

ADH	Hollow auger drilling	EX	Excavator	PQ3	Diamond core - 83 mm
ADT	Auger drilling with tc-bit	HA	Hand auger	PT	Push tube sampling
ADV	Auger drilling with v-bit	HAND	Excavated by hand methods	RAB	Rotary air blast
AIRCORE	Aircore	HMLC	Diamond core - 63 mm	RC	Reverse circulation
AT	Air track	HQ3	Diamond core - 61 mm	RT	Rock roller
BH	Backhoe bucket	JET	Jetting	SONIC	Sonic drilling
CT	Cable tool rig	MZ	Mazier tube sampling	SPT	Standard penetration testing
DTC	Diatube coring	NDD	Non-destructive digging	U	Undisturbed tube sampling
EE	Existing excavation	NMLC	Diamond core - 52 mm	WB	Washbore drilling
EPT	Extruded push tube	NQ3	Diamond core - 45 mm		

PENETRATION/EXCAVATION RESISTANCE

L	**Low resistance.** Rapid penetration possible with little effort from the equipment used.
M	**Medium resistance.** Excavation/possible at an acceptable rate with moderate effort from the equipment used.
H	**High resistance** to penetration/excavation. Further penetration is possible at a slow rate and requires significant effort from the equipment.
R	**Refusal or Practical Refusal.** No further progress possible without the risk of damage or unacceptable wear to the digging implement or machine.

These assessments are subjective and are dependent on many factors including the equipment power, weight, condition of excavation or drilling tools, and the experience of the operator.

WATER

▽	Water level at date shown	◁	Partial water loss
▷	Water inflow	◀	Complete water loss
GROUNDWATER NOT OBSERVED	The observation of groundwater, whether present or not, was not possible due to drilling water, surface seepage or cave in of the borehole/test pit.		
GROUNDWATER NOT ENCOUNTERED	The borehole/test pit was dry soon after excavation. However, groundwater could be present in less permeable strata. Inflow may have been observed had the borehole/test pit been left open for a longer period.		

SAMPLING AND TESTING

SPT	Standard Penetration Test to AS1289.6.3.1-2004
4,7,11 N=18	4,7,11 = Blows per 150mm. N = Blows per 300mm penetration following 150mm seating
30/80 mm	Where practical refusal occurs, the blows and penetration for that interval are reported
RW	Penetration occurred under the rod weight only
HW	Penetration occurred under the hammer and rod weight only
HB	Hammer double bouncing on anvil
DS	Disturbed sample
BDS	Bulk disturbed sample
G	Gas Sample
W	Water Sample
FP	Field permeability test over section noted
FV	Field vane shear test expressed as uncorrected shear strength (sv = peak value, sr = residual value)
PID	Photoionisation Detector reading in ppm
PM	Pressuremeter test over section noted
PP	Pocket penetrometer test expressed as instrument reading in kPa
U63	Thin walled tube sample - number indicates nominal sample diameter in millimetres
WPT	Water pressure test
DCP	Dynamic cone penetration test
CPT	Cone penetration test
CPTu	Cone penetration test with pore pressure (u) measurement

RANKING OF VISUALLY OBSERVABLE CONTAMINATION AND ODOUR (for specific soil contamination assessment projects)

R = 0	No visible evidence of contamination	R = A	No non-natural odours identified
R = 1	Slight evidence of visible contamination	R = B	Slight non-natural odours identified
R = 2	Visible contamination	R = C	Moderate non-natural odours identified
R = 3	Significant visible contamination	R = D	Strong non-natural odours identified

ROCK CORE RECOVERY

TCR = Total Core Recovery (%)	RQD = Rock Quality Designation (%)	SCR = Solid Core Recovery (%)	F = Fracture Frequency
$= \frac{\text{Length of core recovered}}{\text{Length of core run}} \times 100$	$= \frac{\sum \text{Axial lengths of core} > 100\text{ mm}}{\text{Length of core run}} \times 100$	$= \frac{\sum \text{Length of cylindrical core recovered}}{\text{Length of core run}} \times 100$	$= \frac{\text{No. of defects}}{\text{Length of zone (m)}}$

GOLDER

METHOD OF SOIL DESCRIPTION USED ON BOREHOLE AND TEST PIT REPORTS

SYMBOLS

FILL

GRAVEL (GW, GP, GM or GC)

SAND (SW, SP, SM or SC)

SILT (ML or MH)

CLAY (CL, CI or CH)

ORGANIC SOILS (OL, OH or Pt)

COBBLES or BOULDERS

Combinations of these basic symbols may be used to indicate mixed materials such as sandy clay.

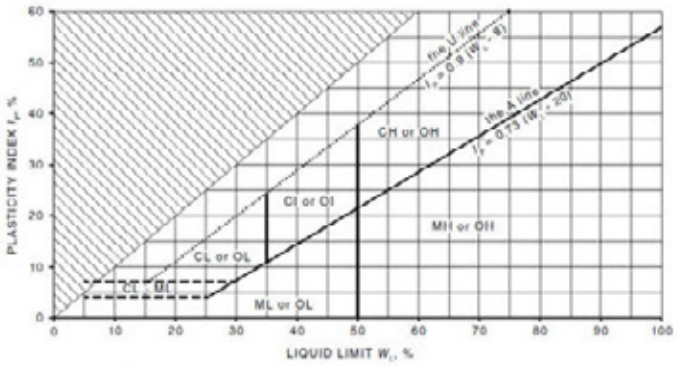
CLASSIFICATION AND INFERRED STRATIGRAPHY

Soil and Rock is classified and described in Reports of Boreholes and Test Pits using the preferred method given in AS1726-2017. The material properties are assessed in the field by visual/tactile methods.

Particle Size

Soil Group	Sub Division	Particle Size
BOULDERS		> 200 mm
COBBLES		63 to 200 mm
GRAVEL	Coarse	19 to 63 mm
	Medium	6.7 to 19 mm
	Fine	2.36 to 6.7 mm
SAND	Coarse	0.6 to 2.36 mm
	Medium	0.21 to 0.6 mm
	Fine	0.075 to 0.21 mm
SILT		0.002 to 0.075 mm
CLAY		< 0.002 mm

Plasticity Properties



MOISTURE CONDITION

Symbol	Term	Description
D	Dry	Sands and gravels are free flowing. Clays and silts may be brittle or friable and powdery.
M	Moist	Soils are darker than in dry condition and may feel cool. Sands and gravels tend to cohere.
W	Wet	Soils exude free water. Sand and gravels tend to cohere.

Moisture condition for fine grained soils is described relative to the plastic limit or liquid limit as specified in AS1726-2017.

CONSISTENCY AND DENSITY

Fine Grained Soils

Symbol	Term	Undrained Shear Strength
VS	Very Soft	0 to 12 kPa
S	Soft	12 to 25 kPa
F	Firm	25 to 50 kPa
St	Stiff	50 to 100 kPa
VSt	Very Stiff	100 to 200 kPa
H	Hard	Above 200 kPa
Fr	Friable	-

Coarse Grained Soils

Symbol	Term	Density Index (%)	SPN "N" *
VL	Very Loose	Less than 15	0 to 4
L	Loose	15 to 35	4 to 10
MD	Medium Dense	35 to 65	10 to 30
D	Dense	65 to 85	30 to 50
VD	Very Dense	Above 85	Above 50

In the absence of test results, consistency and density may be assessed from correlations with the observed behaviour of the material.

* SPT correlations are not stated in AS1726-2017, and may be subject to corrections for overburden pressure and equipment type.

CEMENTATION

Weakly Cemented	The soil may be easily disaggregated by hand in air or water.
Moderately Cemented	Effort is required to disaggregate the soil by hand in air or water.

GOLDER

TERMS FOR ROCK MATERIAL STRENGTH & WEATHERING AND ABBREVIATIONS FOR DEFECT DESCRIPTIONS

STRENGTH

Symbol	Term	UCS (MPa)	Field Guide
VL	Very Low	0.6 to 2	Material crumbles under firm blows with sharp end of pick; can be peeled with knife; too hard to cut a triaxial sample by hand. Pieces up to 30 mm can be broken by finger pressure.
L	Low	2 to 6	Easily scored with a knife; indentations 1 mm to 3 mm show in the specimen with firm blows of pick point; has dull sound under hammer. A piece of core 150 mm long by 50 mm diameter may be broken by hand. Sharp edges of core may be friable and break during handling.
M	Medium	6 to 20	Readily scored with a knife; a piece of core 150 mm long by 50 mm diameter can be broken by hand with difficulty.
H	High	20 to 60	A piece of core 150 mm long by 50 mm diameter cannot be broken by hand but can be broken with pick with a single firm blow; rock rings under hammer.
VH	Very High	60 to 200	Hand specimen breaks with pick after more than one blow; rock rings under hammer.
EH	Extremely High	>200	Specimen requires many blows with geological pick to break through intact material; rock rings under hammer.

Material with strength less than 'Very Low' shall be described using soil characteristics. The presence of an original rock structure, fabric or texture should be noted, if relevant.

ROCK MATERIAL WEATHERING

Symbol		Term	Field Guide
RS		Residual Soil	Material is weathered to such an extent that it has soil properties. Mass structure and material texture and fabric of original rock are no longer visible, but the soil has not been significantly transported.
XW		Extremely Weathered	Material is weathered to such an extent that it has soil properties. Mass structure and material texture and fabric of original rock are still visible.
DW	HW	Highly Weathered	The whole of the rock material is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognizable. Rock strength is significantly changed by weathering. Some primary minerals have weathered to clay minerals. Porosity may be increased by leaching, or may be decreased due to deposition of weathering products in pores.
	MW	Moderately Weathered	The whole of the rock material is discoloured, usually by iron staining or bleaching to the extent that the colour of the original rock is not recognizable, but shows little or no change of strength from fresh rock.
SW		Slightly Weathered	Rock is partially discoloured with staining or bleaching along joints but shows little or no change of strength from fresh rock.
FR		Fresh	Rock shows no sign of decomposition of individual minerals or colour changes.

ABBREVIATIONS FOR DEFECT TYPES AND DESCRIPTIONS

Defect Type	
P	Parting
X	Foliation
L	Cleavage
C	Contact
J	Joint
SSu	Sheared Surface
SS	Sheared Seam
SZ	Sheared Zone
CS	Crushed Seam
IS	Infilled Seam
EWS	Extremely Weathered Seam
V	Vein

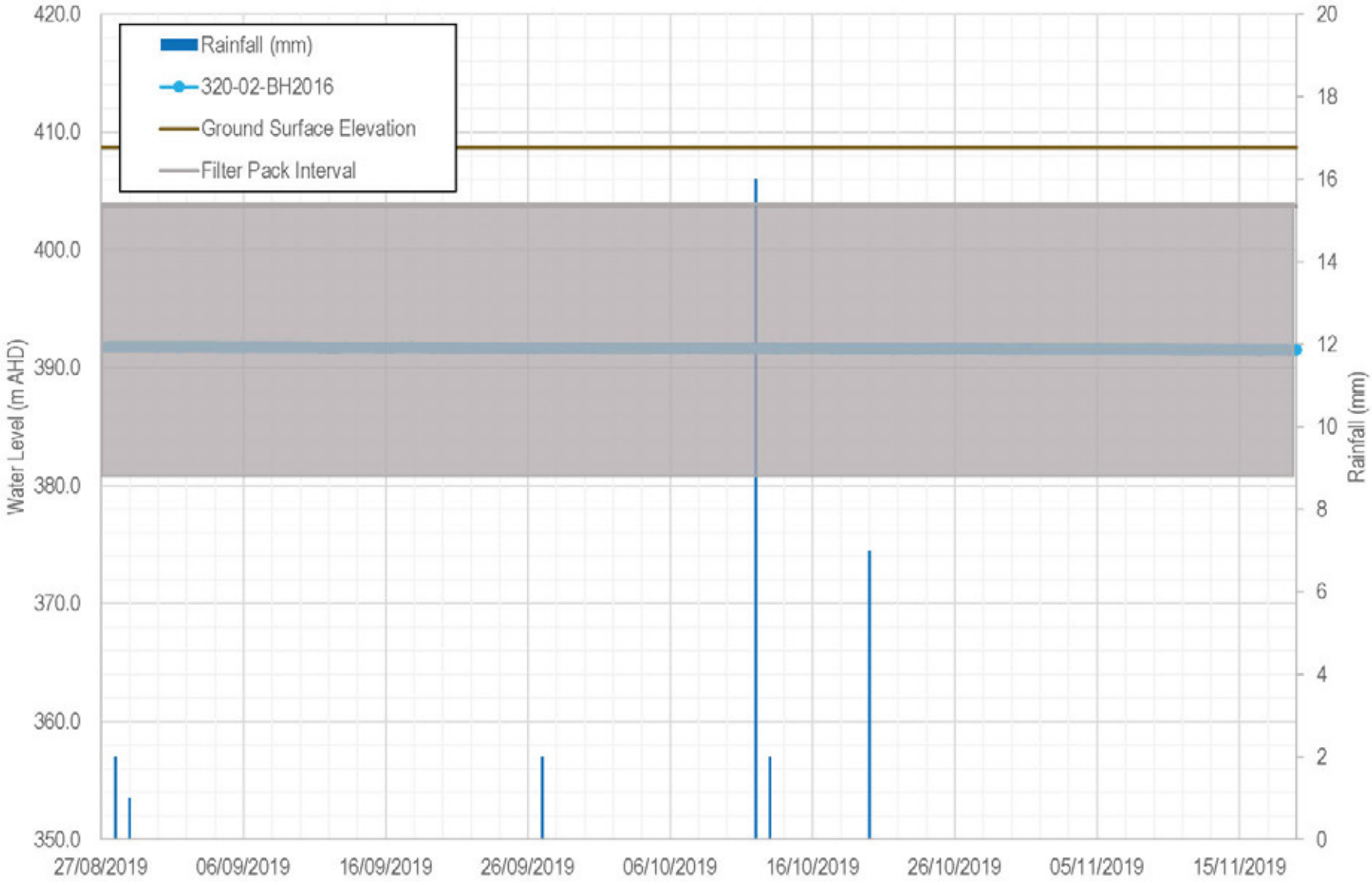
Coating or Infilling	
Cn	Clean
Sn	Stain
Ve	Veneer
Ct	Coating
In	Infill

Planarity	
Pl	Planar
Cv	Curved
Un	Undulating
St	Stepped
Ir	Irregular

Roughness	
VRo	Very Rough
Ro	Rough
Sm	Smooth
Po	Polished
Sl	Slickensided

Vertical Boreholes – The dip (inclination from horizontal) of the defect is given.

Inclined Boreholes – The inclination is measured as the acute angle between the core axis and the vertical direction.


Rainfall (mm)
320-02-BH2016
Ground Surface Elevation
Filter Pack Interval
Water Level (m AHD)
Rainfall (mm)
420.0
410.0
400.0
390.0
380.0
370.0
360.0
350.0
20
18
16
14
12
10
8
6
4
2
0
27/08/2019
06/09/2019
16/09/2019
26/09/2019
06/10/2019
16/10/2019
26/10/2019
05/11/2019
15/11/2019

REPORT OF BOREHOLE: 320-02-BH2016

SHEET: 1 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15/7/19
CHECKED: FHH DATE: 5/12/19

Drilling					Sampling		Field Material Description					
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
ADT		GNE	0	408.71				CI-CH	TOPSOIL: CLAY medium to high plasticity, dark brown, with silt, trace sand, occasional basalt cobbles on surface, rootlets present to 0.5 m bgl	w < PL		TOPSOIL (mixed with basalt cobbles)
				0.50								
			1	408.21	SPT 1.00-1.45 m 1, 14, 20 N=34			CH	Sandy CLAY high plasticity, dark brown, fine to coarse grained sand, with silt, trace fine to medium grained basalt gravel	w ≈ PL	H	Colluvial soil
			2									
RT		GMO			SPT 2.50-2.53 m 30/26mm refusal on basalt cobble							
			3	3.10								
HQ3		0% RETURN		405.61	C 3.10-4.00 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			
				3.57								
				3.67					CORE LOSS			
				405.04								
			4		C 4.00-4.30 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 3.10 m			
					C 4.30-5.40 m							
			5	5.00								
				403.71					CORE LOSS			
				5.40								
				403.31	C 5.40-6.40 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 3.10 m			
			6	6.05								
				402.66					CORE LOSS			
				6.40								
				402.31	C 6.40-6.50 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 3.10 m	W		
					C 6.50-6.80 m							
					C 6.80-7.10 m							
			7		C 7.10-7.50 m							
					C 7.50-7.60 m							
					C 7.60-8.00 m							
				7.85								
				8.00					CORE LOSS			
			8	400.71	C 8.00-8.50 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 3.10 m			
				8.38								
				400.23	C 8.50-9.00 m				CORE LOSS 8.38 to 8.48 m			
									MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 3.10 m			
			9		C 9.00-9.25 m							
RT												
			10	10.00								

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REPORT OF BOREHOLE: 320-02-BH2016

SHEET: 2 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15/7/19
CHECKED: FHH DATE: 5/12/19

Drilling					Sampling		Field Material Description				
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
RT		0% RETURN	10	398.71					MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			Colluvial soil
HQ3			11		C 11.10-11.30 m							
					C 11.30-11.90 m							
			12		C 11.90-12.20 m							
					C 12.20-12.45 m							
RT			13									
			14									
			15		C 15.00-15.30 m					W		
					C 15.30-15.60 m							
					C 15.60-16.80 m							
			16									
HQ3			17		C 16.80-17.40 m							
					C 17.40-18.10 m							
			18	18.00								
				18.10					CORE LOSS			
				390.61	C 18.10-18.80 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 10.00 m			
				18.54								
				18.64					CORE LOSS			
				390.07					MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 10.00 m			
			19		C 18.80-19.78 m							
				19.72								
				19.96	C 19.78-20.50 m				CORE LOSS 19.72 to 19.78 m			
			20									

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INLANDRAIL_GAP 8.16.1 V2 LIB.GLB Log GAP NON-CORED FULL PAGE 320-02H MASTER.GPJ <<DrawingFile>> 25/01/2020 09:36 5.30.004 Calge

REPORT OF BOREHOLE: 320-02-BH2016

SHEET: 3 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1699276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: D8525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15/7/19
CHECKED: FHH DATE: 5/12/19

Drilling					Sampling		Field Material Description					
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
HQ3			20	388.76 20.34	C 19.78 20.50 m			CI	As described in layer at 10.00 m Sandy CLAY medium plasticity, dark grey, fine to medium grained sand, carbonaceous mudstone in places up to 200 mm thick becoming green grey For Continuation Refer to Sheet 4	w~PL	F - St	Extremely weathered sandstone (KOUKANDOWIE FORMATION)
			21									
			22									
			23									
			24									
			25									
			26									
			27									
			28									
			29									
			30									

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INLAND RAIL GAP8_16.*.*1_BGUB Log 3A* NON-CORED FULL PAGE 32E-32N MASTER.GPJ <<DrawingFile>> 25/10/2019 09:38 8.30.04 Cage Tools

REPORT OF BOREHOLE: 320-02-BH2016

SHEET: 4 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15/7/19
CHECKED: FHH DATE: 5/12/19

Drilling						Field Material Description				Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
				20								
					20.50		Continuation of Sheet 3					
HQ3	40% RETURN	100	0	21	388.21		INTERBEDDED SANDSTONE AND MUDSTONE fine to medium grained, pale grey, faintly laminated 5 degrees	XW HW			20.50-49.90 m: KOUKANDOWIE FORMATION 20.68 m: DS, 0°, clay, 25 mm	
		100	100	22	22.22 388.49		becoming orange brown, to 20.00 m	SW MW - SW			22.06 m: B, 5°, Pl, Ro, clay Ct 22.21 m: B, 5°, Pl, Ro, Sn, orange brown 22.36 m: B, 5°, Pl, Vr, clay Ct	
					22.76 388.95		trace beds of fine grained, rounded gravel			PLI(A)=0.30(M) PLI(D)=0.15(M)		
				23	23.00 385.71		fine to coarse grained	SW			22.85 m: B, 5°, Pl-Un, Ro, Sn, orange brown	
		85	80	24						PLI(A)=0.27(M) PLI(D)=0.47(M) UCS=5.9	23.00 m: B, 10°, Pl, Ro, Sn, brown, healed	
											24.41 m: B, 5°, Pl, Ro, clay Ct	
				25								
					25.60 383.11		CORE LOSS	XW			25.47-25.60 m: DS, 5°, Pl, Ro, sandy clay	
				26	26.10 382.61		SANDSTONE fine to medium grained, pale grey, dark brown mudstone laminated 0 to 5 degree, carbonaceous	HW MW				
		100	100	27							26.70 m: J, 00°, Pl-Un, Ro, Cn	
											27.18 m: Jx2, 45°, Un, Ro, Cn, healed	
				28								
					28.55 380.16		x2 gravel beds between 28.55-28.57 m and 28.63-28.75 m, fine grained, rounded	MW - SW			28.68 m: J, 80°, Pl-Un, Ro, Cn	
		100	100	29								
		100	95	30								

