APPENDIX

N

Groundwater Technical Report

HELIDON TO CALVERT ENVIRONMENTAL IMPACT STATEMENT

IR_1381

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

Inland Rail Helidon to Calvert EIS

Appendix N – Groundwater Technical Report

Australian Rail Track Corporation

Reference: 3300

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Abbreviations

Abbreviation	Explanation
AoI	
ARD	Acid Rock Drainage
ARTC	Australian Rail Track Corporation
ASS	Acid Sulfate Soils
BoM	Bureau of Meteorology
C2K	Calvert to Kagaru
CEMP	Construction Environmental Management Plan
Ch	Chainage
CIA	Cumulative impact assessment
CIP	Cast-in-place
CRD	Cumulative rainfall departure
DAFF	Department of Agriculture, Fisheries and Forestry (now DAF)
DAF	Department of Agriculture and Fisheries
DAWE	Department of Agriculture, Water and the Environment
DoE	Department of the Environment (now DAWE)
DERM	Department of Environment and Resource Management (now DES)
DES	Department of Environment and Science
DNRME	Department of Natural Resources, Mines and Energy (now the Department of Regional development, Manufacturing and Water; and Department of Resources)
DRDMW	Department of Regional Development, Manufacturing and Water
DSDMIP	Department of State Development, Manufacturing, Infrastructure and Planning (now DSDILGP)
DSDILGP	Department of State Development, Infrastructure, Local Government and Planning
EIS	Environmental Impact Statement
EP Act	*Environmental Protection Act 1994* (Qld)
EPBC Act	*Environmental Protection and Biodiversity Conservation Act 1999* (Cth)
EPP (Water)	*Environmental Protection (Water) Policy 2009* (Qld)
EV	Environmental Value
FFJV	Future Freight Joint Venture
G2H	Gowrie to Helidon
GABORA	Great Artesian Basin and Other Regional Aquifers
GDE	groundwater dependent ecosystem
GMMP	Groundwater management and monitoring program
H2C	Helidon to Calvert
km	kilometre
m	metre
m AHD	metres above AHD (Australian Height Datum)
ML	megalitres
QLD	Queensland
SDPWO Act	*State Development and Public Works Organisation Act 1971* (Qld)

Abbreviation	Explanation
SEQ	South East Queensland
The Basin	Clarence-Moreton Basin
The Project	The Helidon to Calvert Inland Rail Project
TDS	Total Dissolved Solids
ToR	Terms of Reference
UQ	University of Queensland
Water Act	*Water Act 2000* (Qld)
WQO	Water quality objectives
QA/QC	Quality Assurance/Quality Control

Glossary

Term	Explanation
Acid sulfate soils (ASS)	Soils containing iron sulphides (Pyrite) which can produce sulphuric acids when disturbed (exposed to oxygen) through conversion of Pyrite.
Alignment	The proposed rail line of the Project
Catchment	Catchment at a particular point is the area of land that drains to that point
Chainage	A measure of distance along the rail corridor. The values are progressive from the start of each package (from Melbourne to Brisbane) with the terminus of each the alignment at the interface with the next package leading to Brisbane. For readability, chainage is noted in approximate kilometre throughout the document and in noted in metres for figures.
Cumulative impact area of influence	The area of the Project that incorporates other projects for assessment of cumulative impact. In matters relating to groundwater, cumulative impact area of influence is specifically in relation to intra-catchment interaction between identified strategic projects with the potential to be additive to current Project impacts.
Disturbance footprint	The Disturbance footprint is the disturbance footprint (both temporary and permanent) associated with the Project. The Disturbance footprint is the areas subject to direct disturbance.
Environmental Values (EVs)	The qualities of water that make it suitable for supporting aquatic ecosystems and human water uses
Megalitres (ML)	A unit of measure of fluid, indicating equivalence of 1,000,000 litres
Permanent operational disturbance footprint	The areas of the Project that will be permanently and directly impacted by the operation of the rail line and associated facilities.
pH units	The measurement of presence of Hydrogen ion concentration indicating from a range of 1-14, the degree of acidity or basicity, respectively
Project	The construction and operation of the Helidon to Calvert Project
Total Dissolved Solids (TDS)	The sum of all particulate material dissolved in water. Usually expressed in terms of milligrams per litre (mg/L). It can be measured by evaporating the solvent and measuring the mass of residues left or may be estimated from the electrical conductivity of the water.
Temporary construction disturbance footprint	The areas of the Project that will be directly impacted by the construction of the rail line, lay down areas, and other areas that will only be used during construction and will be rehabilitated prior to operation and will only be used temporarily.
Water Quality Objectives (WQOs)	Long-terms goals for water quality management. Generally, indicators of criteria for receiving waters to protect relevant EVs

1 Introduction

1.1 Project background

Future Freight Joint Venture (FFJV) was engaged by Australian Rail Track Corporation Ltd (ARTC) to undertake a groundwater study in support of an Environment Impact Statement (EIS) for the Helidon to Calvert (H2C) Project (the Project) – part of the Inland Rail Program (Inland Rail), 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 approximately 47 km single-track dual gauge railway with four crossing loops to accommodate double stack container freight trains up to 1,800 metres (m) long. It will also involve the construction of an approximately 850 m long tunnel through the Little Liverpool Range to facilitate the required gradient across the undulating topography. The corridor will be of sufficient width to accommodate future possible upgrades of the track, including a future possible requirement to accommodate trains up to 3,600 m in length. The Project is classed as both greenfield and brownfield development as approximately 50 per cent of the alignment runs parallel to the existing West Moreton System rail corridor.

This groundwater technical report includes:

- A description of relevant Project details
- An overview of existing environmental, geological and hydrogeological conditions
- An assessment of EVs
- 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, operation, and decommissioning 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 address the requirements of the final *Terms of Reference for an EIS: Inland Rail – Helidon to Calvert Project October 2017* (Department of State Development, Manufacturing, Infrastructure and Planning (DSDMIP) 2017(now Department of State Development, Infrastructure, Local Government and Planning)) refer Appendix A: Terms of Reference.

1.2 Project overview

The Project is located within the Lockyer Valley and Ipswich local government areas in South East Queensland (SEQ). The Project runs from Helidon to Calvert and its regional context as well as the EIS investigation corridor is shown in Figure 1.1.

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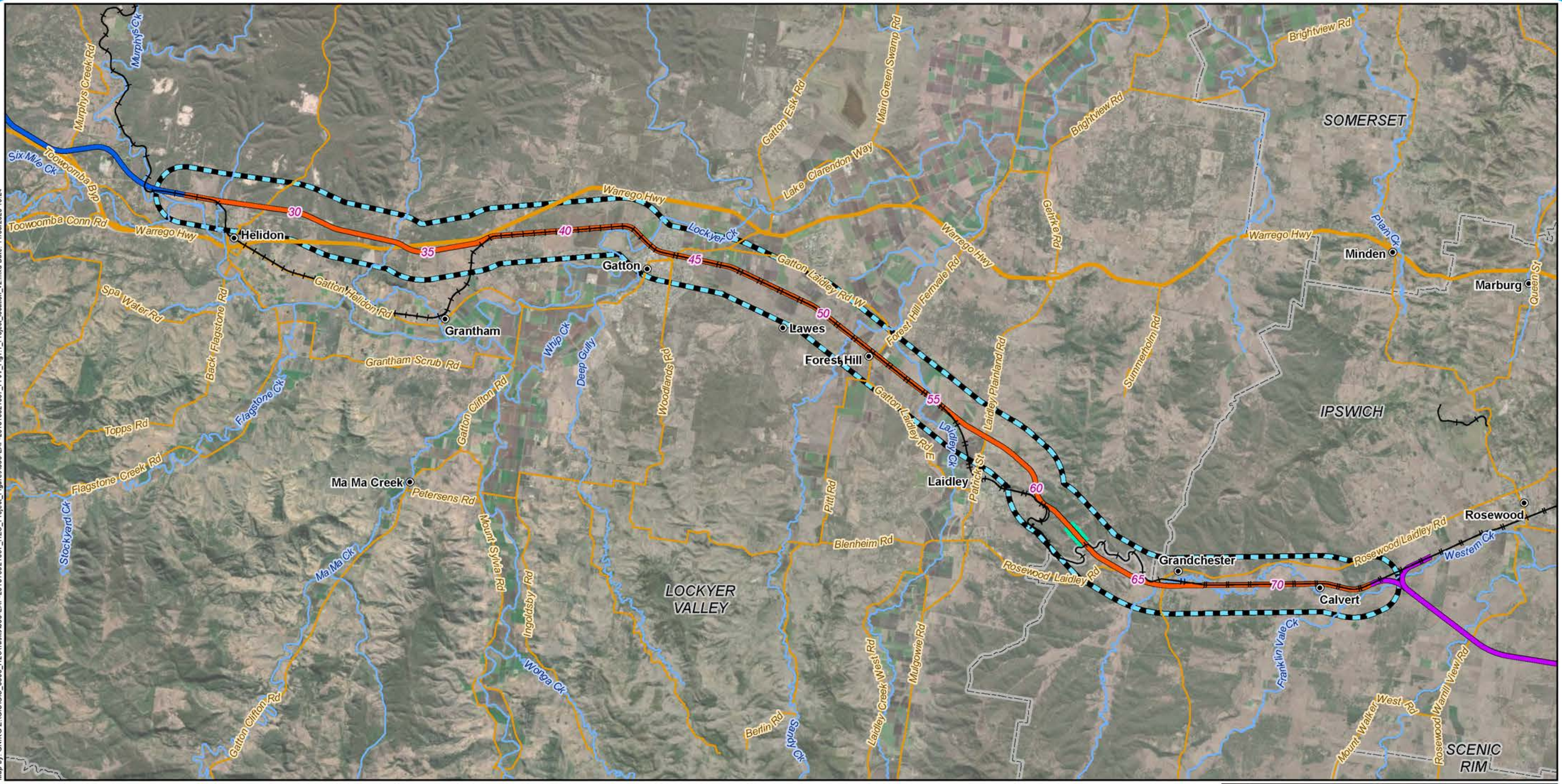

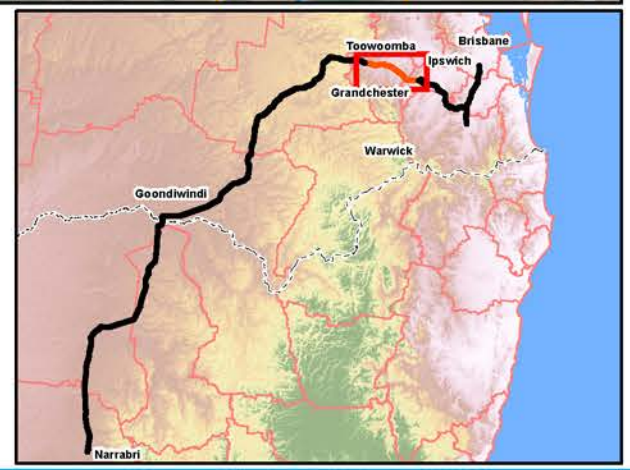

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- Tunnel
- Watercourses
- Major roads
- Minor roads
- G2H project alignment
- H2C project alignment
- C2K project alignment
- Groundwater study area
- Local Government Areas

A3 scale: 1:150,000

0 1 2 3 4 5km

Map by: GN/KG Z:\GIS\GIS_3300_H2C\Tasks\330-EAP-201810021057_H2C_Project_Figures\330-EAP-201810021057_FFJV_Fig1.1_Project_location_v2.mxd Date: 11/05/2020 15:24

Future Freight
Integrating Community, Environment and Engineering

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Coordinate System: GDA 1994 MGA Zone 56

Helidon to Calvert

Figure 1.1: Project location

Key components of the Project, as related to the groundwater assessment, include:

- 47 km of single-track dual gauge rail line with four crossing loops to accommodate 1,800 m long train sets
- The corridor identified for the Project will be 62.5 m wide and of sufficient width to allow for the assessment of the land provision for possible future upgrades to the track to accommodate trains up to 3,600 m in length and future duplication of the freight line to accommodate future possible passenger transport
- The approximately 850 m long tunnel through the Little Liverpool Range (Little Liverpool Tunnel), bridges and viaducts to accommodate topography and Project crossings of waterways, roads and other infrastructure
- Approximately 34 km of embankments (excluding structures) along the length of the alignment, spanning approximately 7.6 km.

The combination of cuttings, embankments, bridges and a tunnel along the proposed 47 km length of new dual-gauge rail line has the potential to affect groundwater levels due to seepage into cuttings and tunnel, and disturbance of shallow groundwater levels, flow and quality from placement of embankments. The construction and operational elements relevant to groundwater have been considered as part of this groundwater technical report.

1.3 Objectives and scope of report

The objective of this report is to support the EIS by addressing all groundwater related requirements of the Terms of Reference (ToR). This groundwater environmental impact assessment includes a description of the groundwater resources, an assessment of EVs, conceptualisation of the 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 construction activities considered relevant to groundwater (including cuttings, tunnel and embankments).

This technical report has been prepared in accordance with the groundwater-related ToR for an EIS: Inland Rail – Helidon to Calvert Project October 2017 (Department of State Development, Manufacturing, Infrastructure and Planning (DSDMIP) 2017 (now Department of State Development, Infrastructure, Local Government and Planning)). The ToR applicable to this technical report are outlined in Table 1.1.

Table 1.1 Terms of Reference requirements - groundwater

Terms of Reference requirements	Where addressed
Information requirements	
11.24. The EIS must also provide details on the current state of groundwater and surface water in the region as well as any use of these resources	Sections 4, 5, 6 and 7; and EIS Chapter 14: Groundwater, Section 14.6
Existing environment	
11.36. Identify the water-related environmental values and describe the existing surface water and ground water regime within the study area and the adjoining waterways in terms of water levels, discharges and freshwater flows	Sections 4, 5, 6 and 7; and EIS Chapter 14: Groundwater, Section 14.6
11.38. At an appropriate scale, detail the chemical, physical and biological characteristics of surface waters and groundwater within the area that may be affected by the Project. Include a description of the natural water quality variability within the study area associated with climatic and seasonal factors, and flows	Sections 4, 6 and 7; and EIS Chapter 14: Groundwater, Section 14.6.4
11.40. Undertake a landholder bore survey to identify the location and source aquifer of licensed groundwater extraction in areas potentially impacted by the Project (e.g. near tunnels and cuttings)	Section 6.4.1; and EIS Chapter 14: Groundwater, Section 14.6.6
Impact assessment	
11.41. The assessment of impacts on water will be in accordance with the DEHP Information guideline for an environmental impact statement – ToR Guideline – Water, where relevant, located on the DEHP website	Sections 3 and 13; and EIS Chapter 14: Groundwater, Sections 14.9 and 14.11

Terms of Reference requirements	Where addressed
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 2.2 and 11.1; and EIS Chapter 14: Groundwater, Sections 14.4, 14.7.4 and 14.9.2
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	Sections 8, 9, 10 and 11; and EIS Chapter 14: Groundwater, Section 14.7, 14.8 and 14.11; and Appendix W: Geotechnical Factual Report, Appendix A
11.55 Provide information on the proposed water usage by the project, including details about: (a) details of the estimated supply required to meet the demand for construction and full operation of the project, including timing of demands (b) details of 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 8, 9 and 10; and EIS Chapter 14: Groundwater, Section 14.8 and 14.9.2
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 the 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 and 6.4.2; and EIS Chapter 14: Groundwater, Section 14.4 and 14.6.2
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 6.4 and 11; and EIS Chapter 14: Groundwater, Sections 14.6.6 and 14.9
Mitigation measure	
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	Section 12.2; and EIS Chapter 14: Groundwater, Section 14.10.2
11.62. Describe measures to minimise impacts on surface water and ground water resources	Section 12; and EIS Chapter 14: Groundwater, Section 14.10
11.63. Provide a policy outline of compensation, mitigation and management measures where impacts are identified	Section 12; and EIS Chapter 14: Groundwater, Section 14.10

2 Legislation, policy, standards, and guidelines

This groundwater technical report has been prepared with consideration of key policies and legislation from the Commonwealth of Australia and the State of Queensland (QLD). 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* (Cth) (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 17 March 2017, the delegate of the Commonwealth Minister for the Environment determined the Inland Rail – Helidon to Calvert Project to be a 'controlled action' under the EPBC Act (reference number EPBC 2017/7883). The controlling provision is listed threatened species and ecological communities.

2.2 Queensland legislation

2.2.1 Water Act 2000

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

- Sustainable management of QLD's water resources by establishing a system for the planning, allocation and use of water
- Sustainable and secure water supply and demand management for the SEQ region and other designated regions
- Management of impacts on underground water caused by the exercise of underground water rights by the resource sector
- Effective operation of water authorities.

The Water Act covers water in a watercourse, lake or spring, underground water (or groundwater), overland flow water, or water that has been collected in a dam.

The Project involves works which may intersect shallow groundwater units and as such the provisions of the Water Act apply.

2.2.2 Water Regulation 2016

The Water Regulation 2016 (Qld) (Water Regulation) is subordinate legislation made under the Water Act and prescribes administrative and operational matters for the Water Act. Such matters governed by the Water Regulation with relevance to the Project 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* (Qld) (Planning Act) and prescribe the associated codes
- Provide requirements for the construction and modification of levees
- 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 water supply (potentially including groundwater), and as such provisions of the Water Regulation apply.

2.2.3 Environmental Protection Act 1994

The *Environmental Protection Act 1994* (Qld) (EP Act) aims to protect QLD's 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 identifies the environmental values (EVs) of QLD waterways, including groundwater located within the groundwater study area, which are protected under the EP Act and subordinate legislation. EVs, as defined by the EP Act, include:

- A quality or physical characteristic of the environment that is conducive to ecological health or public amenity or safety; or
- 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.

2.3 Policies, plans, and guidelines

2.3.1 Environmental Protection (Water and Wetland Biodiversity) Policy 2019

The Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (Qld) (EPP (Water and Wetland Biodiversity)) is subordinate legislation under the EP Act. The objective of the EPP (Water and Wetland Biodiversity) is achieved by the:

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

EVs relevant to the Project are presented in Section 7.

2.3.2 Water Plans

Water Plans have been developed under the Water Act to sustainably manage and allocate water resources in QLD. The *Water Plan (Moreton) 2007* and *Water Plan (Great Artesian Basin and Other Regional Aquifers) (GABORA) 2017* are relevant to the Project.

The purpose of the Water Plans is to:

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

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

This plan applies to the following groundwater units of the groundwater study area:

- Hutton Sandstone groundwater unit:
  - Marburg Subgroup
  - Gatton Sandstone
  - Koukandowie Formation
  - Helidon Sandstone
- Springbok Walloon groundwater unit:
  - Walloon Coal Measures
- Precipice groundwater unit:
  - Woogaroo Subgroup.

2.3.2.2 Water Plan (Moreton) 2007

This plan is applicable to groundwater other than those to which the Water Plan (GABORA) 2017 detailed above.