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INLANDRAIL_GAP 8.10.1 V2.1.IE.GLB Log GAP CORED BOREHOLE 320-02~MASTER.GPJ <<DrawingFile>> 25/01/2020 09:08 3.30.004 Datgel Tools

REPORT OF BOREHOLE: 320-02-BH2016

SHEET: 5 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15/7/19
CHECKED: FHH DATE: 5/12/19

Drilling						Field Material Description					Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
HC3	40% RETURN	100	95	30	30.31 378.40		SANDSTONE fine to medium grained, grey, faintly laminated 5 degrees, trace carbonaceous wisps, trace mudstone laminations	SW MW			29.95 m: J, 45°, Pl, Ro, Cn 30.30 m: J, 15°, Pl, Ro, Cn 30.80 m: J, 70°, Pl, Ro, Cn 30.93 m: J, 70-90°, Pl-Un, Ro, Cn	
				31							31.60 m: J, 50-60°, Pl, Ro, Cn	
					31.83 376.88		MUDSTONE brown, faintly laminated 5 degrees, trace carbonaceous wisps, trace fine grained sandstone laminations				31.84-31.87 m: DS, 5-10°, Pl, Ro, clay 31.93 m: DS, 20-30°, Pl, Ro, clay, 20 mm	
				32							32.15 m: J, 25°, Pl, Ro, Cn 32.28 m: J, 10°, Pl, Sm, Cn 32.31 m: J, 20°, Pl, Ro, Cn	
					32.68 376.03 376.02		SANDSTONE fine to medium grained, grey, laminated 0 to 5 degrees, carbonaceous wisps	SW			32.68-32.68 m: DS, 5°, Pl, clay	
		100	95	33	33.28 375.43		fine grained gravel beds between 32.69-32.70 m, sub-angular fine grained gravel beds between 33.28-33.30 m, sub-angular <10 mm					
				34						UCS=13.4 PLI(A)=0.44(M) PLI(D)=0.29(M)		
				35							34.74 m: B, 5°, Pl, Ro, Cn	
		100	100	36	36.50 372.21		INTERLAMINATED MUDSTONE AND SANDSTONE fine to medium grained, pale grey sandstone, dark brown mudstone, laminated to bedded 5 degrees	MW SW			36.60-36.63 m: DS, 5-10°, Pl-Un, clay	
				37							37.08-37.20 m: Bx3, 0-5°, sp = 30-100 mm, Pl, Ro, Cn 37.55 m: B, 5°, Pl, Ro, Cn	
		100	100	38							38.33 m: B, 10°, Pl, Sm, Cn 38.60-38.61 m: DS, 0°, Pl, Sm, grey clay Ct, 10 mm	
		100	100	39							39.28 m: DS, 10°, Pl, Sm, Ct, clay 39.61 m: J, 10°, Pl, Ro, Cn	
				40								

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INLANDRAIL_GAP 8.16.1 V2 LIB.GLB Log (3A PCORED BOREHOLE 320-02~ MASTER.GPJ <<DrawingFile>> 25/01/2020 09:08 3.39.004 Datgel Tools

REPORT OF BOREHOLE: 320-02-BH2016

SHEET: 6 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15/7/19
CHECKED: FHH DATE: 5/12/19

Drilling						Field Material Description					Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
HC3	40% RETURN	100	100	40			INTERLAMINATED MUDSTONE AND SANDSTONE fine to medium grained, pale grey sandstone, dark brown mudstone, laminated to bedded 5 degrees	SW			40.23 m: B, 0°, Pl, Sm, Cn 40.33 m: J, 20°, Pl, Ro, Cn	
		100	100	41								
		100	100	42	42.60 366.11						41.87 m: D, 0-5°, Pl, Sm, grey clay Ct, 10 mm 42.19 m: DS, sandy clay, 20 mm	
		0	0	43			CORE LOSS drill bit blockage resulted in core being grinded away, inferred sandstone and mudstone as above					
					43.60 365.11		SANDSTONE fine to medium grained, grey, laminated 5 degrees, carbonaceous mudstone laminations	SW - FR				
		100	100	44							44.46 m: J, 30-40°, Pl, Sm, Cn	
		100	100	45	45.38 363.33		siderite cementation, to 46.61 m	MW FR			45.37-45.50 m: J, 40°, St, Ro, Cn, healed	
	3% RETURN	100	100	46	46.00 362.71		INTERBEDDED SANDSTONE AND MUDSTONE fine to medium grained, grey sandstone, dark grey mudstone, laminated 0 to 5 degrees					
		100	100	47								
		100	100	48								
				49	49.10 359.61		with coarse grained sand, to 49.90 m					
				50	49.90		END OF BOREHOLE @ 40.00 m TARGET DEPTH PIEZOMETER INSTALLED					

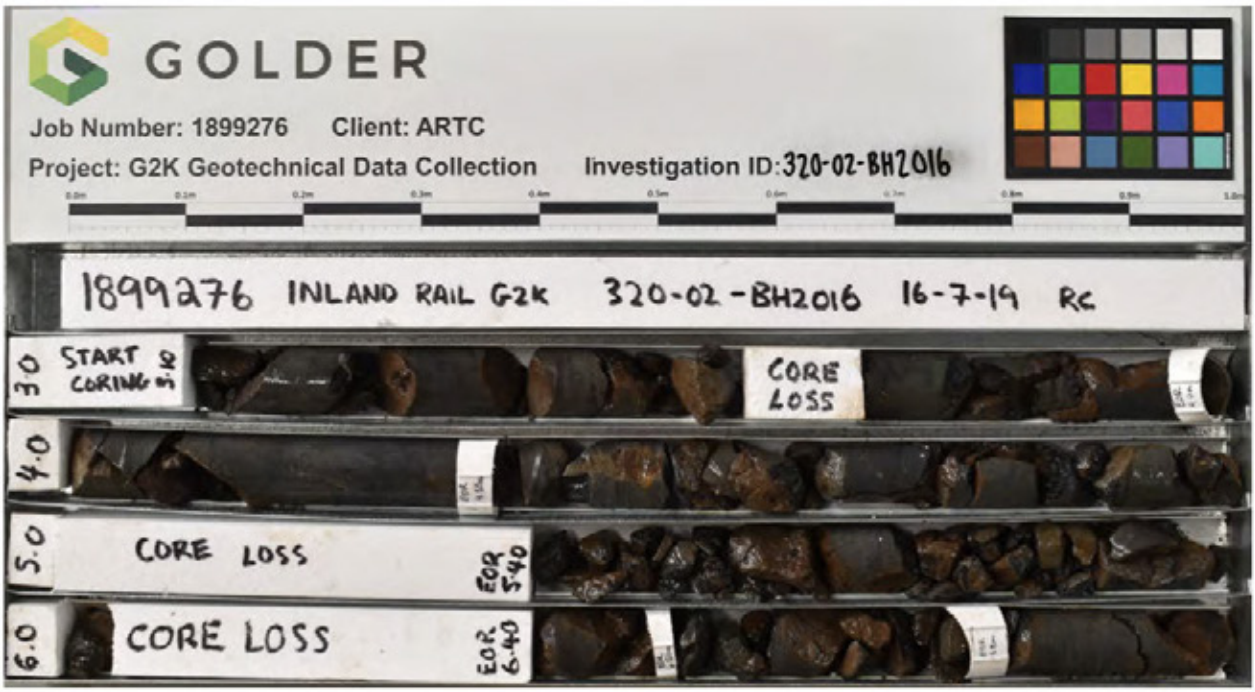
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GAP gINT FN. F02b RL3

INLANDRAIL_GAP 8.16.1 V2 LIB.GLB Log (GAP CORED BOREHOLE 320-02~MASTER.GPJ <<DrawingFile>> 25/01/2020 09:08 3.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2016

CLIENT:	ARTC	COORDS: 397963.2 m E 6955503.0 m N MGA94 56	SHEET: 1 OF 5
PROJECT:	Inland Rail	SURFACE RL: 408.71 m DATUM: AHD	DRILL RIG: DB525
LOCATION:	G2K Geotechnical Data Collection	INCLINATION: -90°	CONTRACTOR: Saxon Drilling
JOB NO:	1899276	HOLE DEPTH: 49.90 m	LOGGED: RC DATE: 15/7/19
			CHECKED: FHH DATE: 5/12/19



320-02-BH2016 3.10 - 7.00 m



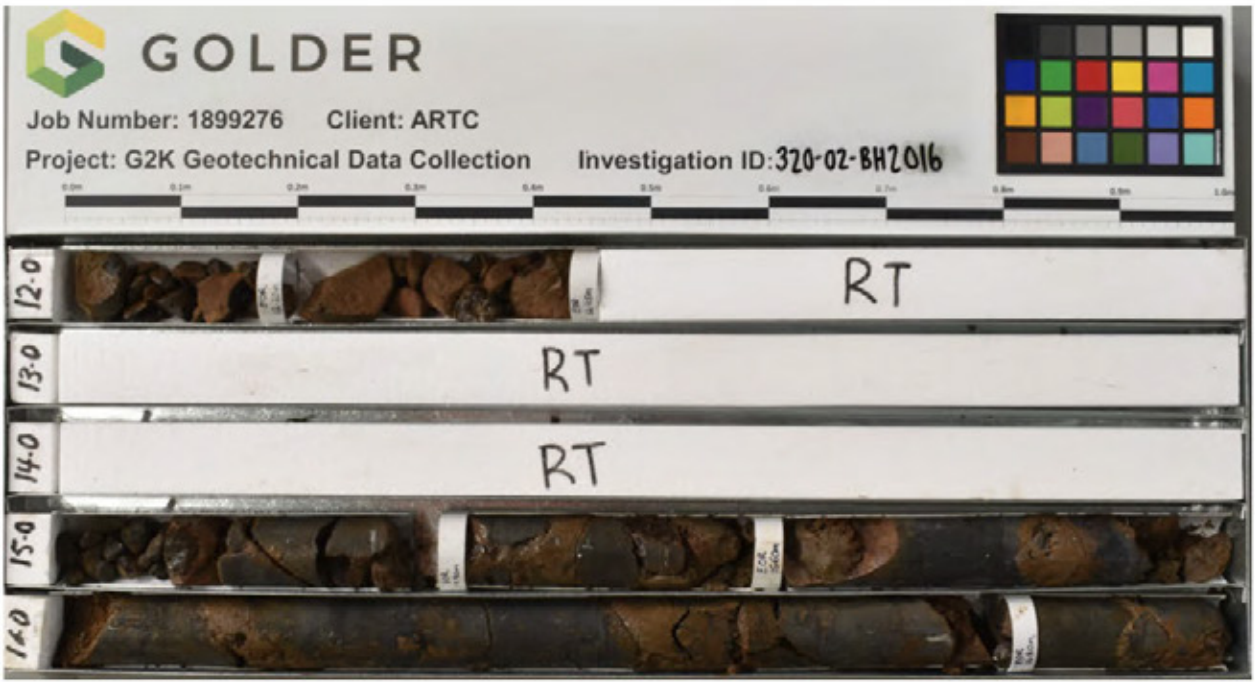
320-02-BH2016 7.00 - 12.00 m

This report of core photographs must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

INLANDRAIL_GAP 8_16.7 V1.LIB.GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:29 8.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2016

CLIENT: ARTC	COORDS: 397963.2 m E 6955503.0 m N MGA94 56	SHEET: 2 OF 5	
PROJECT: Inland Rail	SURFACE RL: 408.71 m DATUM: AHD	DRILL RIG: DB525	
LOCATION: G2K Geotechnical Data Collection	INCLINATION: -90°	CONTRACTOR: Saxon Drilling	
JOB NO: 1899276	HOLE DEPTH: 49.90 m	LOGGED: RC	DATE: 15/7/19
		CHECKED: FHH	DATE: 5/12/19



320-02-BH2016 12.00 - 17.00 m



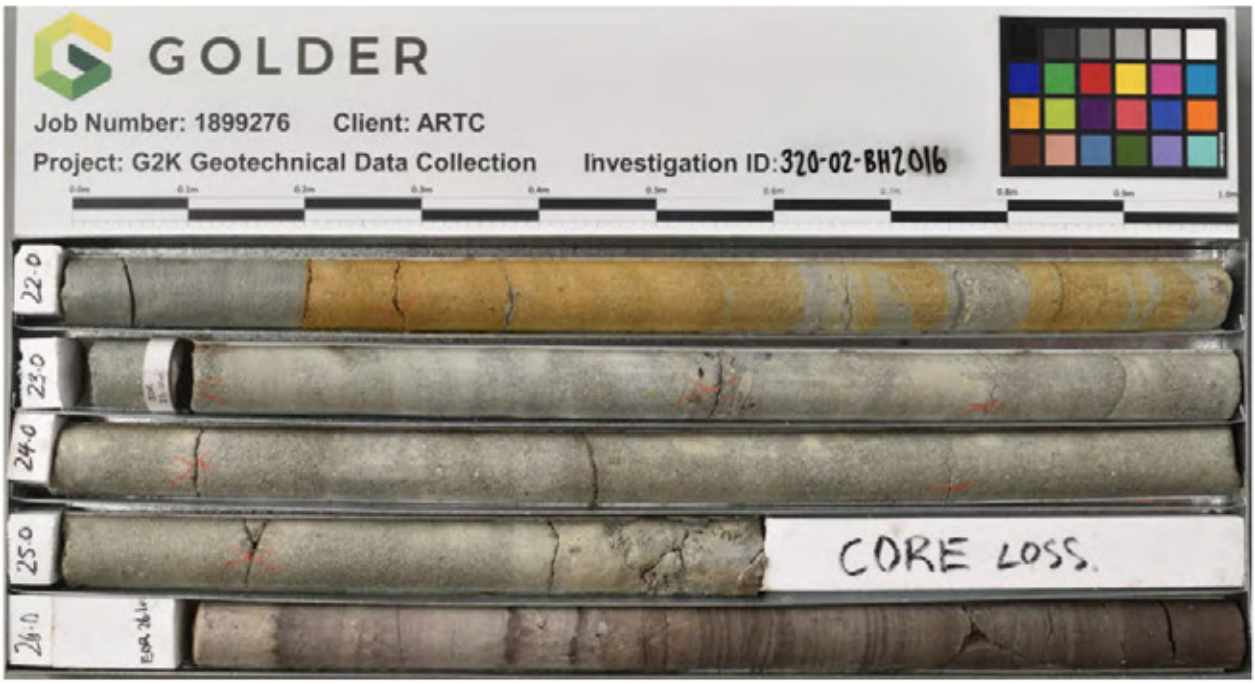
320-02-BH2016 17.00 - 22.00 m

This report of core photographs must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

INLANDRAIL_QAP 8_16.7 V1.LIB.GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:30 8.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2016

CLIENT:	ARTC	COORDS: 397963.2 m E 6955503.0 m N MGA94 56	SHEET: 3 OF 5
PROJECT:	Inland Rail	SURFACE RL: 408.71 m DATUM: AHD	DRILL RIG: DB525
LOCATION:	G2K Geotechnical Data Collection	INCLINATION: -90°	CONTRACTOR: Saxon Drilling
JOB NO:	1899276	HOLE DEPTH: 49.90 m	LOGGED: RC DATE: 15/7/19
			CHECKED: FHH DATE: 5/12/19



320-02-BH2016 22.00 - 27.00 m



320-02-BH2016 27.00 - 32.00 m

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INLANDRAIL_GAP 8_16.7 V1 LIB.GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:30 8.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2016

				SHEET: 4 OF 5	
CLIENT:	ARTC	COORDS: 397963.2 m E 6955503.0 m N MGA94 56		DRILL RIG: DB525	
PROJECT:	Inland Rail	SURFACE RL: 408.71 m DATUM: AHD		CONTRACTOR: Saxon Drilling	
LOCATION:	G2K Geotechnical Data Collection	INCLINATION: -90°		LOGGED: RC	DATE: 15/7/19
JOB NO:	1899276	HOLE DEPTH: 49.90 m		CHECKED: FHH	DATE: 5/12/19



320-02-BH2016 32.00 - 37.00 m



320-02-BH2016 37.00 - 42.00 m

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INLANDRAIL_GAP 8_16.7 V1 LIB.GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:30 8.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2016

CLIENT: ARTC	COORDS: 397963.2 m E 6955503.0 m N MGA94 56	SHEET: 5 OF 5	
PROJECT: Inland Rail	SURFACE RL: 408.71 m DATUM: AHD	DRILL RIG: DB525	
LOCATION: G2K Geotechnical Data Collection	INCLINATION: -90°	CONTRACTOR: Saxon Drilling	
JOB NO: 1899276	HOLE DEPTH: 49.90 m	LOGGED: RC	DATE: 15/7/19
		CHECKED: FHH	DATE: 5/12/19



320-02-BH2016 42.00 - 47.00 m



320-02-BH2016 47.00 - 49.90 m

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GAP gINT FN. F28 RL1

INLANDRAIL_GAP 8_16.7 V1.LIB.GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:30 8.30.004 Datgel Tools

REPORT OF STANDPIPE INSTALLATION: 320-02-BH2016

SHEET: 1 OF 1

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397963.2 m E 6955503.0 m N MGA94 56
SURFACE RL: 408.71 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 49.90 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 15-7-19
CHECKED: FHH DATE: 5-12-19

Drilling				Field Material Description		Instrumentation Details
METHOD	WATER	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	SOIL/ROCK MATERIAL DESCRIPTION	
ADT	GNE	0	408.21		CLAY	1.00, RL407.71 — gatic cover; cement grout
					SANDY CLAY	3.00, RL 405.71 — bentonite seal
RT			3.10			
HQ3			405.04		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
		5	5.00		CORE LOSS	
			6.05		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
			402.31		CORE LOSS	
			7.85			
			400.23		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
RT		10			CORE LOSS	
HQ3					MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
					CORE LOSS	
RT					MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
		15			CORE LOSS	filter pack
					MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
			18.00			
					CORE LOSS	
			19.72		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
		20	20.50		CORE LOSS	
			389.21		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	22.00, RL386.71
					CORE LOSS	
					Boulders/Sandy CLAY	
		25	25.60		SANDY CLAY	slotted PVC
			382.61		INTERBEDDED SANDSTONE AND MUDSTONE	
					CORE LOSS	
					SANDSTONE	28.00, RL380.71 — data logger at 27.50m
		30				bentonite seal
						30.00, RL378.71
			31.63			
			32.68		MUDSTONE	
			378.03		SANDSTONE	
		35	36.50			
			372.21		INTERLAMINATED MUDSTONE AND SANDSTONE	
		40				sand
			42.00			
			43.60		CORE LOSS	
			365.11		SANDSTONE	
		45	46.00			
			362.71		INTERBEDDED SANDSTONE AND MUDSTONE	
			49.90			49.90, RL358.81
		50	358.81		END OF BOREHOLE @ 49.90 m TARGET DEPTH STANDPIPE INSTALLED	

This report of standpipe installation must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

GAP gINT FN. F17
RL1

INLANDRAIL_GAP 8.16.1.V2.1.E.GLB Log GAP WELLS 3 WELLS - COPY.GPJ <<DrawingFile>> 10-01-2020 10:15 8.30.004 Datgel Tools

Golder Associates Pty Ltd
147 Coronation Drive, Milton,
Queensland 4064, Australia
(PO Box 1734, Milton BC, QLD 4064)

GOLDER

GEOPHYSICAL RECORD OF BOREHOLE: 320-02-BH2016

PROJECT	Inland Rail Detailed Design SI	Job #	1899276
CLIENT	ARTC	DATE	09/08/19

LOCATION-	Jones Road, Withcott	LOGGED BY-	LR
EASTING (MGA94) -	397963.16 m E	LOGGED DATE-	24/07/19
NORTHING (MGA94) -	6955503.00 m N	LOGGING DATUM-	Ground Level
ELEVATION (AHD m) -	408.71 m	LOGGED DEPTH-	21.0 to 47.85 m
DRILLED DEPTH-	49.8 m DIAMETER- HQ	DRAWN BY-	RR
PLUNGE-	87 deg AZIMUTH- 247 deg TN	REVIEWED BY-	TR
CASING-	Steel DEPTH- 21.3 m	FILE NAME-	320-02-BH2016_RevD.wcl

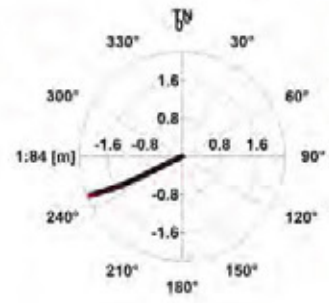
All summary structural data and borehole orientation referenced to True North (Declination 11 degs).

Mechanical caliper log is used for dip corrections.

Magnetic field is stable below 23.5 m below ground level. Image distorted above 22.5 m below ground surface.

Borehole zeroed to ground level. GPS survey of ground level applied for RL conversion.

DEVIATION DATA





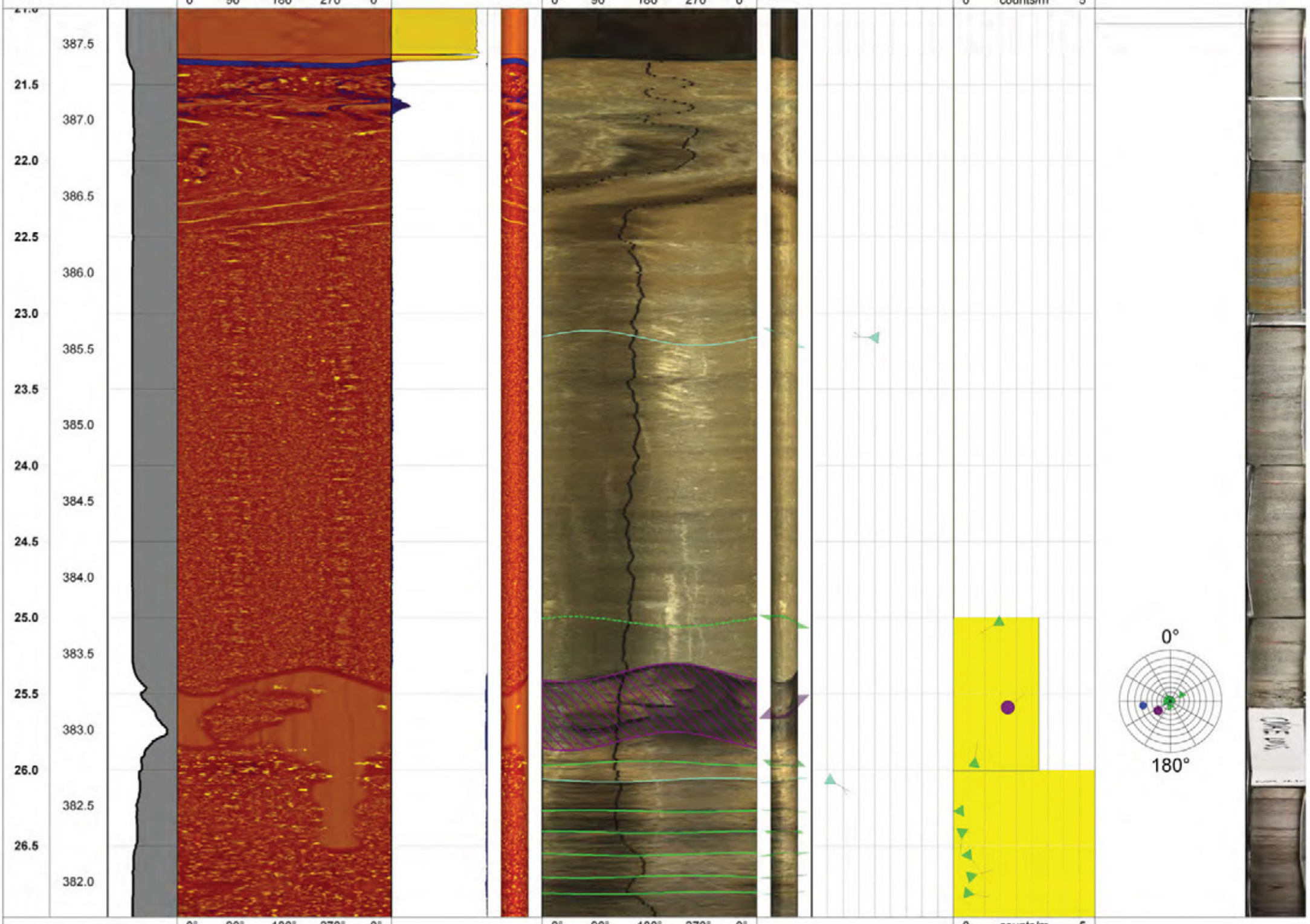
INTERPRETED STRUCTURES

Low Confidence
Medium Confidence
High Confidence

Bedding Parting- Medium Confidence
Bedding Parting - High Confidence
Bedding Fabric
XW Zone - High Confidence
Joint - Medium Confidence
Joint - High Confidence

320-02-BH2016

Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data			Summary Structural Data			Core
		QL40 CAL	Amplitude-NM Normalised	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects		Photo
		0 300	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type		
			ATV Structure Log			OTV Structure Log			Freq/meter			
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 5			

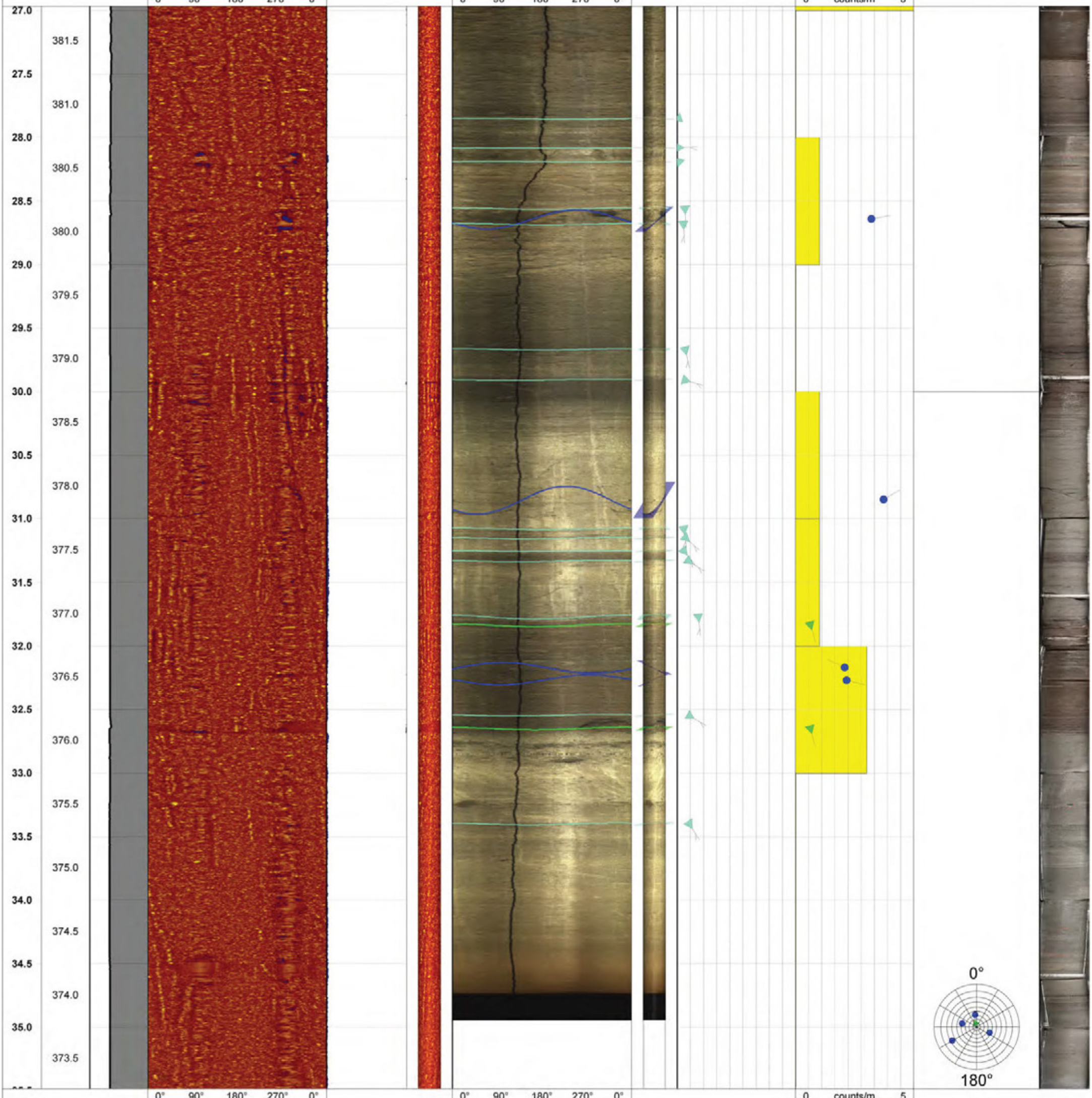


1m:30m Depth	AHD RL m	Caliper	ATV Data			OTV Data			Summary Structural Data			Core
		QL40 CAL	Amplitude-NM Normalised	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects		Photo
		0 300	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type		
			ATV Structure Log			OTV Structure Log			Freq/meter			
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 5			

320-02-BH2016

320-02-BH2016

Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data		Summary Structural Data			Core
		QL40 CAL	Amplitude-NM Normalised	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
		0 300	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
			ATV Structure Log			OTV Structure Log			Freq/meter		
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 5		



			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 5		
			ATV Structure Log			OTV Structure Log			Freq/meter		
		0 300	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
		QL40 CAL	Amplitude-NM Normalised	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
1m:30m Depth	AHD RL m	Caliper	ATV Data			OTV Data		Summary Structural Data			Core

320-02-BH2016

320-02-BH2016

Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data		Summary Structural Data			Core
		QL40 CAL	Amplitude-NM Normalised	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
		0 300	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
			ATV Structure Log			OTV Structure Log			Freq/meter		
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 5		

35.5
36.0
36.5
37.0
37.5
38.0
38.5
39.0
39.5
40.0
40.5
41.0
41.5
42.0
42.5
43.0
43.5

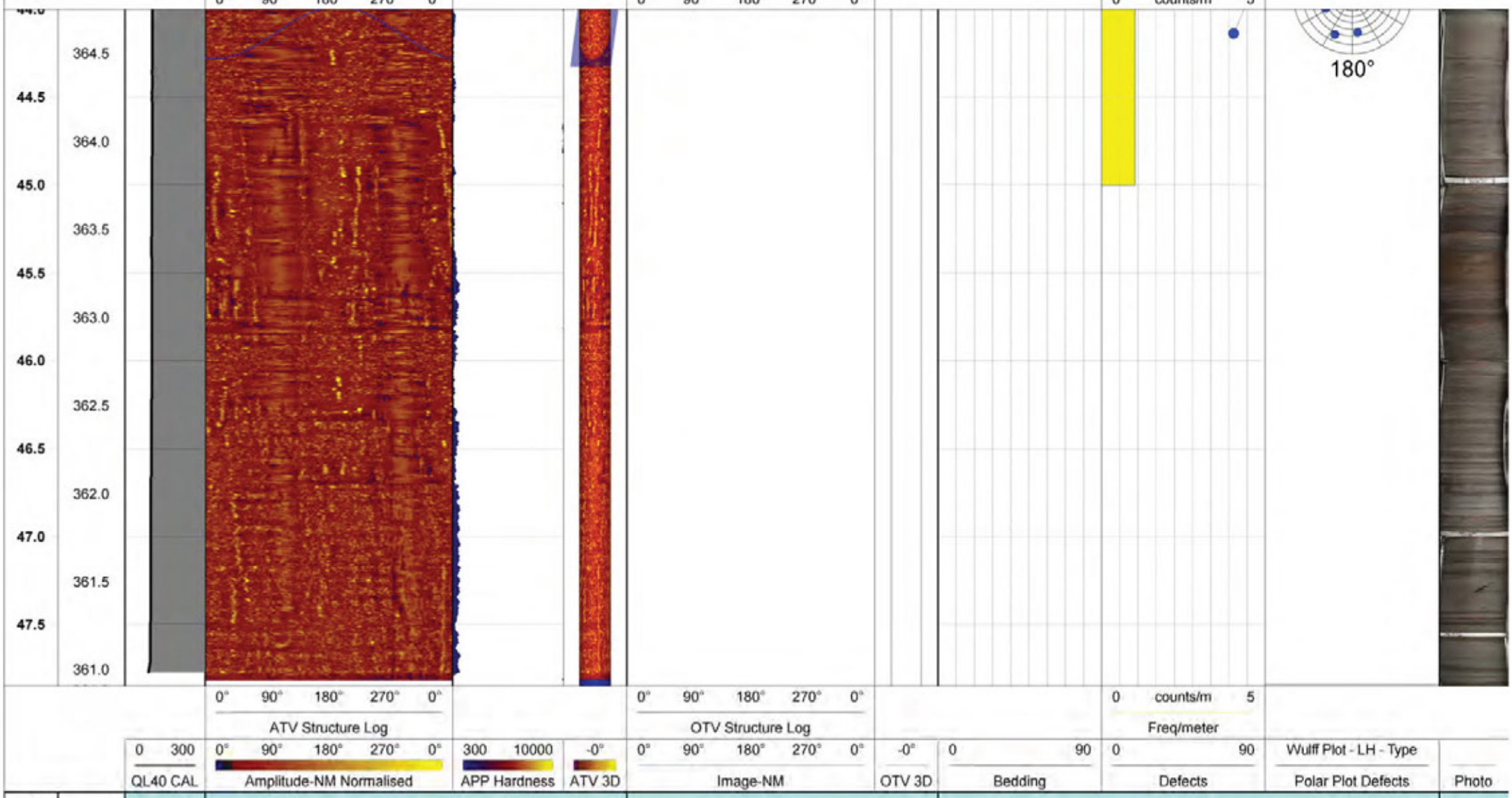
373.0
372.5
372.0
371.5
371.0
370.5
370.0
369.5
369.0
368.5
368.0
367.5
367.0
366.5
366.0
365.5
365.0

0°

		Caliper	ATV Data			OTV Data		Summary Structural Data			Core
		QL40 CAL	Amplitude-NM Normalised	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
		0 300	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
			ATV Structure Log			OTV Structure Log			Freq/meter		
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 5		
Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data		Summary Structural Data			Core

320-02-BH2016

320-02-BH2016



320-02-BH2016

Stereonet (lower hemisphere, equal angle)

Breakouts and Stress Orientation

Feature Dip vs Depth

Feature Dip Direction vs Depth

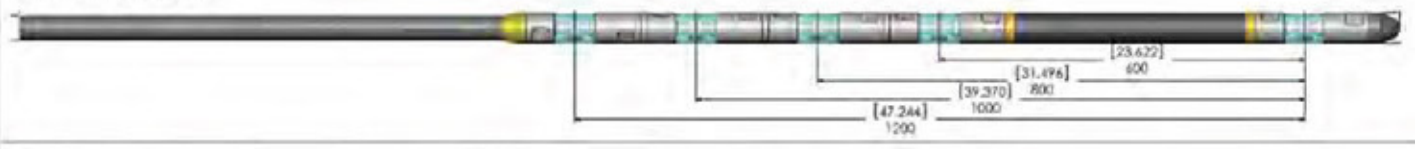
GEOPHYSICAL RECORD OF BOREHOLE: 320-02-BH2016

Golder Associates Pty Ltd
146 Coronation Drive
Milton
Queensland 4064
+61 7 3721 5400

PROJECT	Inland Rail Detailed Design SI	PROJECT #	1899276
CLIENT	ARTC	DATE	19/08/2019

LOCATION-	Jones Rd, Withcott	LOGGED BY-	LR
EASTING (MGA94)-	397963.16 m E	LOGGED DATE-	13/08/19
NORTHING (MGS94)-	6955503.00 m N	LOGGING DATUM-	Ground Level
ELEVATION (AHD m)-	408.71 m	LOGGED DEPTH-	19.5 to 47.0 m
DRILLED DEPTH-	49.8 m DIAMETER- HQ	DRAWN BY-	AR
PLUNGE-	87 deg AZIMUTH- 247 deg TN	REVIEWED BY-	TR
CASING-	Steel DEPTH- 21.3 m	FILE NAME-	320-02-BH2016_FWS_RevD.wcl

TOOL **QL40 FWS**



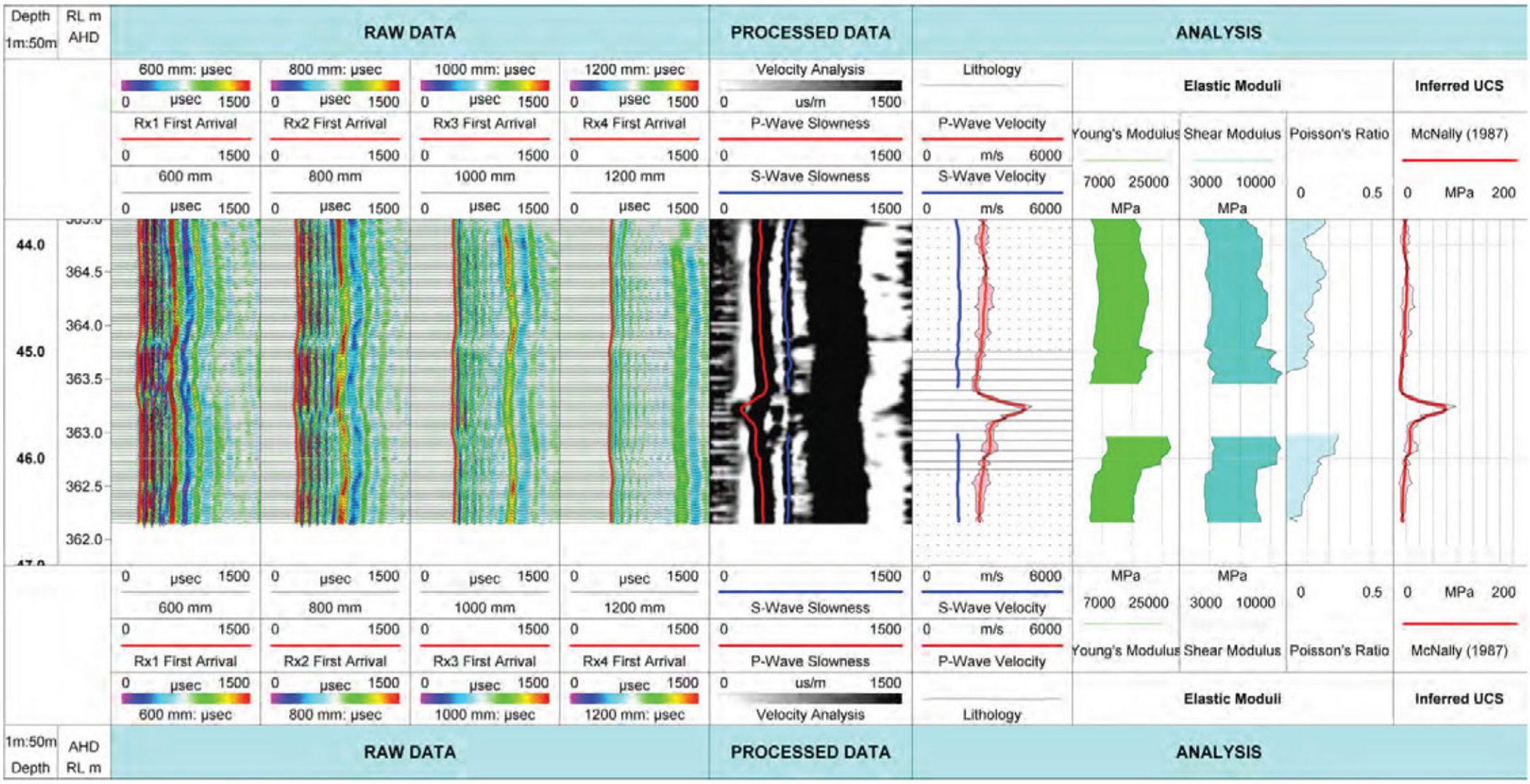
Boulders | Mudstone | Clay Sandy | Core Loss
Clay | Sandstone | Topsoil

NOTES-

1. The depth of penetration of the sonic data is 2.5 cm - 25 cm into the formation which, if adversely affected by localised drilling conditions, may result in misinterpretation of in-situ rock mass conditions.
2. It is possible that Stoneley waves may be misinterpreted as S waves, thus P to S-wave ratios were checked to ensure that S-waves were picked, and the S-wave is not shown if there was any uncertainty.
3. Site-specific correlation between P-wave velocity and UCS values should be developed by designers using regression analysis.
4. FWS results should be used to assess macro geotechnical zones within the rock mass, and not absolute values of strength or elasticity at specific points.