The western portion of the Project (Helidon to Laidley) is located within the Lockyer Valley Groundwater Management Area and the eastern portion (Laidley to Calvert) is in the Warrill-Bremer Alluvial Groundwater Management Area (shown in Figure 2.1). The Lockyer Valley Groundwater Management Area is applicable to alluvial and hard rock aquifers within the Lockyer Creek sub-catchment and the Warrill-Bremer Alluvial Groundwater Management Area is applicable to alluvial sediments within the Bremer River sub-catchment, to ensure management of groundwater from the alluvial in this area.

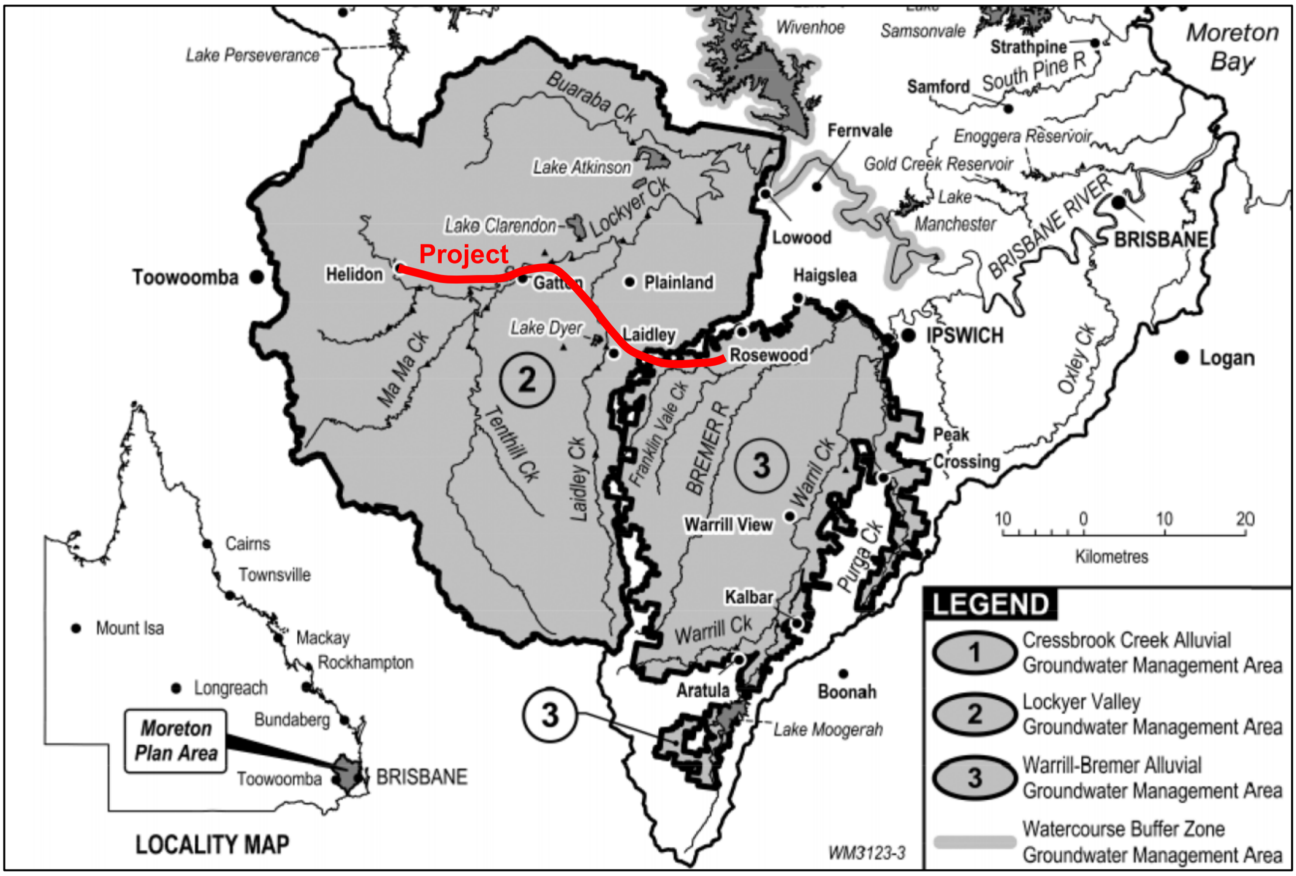


Figure 2.1 **Water Plan (Moreton) 2007**

This plan provides a framework for water entitlements/allocations to be managed under resource operations licence for the Lockyer Valley and Warrill Valley water supply scheme, states the process for granting or amending interim resource operation licences, and interim water allocations for the construction of infrastructure to which the interim resource operation licences related.

The alluvial aquifers of the groundwater study area and consideration for construction water supply options are governed under this plan.

Groundwater within the Lockyer Valley and Warrill Valley water supply schemes are considered medium priority in the Water Plan (defined in Subdivision 2 of the Water Plan). The water supply scheme is then divided into groundwater zones (refer Figure 2.2), which defines the allowable volume available for trading (Part 3 of the Water Plan). The maximum allowable volume to be taken in each groundwater trading zone is 9,532 ML (Table 2 of Division 1 in the Water Plan).

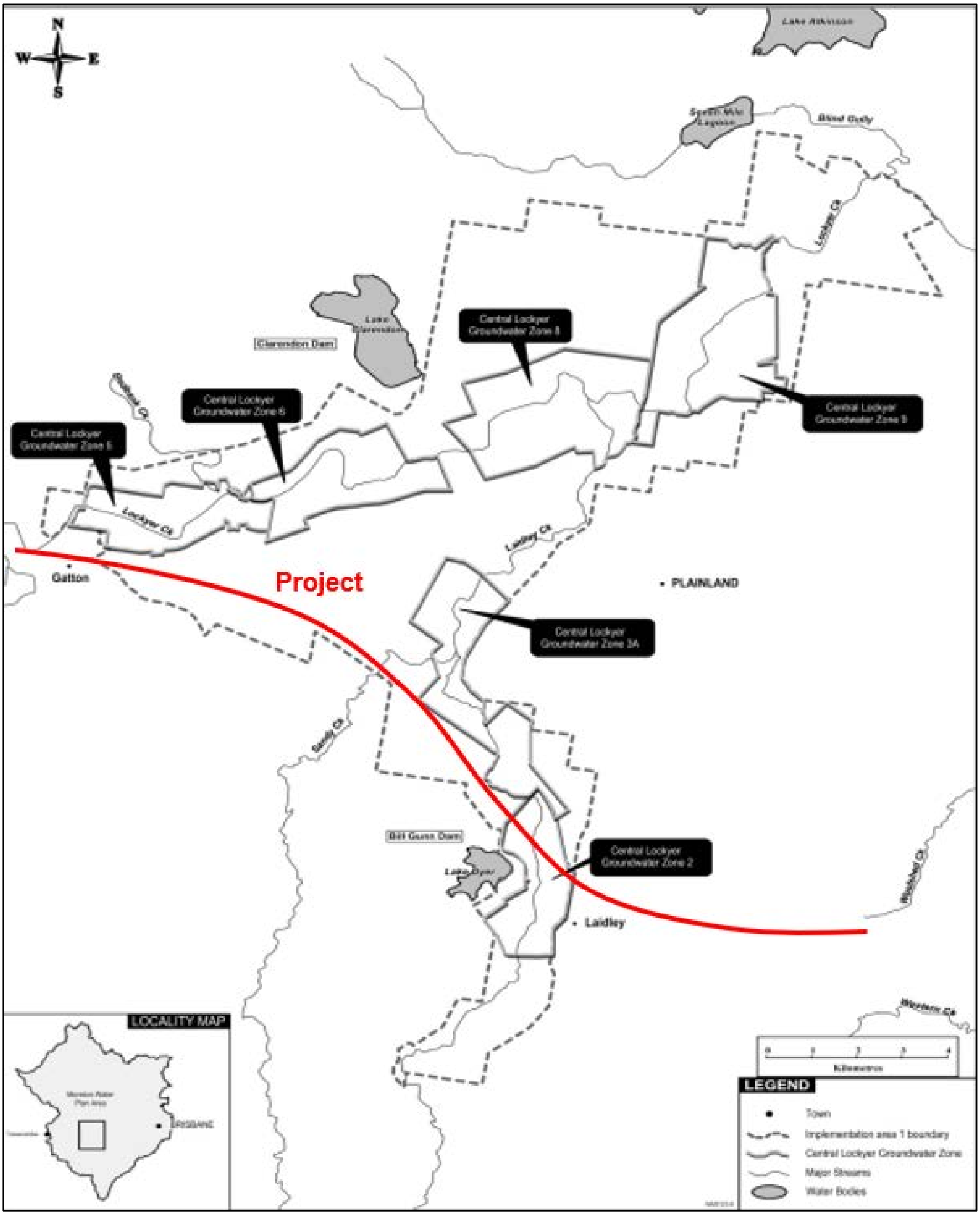


Figure 2.2 Groundwater management zones

3 Methodology

3.1 Groundwater study area

In this groundwater technical report, the EIS investigation corridor (herein referred to as the groundwater study area) is defined as the area within a 1 km of the centre line of the Project alignment. The groundwater study area is illustrated in Figure 1.1.

The groundwater study area includes all activities associated with the Project that have the potential to directly or indirectly affect groundwater resources and was used to identify groundwater users (including registered bores and potential groundwater dependent ecosystems (GDEs).

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 EIS submission
- 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 groundwater assessment of Helidon to Calvert

Data	Source
Hydrology/climate	Historical Climate Database - Bureau of Meteorology (BoM) (http://www.bom.gov.au/climate/data/) Inland Rail Section 330 – Helidon to Calvert Preliminary Hydrogeological Interpretive Report (Golder, March 2020) – provided as Appendix A to this groundwater technical report. Inland Rail: Phase 2 – Helidon to Calvert Geotechnical Factual Report (Golder, January 2019) – refer to EIS Appendix W: Geotechnical factual report. QLD Globe datasets (https://qldglobe.information.qld.gov.au/)
Soil types	Inland Rail Section 330 – Helidon to Calvert Preliminary Hydrogeological Interpretive Report (Golder, March 2020) – provided as Appendix A to this groundwater technical report.

Data	Source
Geology/ Hydrostratigraphy	Inland Rail Section 330 – Helidon to Calvert Preliminary Hydrogeological Interpretive Report (Golder, March 2020) – provided as Appendix A to this groundwater technical report. Department of Natural Resources, Mines and Energy (DNRME) (now Department of Regional Development, Manufacturing and Water) groundwater database (accessed 5 March 2019) Inland Rail: Phase 2 – Helidon to Calvert Geotechnical Factual Report (Golder, January 2019) – refer to EIS Appendix W: Geotechnical factual report. QLD Globe datasets (https://qldglobe.information.qld.gov.au/)
Groundwater levels and quality	DNRME groundwater database (accessed 5 March 2019) Inland Rail Section 330 – Helidon to Calvert Preliminary Hydrogeological Interpretive Report (Golder, March 2020) – provided as Appendix A. Clarence-Moreton Bioregional Assessment [Australian Government Department of Environment (DoE) now Department of Agriculture, Water and the Environment (DAWE)] (Rassam et al, 2014 & Raiber et al, 2016 & 2017) (https://www.bioregionalassessments.gov.au/assessments/clarence-moreton-bioregion) Inland Rail: Phase 2 – Helidon to Calvert Geotechnical Factual Report (Golder, Jan 2019) QLD Globe datasets (https://qldglobe.information.qld.gov.au/)
Groundwater Dependent Ecosystems (GDEs)	BoM: GDE Groundwater Dependent Ecosystem Atlas: http://www.bom.gov.au/water/groundwater/gde/map.shtml Clarence-Moreton Bioregional Assessment (May 2014) (https://www.bioregionalassessments.gov.au/assessments/clarence-moreton-bioregion) QLD Globe datasets (https://qldglobe.information.qld.gov.au/)
Groundwater use and management	DNRME groundwater database (accessed 5 March 2019) DNRME (now Department of Regional Development, Manufacturing and Water) groundwater entitlements database (accessed 21 February 2020) Bureau of Meteorology National Groundwater Information System http://www.bom.gov.au/water/groundwater/ngis/ Clarence-Moreton Bioregional Assessment (May 2014) Water Plan (GABORA) 2017 Water Plan (Moreton) 2007.

3.2.2 Stage 2 – Geotechnical and hydrogeological site investigations

Geotechnical and hydrogeological site investigations along the Project alignment were undertaken by Golder Associates Pty Ltd between July and December 2018 (refer EIS Appendix W: Geotechnical factual report).

Field investigations included:

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

Findings from these investigations are summarised below and compliment the desktop geological and hydrogeological reviews presented in Section 5 and Section 6.

3.2.2.1 Groundwater monitoring bore installation

The drilling and installation of 13 groundwater monitoring bores was conducted in accordance with the Minimum Construction Requirements for Water Bores in Australia (National Water Commission 2012).

All groundwater monitoring bores were equipped with 50 millimetre (mm) diameter class 18 PVC thread 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. 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.

Twelve of the completed groundwater monitoring bores were flushed after installation to remove drilling fluids, and developed using manual bailing and/or pumping techniques, as appropriate. Bores 330-1-BH2227 and 330-1-BH2306 were not developed at the time of the hydrogeological and geotechnical reports (Golder 2019, 2020) due to lack of access.

3.2.2.2 Groundwater level monitoring

A dedicated automatic pressure transducer was installed in 12 monitoring bores for continuous groundwater level monitoring over a 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.

3.2.2.3 Aquifer testing

In situ hydraulic testing using the slug test method was conducted in nine of the completed monitoring bores. Bores 330-1-BH2227 and 330-1-BH2306 were not developed at the time of the hydrogeological and geotechnical reports (Golder 2019, 2020) due to lack of access. 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. Open hole falling head tests at three depths (using packer isolated test intervals) were also carried out in BH330-1-BH2101) prior to standpipe installation

3.2.2.4 Groundwater sampling and laboratory analysis

Groundwater sampling was conducted at the accessible monitoring bores for collection of baseline water quality, durability, and salinity parameters. A total of eight samples were collected, with bores 330-1-BH2227 and 330-1-BH2306 not accessible, and bores 330-1-BH2203, 330-1-BH2301 and 330-1-DH2503 either dry or becoming dry during purging.

Groundwater sampling involved:

- Manual measurement of groundwater levels of each monitoring bore
- Purging of monitoring bores prior to sampling. As part of the purging, a minimum of three bore volumes were removed from each bore and field physicochemical measurements (pH, Electrical conductivity (EC), redox, dissolved oxygen and temperature) were collected during purging to ensure parameters have stabilised.
- Sampling of groundwater for laboratory analysis. Duplicate and triplicate samples were collected to meet adopted Quality Assurance/Quality Control (QA/QC) requirements. Field physicochemical measurements were collected at the time of sampling.
- All samples were collected in appropriate sampling containers for the required analytical parameters, chilled and dispatched under chain of custody documentation to a National Association of Testing Authorities (NATA)-accredited laboratory for analysis.

The analysed chemical parameters for each sample were as follows:

- Major anions and cations (Ca, Mg, Na, K, Cl, F, SO_4, Carbonate and Bicarbonate Alkalinity, Hardness)
- pH
- Conductivity
- Total dissolved solids
- Total and dissolved metals (As, B, Ba, Be, Cd, Cr, Co, Cu, Mn, Fe, Ni, Pb, Se, V, Zn, Hg)
- Nutrients (Nitrate, Nitrite, Ammonia, Reactive Phosphorus, Total Nitrogen, Total Kjeldahl Nitrogen (TKN) Total Phosphorus)
- Sodium Adsorption Ratio.

3.2.3 Stage 3 – Groundwater impact assessment

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 3.3) based on review of construction and rail operations with respect to the current geological and hydrogeological setting.

Geotechnical predictive modelling has been carried out and was used to inform the assessment of potential impacts on groundwater resources because of the construction and operation of the Little Liverpool Tunnel. Preliminary analysis of potential groundwater inflows to cuts along the Project alignment has been carried out and reported as part of the preliminary hydrogeological interpretative assessment. These assessments are provided in EIS Appendix W: Geotechnical factual report.

3.2.4 Stage 4 – Significance assessment

A qualitative significance assessment was undertaken which considers the sensitivity (or vulnerability) of an environmental value 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.

Evaluation of significance classifications, with and without mitigation measures, was then performed. The results were considered to inform a Groundwater Management and Monitoring Plan (to be a sub-plan to the Construction Environmental Management Plan (CEMP), that will be required for ongoing assessment of potential impacts on groundwater (refer Section 12.3).

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, a 'significant impact' 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 EV 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 five 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 11; the impact assessment performed for the Project on groundwater resources is presented in Section 13.

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 EV. 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 EV. 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	Days to months (e.g. 1 to 2 seasons; 3 to 6 months)
Short term	Up to 1 year (i.e. 6 to 12 months)
Medium term	From 2 to 10 years[1]
Long-term/long-lasting	From 11 to 20 years[2]
Permanent or irreversible	More than 21 years[3]

Table notes:

1 Derived from the term 'moderate' EAM Risk Management Framework 2009 (Great Barrier Reef Marine Park Authority 2009)
2 Derived from the term 'major' EAM Risk Management Framework 2009 (Great Barrier Reef Marine Park Authority 2009)
3 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 EV 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 EV is listed on a recognised or statutory state, national or international register as being of conservation significance and/or ▪ The EV is entirely intact and wholly retains its intrinsic value and/or ▪ The EV 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 EV. ▪ Project activities would have an adverse effect on the value.
High	▪ The EV is listed on a recognised or statutory state, national or international register as being of conservation significance and/or ▪ The EV is intact and retains its intrinsic value and/or ▪ The EV 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 EV 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 EV is recorded as being important at a regional level, and may have been nominated for listing on recognised or statutory registers and/or ▪ The EV 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 EV 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 EV 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 EV and/or ▪ The abundance and wide distribution of the EV ensures replacement of unavoidable losses is achievable.
Negligible	▪ The EV 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 EV.

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 EV 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 EV. 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 EV 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 EV ensures it is adequately represented in the region, and that replacement, if required, is achievable.
Low	Occurs where an EV 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 EVs. 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 11. Section 12 includes mitigation measures for the identified potential impacts and Section 13 presents the significance impact assessment (refer Table 13.1).

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 H2C EIS document details the CIA undertaken for groundwater; and a summary of the methodology is presented below.

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

a) Are currently being assessed under Part 1 of the Chapter 3 of the EP Act and, as a minimum, have an IAS available on the DES website

b) Have been declared a 'coordinated project' by the Coordinator-General under the *State Development and Public Works Organisation Act 1971* (Qld) (SDPWO Act) and an EIS is currently being prepared or is complete, or an initial advice statement is available on the DSDMIP website

c) May use resources located within the region (including materials, groundwater, road networks or workforces) that are the same as those to be used by Inland Rail

d) Could potentially compound residual impacts that Inland Rail 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 Inland Rail
    - 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:
    - Gowrie to Helidon Project (G2H)
    - Calvert to Kagaru Project (C2K)
- Identification and mapping of the assessable projects and the Areas of Influence (AoI) of the aspect (e.g. groundwater) to be considered:
  - Current operational projects and commercial or agricultural operations that are within the AoI 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 13.3)
- 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 located within the Ipswich and Lockyer Valley local government areas in SEQ. The Project is the third most-northern package of Inland Rail. The location of the Project and its regional context is shown in Figure 1.1.