Depth 1m:50m	RL m AHD	RAW DATA				PROCESSED DATA	ANALYSIS				
		600 mm: µsec	800 mm: µsec	1000 mm: µsec	1200 mm: µsec	Velocity Analysis	Lithology	Elastic Moduli			Inferred UCS
		Rx1 First Arrival	Rx2 First Arrival	Rx3 First Arrival	Rx4 First Arrival	P-Wave Slowness	P-Wave Velocity	Young's Modulus	Shear Modulus	Poisson's Ratio	McNally (1987)
		600 mm	800 mm	1000 mm	1200 mm	S-Wave Slowness	S-Wave Velocity				
		0 µsec 1500	0 µsec 1500	0 µsec 1500	0 µsec 1500	0 1500	0 m/s 6000	7000 25000 MPa	3000 10000 MPa	0 0.5	0 MPa 200
20.0	389.0										
	388.5										
	388.0										
21.0	387.5										
	387.0										
22.0	386.5										
	386.0										
23.0	385.5										
	385.0										
24.0	384.5										
	384.0										
25.0	383.5										
	383.0										
26.0	382.5										
	382.0										
27.0	381.5										
	381.0										
28.0	380.5										
	380.0										
29.0	379.5										
		0 µsec 1500	0 µsec 1500	0 µsec 1500	0 µsec 1500	0 1500	0 m/s 6000	MPa 7000 25000	MPa 3000 10000	0 0.5	0 MPa 200
		600 mm	800 mm	1000 mm	1200 mm	S-Wave Slowness	S-Wave Velocity				
		0 1500	0 1500	0 1500	0 1500	0 1500	0 m/s 6000	Young's Modulus	Shear Modulus	Poisson's Ratio	McNally (1987)
		Rx1 First Arrival	Rx2 First Arrival	Rx3 First Arrival	Rx4 First Arrival	P-Wave Slowness	P-Wave Velocity				
		0 µsec 1500	0 µsec 1500	0 µsec 1500	0 µsec 1500	0 us/m 1500	Lithology	Elastic Moduli			Inferred UCS
		600 mm: µsec	800 mm: µsec	1000 mm: µsec	1200 mm: µsec	Velocity Analysis					
1m:50m Depth	AHD RL m	RAW DATA				PROCESSED DATA	ANALYSIS				

Depth 1m:50m	RL m AHD	RAW DATA				PROCESSED DATA	ANALYSIS				
		600 mm: µsec	800 mm: µsec	1000 mm: µsec	1200 mm: µsec	Velocity Analysis	Lithology	Elastic Moduli			Inferred UCS
		Rx1 First Arrival	Rx2 First Arrival	Rx3 First Arrival	Rx4 First Arrival	P-Wave Slowness	P-Wave Velocity	Young's Modulus	Shear Modulus	Poisson's Ratio	McNally (1987)
		600 mm	800 mm	1000 mm	1200 mm	S-Wave Slowness	S-Wave Velocity				
		0 µsec 1500	0 µsec 1500	0 µsec 1500	0 µsec 1500	0 1500	0 m/s 6000	7000 25000 MPa	3000 10000 MPa	0 0.5	0 MPa 200
30.0	379.0										
	378.5										
31.0	378.0										
	377.5										
32.0	377.0										
	376.5										
33.0	376.0										
	375.5										
34.0	375.0										
	374.5										
35.0	374.0										
	373.5										
36.0	373.0										
	372.5										
37.0	372.0										
	371.5										
38.0	371.0										
	370.5										
39.0	370.0										
	369.5										
40.0	369.0										
	368.5										
41.0	368.0										
	367.5										
42.0	367.0										
	366.5										
43.0	366.0										
	365.5										
		0 µsec 1500	0 µsec 1500	0 µsec 1500	0 µsec 1500	0 1500	0 m/s 6000	MPa 7000 25000	MPa 3000 10000	0 0.5	0 MPa 200
		600 mm	800 mm	1000 mm	1200 mm	S-Wave Slowness	S-Wave Velocity				
		0 1500	0 1500	0 1500	0 1500	0 1500	0 m/s 6000	Young's Modulus	Shear Modulus	Poisson's Ratio	McNally (1987)
		Rx1 First Arrival	Rx2 First Arrival	Rx3 First Arrival	Rx4 First Arrival	P-Wave Slowness	P-Wave Velocity				
		0 µsec 1500	0 µsec 1500	0 µsec 1500	0 µsec 1500	0 us/m 1500		Elastic Moduli			Inferred UCS
		600 mm: µsec	800 mm: µsec	1000 mm: µsec	1200 mm: µsec	Velocity Analysis	Lithology				
1m:50m Depth	AHD RL m	RAW DATA				PROCESSED DATA	ANALYSIS				


Depth
1m:50m
RL m
AHD
RAW DATA
PROCESSED DATA
ANALYSIS
600 mm: µsec
800 mm: µsec
1000 mm: µsec
1200 mm: µsec
0 µsec 1500
Velocity Analysis
0 us/m 1500
Lithology
Elastic Moduli
Inferred UCS
Rx1 First Arrival
Rx2 First Arrival
Rx3 First Arrival
Rx4 First Arrival
P-Wave Slowness
P-Wave Velocity
0 m/s 6000
Young's Modulus
Shear Modulus
Poisson's Ratio
McNally (1987)
600 mm
800 mm
1000 mm
1200 mm
S-Wave Slowness
S-Wave Velocity
7000 25000
MPa
3000 10000
0 0.5
0 MPa 200
44.0
45.0
46.0
364.5
364.0
363.5
363.0
362.5
362.0

REPORT OF BOREHOLE: 320-02-BH2017

SHEET: 1 OF 3

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1099276

COORDS: 398102.3 m E 6955507.4 m N MGA94 56
SURFACE RL: 386.78 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 20.00 m

DRILL RIG: Commacio MC450P
CONTRACTOR: Proactive
LOGGED: STVM DATE: 13/9/19
CHECKED: FHH DATE: 9/12/19

Drilling					Sampling		Field Material Description					
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
ADV	H	GNE	0	386.78	SPT 0.50-0.95 m 7, 24, 30 N=54			CL CI	CLAY low to medium plasticity, brown, fine to coarse grained basalt gravel , trace fine to coarse grained sand, trace rootlets	W < PL	VSt	Colluvial soil
RD	H	GNO	1								H	
			2						For Continuation Refer to Sheet 2			
			3									
			4									
			5									
			6									
			7									
			8									
			9									
			10									

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INLAND RAIL GAP 16.1.GLB Log SA NON-CORED FULL PAGE 320-32H MASTER.GPJ <<DrawingFile>> 25/11/2020 09:38 8.30.04 Daga Tools

REPORT OF BOREHOLE: 320-02-BH2017

SHEET: 2 OF 3

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 398102.3 m E 6955507.4 m N MGA94 56
SURFACE RL: 386.78 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 20.00 m

DRILL RIG: Commacio MC450P
CONTRACTOR: Proactive
LOGGED: STVM DATE: 13/9/19
CHECKED: FHH DATE: 9/12/19

Drilling						Field Material Description				Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
				0								
				1								
					1.80		Continuation of Sheet 1					
HQ3	90-100% RETURN	100	0	2	384.98		MIXTURE OF Clayey GRAVEL AND COBBLES fine to coarse grained, dark grey, angular to sub-angular basalt gravel, high plasticity brown clay, high to very high strength basalt cobbles up to 150 mm					
		100	15									
		100	0	3								
		100	0									
		100	0	4								
		100	0									
		100	0	5								
		100	0									
		100	0	6								
		65	0	7	7.40							
					7.65		CORE LOSS					
					379.12		MIXTURE OF Clayey GRAVEL AND COBBLES as described in layer at 1.80 m					
				8	8.00							
					378.78		CORE LOSS					
		65	0		8.45							
					378.33		MIXTURE OF Clayey GRAVEL AND COBBLES as described in layer at 1.80 m					
				9	9.10							
		100	45		377.68		SANDSTONE fine to medium grained, orange brown minor grey, minor ferruginous staining, bedded at 5 to 15 degrees	XW MW		PLi(A)=0.28(M) PLi(D)=0.14(M)	9.10-20.00 m: KOUKANDOWIE FORMATION 9.10-9.50 m: DZ, recovered as Clayey SAND 9.84 m: J, 35°, Un, Ro, orange brown mineral	
				10								

This report of borehole must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

INLANDRAIL_GAP_8_10.1.V3.1.IE.GLB Log GAP CORED BOREHOLE 320-02~MASTER.GPJ <<DrawingFile>> 25/01/2020 09:08 3.30.004 Datgel Tools

REPORT OF BOREHOLE: 320-02-BH2017

SHEET: 3 OF 3

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 398102.3 m E 6955507.4 m N MGA94 56
SURFACE RL: 386.78 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 20.00 m

DRILL RIG: Commacio MC450P
CONTRACTOR: Proactive
LOGGED: STVM DATE: 13/9/19
CHECKED: FHH DATE: 9/12/19

Drilling						Field Material Description					Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
HC3	90-100% RETURN	100	45	10			SANDSTONE fine to medium grained, orange brown minor grey, minor ferruginous staining, bedded at 5 to 15 degrees	MW			Sn 9.94 m: J, 30°, Un, Ro, clay Ve 10.17 m: B, 0°, Pl, Ro, clay Ct, =10 mm 10.31 m: B, 0°, Un, Ro, clay Ct, =10 mm	
		100	70	11				MW - SW			10.67-10.72 m: Jx2, 25°, Pl Un, Ro, clay Ve Ct, <3 mm 10.78 m: J, 10°, Pl, Ro, clay Ct, =2 mm 10.93 m: J, 20°, Un, Ro, clay Ve 10.95 m: B, 10°, Un, Ro, clay Ve 11.07 m: D, 5°, Pl, Ro, orange brown mineral Sn 11.16 m: B, 10°, Un, Ro, clay Ve 11.38 m: J, 25°, Un, Ro, orange brown mineral Sn	
		100	75	12	12.05 374.73		becoming pale grey, minor orange brown	SW		PLI(A)=0.23(M) PLI(D)=0.18(M) UCS=0.5	11.58 m: B, 10°, Un, Ro, orange brown mineral Sn	
		100	100	13						PLI(A)=0.45(M)	12.47 m: J, 40°, Pl, Ro, Cn 12.51 m: B, 15°, Pl, Ro, clay Ve 12.56 m: D, 5°, Un, Ro, Cn 12.69-12.74 m: Jx2, 5°, Un, Ro, Cn 12.80 m: J, 20°, Ir, Ro 12.89 m: B, 10°, Pl, Ro, Cn 13.05 m: D, 0°, Pl, Ro, Cn 13.20 m: J, 5°, Un, Ro, Cn 13.28 m: J, 15°, Un, Ro	
		35	25	14	14.05 372.73		CORE LOSS				13.95 m: D, 5°, Pl, Ro, orange brown Sn	
				15	14.91 371.87		SANDSTONE fine to medium grained, pale grey, bedded at 5 to 10 degrees, cross bedded in parts	SW			15.16 m: J, 0°, Un, Ro, Cn	
	0% RETURN	100	100	16	16.40 370.38		with some dark brown sideritic beds, trace thinly bedded mudstone lenses			PLI(A)=0.13(B) PLI(D)=1.14(M) UCS=11.0 PLI(A)=0.57(M) PLI(D)=0.52(M)		
		100	95	17							16.90-17.20 m: SS, 75°, Pl, Sm, clay Ct, 2-3 mm, offset 20 mm 17.18 m: B, 10°, Un, Ro, clay Ve 17.42 m: B, 5°, Un, Ro, clay Ve	
				18						PLI(A)=0.90(M) PLI(D)=0.77(B) UCS=26.0	17.93 m: J, 10°, Un, Ro, Cn 18.07 m: J, 25°, Un, Ro, Cn	
		100	95	19						PLI(A)=2.69(W) PLI(D)=0.52(B) UCS=16.0 PLI(A)=2.45(M) PLI(D)=0.33(B)	18.49 m: J, 15°, Un, Ro, Cn 18.65 m: J, 15°, Un, Ro, Cn 19.06 m: B, 5°, Un, Ro, Cn 19.28 m: J, 20°, Un, Ro, Cn	
				20	20.00		END OF BOREHOLE @ 20.00 m TARGET DEPTH BACKFILLED				19.64 m: J, 10°, Un, Ro, Cn 19.58 m: B, 0°, Un, Ro, Cn 19.69 m: D, 0°, Un, Ro 19.74 m: B, 0°, Un, Ro, clay Ve	

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INLANDRAIL_GAP.8.16.1.V21.GLB Log (GAP CORED BOREHOLE 320-02~MASTER.GPJ <<DrawingFile>> 25/01/2020 09:08 3.30.004 DataTools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2017

SHEET: 1 OF 2

CLIENT:	ARTC	COORDS:	398102.3 m E 6955507.4 m N MGA94 56	DRILL RIG:	Commacio MC450P
PROJECT:	Inland Rail	SURFACE RL:	386.78 m DATUM: AHD	CONTRACTOR:	Proactive
LOCATION:	G2K Geotechnical Data Collection	INCLINATION:	-90°	LOGGED: STVM	DATE: 13/9/19
JOB NO:	1899276	HOLE DEPTH:	20.00 m	CHECKED: FHH	DATE: 9/12/19



320-02-BH2017 1.80 - 6.00 m



320-02-BH2017 6.00 - 11.00 m

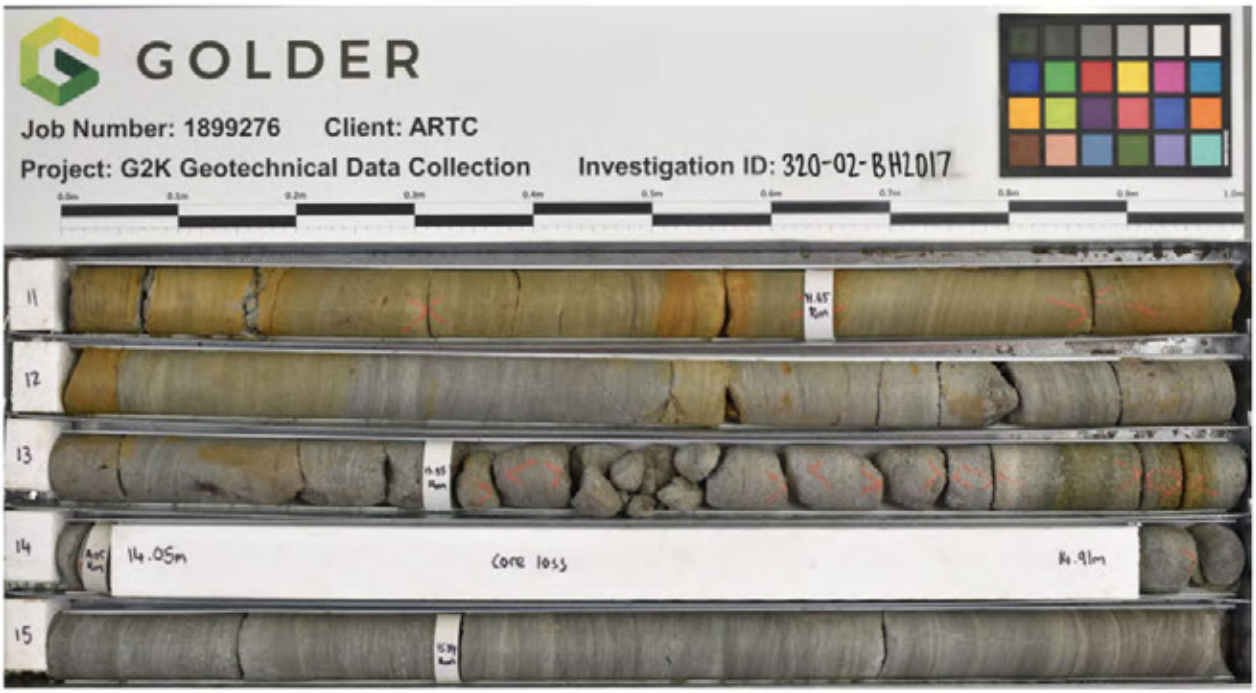
This report of core photographs must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

INLANDRAIL_GAP 8.16.7 V1 LIB:GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:32 8.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH2017

SHEET: 2 OF 2

CLIENT:	ARTC	COORDS:	398102.3 m E 6955507.4 m N MGA94 56	DRILL RIG:	Commacio MC450P
PROJECT:	Inland Rail	SURFACE RL:	386.78 m DATUM: AHD	CONTRACTOR:	Proactive
LOCATION:	G2K Geotechnical Data Collection	INCLINATION:	-90°	LOGGED: STVM	DATE: 13/9/19
JOB NO:	1899276	HOLE DEPTH:	20.00 m	CHECKED: FHH	DATE: 9/12/19



320-02-BH2017 11.00 - 16.00 m

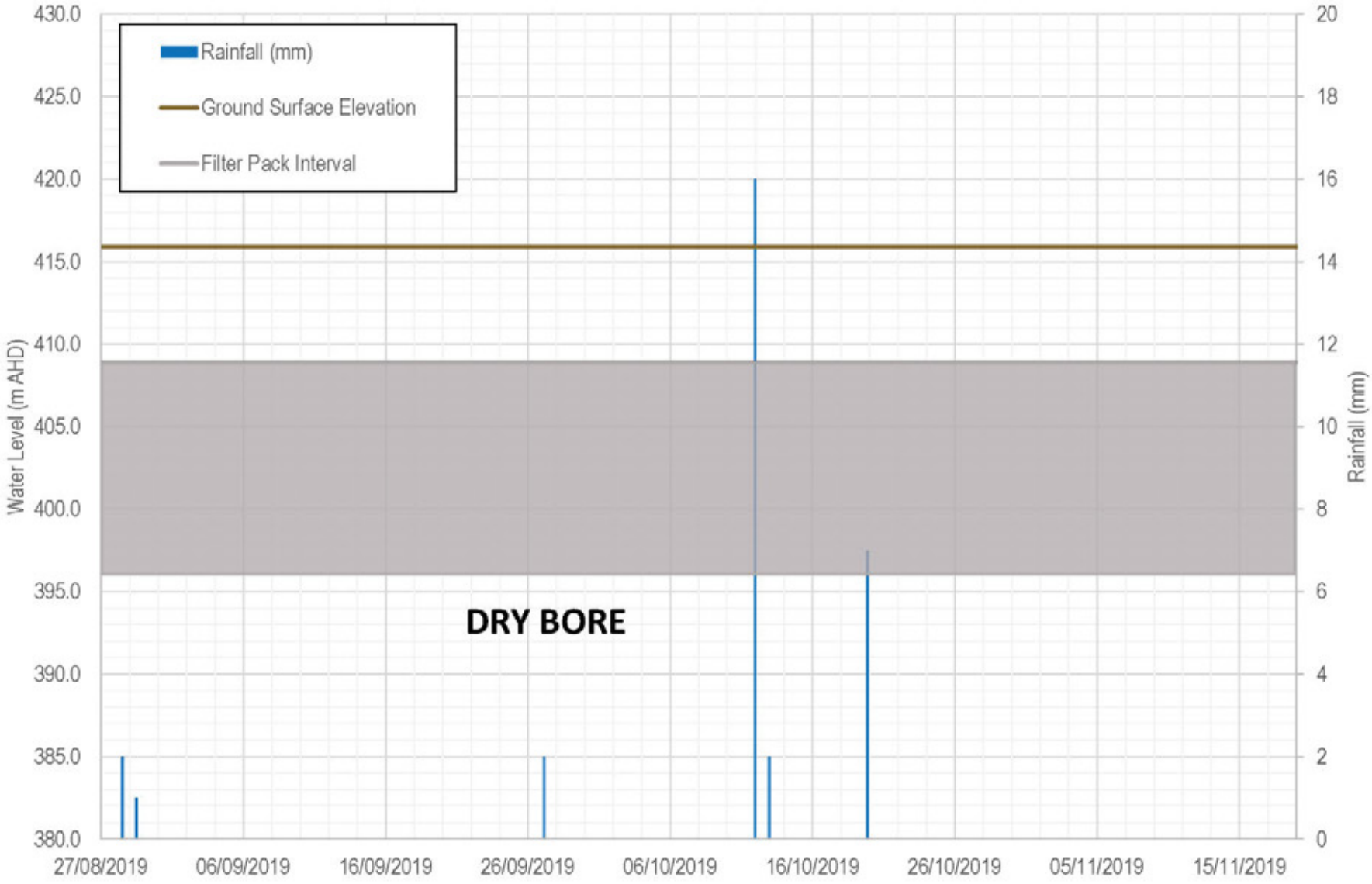


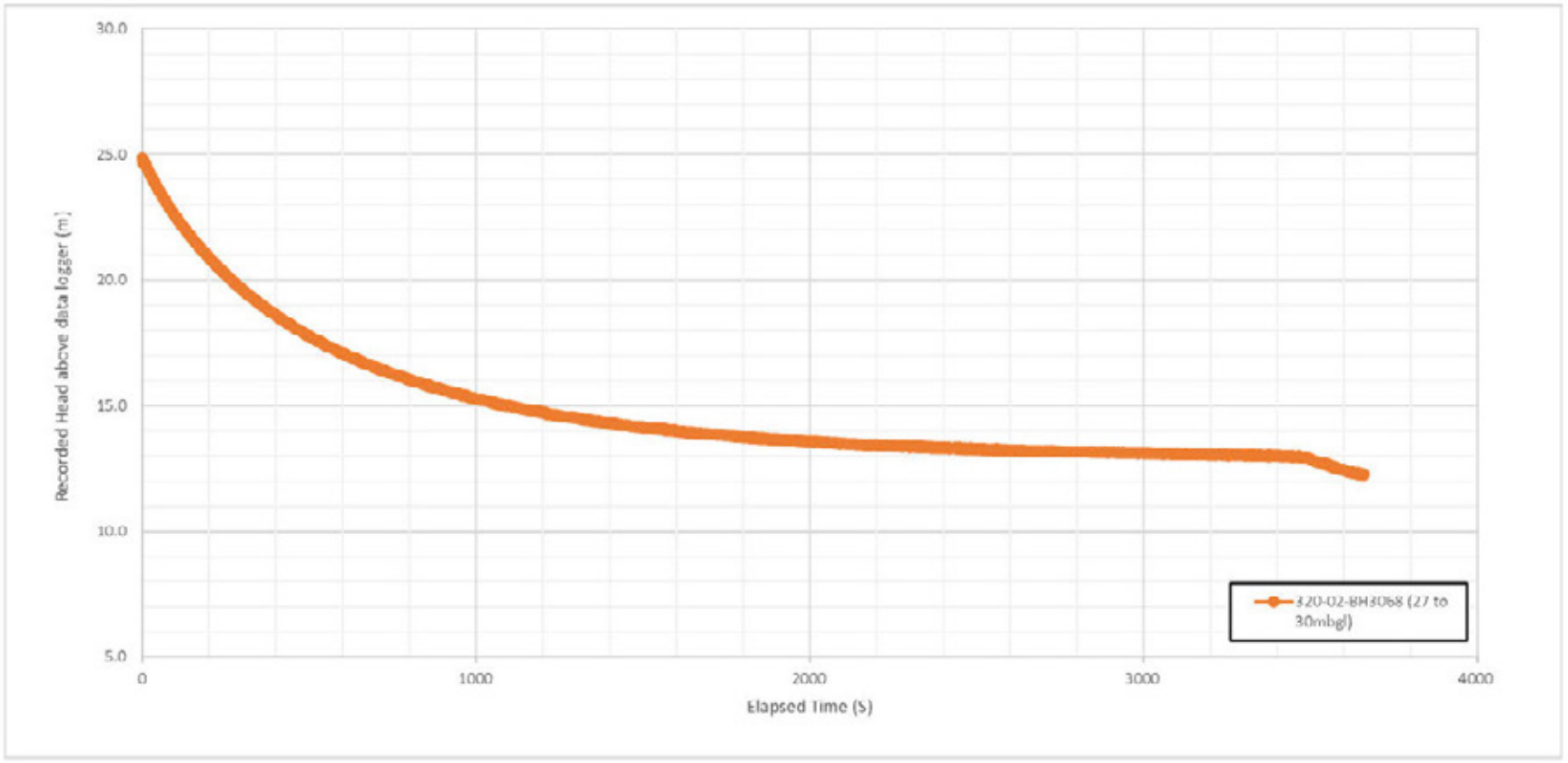
320-02-BH2017 16.00 - 20.00 m

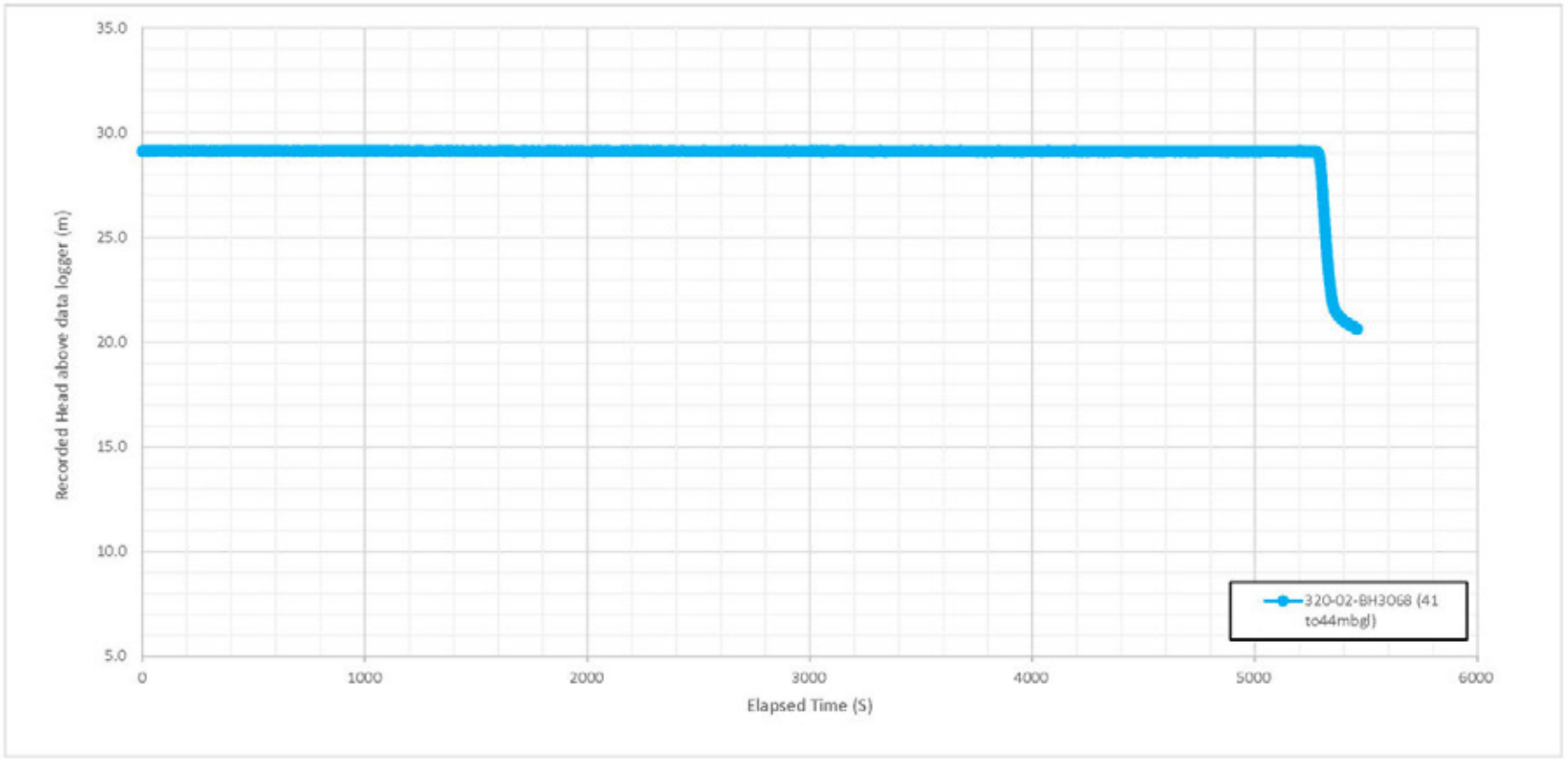
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GAP gINT FN. F28 RL1

INLANDRAIL_GAP 8_16.7 V1.LIB.GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 22/01/2020 17:33 8.30.004 Datgel Tools


Rainfall (mm)
Ground Surface Elevation
Filter Pack Interval
DRY BORE
Water Level (m AHD)
Rainfall (mm)
430.0
425.0
420.0
415.0
410.0
405.0
400.0
395.0
390.0
385.0
380.0
20
18
16
14
12
10
8
6
4
2
0
27/08/2019
06/09/2019
16/09/2019
26/09/2019
06/10/2019
16/10/2019
26/10/2019
05/11/2019
15/11/2019


30.0
25.0
20.0
15.0
10.0
5.0
Recorded Head above data logger (m)
0
1000
2000
3000
4000
Elapsed Time (S)
320-02-BH8068 (27 to 30mbgl)


35.0
30.0
25.0
20.0
15.0
10.0
5.0
Recorded Head above data logger (m)
0
1000
2000
3000
4000
5000
6000
Elapsed Time (S)
320-02-BH3068 (41 to44mbgl)

REPORT OF BOREHOLE: 320-02-BH3068

SHEET: 1 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397911.7 m E 6955519.1 m N MGA94 56
SURFACE RL: 415.90 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 50.00 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 25/7/19
CHECKED: GR DATE: 5/12/19

Drilling					Sampling		Field Material Description				
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
NDT		SWE	0	415.90 0.20				CI-CH	TOPSOIL: CLAY medium to high plasticity, dark brown, pale grey basalt ranging in size from gravel to boulders	w < PL	F - H	TOPSOIL
				415.70					MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			Colluvial soil
			1									
				1.80 414.10					inferred clay bed, to 2.0 m			
			2									
			3									
RT	H	GNO	4									
			5									
										w < PL w ~ PL	VD	
			6									
				6.50 409.40	C 6.50-6.70 m				CORE LOSS			
HQ3		0% RETURN		7.00	C 6.70-7.20 m							
			7	408.90					MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			
RT		GNO	8									
			9	9.30	C 9.20-9.65 m							
HQ3		80% RETURN		406.55					CORE LOSS			
				9.80 400.10	C 9.65-10.70 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY As described in layer at 7.00 m			
			10						CORE LOSS			

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GAP gINT FN. F01a
RL3

INLANDRAIL_GAP_8_16.7.V3.LIB.GLB Log (3A PNDN-CORED FULL PAGE 320-02H MASTER.GPJ <<DrawingFile>> 25/07/2020 10:10 8.30.004 Edge.7.ccs

REPORT OF BOREHOLE: 320-02-BH3068

SHEET: 2 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397911.7 m E 6955519.1 m N MGA94 56
SURFACE RL: 415.90 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 50.00 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 25/7/19
CHECKED: GR DATE: 5/12/19

Drilling					Sampling		Field Material Description					
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
HC3	H	80% RETURN	10	10.10 405.80	C 9.65-10.70 m				MIXTURE OF CORBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			Colluvial soil
					C 10.70-11.40 m							
			11	11.00 404.82					CORE LOSS			
					C 11.40-12.35 m				MIXTURE OF CORBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			
			12		C 12.35-12.50 m C 12.50-14.00 m							
			13		C 13.20 m C 13.25 m							
				13.83								
			14	14.00 401.90	C 14.00-15.00 m				CORE LOSS MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand	W < PL - W ~ PL	VD	
			15		C 15.00-15.60 m							
					C 15.60-16.50 m							
			16		C 16.50-17.10 m							
			17		C 17.10-18.00 m							
			18		C 18.00-18.50 m							
				18.32 397.58					CORE LOSS			
				18.70 397.20	C 18.50-20.30 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub-angular to rounded, with brown, high plasticity clay, fine to medium grained sand			
			19									
				19.87 20.00					CORE LOSS			
			20									

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INLANDRAIL_GAP 8.16.1 V2 LIBRARY.GLB Log (GAP NON-CORED FULL PAGE 320-02H MASTER.GPJ <<DrawingFile>> 25/01/2020 10:10 8:30:004 Edge™.com

REPORT OF BOREHOLE: 320-02-BH3068

SHEET: 3 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1699276

COORDS: 397911.7 m E 6955519.1 m N MGA94 56
SURFACE RL: 415.90 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 50.00 m

DRILL RIG: D8525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 25/7/19
CHECKED: GR DATE: 5/12/19

Drilling					Sampling		Field Material Description				
METHOD	PENETRATION RESISTANCE	WATER	DEPTH (metres)	DEPTH RL	SAMPLE OR FIELD TEST	RECOVERED	GRAPHIC LOG	GROUP SYMBOL	SOIL/ROCK MATERIAL DESCRIPTION	MOISTURE CONDITION	CONSISTENCY DENSITY	STRUCTURE AND ADDITIONAL OBSERVATIONS
HQ3	H		20	395.90	C 18.50 20.30 m				MIXTURE OF COBBLES/BOULDERS AND Sandy CLAY grey stained orange brown, high to very high strength basalt clasts ranging from fine grained gravel to boulders, sub angular to rounded, with brown, high plasticity clay, fine to medium grained sand	w< PL - w~ PL	VD	Colluvial soil
									For Continuation Refer to Sheet 4			
			21									
			22									
			23									
			24									
			25									
			26									
			27									
			28									
			29									
			30									

This report of borehole must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

INLAND RAIL GAP8_16.*.*1_BGUB Log 3A* NON-CORED FULL PAGE 320-32H MASTER.GPJ <<DrawingFile>> 25/12/2019 10:16 8.30.04 Cage Tools

REPORT OF BOREHOLE: 320-02-BH3068

SHEET: 4 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397911.7 m E 6955519.1 m N MGA94 56
SURFACE RL: 415.90 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 50.00 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 25/7/19
CHECKED: GR DATE: 5/12/19

Drilling						Field Material Description				Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
				20	20.30		Continuation of Sheet 3					
HQ3	60% RETURN	100	100		395.60		INTERBEDDED MUDSTONE AND SANDSTONE fine to medium grained, dark brown grey and blue green, irregular bedding, with sandstone beds to 100 mm and mudstone beds to 100 mm	XW			20.30-50.00 m: KOURANDOWIE FORMATION	
					20.65 395.25 20.91			HW				
				21	394.99		MUDSTONE dark brown, irregular bedding	SW - FR			20.92 m: B, 0-3°, Pl-Un, Sm, Cn	
							SANDSTONE fine to medium grained, blue green, irregularly bedded 0 to 8 degrees, occassional mudstone lamination to 10 mm			PLI(A)=0.08(M) PLI(D)=0.09(W)	21.23 m: J, 30-50°, Pl-Un, Sm, Cn	
					21.64 394.26		increasing percentage of fine grains to 21.97 m					
	60% RETURN	100	100	22	22.02 393.88		orange brown staining along healed defects to 22.40 m	MW				
					22.40 393.50		dark brown mudstone bed to 22.55 m	SW				
					22.70 393.20		interlaminated with mudstone to 23.43 m					
				23	23.61 392.29							
	50% RETURN	100	95		392.24		MUDSTONE AND SANDSTONE pale to dark brown mudstone beds to 30 mm and blue green to pale grey sandstone beds to 40 mm, occassional orange brown staining, interlaminated to interbedded, bedded 0 to 10 degrees	HW - MW			23.97-24.05 m: DS, 0-5°, sp = 60 mm, Pl, Sm, clayey sand	
							carbonaceous bed at 23.66 m					
				24	24.60 391.30		SANDSTONE fine to coarse grained, blue green, trace fine rounded gravels throughout					
					25.96 389.94		weathered clay beds to 20.70 m, x4 up to 40 mm				25.95-26.23 m: DSx3, 0-5°, sp = 10-40 mm, Pl, Sm, clay	
				25	26.84 389.06						26.68-26.73 m: DS, 0-5°, Pl, Sm, clay	
	80% RETURN	100	75				MUDSTONE dark brown, indistinct bedding, 0 to 10 degrees, occassional carbonaceous wisp	FR			27.00-27.13 m: Jv3, 40-55°, sp = 20-70 mm, Pl, Sm, Cn	
				26	27.20 388.70		orange brown staining to 27.44 m	MW - SW				
					27.44 388.46		SANDSTONE fine to medium grained, blue green, indistinct bedding, dipping at 0 to 5 degrees, occassional mudstone lamination	SW				
				27						PLI(A)=0.12(M) PLI(D)=0.05(J)		
					28.08 387.82		mudstone laminations, to 10 mm, to 28.41 m, laminations between 28.19-28.25 m are stained orange brown					
				28	28.28 387.65		coarse grained sand below 28.25 m					
	80% RETURN	100	95		29.00		CORE LOSS				28.93-28.95 m: Bx2, 5-10°, sp = 20 mm, Pl, Ro, Cn	
				29	29.20 386.70		SANDSTONE fine to coarse grained, grey, indistinct bedding, 0 to 5 degrees, medium grained, rounded gravel bed to 29.30 m, trace fine grained gravel throughout	SW - FR			29.20-29.32 m: DS, 0-5°, Pl, Sm, sand and gravel 29.33-29.55 m: J, 70-90°, Pl, Ro, Cn	
				30								

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INLANDRAIL_GAP 8.16.1.V3.1.E.GLB Log (3A-CORED BOREHOLE 320-02~ MASTER.GPJ <<DrawingFile>> 25/01/2020 10:39:004 Datgel Tools

REPORT OF BOREHOLE: 320-02-BH3068

SHEET: 5 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397911.7 m E 6955519.1 m N MGA94 56
SURFACE RL: 415.90 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 50.00 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 25/7/19
CHECKED: GR DATE: 5/12/19

Drilling						Field Material Description				Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
HC3	80% RETURN	100	95	30			SANDSTONE fine to coarse grained, grey, indistinct bedding, 0 to 5 degrees, medium grained, rounded gravel bed to 29.80 m, trace fine grained gravel throughout	SW - FR		PLI(D)=0.32(M) UCS=6.5		
				31	31.50 31.60 384.30		CORE LOSS SANDSTONE fine to coarse grained, grey, indistinct bedding, 0 to 5 degrees, with fine to medium grained, rounded gravel throughout	SW - FR			31.58 m: B, 2°, Pl, Ro, Cn 32.07 m: B, 4°, Pl, Ro, Cn 32.77-32.82 m: DS, 0°, Pl, Ro, sand	
	80% RETURN	100	85	32								
				33	33.90					PLI(A)=0.29(M) PLI(D)=0.28(M)		
				34	382.00 34.22 381.68		INTERLAMINATED MUDSTONE AND SANDSTONE fine to medium grained, grey and dark brown, bedded, 0 to 5 degrees, laminitons to 7 mm					
					34.71 381.19		MUDSTONE dark brown, laminated, 0 to 10 degrees, with carbonaceous wisps carbonaceous laminations to 34.75 m					
	80% RETURN	100	100	35	34.97 380.93		INTERBEDDED MUDSTONE AND SANDSTONE fine to medium grained, grey and dark brown, bedded 0 to 5 degrees, sandstone beds to 30 mm, mudstone beds to 50 mm, occassional siderite beds, <50 mm				35.75-35.90 m: J, 70-80°, Pl, Ro, Cn	
					35.70 380.20		bed of fine to coarse grained sandstone to 35.89 m					
				36	36.30 379.60		predominately mudstone to 37.00 m, with fine to medium grained sandstone laminations to 3 mm					
				37	37.00 378.90		SANDSTONE fine to medium grained, pale grey, bedded, 0 to 5 degrees, cross bedded, rounded mudstone clast to 30 mm					
					37.33 378.57		INTERBEDDED MUDSTONE AND SANDSTONE fine to medium grained, pale grey and dark brown, bedded, 0 to 10 degrees, sandstone beds to ~30 mm, mudstone beds to 60 mm					
	80% RETURN	100	100	38	38.20 377.70		SANDSTONE fine to medium grained, pale grey, indistinct bedding, 0 to 5 degrees, cross bedded, occassional elongated mudtone clast, occasional siderite beds, <160 mm				38.29-38.31 m: DS, 0-3°, Pl, Sm, clay	
				39						UCS=11.9 PLI(A)=1.06(M) PLI(D)=0.53(M)		
				40	40.00							

This report of borehole must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

INLANDRAIL_GAP 8.16.1.V2.1.GLB Log (3A) CORED BOREHOLE 320-02~MASTER.GPJ <<DrawingFile>> 25/01/2020 10:39:004 Datgel Tools