The preferred alignment is generally consistent with the alignment of the Gowrie to Grandchester future public passenger transport corridor protected under the *Transport Planning and Coordination Act 1994* (Qld) with a deviation at Helidon.

The preferred alignment commences at Helidon deviating from the existing West Moreton System rail corridor along Airforce Road, and continues south-east crossing the Warrego Highway, then continuing east between the highway and the existing rail corridor until it runs immediately parallel with the existing rail corridor slightly North of Placid Hills.

The new track continues parallel to the north of the existing rail corridor, through Gatton and the northern side of the existing Gatton rail station, through Forest Hill and then deviates from the existing rail corridor in a southeast direction just north of Laidley township across Laidley Plainlands Road. The preferred alignment then continues and once again briefly runs parallel to the existing rail corridor before reaching a new 850 m tunnel section through the Little Liverpool Range.

After exiting the eastern tunnel portal at the Little Liverpool Range, the Project crosses under the existing Queensland Rail rail line, and over the Rosewood Laidley Road bypassing the existing Grandchester Station to the south, running parallel to the existing rail corridor, and then connecting into the C2K Inland Rail project west of Calvert. The Project at Calvert will connect to the Queensland Rail West Moreton System rail corridor.

4.2 Land use

Land use within the preferred alignment is predominantly rural and rural residential interspersed between the townships of Helidon, Gatton, Forest Hill, Laidley, Grandchester and Calvert, and includes significant transport infrastructure of the Warrego Highway and West Moreton System rail corridor. Approximately 24 km of the proposed rail corridor runs parallel with the existing West Moreton System rail corridor.

The intended land use for the Project is rail and associated infrastructure, including road realignments, grade separations and ancillary infrastructure.

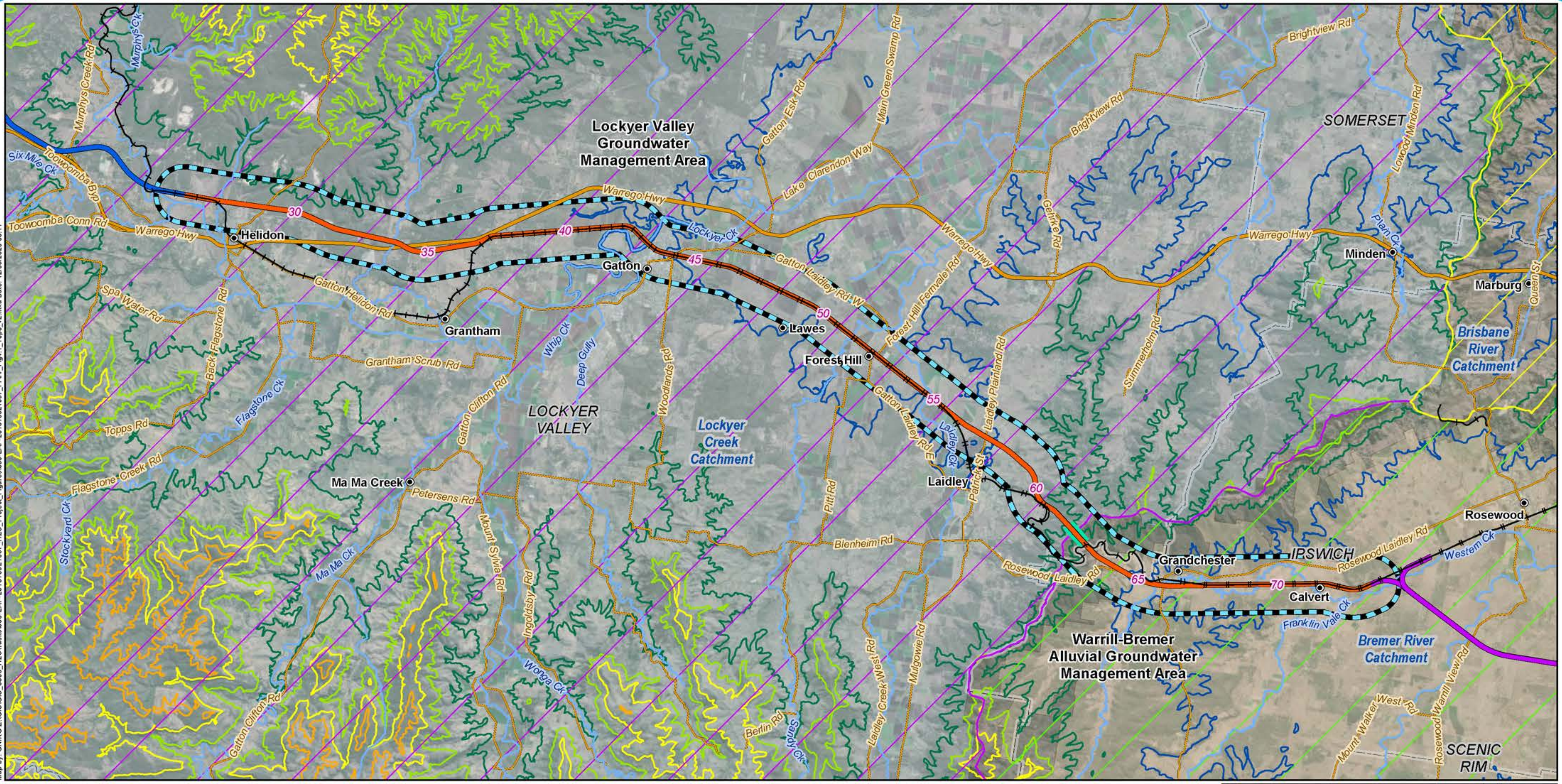
Land use is predominantly rural and rural residential interspersed between the townships of Helidon, Gatton, Forest Hill, Laidley, Grandchester and Calvert, and includes significant transport infrastructure of the Warrego Highway and West Moreton System rail corridor. Approximately 50 per cent of the proposed rail corridor runs parallel to the existing West Moreton System rail corridor.

4.3 Topography and drainage

In the western portion of the Project, between Helidon and Gatton, the alignment crosses the southern edge of the Helidon Hills. The topography is moderately undulating as it runs generally parallel to, and north of, the Lockyer Creek with the alignment crossing ridges, river terraces and flood plains. The Project alignment then traverses the broad alluvial plains of the Lockyer Valley, crossing the Lockyer Creek at Gatton and continuing south-eastwards across alluvial plains to Laidley. Between Laidley and Grandchester, the alignment rises into the relatively high topography of the Little Liverpool Range, before it descends into the adjacent Western Creek catchment and its alluvial plains, as far as the eastern extent of the Project that lies approximately 2 km east of Calvert (refer Figure 4.1).

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

Map by: GN/KG Z:\GIS\GIS_3300_H2C\Tasks\330-EAP-201810021057_H2C_Project_Figures\330-EAP-201810021057_FFJV_Fig4_1_Topo_v2.mxd Date: 12/05/2020 08:11



Legend

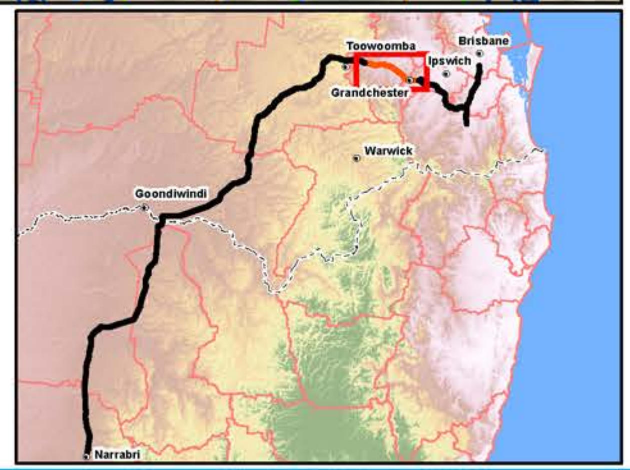
- 5 Chainage (km)
- Localities
- Tunnel
- Existing rail
- G2H project alignment
- H2C project alignment
- C2K project alignment
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area
- Warrill-Bremer Alluvial Groundwater Management Area

Catchment

- Bremer River
- Brisbane River
- Lockyer Creek

Elevation, m AHD

- 100
- 200
- 300
- 400
- 500



A3 scale: 1:150,000

0 1 2 3 4 5km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 12/05/2020 Version: 2

Coordinate System: GDA 1994 MGA Zone 56

Helidon to Calvert

Figure 4.1: Topography and surface water features

The western part of the Project is drained by the Lockyer Creek and its tributaries. The Lockyer Creek drains in an easterly direction joining the Brisbane River just downstream from Wivenhoe Dam.

Western Creek on the eastern side of the Little Liverpool Range is part of the larger Bremer River catchment that joins the Brisbane River at Dinmore.

The creeks within the groundwater study area are typically deeply incised in their upper reaches, and there are extensive terrace deposits on their margins.

The lower reaches (Lockyer Creek east from Grantham, and Western Creek east of Grandchester) have more developed meandering bends but remain relatively deeply incised into flat 'overbank deposited' alluvial plains (Golder 2019, refer EIS Appendix W: Geotechnical factual report).

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 30°C in summer to 20°C in winter.

The University of Queensland (UQ) Gatton BoM (040082) weather station is approximately 6 km northeast of Gatton and has long-term statistical climate data. A summary of climate data is provided in Table 4.1.

Table 4.1 Climate summary for University of Gatton for the period 1897 to 2018

Month	Mean maximum temperature[1] (ºC)	Mean minimum temperature[1] (ºC)	Mean monthly rainfall[2] (mm)
January	31.6	19.1	111.1
February	30.8	19.0	100.2
March	29.6	17.3	79.3
April	27.2	13.7	48.6
May	23.8	10.2	45.4
June	21.1	7.6	41.7
July	20.8	6.2	36.4
August	22.5	6.7	26.7
September	25.6	9.5	34.8
October	28.2	13.2	65.0
November	30.2	16.0	79.0
December	31.3	18.1	99.7
Annual mean total	-	-	**772.4**

Table notes:

University of Gatton - Bureau of Meteorology Station 040082
1 Record from 1913 to 2018
2 Record from 1897 to 2018

The UQ Gatton BoM (040082) weather station has records for daily pan evaporation data from 1968 to 2002 and mean monthly rainfall data from 1897 to present. Average monthly evaporation (estimated from mean daily values) is compared to mean monthly rainfall data in Figure 4.2 and shows that pan evaporation exceeds rainfall for each month of the year.

An overall negative climate budget generally prevails in the region, with a mean annual rainfall of 772 mm per year compared to a mean annual pan evaporation of 1,753 mm at UQ Gatton BoM (040082).

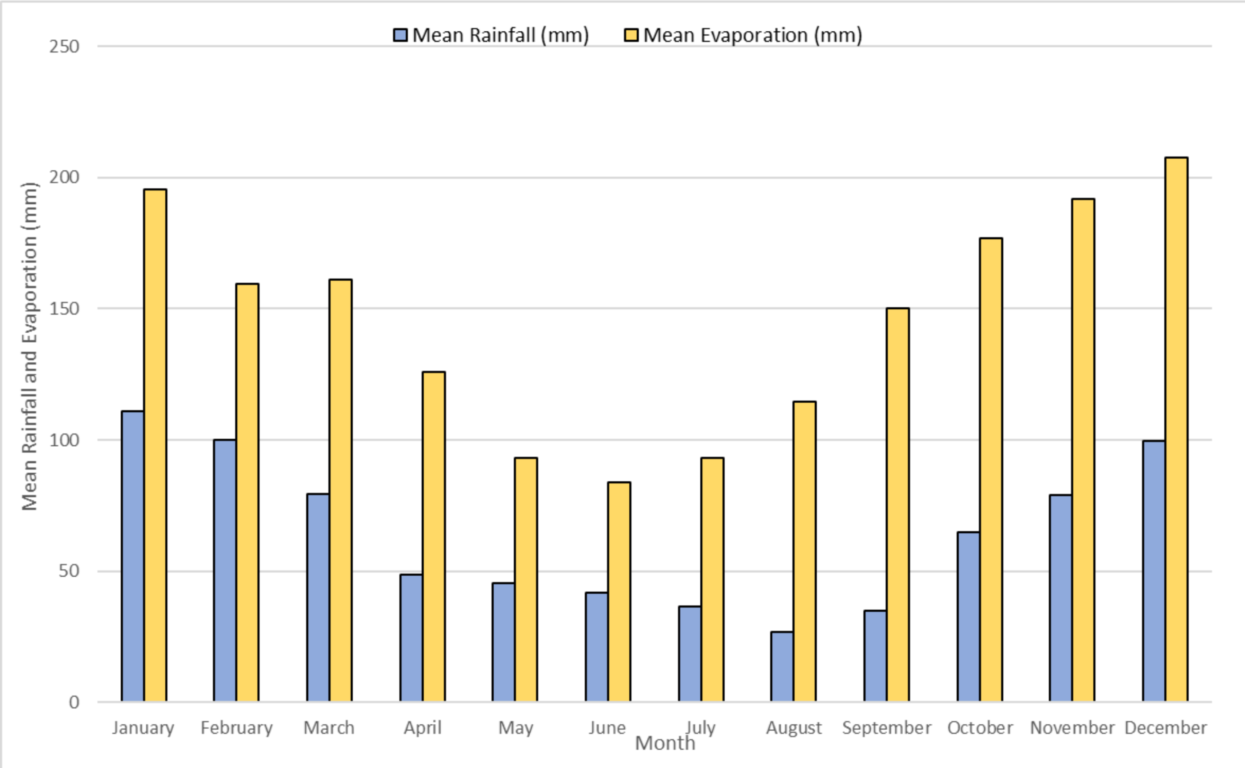


Figure 4.2 **Mean monthly pan evaporation and rainfall at University of Queensland Gatton Bureau of Meteorology station (040082)**

4.4.2 Cumulative Rainfall Departure

The Cumulative Rainfall Departure (CRD) method (Weber and Stewart 2004) evaluates 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 could be expected to reflect trends in the CRD.

Annual rainfall records were used to calculate rainfall residuals and the CRD, for the UQ Gatton BoM station (refer Figure 4.3). It should be noted that rainfall data for three data points from January 2002, January 2011 and June 2016 were used from the Gatton Department of Agriculture and Fisheries (DAF) (formerly Department of Agriculture, Fisheries and Forestry (DAFF)) Research station to address data gaps for missing monthly rainfall data from the UQ Gatton station for the CRD analysis (Golder 2020, refer Appendix A).

The CRD underwent multiple cycles, generally increasing from 1922 to 1976 and then generally decreased until 2007 with several wetter than average periods during this time. Negative CRD was experienced between 1998 until 2008 resulting in drought conditions. From 2008, the CRD graph shows a positive trend until 2014 (Golder 2020, refer Appendix A). These clear trends at observed at Gatton are likely along the entire Project alignment.

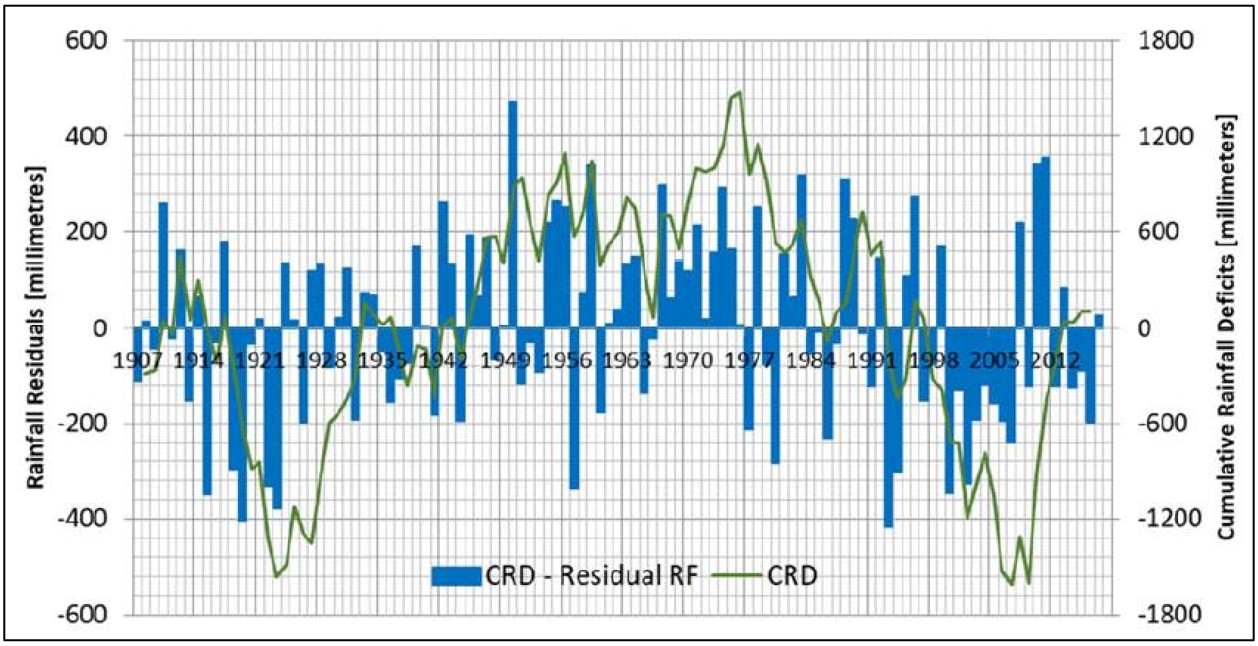


Figure 4.3 **Cumulative Rainfall Departure for University of Queensland Gatton Bureau of Meteorology Station (0400082)**

Source: Golder 2020, refer Appendix A

5 Geology

5.1 Regional geology

The groundwater study area is underlain by the geologic Clarence-Moreton Basin (the Basin), an elongated intracratonic sag basin overlying the middle- to upper-Palaeozoic rocks of the New England Orogen. It comprises three sub-basins: Cecil Plains sub-basin, Laidley sub-basin and Logan sub-basin.

Understanding of the tectonic setting and structural elements in the Basin 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. 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 5.1 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 Clarence-Moreton Basin 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 Clarence - Moreton Basin covers approximately 43,000 square kilometres ($km^{2)}$ 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 is present across some parts of the Basin, as well as Quaternary age alluvial deposits associated with the various water courses that flow through the groundwater study area.

A summary of the Basin stratigraphy (and overlying cover) is provided as Table 5.1, from youngest to oldest, with units relevant to the groundwater study area circled.