REPORT OF BOREHOLE: 320-02-BH3068

SHEET: 6 OF 6

CLIENT: ARTC
PROJECT: Inland Rail
LOCATION: G2K Geotechnical Data Collection
JOB NO: 1899276

COORDS: 397911.7 m E 6955519.1 m N MGA94 56
SURFACE RL: 415.90 m DATUM: AHD
INCLINATION: -90°
HOLE DEPTH: 50.00 m

DRILL RIG: DB525
CONTRACTOR: Saxon Drilling
LOGGED: RC DATE: 25/7/19
CHECKED: GR DATE: 5/12/19

Drilling						Field Material Description					Defect Information	
METHOD	WATER	TCR	RQD	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	ROCK / SOIL MATERIAL DESCRIPTION	WEATHERING	INFERRED STRENGTH UCS MPa	LABORATORY STRENGTH (MPa)	DEFECT DESCRIPTION & Additional Observations	FRACTURE FREQUENCY (Defects per unit metre length)
HC3	50% RETURN	100	100	40	375.90		SANDSTONE fine to medium grained, pale grey, indistinct bedding, 0 to 5 degrees, cross bedded, occassional elongated mudstone clast within matrix	SW - FR		PLI(A)=1.16(M) PLI(D)=1.50(M)		
					40.52 375.38		siderite bed to 40.70 m				40.69 m: B, 2-5°, Pl-Un, Sm, Cn	
				41						UCS=12.2 PLI(A)=0.84(M) PLI(D)=1.10(M)		
					42.00 373.90		carbonaceous laminations to 42.50 m, concentrated between 42.42-42.50 m				42.31 m: B, 2-4°, Pl, Ro, Cn	
				42	42.84							
					373.06		fine to coarse grained sandstone, with coarse grained sandstone beds, to 43.62 m			UCS=19.7		
				43							43.41 m: J, 10-20°, Pl-Un, Ro, Cn	
					43.04 372.26		INTERBEDDED MUDSTONE AND SANDSTONE fine to medium grained, pale grey and dark brown, bedded, 0 to 5 degrees, sandstone beds to 30 mm, mudstone beds to 60 mm, trace siderite beds, <30 mm				43.65-43.67 m: DS, 5°, Pl, Sm, clay	
	80% RETURN	100	95	44							44.40 m: J, 10-15°, Pl, Sm, Cn 44.60 m: J, 5-10°, Pl, Sm, Cn 44.71 m: J, 10-20°, Pl, Sm, Cn	
				45							45.61 m: J, 30°, Pl, Sm, Cn 45.71 m: B, 3-5°, Pl, Sm, Cn	
				46							46.16 m: B, 5°, Pl, Sm, Cn 46.40 m: J, 50°, Pl, Sm, Cn	
	80% RETURN	100	100	47								
				48							47.90 m: J, 20°, Pl, Sm, Cn	
				49	49.05 366.84		fine grained, sub-rounded gravel bed at 49.05 m					
	80% RETURN	100	100				END OF BOREHOLE @ 50.00 m TARGET DEPTH PIEZOMETER INSTALLED					
				50	50.00							

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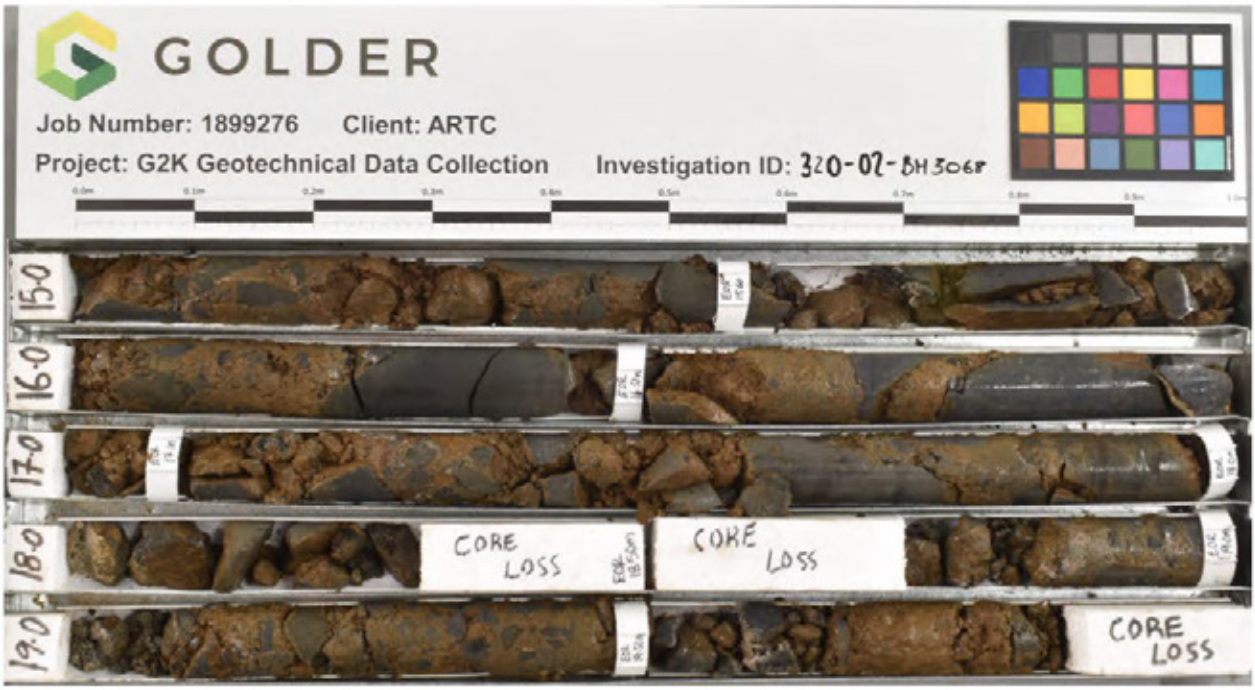
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REPORT OF CORE PHOTOGRAPHS: 320-02-BH3068

SHEET: 1 OF 4

CLIENT:	ARTC	COORDS:	397911.7 m E 6955519.1 m N MGA94 56	DRILL RIG:	DB525
PROJECT:	Inland Rail	SURFACE RL:	415.90 m DATUM: AHD	CONTRACTOR:	Saxon Drilling
LOCATION:	G2K Geotechnical Data Collection	INCLINATION:	-90°	LOGGED: RC	DATE: 25/7/19
JOB NO:	1899276	HOLE DEPTH:	50.00 m	CHECKED: GR	DATE: 5/12/19





This report of core photographs must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

GAP gINT FN. F28 RL1

INLANDRAIL_QAP 8. 16.7 V2 LIB:GLB GrfcTbl GAP CORE PHOTO 2 PER PAGE 320-02H MASTER.GPJ <<DrawingFile>> 29/01/2020 12:46 8.30.004 Datgel Tools

REPORT OF CORE PHOTOGRAPHS: 320-02-BH3068

SHEET: 2 OF 4

CLIENT:	ARTC	COORDS:	397911.7 m E 6955519.1 m N MGA94 56	DRILL RIG:	DB525
PROJECT:	Inland Rail	SURFACE RL:	415.90 m DATUM: AHD	CONTRACTOR:	Saxon Drilling
LOCATION:	G2K Geotechnical Data Collection	INCLINATION:	-90°	LOGGED: RC	DATE: 25/7/19
JOB NO:	1899276	HOLE DEPTH:	50.00 m	CHECKED: GR	DATE: 5/12/19





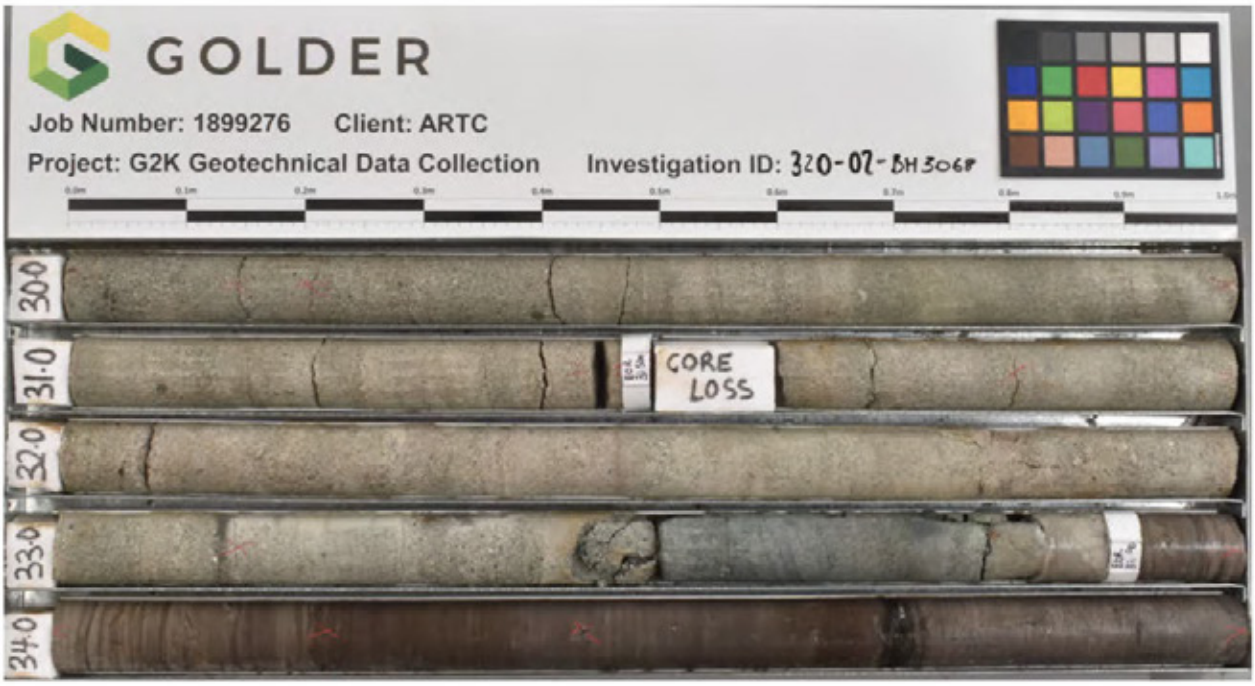
This report of core photographs must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

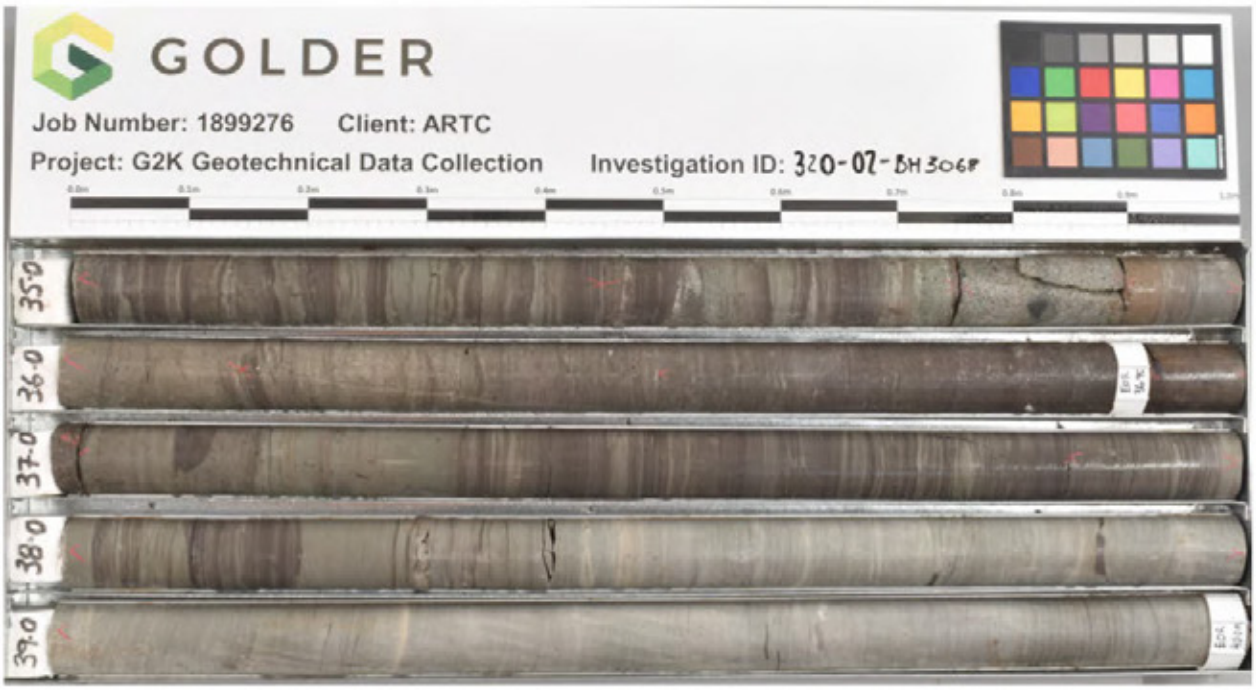
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REPORT OF CORE PHOTOGRAPHS: 320-02-BH3068

SHEET: 3 OF 4

CLIENT:	ARTC	COORDS:	397911.7 m E 6955519.1 m N MGA94 56	DRILL RIG:	DB525
PROJECT:	Inland Rail	SURFACE RL:	415.90 m DATUM: AHD	CONTRACTOR:	Saxon Drilling
LOCATION:	G2K Geotechnical Data Collection	INCLINATION:	-90°	LOGGED: RC	DATE: 25/7/19
JOB NO:	1899276	HOLE DEPTH:	50.00 m	CHECKED: GR	DATE: 5/12/19





This report of core photographs must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

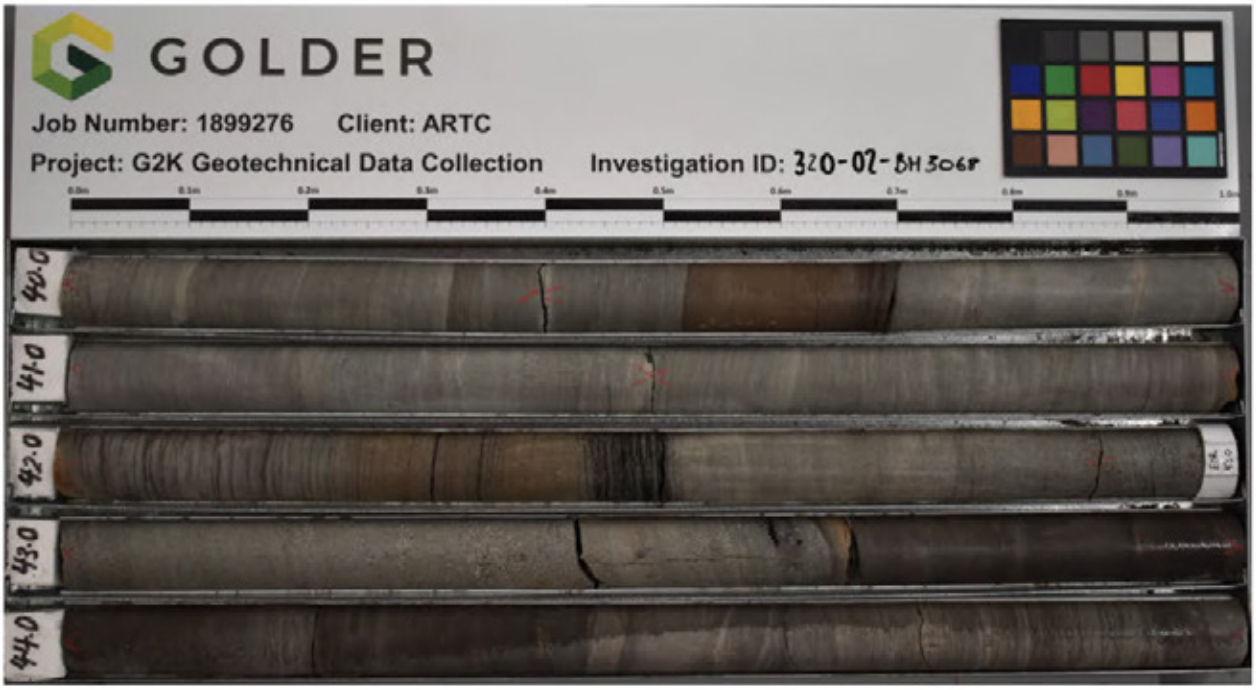
GAP gINT FN. F28 RL1

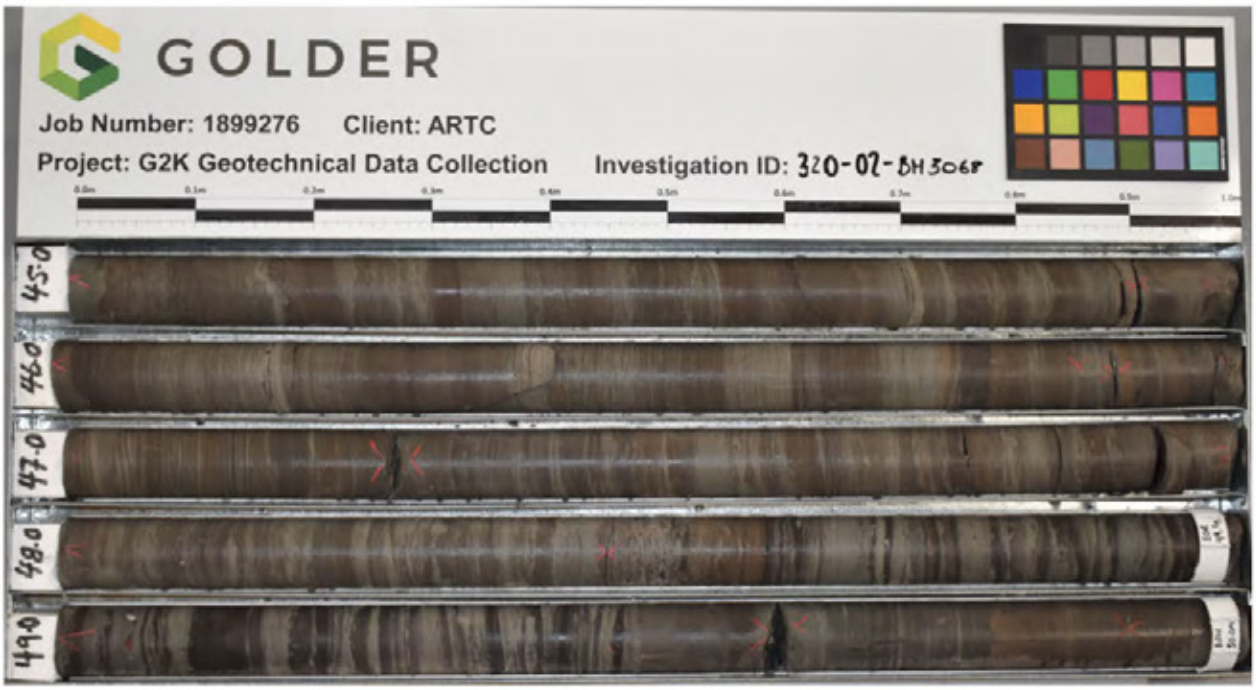
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REPORT OF CORE PHOTOGRAPHS: 320-02-BH3068

SHEET: 4 OF 4

CLIENT:	ARTC	COORDS: 397911.7 m E 6955519.1 m N MGA94 56	DRILL RIG: DB525
PROJECT:	Inland Rail	SURFACE RL: 415.90 m DATUM: AHD	CONTRACTOR: Saxon Drilling
LOCATION:	G2K Geotechnical Data Collection	INCLINATION: -90°	LOGGED: RC DATE: 25/7/19
JOB NO:	1899276	HOLE DEPTH: 50.00 m	CHECKED: GR DATE: 5/12/19





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GAP gINT FN. F28
RL1

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REPORT OF STANDPIPE INSTALLATION: 320-02-BH3068

SHEET: 1 OF 1

CLIENT:	ARTC	COORDS: 397911.7 m E 6955519.1 m N MGA94 56	DRILL RIG: DB525
PROJECT:	Inland Rail	SURFACE RL: 415.90 m DATUM: AHD	CONTRACTOR: Saxon Drilling
LOCATION:	G2K Geotechnical Data Collection	INCLINATION: -90°	LOGGED: RC DATE: 25-7-19
JOB NO:	1899276	HOLE DEPTH: 50.00 m	CHECKED: GR DATE: 5-12-19

Drilling				Field Material Description		Instrumentation Details
METHOD	WATER	DEPTH (metres)	DEPTH RL	GRAPHIC LOG	SOIL/ROCK MATERIAL DESCRIPTION	
AD/T	GNE	0	415.70		CLAY	gatic
					MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	cement grout
RT						3.00, RL412.90
						bentonite seal
			6.50			5.00, RL410.00
HQ3			408.90		CORE LOSS	
RT					MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
			9.30			
		10			CORE LOSS	filter pack
			11.00		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
			404.82		CORE LOSS	
			13.63		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
HQ3			401.90		CORE LOSS	15.00, RL400.90
					MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	slotted PVC
			18.32		CORE LOSS	
			19.87		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
		20	20.20		CORE LOSS	21.00, RL394.90 data logger at 20.50m
			394.99		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
			23.61		CORE LOSS	
			24.60		MIXTURE OF COBBLES/BOULDERS AND SANDY CLAY	
	GNC		391.30		INTERBEDDED MUDSTONE AND SANDSTONE	
			26.84		MUDSTONE	
			27.44		SANDSTONE	
			388.46		MUDSTONE AND SANDSTONE	
			29.00		SANDSTONE	
		30	386.70		MUDSTONE	backfill
			31.60		SANDSTONE	
			384.30		CORE LOSS	
			33.90		SANDSTONE	
HQ3			34.97		CORE LOSS	
			380.93		SANDSTONE	
			37.00		INTERLAMINATED MUDSTONE AND SANDSTONE	
			38.20		MUDSTONE	
			377.70		INTERBEDDED MUDSTONE AND SANDSTONE	
		40			SANDSTONE	
					INTERBEDDED MUDSTONE AND SANDSTONE	
					SANDSTONE	
			43.64			
			372.26		INTERBEDDED MUDSTONE AND SANDSTONE	
		50	50.00			50.00, RL365.90
			365.90		END OF BOREHOLE @ 50.00 m TARGET DEPTH STANDPIPE INSTALLED	
		60				

This report of standpipe installation must be read in conjunction with accompanying notes and abbreviations. It has been prepared for geotechnical purposes only, without attempt to assess possible contamination. Any references to potential contamination are for information only and do not necessarily indicate the presence or absence of soil or groundwater contamination.