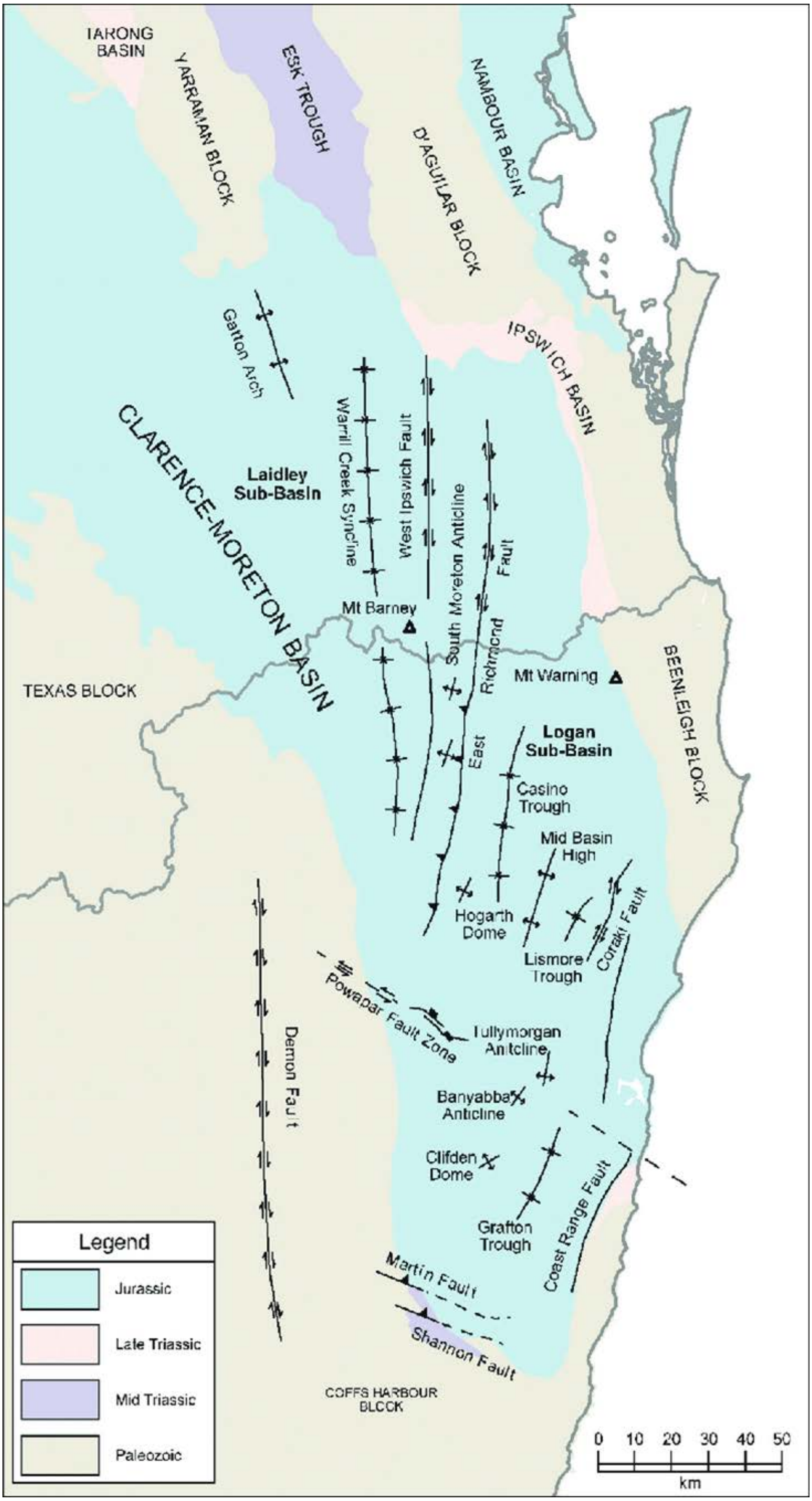


Figure 5.1 Clarence-Moreton Basin and key structural features

Source: Doig, A & Stanmore, Peter (2012)

Table 5.1 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	Main Range Volcanics/ Lamington Volcanics		Aquifer (unconfined)
Jurassic	Early Cretaceous	Grafton Formation	Rapville Member		Aquicludes?
			Piora Member		Aquifer/Aquitard
	Late Jurassic	Orara Formation (Kangaroo Creek Sandstone)	Bungawalbin Member	Fluvial to low-energy overbank	Aquicludes?
			Kangaroo Creek Sst Member	Fluvial channel	Aquifer/Aquitard
	Middle Jurassic	Walloon Coal Measures	Maclean Sandstone Member	Sinuous meandering streams and backswamps	Aquifer/Aquitard
		Koukandowie Formation	Heifer Creek Sandstone Member	Sandy bedload channels	Low permeability aquifer/aquitard
			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	
		Woogaroo Subgroup	Ripley Road Sandstone	Point bars and channel fills	Good aquifer
Triassic	Late Triassic		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

5.2 Local geology

Most of the groundwater study area lies in floodplains between the base of the Toowoomba Range in the west (near Helidon) and the Little Liverpool Range in the east (near Calvert).

The western part of the groundwater study area is typically underlain by Woogaroo Subgroup sediments that crop out to form the higher relief along this section of the Project alignment (Helidon Hills). In the central portion of the groundwater study area the Gatton Sandstone is overlain by alluvial sediments associated with watercourses including Lockyer Creek and Laidley Creek. The eastern part of the alignment is underlain by the Koukandowie Formation which forms the highest relief in the groundwater study area (at approximately 250 m AHD (metres above Australian Height Datum)) - where it crops out to form the Little Liverpool Range. On the eastern flanks of the range, alluvial sediments associated with Western Creek overlay the Koukandowie Formation from approximately Chainage (Ch) 64.00 km to Ch 72.00 km (i.e. kilometre point chainage along the Project alignment) and overlay the Walloon Coal Measures for approximately the final kilometre of the alignment.

The units cropping out and sub-cropping within the groundwater study area are described below, from oldest to youngest (based on Rassam et al 2014 and Golder 2020, refer Appendix A), and surficial geology is depicted on Figure 5.2.

5.2.1 Woogaroo Subgroup

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 (Golder 2020, refer Appendix A). These sedimentary rocks originated from terrestrial stream and overbank flood wetland (back swamp) deposition that created a series of coarse-grained rising through to fine-grained rocks (sandstones and mudstones) potentially incorporating organic materials that are preserved as wispy coal.

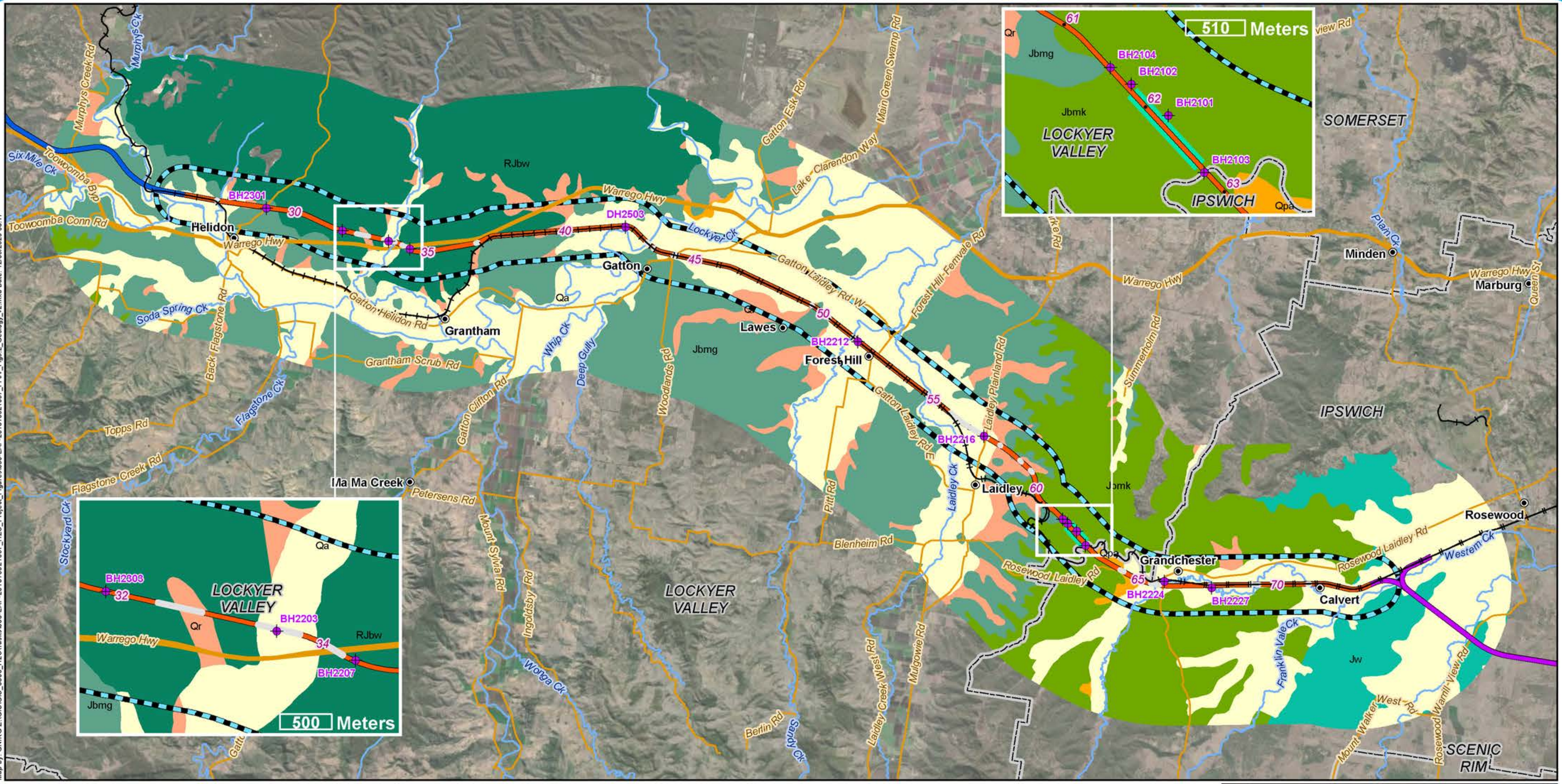
The Woogaroo Subgroup that forms the lower part of the Bundamba Group has a thickness of 1,000 to 1,200 m. The upper unit (the Ripley Road Sandstone) is equivalent to a facies variant within the Woogaroo Subgroup (formerly referred to as the Helidon Sandstone). The unit outcrops in the western parts of the alignment, forming the Helidon Hills, underlie approximately 11 per cent of the Project alignment; including sections of deep cuttings.

The Ripley Road Sandstone comprises a coarse-grained and predominantly clean quartz rich sandstone as well as quartz rich granule conglomerate and is considered the equivalent to the Precipice Sandstone of the Surat Basin (west of the Toowoomba Ranges).

5.2.2 Gatton Sandstone (Marburg Subgroup)

The Early Jurassic Gatton Sandstone is the basal unit of the Marburg Subgroup. It underlies the Koukandowie Formation and rests conformably on the Triassic to Jurassic Woogaroo Subgroup. 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. The Gatton Sandstone outcrops along approximately 8 per cent of the Project alignment, but sub-crops beneath Quaternary age alluvium along substantial portions of the alignment. It forms a low permeability fractured rock aquifer.

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

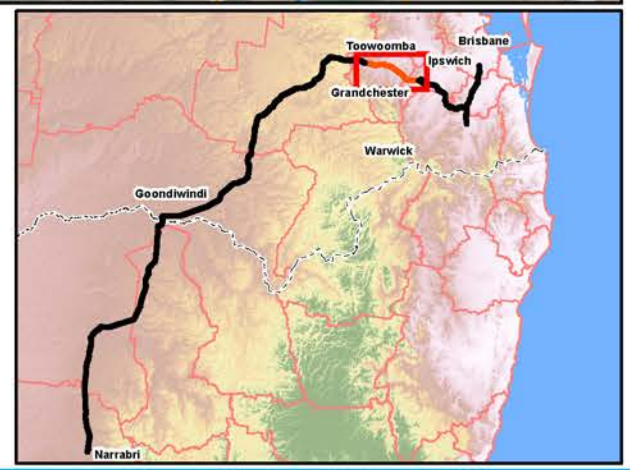


Legend

- Geotechnical SI Monitoring Bores (2018)
- 5 Chainage (km)
- Localities
- Existing rail
- Tunnel
- Watercourses
- Major roads
- Minor roads
- G2H project alignment
- H2C project alignment
- C2K project alignment
- Bridge
- Groundwater study area
- Local Government Areas

Detailed surface geology

- Qpa-QLD (Qpa)
- Qr-QLD (Qr)
- Qa-QLD (Qa)
- Walloon Coal Measures (Jw)
- Koukandowie Formation (Jbmk)
- Gatton Sandstone (Jbmg)
- Woogaroo Subgroup (RJbw)



A3 scale: 1:150,000

0 1 2 3 4 5km

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Coordinate System: GDA 1994 MGA Zone 56

Helidon to Calvert

Figure 5.2: Geology

5.2.3 Koukandowie Formation (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. Koukandowie Formation is the upper unit of the Marburg Subgroup. The formation consists of sheets of interbedded sandstone, siltstone, claystone and minor coal. It is conformably overlain by the Walloon Coal Measures and conformably rests on the Gatton Sandstone. The formation has three members: Heifer Creek Sandstone Member, the Ma Ma Creek Member and the Towallum Basalt. The Heifer Creek Sandstone Member is a major regional unit composed of resistant medium- to coarse-grained and cross-bedded quartzose sandstone, with conglomeratic sandstone towards the top. The middle member of the formation, Ma Ma Creek Member, is primarily composed of finer-grained shales, siltstone and interbedded sandstone with minor fossil woods and conglomerate bands. The lower member is the Towallum Basalt occurring at the base of the Koukandowie Formation. The Koukandowie Formation outcrops on the eastern side of the Project alignment forming the Little Liverpool Range and underlies approximately 7 per cent of the Project alignment. It is a significant geological formation in terms of the groundwater study because of the proposed tunnelling required through the Little Liverpool Range. It is a low permeable fractured rock aquifer/aquitard.

5.2.4 Walloon Coal Measures

The Middle Jurassic aged Walloon Coal Measures are composed of volcaniclastic, lithic and silty sandstone with interbedded mudstone and siltstone, and numerous coal seams and carbonaceous coal shale. These Walloon Coal Measures were deposited in low energy depositional environments across wide floodplains and shallow back swamps. In the groundwater study area, the Walloon Coal Measures are unconformably overlain by the volcanic and sedimentary rocks of the Tertiary age Main Range Volcanics. The Walloon Coal Measures subcrop beneath approximately 2 per cent of the far eastern Project alignment and is considered of low significance with respect to the groundwater study.

5.2.5 Quaternary alluvium and colluvium

Extensive alluvial sequences have infilled river basins in the Clarence-Moreton Basin in SEQ. The headwaters of the QLD alluvial systems are deeply incised into the Cenozoic Volcanics (e.g. Main Range Volcanics south-west of the groundwater study area), which gives rise to the characteristic black soils in these regions.

Sediment thicknesses typically increase downstream from headwaters to lower parts of the river basin. There is a distinct fining upwards sequence of gravels and coarse sands at the base, and fine-grained flood-plain sediments at the top.

Alluvial sediments of the Lockyer Valley are associated with various drainage lines in the groundwater study area, such as the Lockyer Creek and its tributaries (including Sandy Creek and Laidley Creek), form a relatively thin veneer overlying Gatton Sandstone. East of the Little Liverpool Range (near Calvert) the alignment is underlain by alluvial sediments associated with Western Creek.

In the Lockyer Valley thicknesses of around 30 to 35 m have been reported for alluvial sediments, with a distinct fining upwards sequence of gravels and coarse sands at the base, and fine-grained floodplain sediments at the top (Rassam et al 2014).

These Quaternary sediments are significant to the Project in terms of groundwater because they underlie an estimated 72 per cent of the Project alignment. Further to this, these sediments form a significant aquifer that is predominantly and readily recharged by rainfall and associated stream flow and it is relied upon as an important water resource.

5.3 Acid sulfate soils

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 waterways and result in damage to ecosystems (Rassam et al. 2014).

The probability of encountering ASS is considered low to extremely low within the groundwater study area as mapped by the Atlas of Australian Acid Sulfate Soils (Fitzpatrick et al. 2011), except for a dam located immediately to the east of the Cunningham Highway. The dam is mapped as having a high probability of containing ASS. No known occurrence of ASS was identified in the groundwater study area.

Geotechnical investigations did not report the presence of ASS within the groundwater study area. Furthermore, due to the underlying geology of the groundwater study area and existing ASS mapping there is a low risk of inland ASS or potential inland ASS being present within the groundwater study area.

6 Hydrogeology

6.1 Hydrostratigraphy

There are four major hydrostratigraphic units in the region, with three considered relevant to the Project:

- Quaternary alluvium – shallow predominantly unconfined (water table) alluvial systems of porous materials such as clays, sands, gravel and silts along river valleys within the Basin
- Jurassic to Cretaceous sandstones – including the Walloon Coal Measures, unconfined (ridge areas) to confined (river plains) Koukandowie Formation and Gatton Sandstone (typically unconfined in ridge areas and river plains), which are predominantly fractured-rock aquifers
- Woogaroo Subgroup –Triassic to Lower Jurassic predominantly semi-confined to confined, porous and fractured-rock aquifer.

Water-bearing strata considered relevant in the groundwater study area are summarised in Table 6.1 based on the mapped surficial geology (Raiber et al, 2014) and the proposed alignment.

Table 6.1 Hydrostratigraphic summary of the groundwater study area

Stratigraphic unit	Main occurrences	Approximate proportion of alignment	Thickness (m)[1]	Lithology	Characteristics
Alluvium	Floodplains between Toowoomba Range (west of Helidon) and the Little Liverpool Range near Calvert - associated with Lockyer Creek, and Laidley Creek and their tributaries. Also associated with Western Creek floodplain to the east of the Little Liverpool Range.	72%	20 to 35 m	Clay, silt, sand and gravel; in a generally fining upward sequence.	Unconfined porous aquifer
Walloon Coal Measures	Present at the eastern extent of the groundwater study area (east of the Little Liverpool Ranges). Overlain by alluvial sediments of Western Creek.	2%	400 – 600 m	Lithic and silty sandstone with interbedded mudstone and siltstone	Fractured rock aquifer/aquitard
Koukandowie Formation	Crops out as the topographic high of the Little Liverpool Range. Subcrops below Western Creek alluvial sediments on the eastern flanks.	7%	> 1,000 m	Interbedded sandstone, siltstone, claystone and minor coal	Low permeability fractured rock aquifer/aquitard
Gatton Sandstone	Present at the western extent of the Project and central section between Toowoomba Range and Little Liverpool Range. Small areas of outcrop, but typically overlain by alluvial sediments of Lockyer Creek and Laidley Creek.	8%	Up to 800 m	Medium- to coarse-grained sandstone	Low permeability fractured rock aquifer/aquitard

Stratigraphic unit	Main occurrences	Approximate proportion of alignment	Thickness (m)[1]	Lithology	Characteristics
Woogaroo Subgroup	Forms the Helidon Hills north of Helidon, the southern flanks of which are intersected by the Project.	11%	Up to 1,200 m	Interbedded conglomerate, quartz, sand and fine-grained gravel, silty sandstone and laminated claystone.	Porous and fractured rock aquifer (unconfined to confined)

Table note:

1 Data sourced from the Clarence-Moreton Bioregional Assessment (Raiber et al 2014) and reflects the upper thickness range in the region, not specifically within the groundwater study area

6.2 Groundwater occurrence

6.2.1 Groundwater levels

The water table is typically a subdued version of topography, with the depth to groundwater increasing beneath topographic highs (for example the Toowoomba Range, Helidon Hills and Little Liverpool Range), and shallower groundwater in lower lying reaches (such as close to surface water drainage lines). Depths to shallow groundwater will be affected by a number of 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.