GAP gINT FN. F17 RL1

INLANDRAIL_GAP 8.16.1.V2.1.GLB Log GAPWELL3 WELLS - COPY.GPJ <<DrawingFile>> 10-01-2020 12:31 8.30.04 Datgel Tools

Golder Associates Pty Ltd
147 Coronation Drive, Milton,
Queensland 4064, Australia
(PO Box 1734, Milton BC, QLD 4064)

GOLDER

GEOPHYSICAL RECORD OF BOREHOLE: 320-02-BH3068

PROJECT	Inland Rail Detailed Design SI	Job #	1899276
CLIENT	ARTC	DATE	13/08/19

LOCATION-	Toowoomba	LOGGED BY-	AR
EASTING (MGA94) -	397911.67 m E	LOGGED DATE:	30/07/19
NORTHING (MGA94) -	6955519.08 m N	LOGGING DATUM-	Ground Level
ELEVATION (AHD m) -	415.90 m	LOGGED DEPTH-	20.39 to 49.8 m
DRILLED DEPTH-	50.0 m DIAMETER- HQ	DRAWN BY-	RR
PLUNGE-	87 deg AZIMUTH- 227 deg TN	REVIEWED BY-	TR
CASING-	Steel DEPTH- 20.39 m	FILE NAME-	320-02-BH3068_RevD.wcl

All summary structural data and borehole orientation referenced to True North (Declination 11 degs).

Mechanical caliper log is used for dip corrections.

Magnetic field is stable below 22.6 m below ground level. Image distorted above 21.4 m below ground level.

Borehole zeroed to ground level. GPS survey of ground level applied for RL conversion.

DEVIATION DATA



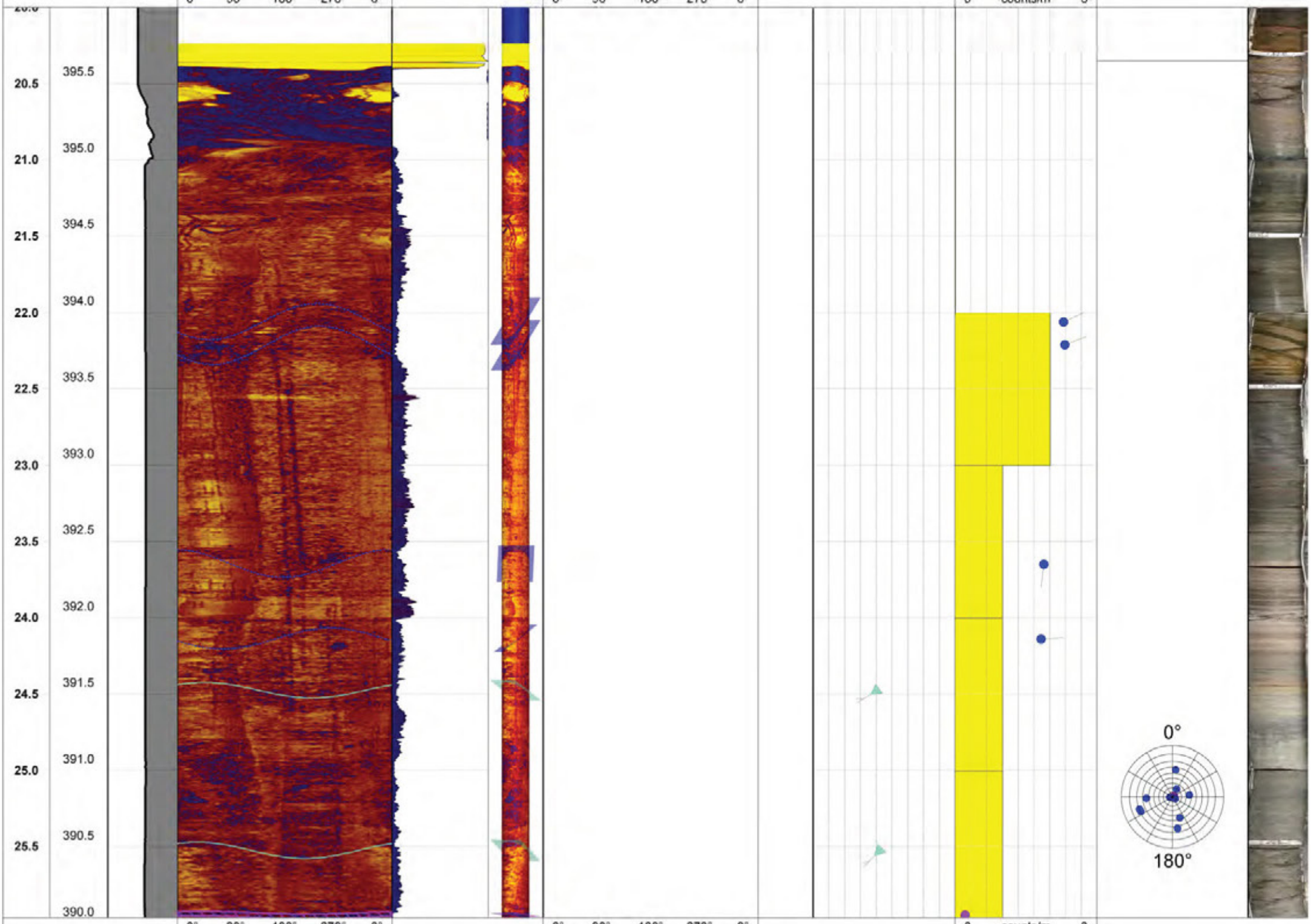


INTERPRETED STRUCTURES

Low Confidence
Medium Confidence
High Confidence

Bedding Parting- Medium Confidence
Bedding Parting - High Confidence
Bedding Fabric
XW Seam - High Confidence
Joint - Medium Confidence
Joint - High Confidence
Healed Joint - Medium Confidence

320-02-BH3068



320-02-BH3068

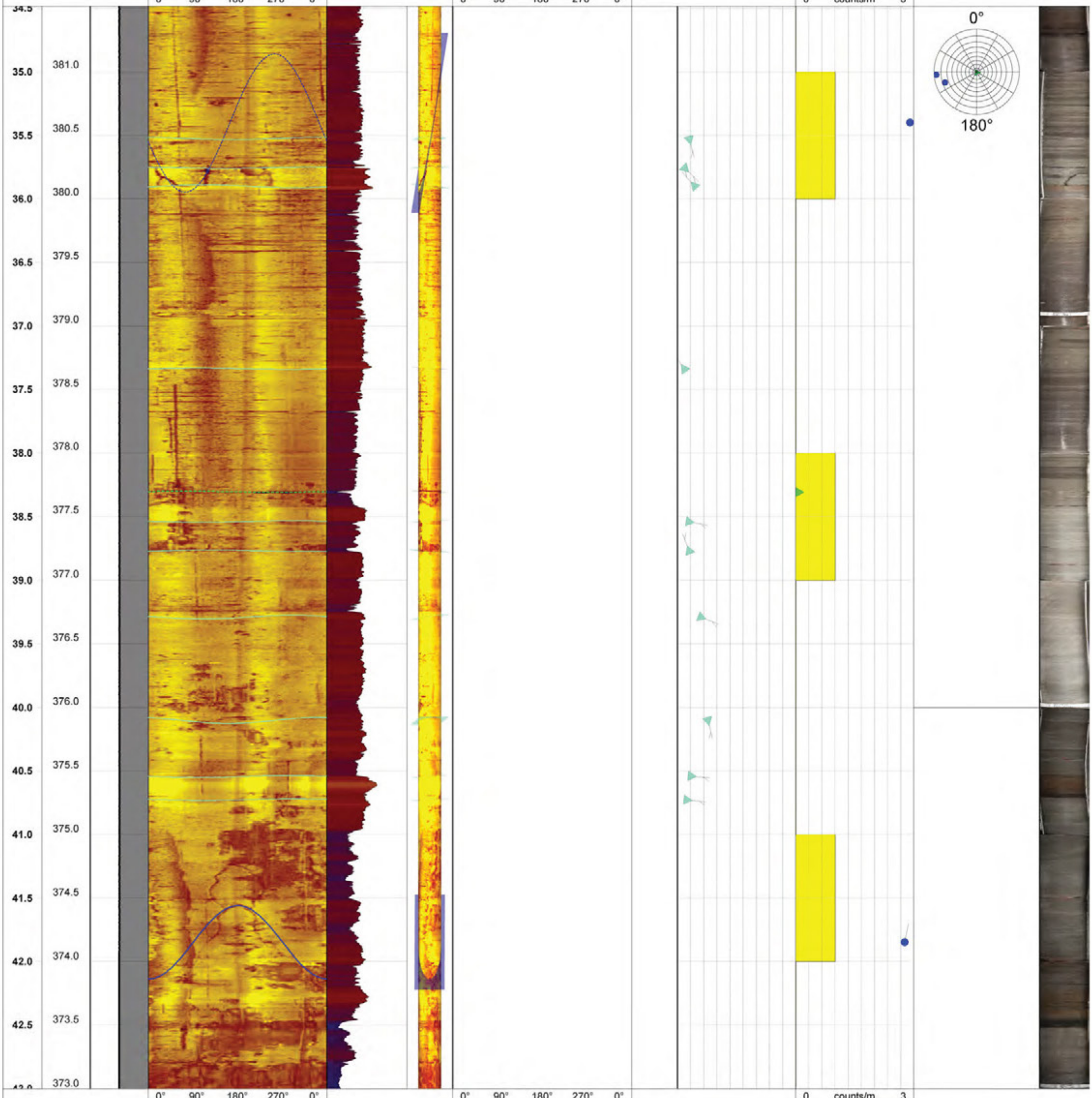
320-02-BH3068

Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data		Summary Structural Data			Core
		QL40 CAL	Amplitude-NM	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
		0 200	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
			ATV Structure Log			OTV Structure Log			Freq/meter		
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 3		
26.0											
26.5	389.5										
27.0	389.0										
27.5	388.5										
28.0	388.0										
28.5	387.5										
29.0	387.0										
29.5	386.5										
30.0	386.0										
30.5	385.5										
31.0	385.0										
31.5	384.5										
32.0	384.0										
32.5	383.5										
33.0	383.0										
33.5	382.5										
34.0	382.0										
	381.5										
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 3		
			ATV Structure Log			OTV Structure Log			Freq/meter		
		0 200	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
		QL40 CAL	Amplitude-NM	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
1m:30m Depth	AHD RL m	Caliper	ATV Data			OTV Data		Summary Structural Data			Core

320-02-BH3068

320-02-BH3068

Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data			Summary Structural Data			Core
		QL40 CAL	Amplitude-NM	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo	
		0 200	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type		
			ATV Structure Log			OTV Structure Log			Freq/meter			
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 3			

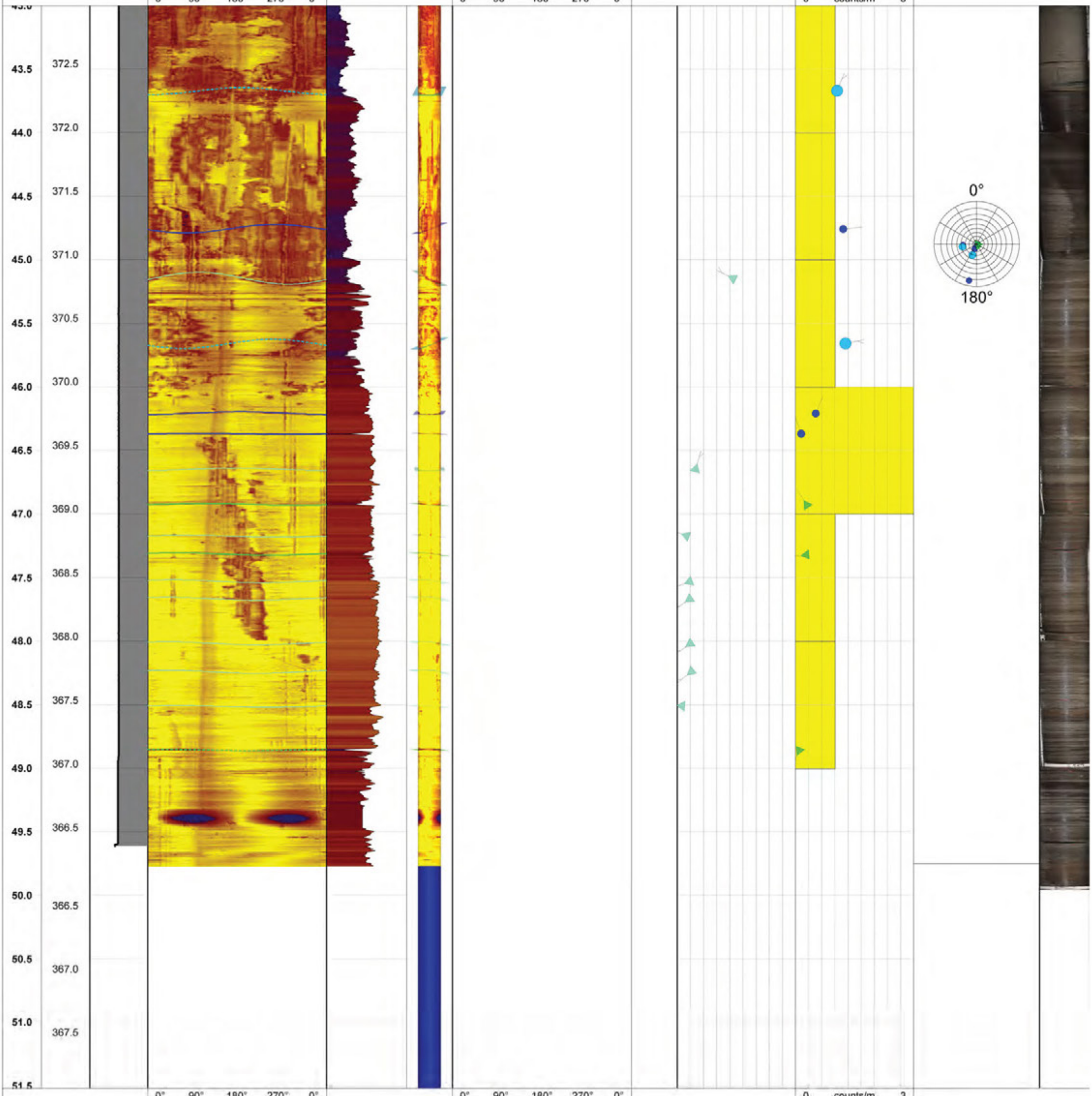


			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 3			
			ATV Structure Log			OTV Structure Log			Freq/meter			
		0 200	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type		
1m:30m Depth	AHD RL m	Caliper	ATV Data			OTV Data			Summary Structural Data			Core

320-02-BH3068

320-02-BH3068

Depth 1m:30m	RL m AHD	Caliper	ATV Data			OTV Data		Summary Structural Data			Core
		QL40 CAL	Amplitude-NM	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
		0 200	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
			ATV Structure Log			OTV Structure Log			Freq/meter		
			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 3		



			0° 90° 180° 270° 0°			0° 90° 180° 270° 0°			0 counts/m 3		
			ATV Structure Log			OTV Structure Log			Freq/meter		
		0 200	0° 90° 180° 270° 0°	300 10000	-0°	0° 90° 180° 270° 0°	-0°	0 90	0 90	Wulff Plot - LH - Type	
		QL40 CAL	Amplitude-NM	APP Hardness	ATV 3D	Image-NM	OTV 3D	Bedding	Defects	Polar Plot Defects	Photo
1m:30m Depth	AHD RL m	Caliper	ATV Data			OTV Data		Summary Structural Data			Core

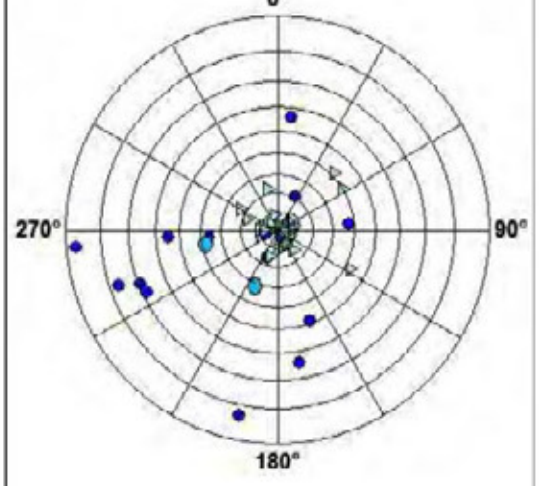
320-02-BH3068

320-02-BH3068

Depth 1m:30m	RL m AHD	Caliper	ATV Data	OTV Data	Summary Structural Data	Core
		QL40 CAL 0 200	Amplitude-NM 0° 90° 180° 270° 0° APP Hardness 300 10000 ATV 3D 0° ATV Structure Log 0° 90° 180° 270° 0°	Image-NM 0° 90° 180° 270° 0° OTV 3D 0° OTV Structure Log 0° 90° 180° 270° 0°	Bedding 0 90 Defects 0 90 Freq/meter 0 counts/m 3 Polar Plot Defects Wulff Plot - LH - Type	Photo
	368.0		0° 90° 180° 270° 0° ATV Structure Log 0° 90° 180° 270° 0° Amplitude-NM 0 200 QL40 CAL APP Hardness 300 10000 ATV 3D -0°	0° 90° 180° 270° 0° OTV Structure Log 0° 90° 180° 270° 0° Image-NM -0° OTV 3D	0 counts/m 3 Freq/meter 0 90 Bedding 0 90 Defects Wulff Plot - LH - Type Polar Plot Defects	Photo
1m:30m Depth	AHD RL m	Caliper	ATV Data	OTV Data	Summary Structural Data	Core

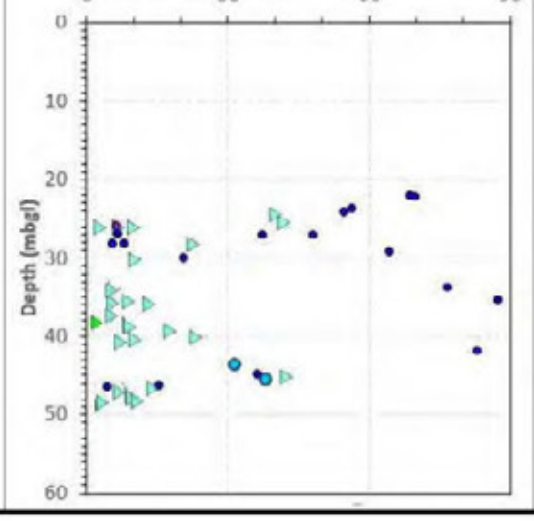
320-02-BH3068

Stereonet (lower hemisphere, equal angle)

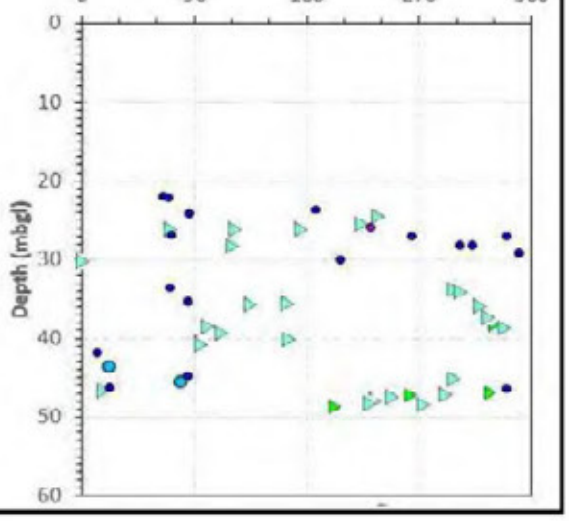


Breakouts and Stress Orientation

Feature Dip vs Depth



Feature Dip Direction vs Depth



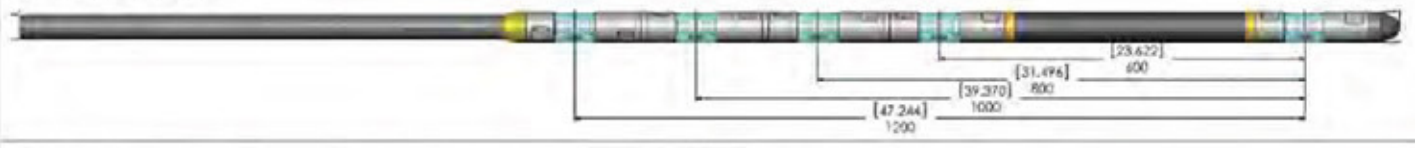
GEOPHYSICAL RECORD OF BOREHOLE: 320-02-BH3068

Golder Associates Pty Ltd
146 Coronation Drive
Milton
Queensland 4064
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PROJECT	Inland Rail Detailed Design SI	PROJECT #	1899276
CLIENT	ARTC	DATE	13/08/19

LOCATION-	Toowoomba	LOGGED BY-	AR
EASTING (MGA94)-	397911.67 m E	LOGGED DATE-	30/07/19
NORTHING (MGS94)-	6955519.08 m N	LOGGING DATUM-	Ground Level
ELEVATION (AHD m)-	415.90 m	LOGGED DEPTH-	19.9 to 50 m
DRILLED DEPTH-	50.0 m DIAMETER- HQ	DRAWN BY-	AR
PLUNGE-	87 deg AZIMUTH- 227 deg TN	REVIEWED BY-	TR
CASING-	Steel DEPTH- 20.5 m	FILE NAME-	320-02-BH3068_FWS_RevD.wcl

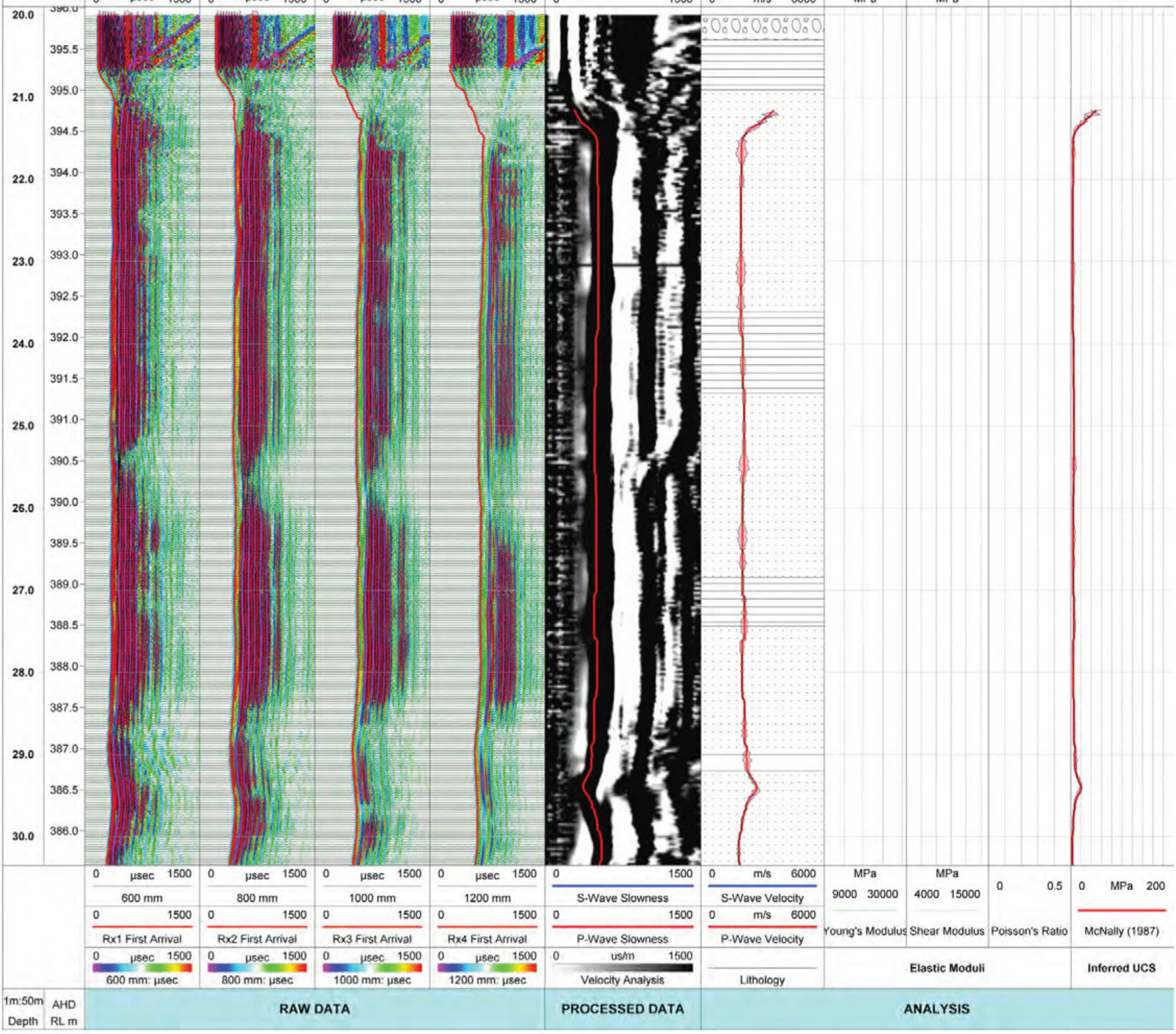
TOOL **QL40 FWS**



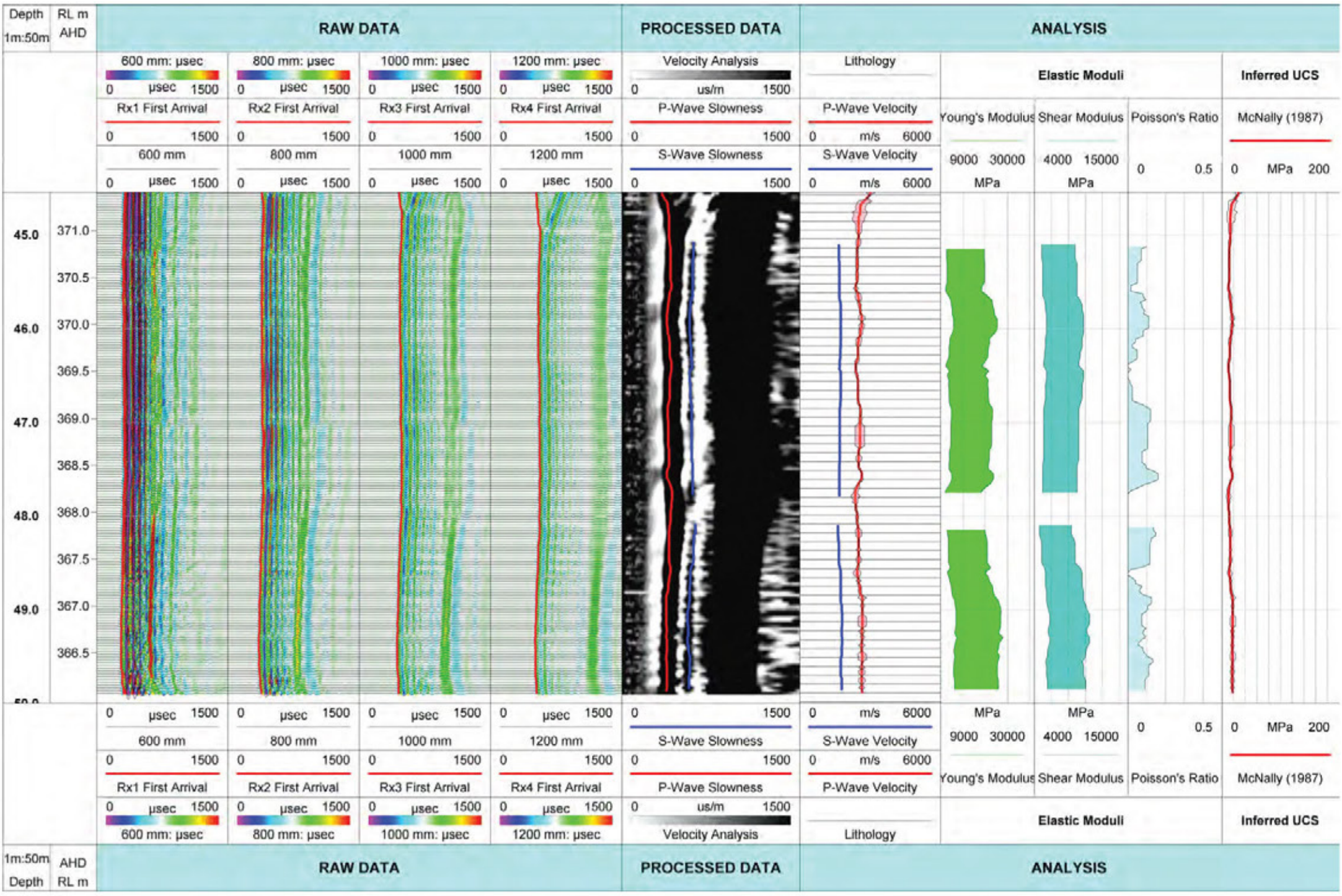
Boulders | Mudstone | Sandstone | Topsoil | Core Loss

NOTES-

1. The depth of penetration of the sonic data is 2.5 cm - 25 cm into the formation which, if adversely affected by localised drilling conditions, may result in misinterpretation of in-situ rock mass conditions.
2. It is possible that Stoneley waves may be misinterpreted as S waves, thus P to S-wave ratios were checked to ensure that S-waves were picked, and the S-wave is not shown if there was any uncertainty.
3. Site-specific correlation between P-wave velocity and UCS values should be developed by designers using regression analysis.
4. FWS results should be used to assess macro geotechnical zones within the rock mass, and not absolute values of strength or elasticity at specific points.



Depth 1m:50m	RL m AHD	RAW DATA				PROCESSED DATA	ANALYSIS				
		600 mm: µsec 0 µsec 1500	800 mm: µsec 0 µsec 1500	1000 mm: µsec 0 µsec 1500	1200 mm: µsec 0 µsec 1500	Velocity Analysis 0 us/m 1500	Lithology	Elastic Moduli			Inferred UCS
		Rx1 First Arrival 0 1500	Rx2 First Arrival 0 1500	Rx3 First Arrival 0 1500	Rx4 First Arrival 0 1500	P-Wave Slowness 0 1500	P-Wave Velocity 0 m/s 6000	Young's Modulus 9000 30000 MPa	Shear Modulus 4000 15000 MPa	Poisson's Ratio 0 0.5	McNally (1987) 0 MPa 200
		600 mm 0 µsec 1500	800 mm 0 µsec 1500	1000 mm 0 µsec 1500	1200 mm 0 µsec 1500	S-Wave Slowness 0 1500	S-Wave Velocity 0 m/s 6000				
31.0	385.5										
	385.0										
	384.5										
32.0	384.0										
	383.5										
33.0	383.0										
	382.5										
34.0	382.0										
	381.5										
35.0	381.0										
	380.5										
36.0	380.0										
	379.5										
37.0	379.0										
	378.5										
38.0	378.0										
	377.5										
39.0	377.0										
	376.5										
40.0	376.0										
	375.5										
41.0	375.0										
	374.5										
42.0	374.0										
	373.5										
43.0	373.0										
	372.5										
44.0	372.0										
	371.5										
		0 µsec 1500 600 mm	0 µsec 1500 800 mm	0 µsec 1500 1000 mm	0 µsec 1500 1200 mm	0 1500 S-Wave Slowness	0 m/s 6000 S-Wave Velocity	MPa 9000 30000 Young's Modulus	MPa 4000 15000 Shear Modulus	0 0.5 Poisson's Ratio	0 MPa 200 McNally (1987)
		0 1500 Rx1 First Arrival	0 1500 Rx2 First Arrival	0 1500 Rx3 First Arrival	0 1500 Rx4 First Arrival	0 1500 P-Wave Slowness	0 m/s 6000 P-Wave Velocity				
		0 µsec 1500 600 mm: µsec	0 µsec 1500 800 mm: µsec	0 µsec 1500 1000 mm: µsec	0 µsec 1500 1200 mm: µsec	0 us/m 1500 Velocity Analysis	Lithology	Elastic Moduli			Inferred UCS
1m:50m Depth	AHD RL m	RAW DATA				PROCESSED DATA	ANALYSIS				


Depth 1m:50m
RL m AHD
RAW DATA
PROCESSED DATA
ANALYSIS
600 mm: µsec
800 mm: µsec
1000 mm: µsec
1200 mm: µsec
0 µsec 1500
Velocity Analysis
0 us/m 1500
Lithology
Elastic Moduli
Inferred UCS
Rx1 First Arrival
Rx2 First Arrival
Rx3 First Arrival
Rx4 First Arrival
P-Wave Slowness
P-Wave Velocity
0 m/s 6000
Young's Modulus
Shear Modulus
Poisson's Ratio
McNally (1987)
600 mm
800 mm
1000 mm
1200 mm
S-Wave Slowness
S-Wave Velocity
9000 30000
MPa
4000 15000
0 0.5
0 MPa 200
45.0
46.0
47.0
48.0
49.0
371.0
370.5
370.0
369.5
369.0
368.5
368.0
367.5
367.0
366.5

Appendix H
Important information relating to this report

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT



The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder's Client and persons acting on the Client's behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification

APPENDIX

N

Groundwater Technical Report

Appendix B Registered bore holes predicted to be impacted (outside of the groundwater study area)

GOWRIE TO HELIDON ENVIRONMENTAL IMPACT STATEMENT

Appendix B

Registered bore holes predicted to be impacted (outside of the groundwater study area)

Registered bore ID	Status	Easting	Northing	Source aquifer
9514	AD	396237	6951762	MAIN RANGE VOLCANICS
11311	AD	397154	6954040	MAIN RANGE VOLCANICS
16977	EX	397742	6952981	MAIN RANGE VOLCANICS
17160	AU	395777	6954913	MAIN RANGE VOLCANICS
31318	AD	395672	6953042	MAIN RANGE VOLCANICS
43361	AD	395659	6953084	MAIN RANGE VOLCANICS
44027	EX	398114	6951656	MAIN RANGE VOLCANICS
52700	AD	396355	6952535	MAIN RANGE VOLCANICS
52708	EX	395860	6953308	MAIN RANGE VOLCANICS
52709	EX	394415	6952435	MAIN RANGE VOLCANICS
61008	EX	395267	6951814	MAIN RANGE VOLCANICS
64165	AD	396137	6951850	MAIN RANGE VOLCANICS
64806	EX	395843	6954909	MAIN RANGE VOLCANICS
66723	EX	395371	6952917	MAIN RANGE VOLCANICS
71480	EX	397511	6953924	MAIN RANGE VOLCANICS
83111	EX	394913	6953893	MAIN RANGE VOLCANICS
86581	EX	397158	6953655	MAIN RANGE VOLCANICS
87029	EX	395443	6952221	MAIN RANGE VOLCANICS
87031	EX	394669	6953253	MAIN RANGE VOLCANICS
87861	EX	395788	6954970	MAIN RANGE VOLCANICS
94026	EX	397765	6951805	MAIN RANGE VOLCANICS
94215	EX	394521	6953754	MAIN RANGE VOLCANICS
94694	EX	396982	6953892	MAIN RANGE VOLCANICS
107836	EX	394743	6951976	MAIN RANGE VOLCANICS
119521	EX	395704	6951954	MAIN RANGE VOLCANICS
119629	EX	397859	6953561	MAIN RANGE VOLCANICS
119631	EX	396877	6954396	MAIN RANGE VOLCANICS
119642	EX	394641	6954311	MAIN RANGE VOLCANICS
119649	EX	396507	6953423	MAIN RANGE VOLCANICS
119653	EX	395306	6953708	MAIN RANGE VOLCANICS
119654	EX	395253	6952863	MAIN RANGE VOLCANICS
119688	EX	397908	6954004	MAIN RANGE VOLCANICS
119728	EX	397009	6953257	MAIN RANGE VOLCANICS
119800	EX	394927	6952932	MAIN RANGE VOLCANICS
119916	EX	397935	6954065	MAIN RANGE VOLCANICS
119919	EX	397990	6954004	MAIN RANGE VOLCANICS

Registered bore ID	Status	Easting	Northing	Source aquifer
119922	EX	397824	6954188	MAIN RANGE VOLCANICS
137153	EX	397199	6953536	MAIN RANGE VOLCANICS
137174	EX	394411	6952002	MAIN RANGE VOLCANICS
137306	EX	398108	6953113	MAIN RANGE VOLCANICS
137501	EX	396597	6952808	MAIN RANGE VOLCANICS
137634	EX	396450	6954484	MAIN RANGE VOLCANICS
137691	EX	395140	6953672	MAIN RANGE VOLCANICS
137709	EX	397376	6951999	MAIN RANGE VOLCANICS
137889	EX	395687	6953269	MAIN RANGE VOLCANICS
137890	EX	395692	6953308	MAIN RANGE VOLCANICS
137892	EX	395674	6953305	MAIN RANGE VOLCANICS
137893	EX	395675	6953308	MAIN RANGE VOLCANICS
137894	EX	395692	6953339	MAIN RANGE VOLCANICS
137895	EX	395693	6953262	MAIN RANGE VOLCANICS
137896	EX	395692	6953277	MAIN RANGE VOLCANICS
137897	EX	395692	6953369	MAIN RANGE VOLCANICS
137898	EX	395684	6953363	MAIN RANGE VOLCANICS
137899	EX	395684	6953369	MAIN RANGE VOLCANICS
172383	EX	396799	6952148	MAIN RANGE VOLCANICS
172384	EX	396772	6952148	MAIN RANGE VOLCANICS
172385	EX	396772	6952148	MAIN RANGE VOLCANICS
172386	EX	396799	6952179	MAIN RANGE VOLCANICS
42231656	EX	394175	6953969	MAIN RANGE VOLCANICS
42231657	EX	394171	6953970	MAIN RANGE VOLCANICS
42231659	EX	395654	6953149	MAIN RANGE VOLCANICS
42231660	EX	395988	6954561	MAIN RANGE VOLCANICS
42231662	EX	395988	6954557	MAIN RANGE VOLCANICS
19295	EX	395288	6952833	NR
19683	EX	394737	6952483	NR
64164	AD	396327	6951994	NR
64201	AD	397439	6953849	NR
64202	EX	397056	6953841	NR
66230	AD	395788	6954970	NR
66231	AD	395788	6954878	NR
66232	AD	395788	6954878	NR
71387	AD	394656	6954580	NR
86894	AD	395543	6952066	NR
87591	PR	397111	6953464	NR
94273	EX	397760	6952002	NR
107153	EX	396437	6953384	NR
107154	EX	396388	6953386	NR
107155	EX	396416	6953337	NR

Registered bore ID	Status	Easting	Northing	Source aquifer
119927	EX	396216	6953869	NR
137864	EX	398027	6952866	NR
137865	EX	395192	6953940	NR
42231658	AD	395656	6953150	NR

Table notes:

EX - existing

AD - abandoned and destroyed

PR - propose

AU - abandoned but usable

NR - not reported

Data sourced from the groundwater database - Queensland via Qspatial (DNRME, 2020)