The water table will occur in the alluvial sediments of Laidley Creek and Lockyer Creek through much of the central part of the groundwater study area, and Western Creek alluvial sediments east of Little Liverpool Range. The Woogaroo Subgroup (west), Gatton Sandstone (central) and Koukandowie Formation (east) will form the water table aquifer where they crop out along limited sections of the groundwater study area.

Rassam et al (2014) found that adequate regional monitoring information is generally only available for the alluvial aquifers within the Clarence-Moreton bioregion. For example, the Lockyer Valley alluvial aquifer has approximately 400 existing monitoring bores located throughout the valley, whereas monitoring in underlying sedimentary bedrock aquifers is limited to only a few locations across the Clarence-Moreton basin. Inferred groundwater elevations for the alluvial, Gatton Sandstone and Woogaroo Subgroup aquifers are provided in Figure 6.2 (from Raiber et al. 2016).

Groundwater levels were recorded in September/October 2018 at 12 of 13 monitoring bores installed along the Project alignment - as part of the geotechnical investigation (Golder 2019, refer EIS Appendix W: Geotechnical factual report). A summary is provided in Table 6.2. Where discrepancies occur between the nominated aquifer in Golder's preliminary hydrogeological report (Golder 2020, refer Appendix A) and factual geotechnical report (Golder 2019), the interpretation in Golder (2020) has been used.

Table 6.2 Groundwater level data

Bore ID	Aquifer[1]	Filter pack interval (mbgs)	Depth to groundwater (mbgs)[2]	Approximate groundwater elevation (m AHD)[2]	Comment
330-01-BH2101	Koukandowie Formation	100 - 129	82.5	162.5	Ch 62.20 km tunnel section.
330-01-BH2102	Koukandowie Formation	25 – 50	26.4	138.6	Ch 61.75 km tunnel section – west portal. Water table elevation.

Bore ID	Aquifer[1]	Filter pack interval (mbgs)	Depth to groundwater (mbgs)[2]	Approximate groundwater elevation (m AHD)[2]	Comment
330-01-BH2103	Koukandowie Formation	16 – 30	13.1	140.9	Ch 62.75 km tunnel section – east portal. Water table elevation.
330-01-BH2104	Koukandowie Formation	15 – 31	15.6	142.4	Ch 61.50 km tunnel section – west portal. Water table elevation.
330-01-BH2203	Alluvium	6 – 12.2	Dry	Dry	Ch 33.50 km bridge section. Water table > 12 mbgs
330-01-BH2207	Woogaroo Subgroup	11.5 – 20.5	9.7	131.4	Ch 34.50 km Bridge section. Water table elevation (Noting water level above top of monitoring interval).
330-01-BH2212	Gatton Sandstone	23 – 27	Not Reported	Not Reported	Ch 51.50 km bridge section. Screened below alluvium.
330-01-BH2216	Gatton Sandstone	18.5 – 22.5	2.9	94.1	Ch 57.25 km bridge section. Screened across Alluvium and Gatton Sandstone.
330-01-BH2224	Gatton Sandstone	8.5 – 21.5	Not Reported	Not Reported	Ch 66.00 km bridge section. Screened across Alluvium and Gatton Sandstone.
330-01-BH2227	Koukandowie Formation	16 – 20	Not developed or tested due to access issues.		Ch 67.75 km bridge section
330-01-BH2301	Gatton Sandstone	12 -30	28.3	159.7	Ch 29.00 km cut section. Water table elevation.
330-01-BH2303	Woogaroo Subgroup	15 – 30	24.3	150.7	Ch 32.00 km cut section. Water table elevation.
330-01-DH2503	Gatton Sandstone	8 - 15	13.0	92.0	Ch 42.00 km fill section. Water table elevation.

Table notes:

mbgs – metres below ground surface; m AHD – Australian Height Datum
NR – No measurement available at time of reporting (Golder, 2020)

1 From Golder (2020)
2 Based on a review of Table 11 and hydrographs (Appendix G of Golder 2019, refer EIS Appendix W: Geotechnical factual report)
3 Based on location, construction and surface geology (after Golder 2019)

Regional mapping indicated a mean groundwater depth of 5 to 15 m in Lockyer Valley basin alluvium for a wet period in 2008 to 2012 (Raiber et al 2016). Under current management and climatic conditions, the Lockyer Valley alluvial aquifer remains under stress, with pumping often continued until bore yields decline significantly. However, groundwater levels partially recover during high rainfall years, and since the break of drought in 2008, and the flooding of 2011, significant recovery of groundwater levels have occurred in the Lockyer Valley (Raiber et al 2016). Hydrographs are presented in Figure 6.1 for seven registered groundwater bores completed in alluvium. These bores are within 500 m of the Project alignment and were selected because they have complete datasets for the time period considered. The hydrographs capture groundwater level data from 2000 as this period is considered most relevant to understanding existing aquifer conditions.

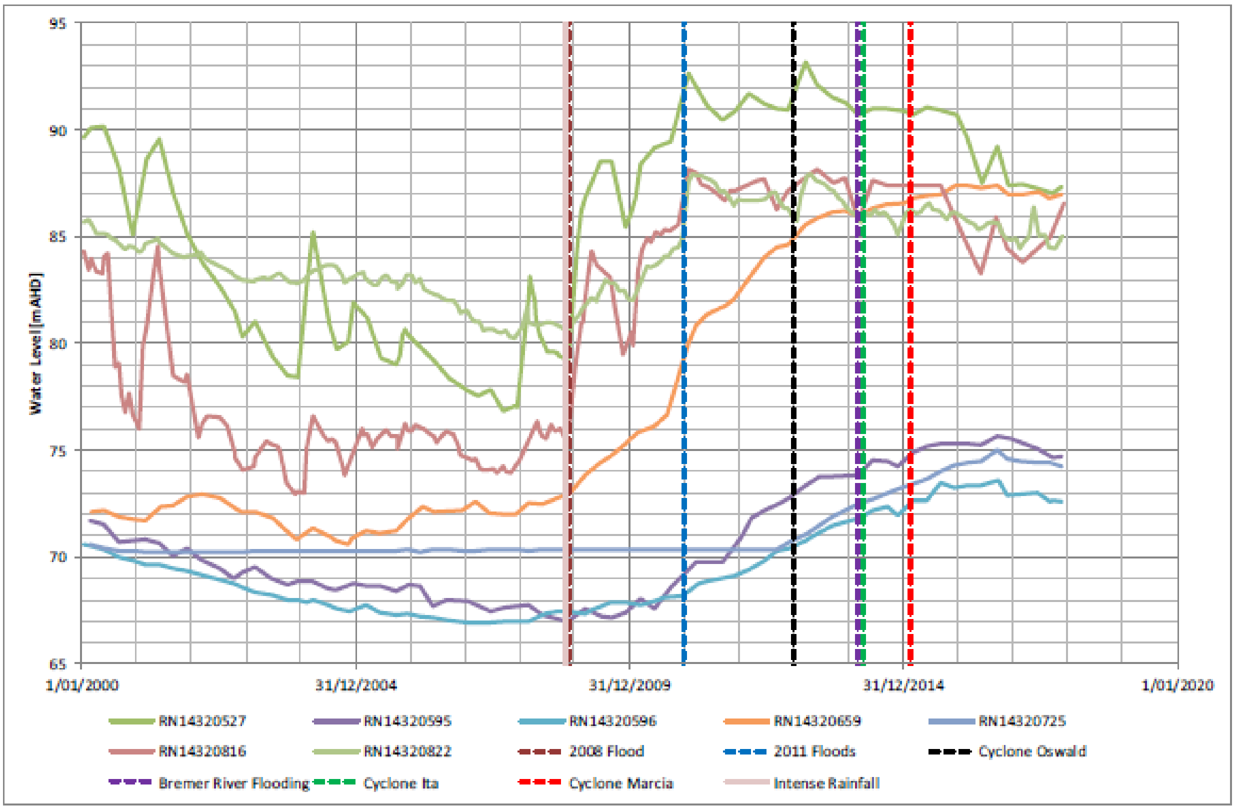

Figure 6.1 **Groundwater levels for alluvial sediment bores within 500 m of alignment**

Source: Golder (2020)

Mean groundwater level elevations for the Gatton Sandstone and Woogaroo Subgroup were presented by Raiber et al (2016) for the Lockyer Valley and Bremer River basins. The pattern was similar in both formations, indicating mean groundwater elevations in the order of 100 to 150 m AHD west of Gatton (approximately Ch 43.00 km), decreasing to and 75 to 100 m AHD east of Gatton. This is broadly consistent with those recorded as part of the ongoing Project geotechnical investigations (refer Table 6.2).

Four geotechnical site investigation monitoring bores (BH201 to BH204) were installed in the Marburg Subgroup (Koukandowie Formation and Gatton Sandstone) to target groundwater levels near the proposed Little Liverpool Range Tunnel and portals (refer Figure 5.2). A groundwater divide (i.e. mounding of groundwater beneath the major ridgeline) is evident with depths to groundwater of around 15 m below ground surface (140 m AHD) near the western and eastern portals (BH2104 and BH2103), increasing to a depth of 80 m below ground surface (160 m AHD) beneath the topographic high of the Little Liverpool Range (at BH2101).

6.2.2 Groundwater flow

Intermediate and regional groundwater flow systems in alluvial sediments flow to the northeast and north through the western groundwater study area following the associated rivers and creeks as they ultimately drain into the Brisbane River. East of the Little Liverpool Range, groundwater within the alluvial sediments flows to the east and northeast as the Western Creek drains into the Bremer River system (refer Figure 6.2). Local groundwater flow systems will be influenced by surface water-groundwater interaction where there is a hydraulic connection.

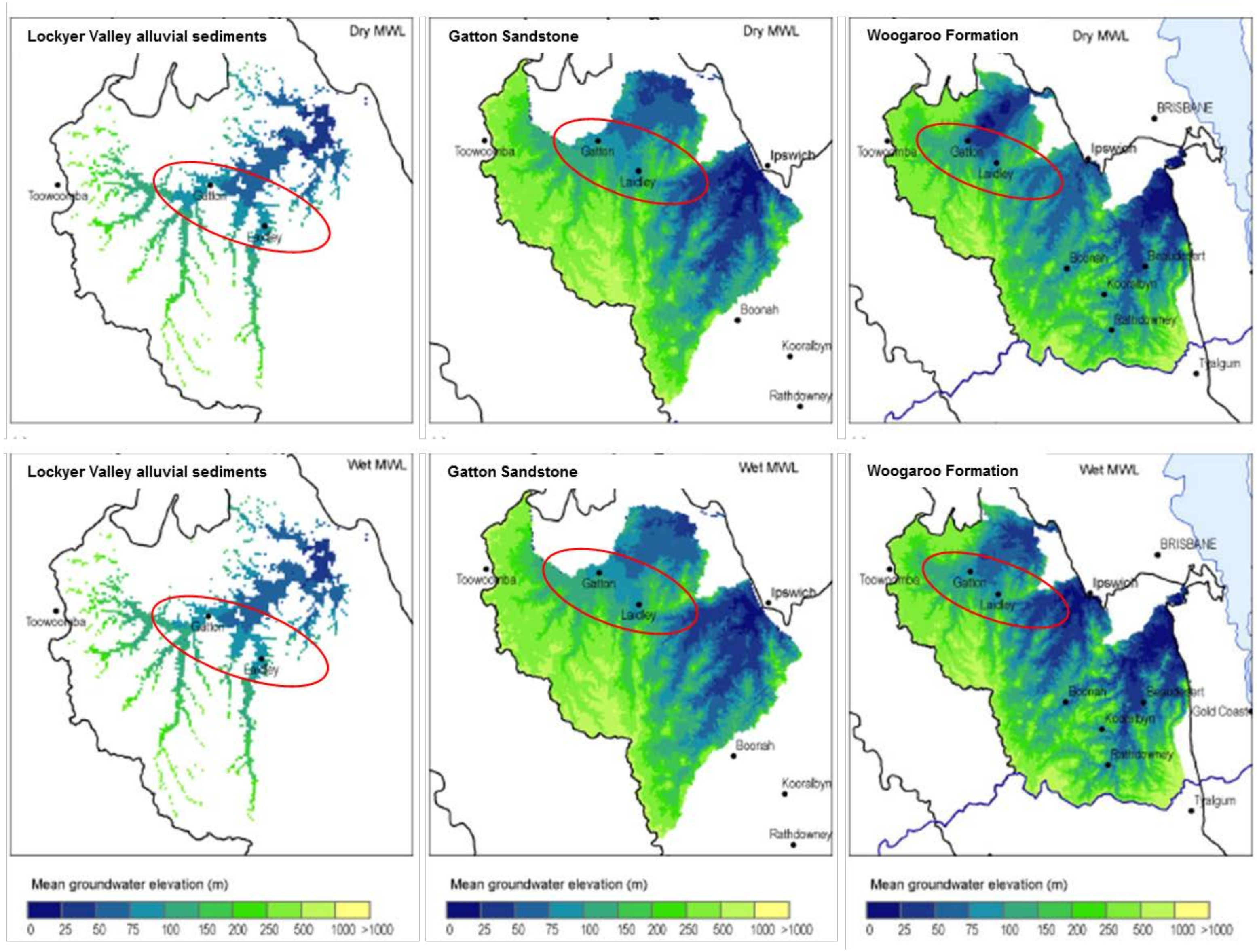

Figure 6.2 **Mean groundwater level elevation during dry period (2000 to 2007) and a wet period (2008 to 2012)**

Source: Raiber et al. (2016)

Groundwater levels in the shallow bedrock, including the Woogaroo Subgroup, generally reflect the topography. Regional groundwater in the shallow bedrock generally flows to the northeast with local variations in flow directions possible but is not considered significant to understanding potential impact to groundwater from the Project. Mapping of Woogaroo Subgroup and Gatton Sandstone groundwater elevations indicate that groundwater flowpaths are influenced by the Lockyer Creek and Bremer River systems (refer Figure 6.2). The potentiometric surface indicates that lower groundwater elevations correspond to alluvial sediments suggesting these act as regional discharge areas for the underlying and flanking Clarence-Moreton Basin sedimentary sequence (for example, Gatton Sandstone in the groundwater study area).

In the groundwater study area, the Koukandowie Formation crops out in the Little Liverpool Range, and groundwater flow direction is controlled locally by a groundwater divide beneath the main ridge line. Groundwater will flow west (beneath the western flanks) and east (beneath the eastern slopes). The height of groundwater above the tunnel and the hydraulic gradient either side of the divide will affect 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.

6.2.3 Groundwater recharge

There is a net monthly and annual deficit of rainfall, with average evaporation exceeding average rainfall for all months (refer Figure 4.2). 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 occur in response to higher or more continuous rainfall events, and overall net recharge rates in the groundwater study area are expected to be low.

In areas with alluvial or colluvial materials, recharge is anticipated to be supplied by the following:

- Direct infiltration of rainfall and associated stream flow
- Seepage from ephemeral streams during periods of flow following rainfall (i.e. losing streams)
- Infiltration by surface water releases from Bill Gunn Dam (Lake Dyer) and Lake Clarendon Dam (off-stream storages that release water back into the creeks of the Central Lockyer as part of the Central Lockyer Water Supply Scheme)
- Sub-cropping rock below alluvium may also act as a source of recharge where upward vertical gradients and hydraulic connection occur, such as vertical discharge from the Gatton Sandstone into overlying alluvial sediments associated with watercourses (such as Lockyer Creek and Laidley Creek).

The two dams are located east of Gatton and are filled by diverting water from nearby creeks during significant rainfall events. The dams supply water for the Morton Vale Pipeline and recharge groundwater areas adjacent to Lockyer Creek (including Laidley Creek in the groundwater study area), as well as supply downstream area-based surface water entitlements. The water levels in both dams have been below minimum supply levels since 2018 and no water supply is possible until rainfall is sufficient to allow Seqwater to increase the allocation above zero percent (Seqwater 2019).

Recharge to the water table in rock formations occurs via direct infiltration of rainfall where the formations are exposed at the surface or blanketed by a thin layer of soil. For example, along ridgelines formed by the Woogaroo Subgroup and Koukandowie Formation, and in lower lying areas where the Gatton Sandstone is not overlain by alluvial sediments. Recharge from overlying alluvial sediments will also occur where a downward hydraulic gradient is present (i.e. where groundwater elevations in the alluvial sediments are higher than those in the underlying bedrock sediments).

Groundwater recharge values were estimated using chloride mass balance by Raiber et al (2016) and these are summarised in Table 6.3 for the main hydrostratigraphic units in the groundwater study area (from Golder 2020, refer Appendix A). It is noted that the estimated recharge is much greater for the Woogaroo Subgroup than other formations and is consistent with the generally lower salinity groundwater in this aquifer (refer Section 6.2.5). This may be attributed to a shallower weathering profile and/or connected fracture networks within a rock formation that already has a high primary porosity.

Table 6.3 Regional rainfall recharge estimates

Formation	Number of samples/tests	Lower (mm/year)	Typical (mm/year)	Upper (mm/year)
Alluvium	2,594	3.9	10.6	32.0
Walloon Coal Measures	52	1.1	2.9	6.0
Koukandowie Formation	21	1.6	2.7	5.9
Gatton Sandstone	242	1.1	3.7	10.2
Woogaroo Subgroup	242	12.2	29.2	68.9

Source: Golder (2020) – after Australian Government 2014. *Clarence-Moreton Basin Groundwater Recharge Estimates Chloride Mass Balance.*

6.2.4 Groundwater discharge

In areas with alluvial or colluvial materials, discharge may occur via seepage to ephemeral streams and into underlying bedrock units during periods of higher groundwater levels. Discharge out of the groundwater study area will also occur as 'underflow' in alluvial sediments beneath creek channels. Evapotranspiration from vegetation growing in the creek beds and along the banks are also a primary discharge mechanism from this unit.

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. Discharge will also occur via evapotranspiration, typically along the ridgelines and in outcrop areas.

Groundwater discharge will also occur via pumping bores, particularly from the alluvial sediments which are heavily utilised in the Lockyer Valley, as discussed in Section 6.4.1.

6.2.5 Groundwater quality and yield

6.2.5.1 Groundwater quality

Groundwater quality is discussed here in terms of salinity, total dissolved solids (TDS) as milligrams per litre (mg/L) and/or EC as microSiemens per centimetre (µS/cm)[1]. 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 10,000 mg/L groundwater is considered brine (Fetter 2014).

Typically, groundwater in the alluvium is fresher than groundwater in the underlying sedimentary bedrock (primarily the Gatton Sandstone in the groundwater study area). The groundwater quality in the Lockyer Valley alluvium is however spatially and temporally highly variable ranging from fresh to very saline. The primary controls of the spatial variability are the nature of connectivity of the alluvial aquifer with surface water and the underlying bedrock. For example, groundwater is commonly fresh, near the headwaters of the Lockyer Creek and in the upper parts of the tributaries to the Lockyer Creek (south of the groundwater study area) - marking the good quality groundwater of the Main Range Volcanics as a major source of recharge to the alluvial aquifer (Rassam et al 2014). Groundwater in the Lockyer Valley alluvium gradually becomes more saline (i.e. the quality decreases) down gradient, likely due to increasing influence of upwards leakage of more saline groundwater from the underlying bedrock (predominantly Gatton Sandstone within the groundwater study area).

[1] 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 0.64).

There was a distinct improvement in the groundwater quality (i.e. lower salinity) of the alluvial systems of the Lockyer Valley following the 2011 floods. There was a significant decrease in salinity following the progressive increases that had occurred due to a lack of surface water recharge and upward discharge from underlying bedrock, induced by continuous pumping of the alluvial aquifers (Rassam et al 2014).

Water quality in the bedrock sediments varies from fresh to saline across the region for reasons including lithological variability, relative position in the basin, recharge processes, depth, and surface-water interaction (Rassam et al 2014). The Woogaroo Subgroup contains the freshest groundwater of all sedimentary bedrock units, which reflects the higher recharge rate and higher hydraulic conductivities compared to the other hydrostratigraphic units (refer Table 6.3 and Table 6.7). With potentially high yields, the Woogaroo Subgroup aquifer is extensively used for groundwater extraction in QLD near the northern margin of the sedimentary basin in the Lockyer Valley, where the unit occurs at shallow depths (Raiber 2017).

An assessment of salinity and EC in the Clarence-Moreton Basin was provided by Rassam et al (2014) based on multiple references and data sets. A summary is provided in Table 6.4, together with data from bores within the groundwater study area where available.

Table 6.4 Summary of groundwater salinity – regional

Aquifer unit	No. samples	Salinity[#] (mg/L)			EC (µS/cm)			Groundwater study area[1]
		Min	Mean	Max	Min	Mean	Max	
Lockyer Valley alluvium	307[a]	91 (approx.)	1,904	18,000	-			1,200 – 6,600 µS/cm (Laidley Creek) 1,750 – 4,040 µS/cm (Lockyer Creek) – qualitative descriptor is 'potable'
	Not Reported[a]					3,327		
	100[c]				350		25,000	
Koukandowie Formation	9[a]	359	4,248	14,496	-	6,607	-	No data available (Koukandowie Formation)
Gatton Sandstone	42[a]	333	6,452	24,294	-	9,971	-	1,042 µS/cm (Gatton Sandstone)[2] 700 – 3,890 µS/cm (Marburg Subgroup) – qualitative descriptors are 'potable' to 'brackish'
	11[c]					7,643		
Woogaroo Subgroup	6[a]	961	2,518	4,147	-	4,225	-	No data available – qualitative descriptors is 'potable'
	7[d]	-	866	-	-	-	-	

Source: As referenced by Raiber et al (2014): a – Pearce et al (2007a); b – DNRM (2013); c – Pearce et al (2007b); d – McKibbin (1995)

Table notes:

Salinity term used by Raiber et al (2014), rather than TDS (refer to Section 6.2.5.1 for the definition of salinity)
1 Data sourced from the DNRME groundwater database and is taken as the range for the bores identified within the unit
2 A single value is recorded in the DNRME groundwater database for this unit within the groundwater study area

Samples were taken from eight of the site investigation monitoring bores installed as part of the groundwater sampling conducted in October 2018. Laboratory results for EC and TDS are summarised in Table 6.5. Field measurements of EC are provided where laboratory results were not available.

Table 6.5 Summary of groundwater salinity - site investigations

Bore ID	Formation sampled	TDS (mg/L)	EC (uS/cm)
330-01-BH2101	Koukandowie Formation	-	1,746 (field EC)
330-01-BH2102	Koukandowie Formation	2,340	4,260
330-01-BH2103	Koukandowie Formation	2,170	3,810
330-01-BH2104[1]	Koukandowie Formation	2,390	4,260
330-01-BH2203	Alluvium	Dry bore	
330-01-BH2207[2]	Woogaroo Subgroup	995	1,730

Bore ID	Formation sampled	TDS (mg/L)	EC (uS/cm)
330-01-BH2212	Gatton Sandstone	2,940	5,500
330-01-BH2216*	Gatton Sandstone	1,180	2,530
330-01-BH2224*	Gatton Sandstone	-	1,284 (field EC)
330-01-BH2227	Koukandowie Formation	No development or sampling conducted due to access issues.	
330-01-BH2301	Gatton Sandstone	Dry bore	
330-01-BH2303	Woogaroo Subgroup	999	1,720
330-01-DH2503	Gatton Sandstone	Became dry during bore development	

Table notes:

1 Stated as BH22104 on laboratory Certificate of Analysis; 2 – Stated as BH2307 on laboratory Certificate of Analysis
* BH2216 and BH2224 screened across alluvium and Gatton Sandstone.

The TDS and EC ranges are generally consistent with the findings of Rassam et al (2014) for the wider Clarence-Moreton Basin (refer Table 6.4), with TDS values in groundwater from sedimentary bedrock formations in the groundwater study area typically brackish (i.e. between 1,001 and 10,0000 mg/L TDS).

6.2.5.2 Groundwater yield

Yields from bores in the alluvium vary between 0.5 to 37.8 litres per second (L/s) across the groundwater study area (based on the data available). 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.

Regional studies have shown that the pre-Cenozoic aquifers within the Clarence-Moreton Basin sequence are generally low yielding. Average yields ranging from 0.5 to 2.5 L/s in the sandstone, siltstone and conglomerate of the Bundamba Group, which includes the Woogaroo Subgroup, the Gatton Sandstone, and the Koukandowie Formation (Rassam et al 2014).

The Ripley Road Sandstone forms the upper unit of the Woogaroo Subgroup and is equivalent to the Precipice Sandstone of the Surat Basin (west of the Toowoomba Ranges). The unit comprises a coarse-grained and predominantly clean quartz rich sandstone as well as quartz rich granule conglomerate. It is a reliable producer of good quality water, with yields of up to 6.3 L/s (DNRME groundwater database) thus providing base flow to the creeks where it is present within the Lockyer Creek.

A summary of bore yields in the groundwater study area is provided in Table 6.6. Yields are generally low for the sedimentary bedrock aquifers, but dependent on the lithology intersected (sandstone, siltstone, mudstone) and frequency, size, and interconnectivity of fractures. Some higher yields are recorded for alluvial aquifer bores, generally consistent with regional studies. No yield data were available for the Gatton Sandstone in the groundwater study area based on a search of the DNRME groundwater database.

It is noted that individual bore yield estimates will also be affected by the available drawdown, bore construction and capacity of the pump used during testing.

Table 6.6 Groundwater study area bore yields

Aquifer unit	No. of bores	Yield (L/s)		
		Minimum	Mean	Maximum
Alluvium	36	0.5	12.5	37.8
Koukandowie Formation	1	0.5	0.5	0.5
Gatton Sandstone	-	-	-	-
Marburg Subgroup (Undifferentiated)	5	0.6	1.2	2.5
Woogaroo Subgroup	8	0.6	1.5	6.3

Source: DNRME groundwater database

6.3 Hydraulic properties

A review of aquifer parameters and pumping test data in the DNRME groundwater database was carried out by Raiber et al (2016) to provide a range of hydraulic conductivities for hydrostratigraphic units in the Clarence-Moreton Basin. A further review of hydrogeological parameters was included in Golder (2020), and site-specific hydraulic conductivity values were estimated from slug tests (falling and/or rising head test) conducted in October and November 2018 at nine of the 14 groundwater monitoring bores constructed during Project geotechnical site investigation (Golder 2019, refer EIS Appendix W: Geotechnical factual report). Falling head packer testing was also carried out at three depths in 330-01-BH2101 (Golder 2019).

A summary is provided in Table 6.7 for units relevant to the groundwater study area.

Table 6.7 Summary of hydraulic conductivity values

Formation	Literature review (Raiber et al 2016)		Literature review (Golder 2020[d])		Slug tests (Golder 2020[d])	
	No. of bores	Hydraulic conductivity (m/day)	No. of tests	Hydraulic conductivity (m/day)	No. of locations (No. of tests)	Hydraulic conductivity (m/day) [c]
Alluvium	193	0.09 to 1,500	NR	0.09 to 276	1 (2)	0.285
Marburg Subgroup (undifferentiated)	8	0.03 to 5.8	-	-	1 (1)	0.0007 to 0.0073
Marburg Subgroup: Koukandowie Formation	-	-	61	0.003 to 0.08	1 (3)[b]	0.25
Marburg Subgroup: Gatton Sandstone	2	1.1 to 4.9	88	0.002 to 0.12	4 (5)*	0.0002 to 0.31
Woogaroo Subgroup	11	0.008 to 23.9	NR	0.04 to 4.3	1 (2)	0.001 to 0.49

Table notes:

NR – Not reported

a Raiber et al (2016)

b Falling head packer testing at three depths at 330-01-BH2101

c Tests were analysed using the Hvorslev (1961) and KGS (Hyder et al 1994) methodologies

d Refer Appendix A

e Refer EIS Appendix W: Geotechnical factual report

Bore construction logs (Appendix C of Golder 2019, refer EIS Appendix W: Geotechnical factual report) indicate that bores BH2212 and BH2216 are screened across the alluvial sediments and underlying Gatton Sandstone making it impossible to attribute the test results to either aquifer. The hydraulic conductivity values of 0.52 m/day (BH2212*) and 0.38 m/day (BH2216*) have therefore not been included in Table 6.7.

All formations exhibit a wide range of hydraulic conductivity values, typical of fractured aquifer systems and the heterogeneity of alluvial sediments.

It is expected that hydraulic conductivities in the upper portions of the alluvium, most relevant to the Project scope due to the shallow depth of disturbance associated with the Project, will be at the lower end of the values provided in Table 6.7. This is due to the fining upwards sequence of gravels and coarse sands at the base, and fine-grained flood-plain sediments at the top. Estimates of hydraulic conductivity along the alignment are used when considering inflows and drawdown impacts from cuttings and tunnel and help to constrain values used in modelling of groundwater impacts.

6.4 Groundwater users

6.4.1 Registered bores

Based on a search of the DNRME groundwater database (accessed 5 March 2019), a total of 510 groundwater bores were identified within groundwater study area. Two of unknown status, 124 decommissioned, abandoned or proposed, and the remaining 384 are designated as 'existing'. The DNRME groundwater database includes all licenced bores within the groundwater study area however there are potentially unregistered bores within the groundwater study area, further explanation is provided in Section 6.4.3.

A summary of the 386 bores(384 existing and two unknown status) is provided in Table 6.8, and bore locations are shown on Figure 6.3. The number and distribution of bores reflect the heavy utilisation of groundwater in the groundwater study area for water supply purposes, particularly from the alluvial aquifers of the Lockyer Valley.

Table 6.8 Summary of registered bores within 1 km of Project alignment

Aquifer unit	Total number of bores	Depths[2]	Uses[1]
Alluvium	176	9 x shallow 160 x deep 7 x unknown	18 x **IN**; 6 x **SM**; 6 x **TW**; 92 x **WS**; 54 x unknown
Koukandowie Formation	1	1 x deep	1 x **WS**
Gatton Sandstone	1	1 x deep	1 x unknown
Marburg Subgroup (undifferentiated)	29	6 x shallow 23 x deep	1 x **IN**; 5 x **SM**; 19 x **WS**; 4 x unknown
Woogaroo Subgroup	16	16 x deep	2 x **SM**; 12 x **WS**; 2 x unknown
Unknown	163	24 x shallow 109 x deep 30 x unknown	1 x **SM**; 68 x **WS**; 92 x unknown

Table notes:

1 **IN** – Investigation; **SM** – Sub-artesian Monitoring; **TW** – Town Water; **WS** – Water Supply
2 Shallow bores: less than or equal to 15 m and deep bores: greater than 15 m

6.4.2 Groundwater entitlements

Water usage within the groundwater study area is dominated by irrigation use (92% of all entitlements are irrigation). A summary of groundwater entitlements relevant to the groundwater study area is provided in Table 6.9 Water access licences data has been sourced from the DNRME groundwater entitlements database (accessed 21 February 2020).

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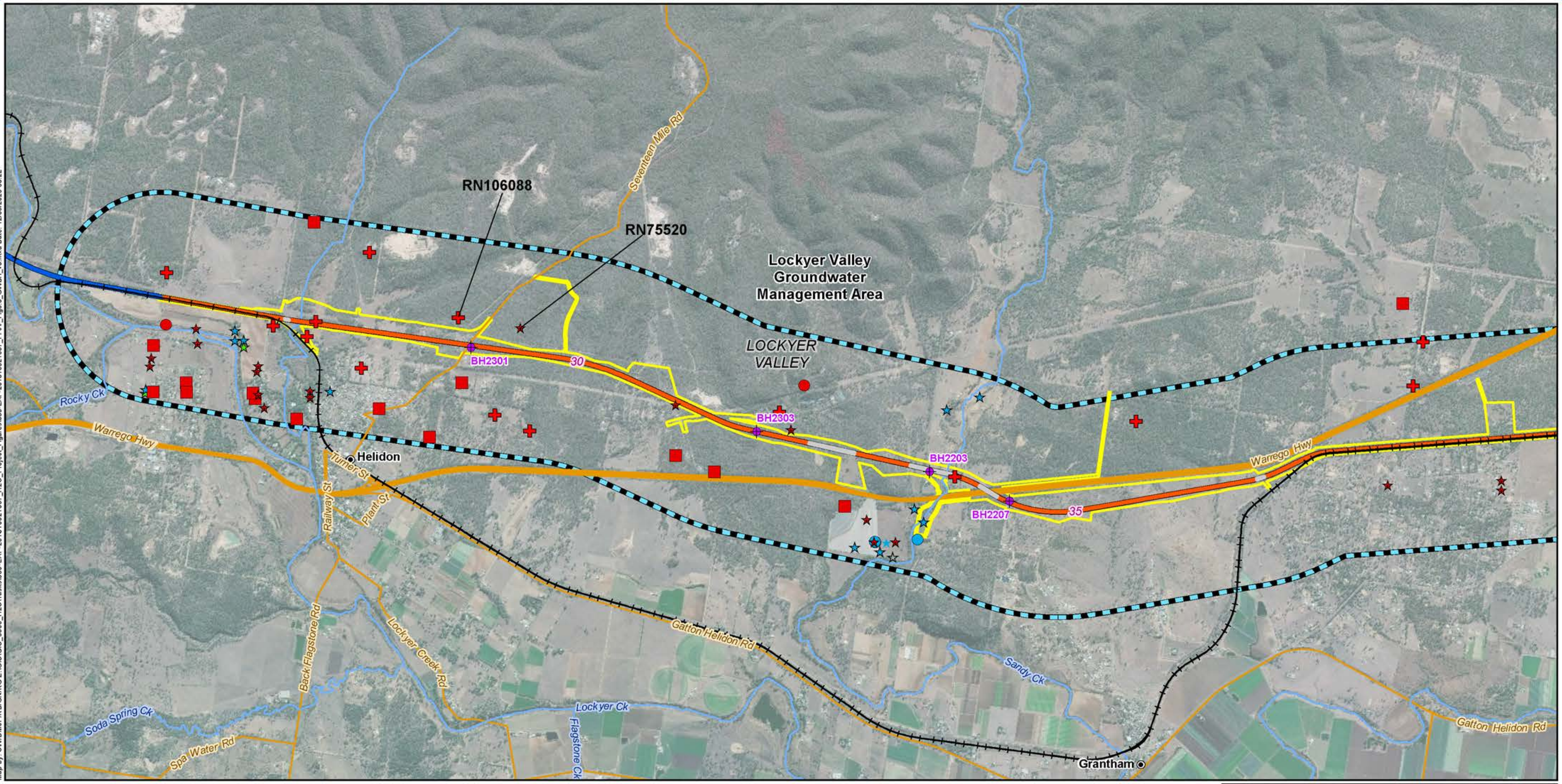
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



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Legend

- Geotechnical SI Monitoring Bores (2018)

Aquifer symbol

- Alluvium
- Marburg Subgroup
- Unknown
- Woogaroo Subgroup

Bore depth colour

- Shallow (<15m)
- Deep (>15m)
- Unknown

- 5 Chainage (km)
- Localities
- Existing rail
- G2H project alignment
- H2C project alignment
- Watercourses
- Major roads
- Minor roads

- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area

A3 scale: 1:40,000

0 0.5 1 1.5 2 2.5 km

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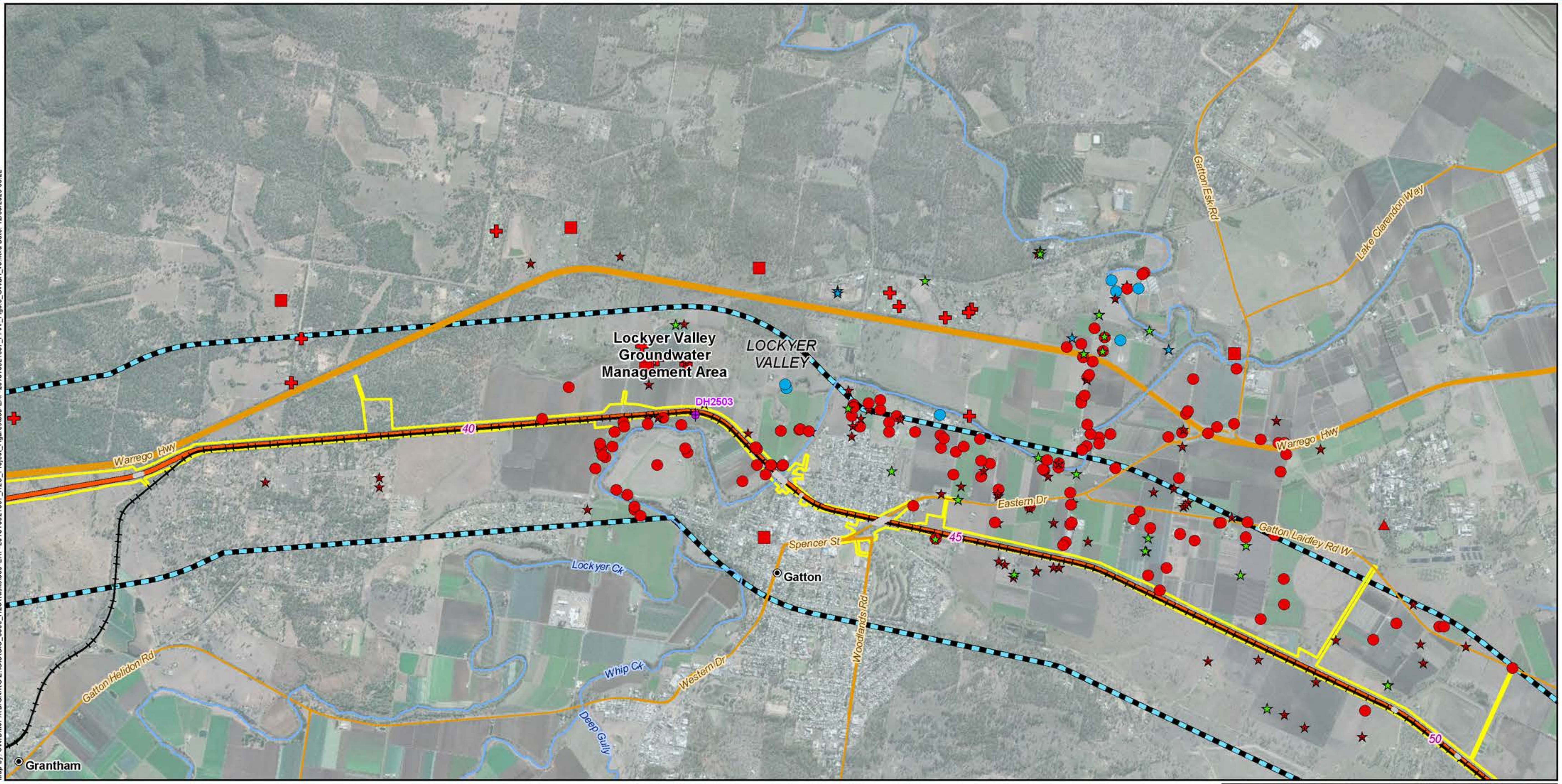
Helidon to Calvert

Figure 6.3a: Registered groundwater bores

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



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Legend

- Geotechnical SI Monitoring Bores (2018)

Aquifer symbol

- Alluvium
- Marburg Subgroup
- Unknown
- Woogaroo Subgroup

Bore depth colour

- Shallow (<15m)
- Deep (>15m)
- Unknown

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

A3 scale: 1:40,000

0 0.5 1 1.5 2 2.5 km

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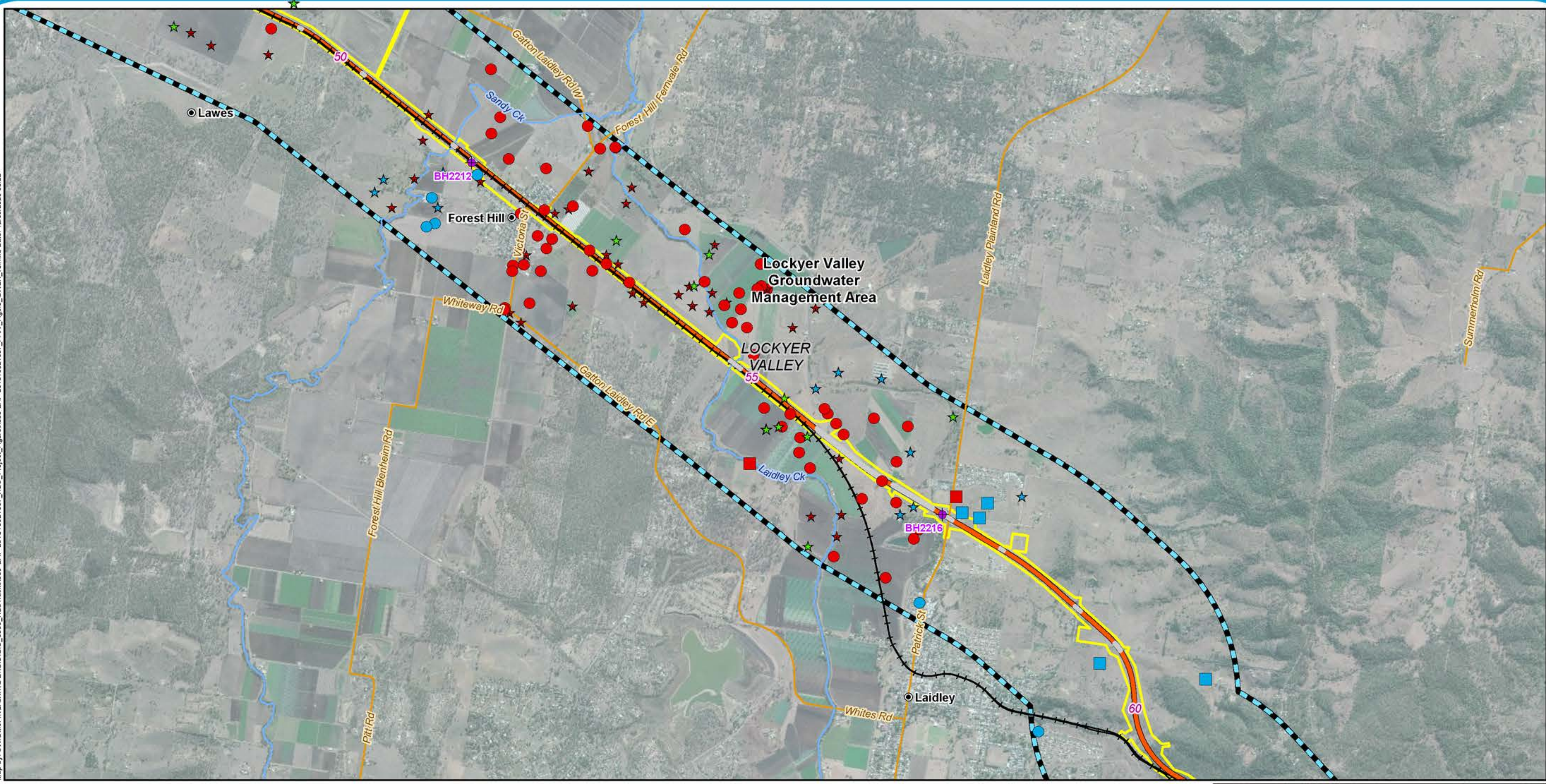
Helidon to Calvert
Figure 6.3b: Registered groundwater bores

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



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Legend

- Geotechnical SI Monitoring Bores (2018)

Aquifer symbol

- Alluvium
- Marburg Subgroup
- Unknown
- Woogaroo Subgroup

Bore depth colour

- Shallow (<15m)
- Deep (>15m)
- Unknown

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- Watercourses
- Minor roads

- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area

A3 scale: 1:40,000

0 0.5 1 1.5 2 2.5 km

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Helidon to Calvert

Figure 6.3c: Registered groundwater bores

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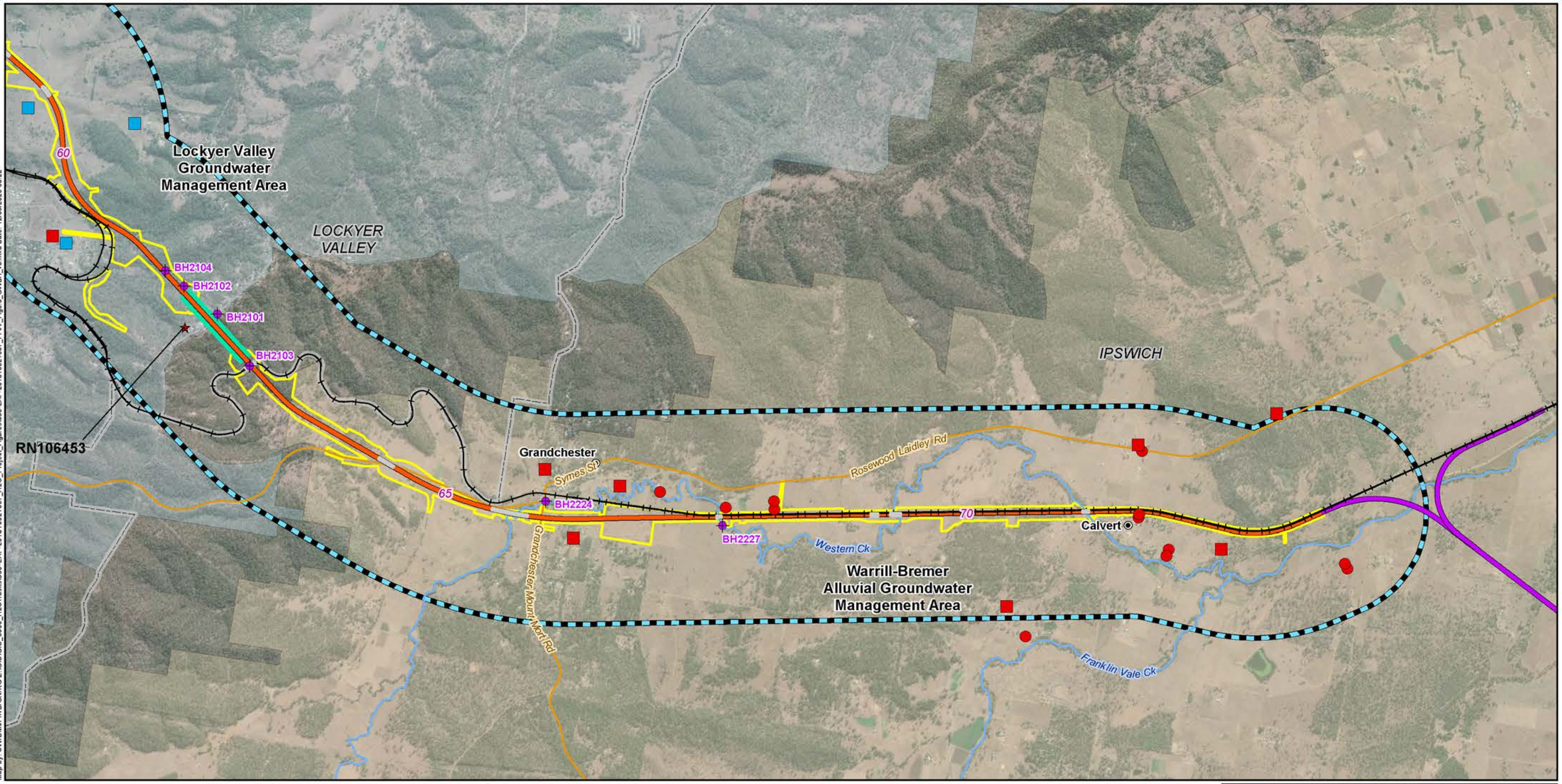

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Legend

- Geotechnical SI Monitoring Bores (2018)

Aquifer symbol

- Alluvium
- Marburg Subgroup
- Unknown
- Woogaroo Subgroup

Bore depth colour

- Shallow (<15m)
- Deep (>15m)
- Unknown

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Watercourses
- Minor roads
- Tunnel

- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area
- Warrill-Bremer Alluvial Groundwater Management Area

A3 scale: 1:40,000

0 0.5 1 1.5 2 2.5 km

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Helidon to Calvert

Figure 6.3d: Registered groundwater bores

Table 6.9 **Summary of groundwater entitlements from aquifers surrounding the Project**

QLD Water Plan	Groundwater source	Licenced purpose	No. of entitlements	Water made available (ML/year)	% of assigned water volume
Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017	Marburg Subgroup (including Koukandowie Formation and Gatton Sandstone)[1]	Industrial	2	1	100[a]
		Domestic	1	12	
	Woogaroo Subgroup[2]	Domestic	5	4	100[a]
	Helidon Sandstone[2]	Amenities	1	4	100[a]
		Domestic	9	25	
		Industrial	2	51	
		Irrigation	4	5	
	Walloon Coal Measures	None	-	-	-
Water Plan (Moreton) 2007	Laidley Creek alluvium	Irrigation	103	50	< 2[b]
	Lockyer Creek alluvium	Industrial	2	Null	
		Irrigation	174	Null	
		Town water supply	1	Null	
	Redbank Creek alluvium	Industrial	1	78	
		Irrigation	2	Null	
	Sandy Creek alluvium	Irrigation	7	Null	

Table notes:

1 This is listed under the Murphys Creek Marburg Groundwater Management Subgroup.
2 This is listed under the Murphys Creek Woogaroo Groundwater Management Subgroup.
a Listed in Schedule 4: volume of unallocated water for water licences to be granted from reserves of the Water Plan (GABORA) 2017.
b The maximum allowable volume to be taken in each groundwater trading zone is 9,532 ML (Table 2 of Division 1 in the Water Plan (Moreton) 2007).

6.4.3 Unregistered bores

The DNRME groundwater database includes all registered bores within the groundwater study area however there are potentially unregistered bores within the groundwater study area. Bores constructed prior to 2002 were not required to register with DNRME (now Department of Regional Development, Manufacturing and Water) and, as a result, the DRNME groundwater database is not a complete record of bores within the groundwater study area however it is the most accurate and recent information available publicly. A groundwater bore survey will be required during the detailed design phase to accurately capture all groundwater bores within the groundwater study area through physical survey via liaison with landholders. This will include questioning the landholder regarding the presence of any unregistered bores (old and new bores not yet registered with the DNRME groundwater database).

6.5 Groundwater dependent ecosystems

The Groundwater Dependent Ecosystems Atlas (GDE Atlas) was developed as a national dataset of Australian GDEs and potential GDEs (http://www.bom.gov.au/water/groundwater/gde/map.shtml). 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 identification of potential GDEs in the Atlas does not confirm that the ecosystem is groundwater dependent.

6.5.1 Potential aquatic groundwater dependent ecosystems

There are numerous moderate and low potential aquatic GDEs (from regional studies) within the groundwater study area, including the Lockyer Creek, Laidley Creek and Western Creek (and their tributaries).

These are generally described as wetlands associated with alluvial aquifers on the BoM GDE Atlas (the GDE Atlas) (**http://www.bom.gov.au/water/groundwater/gde/**).

The locations of potential aquatic GDEs are shown on Figure 6.4.

There are no registered groundwater springs within the groundwater study area based on a review of the QLD Globe website (**https://qldglobe.information.qld.gov.au/**), with the nearest being Helidon Spring located 4 km south of Ch 26.00 km.

As no field-truthing of these environments was undertaken, it has been assumed for the purposes of the EIS, that the modelled extent of the aquatic GDEs are accepted as true presence, and thus form a potentially sensitive receptor.

6.5.2 Potential terrestrial groundwater dependent ecosystems

There are numerous moderate potential terrestrial GDEs (from regional studies) in the groundwater study area between Helidon to Gatton (approximately Ch 26.00 km to Ch 44.00 km). Between Laidley and Calvert (approximately Ch 61.00 km to Ch 72.00 km) there are also numerous moderate potential and low potential GDEs (from regional studies). These are generally described as wetlands associated with alluvial aquifers on the GDE Atlas (**http://www.bom.gov.au/water/groundwater/gde/**).

The locations of potential terrestrial GDEs are shown on Figure 6.5.

As no field-truthing of these environments was undertaken, it has been assumed for the purposes of the EIS, that the extent of the terrestrial GDEs as depicted in the GDE Atlas are accepted as true presence, and thus form a potentially sensitive receptor.

6.5.3 Potential subterranean groundwater dependent ecosystems

No potential subterranean GDEs were identified within the groundwater study area from review of the Atlas (**http://www.bom.gov.au/water/groundwater/gde/**).

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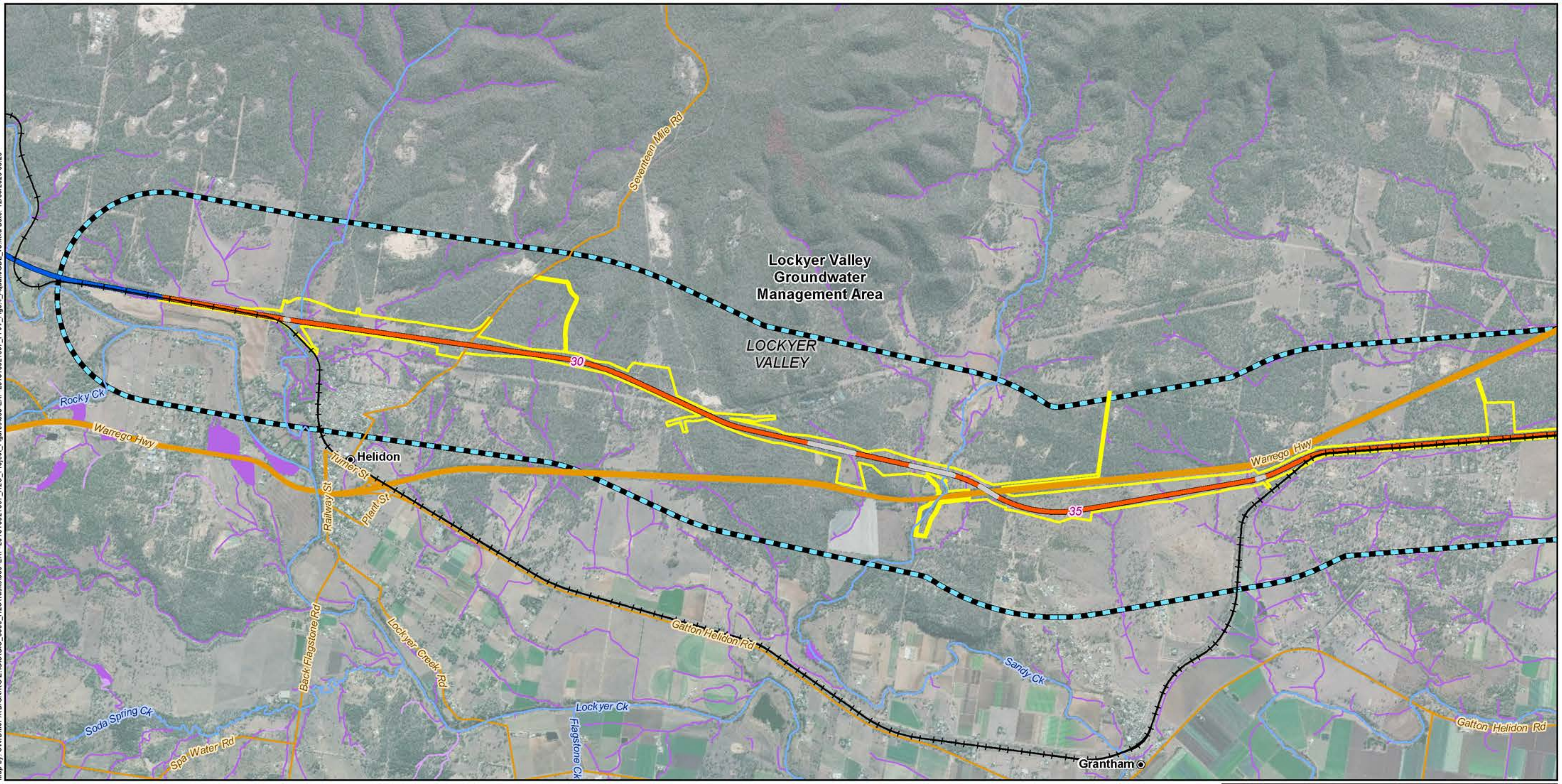
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



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Legend

- 5 Chainage (km)
- Localities
- Existing rail
- G2H project alignment
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- 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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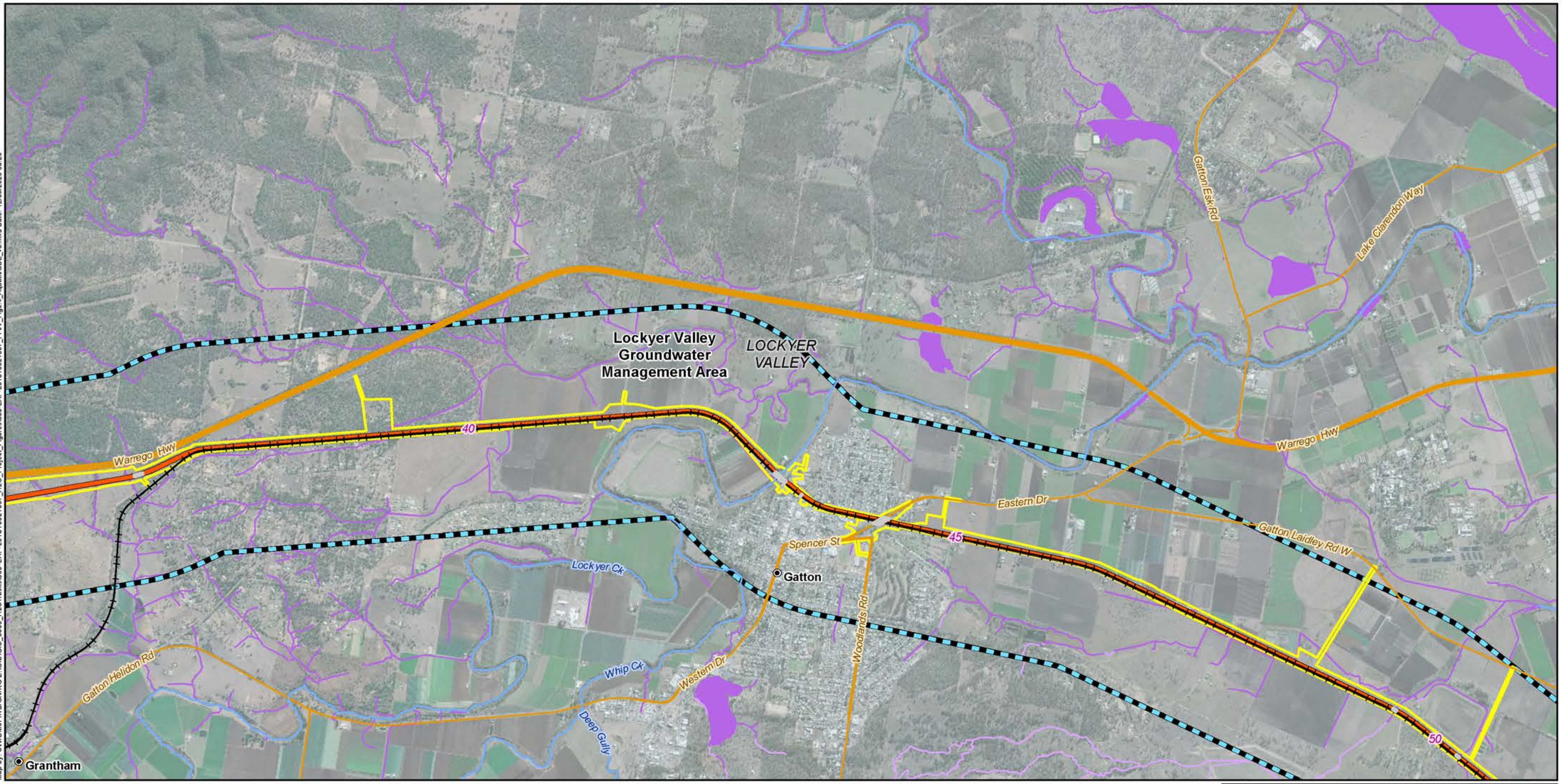
Helidon to Calvert

Figure 6.4a: Potential aquatic GDEs

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



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Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- 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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Helidon to Calvert

Figure 6.4b: Potential aquatic GDEs

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

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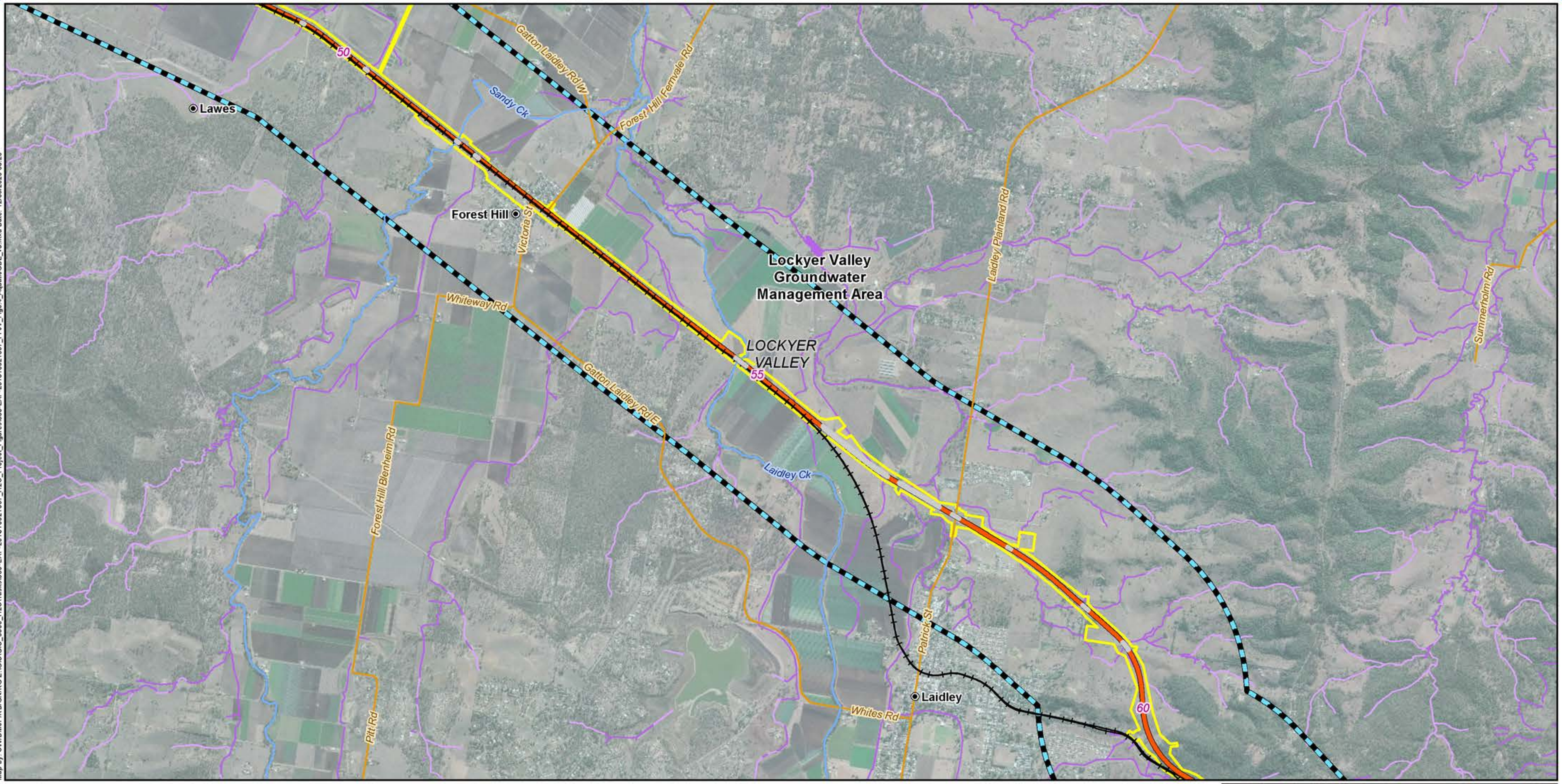

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- Watercourses
- Minor roads
- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- 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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Helidon to Calvert

Figure 6.4c: Potential aquatic GDEs

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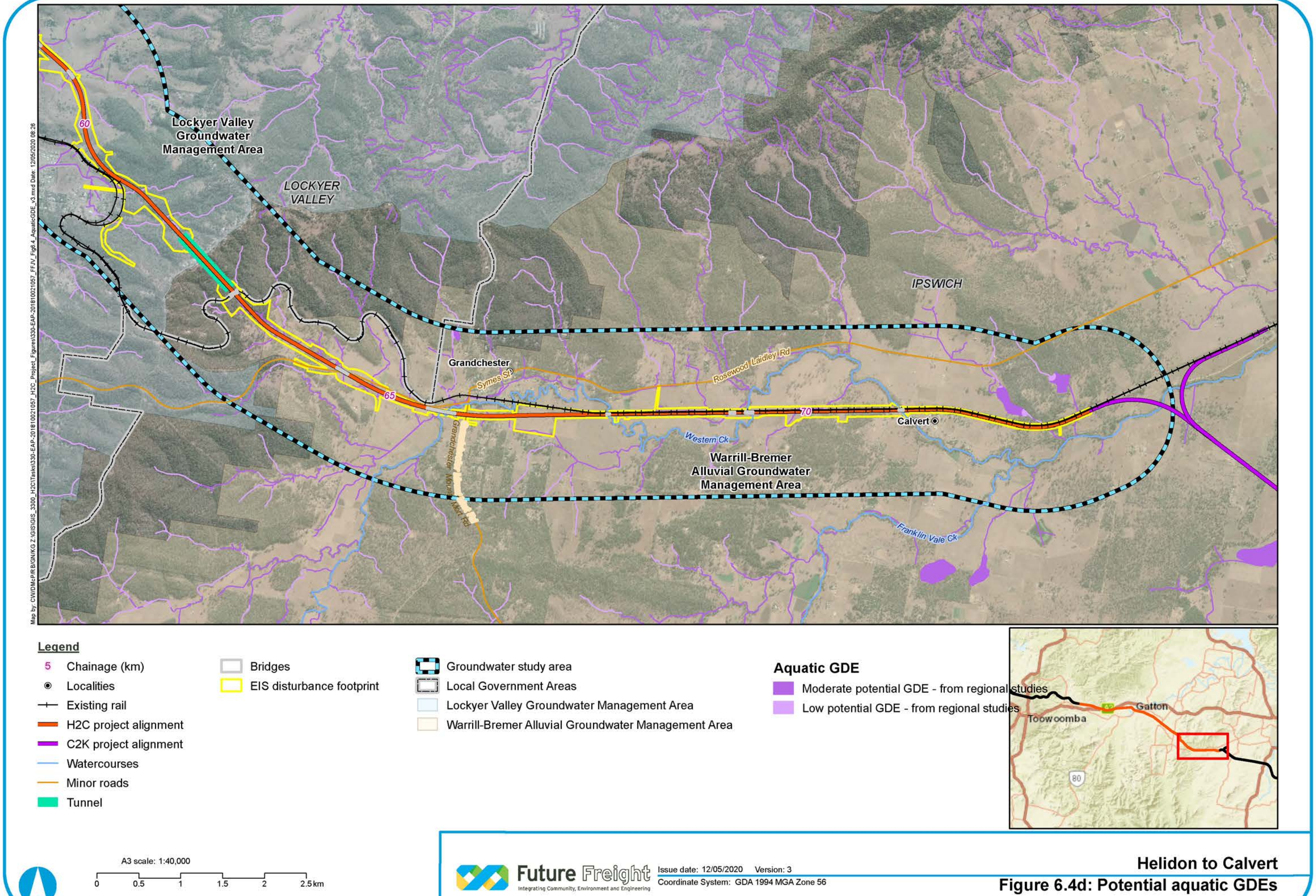
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community



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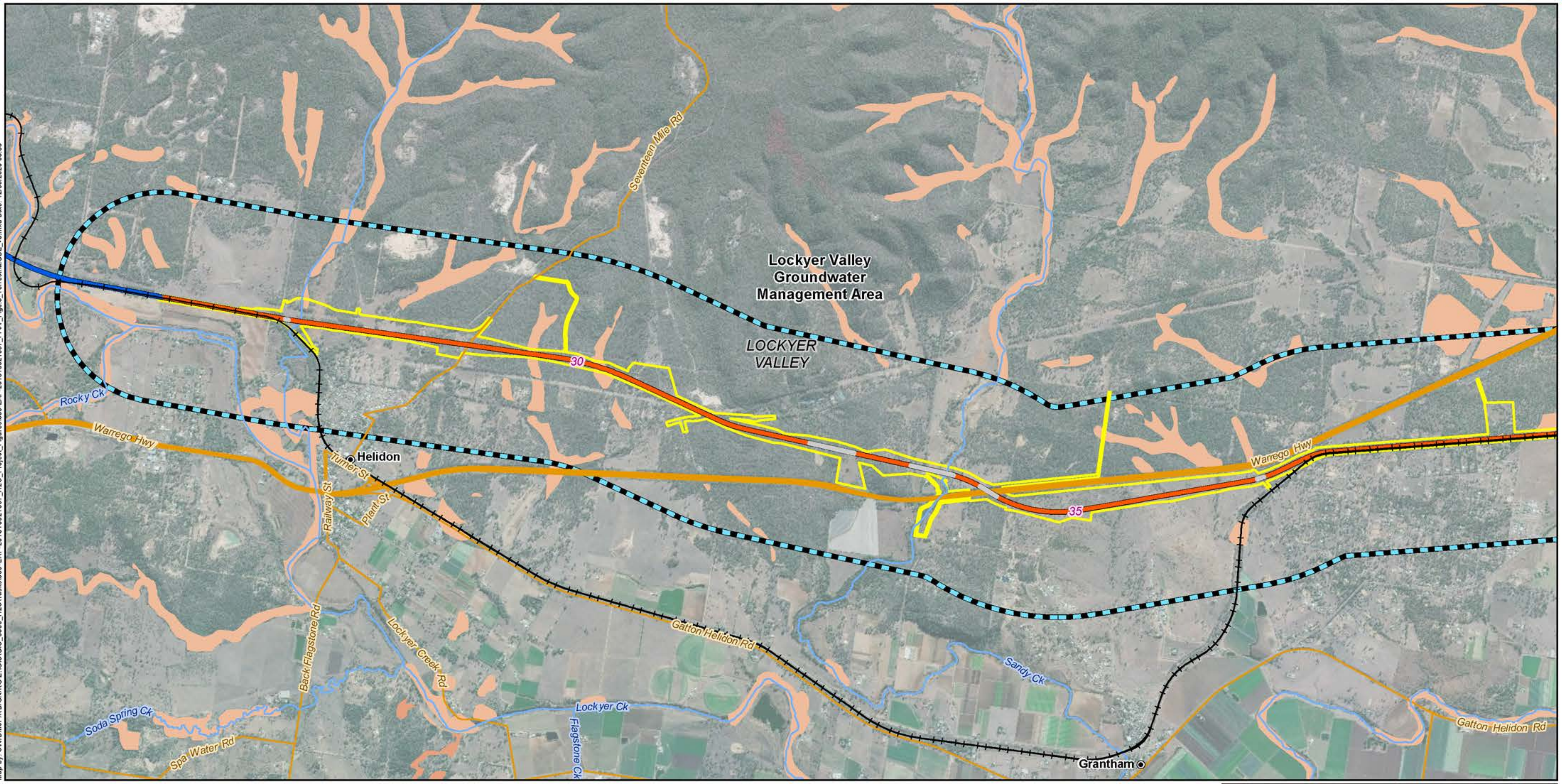
Helidon to Calvert

Figure 6.4d: Potential aquatic GDEs



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- G2H project alignment
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Bridges
- 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 2.5 km

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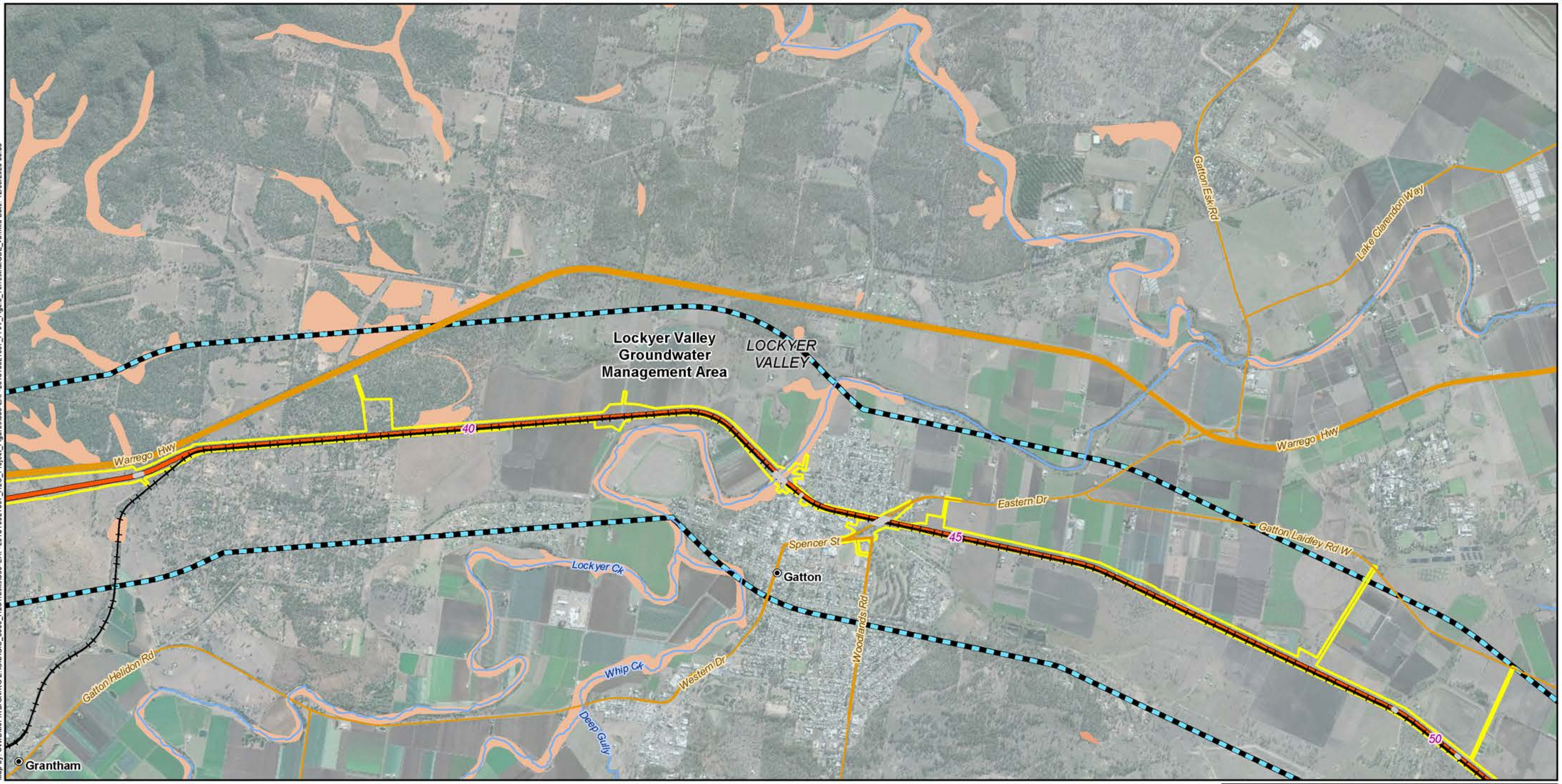
Helidon to Calvert

Figure 6.5a: Potential terrestrial GDEs

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



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Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Bridges
- 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 2.5 km

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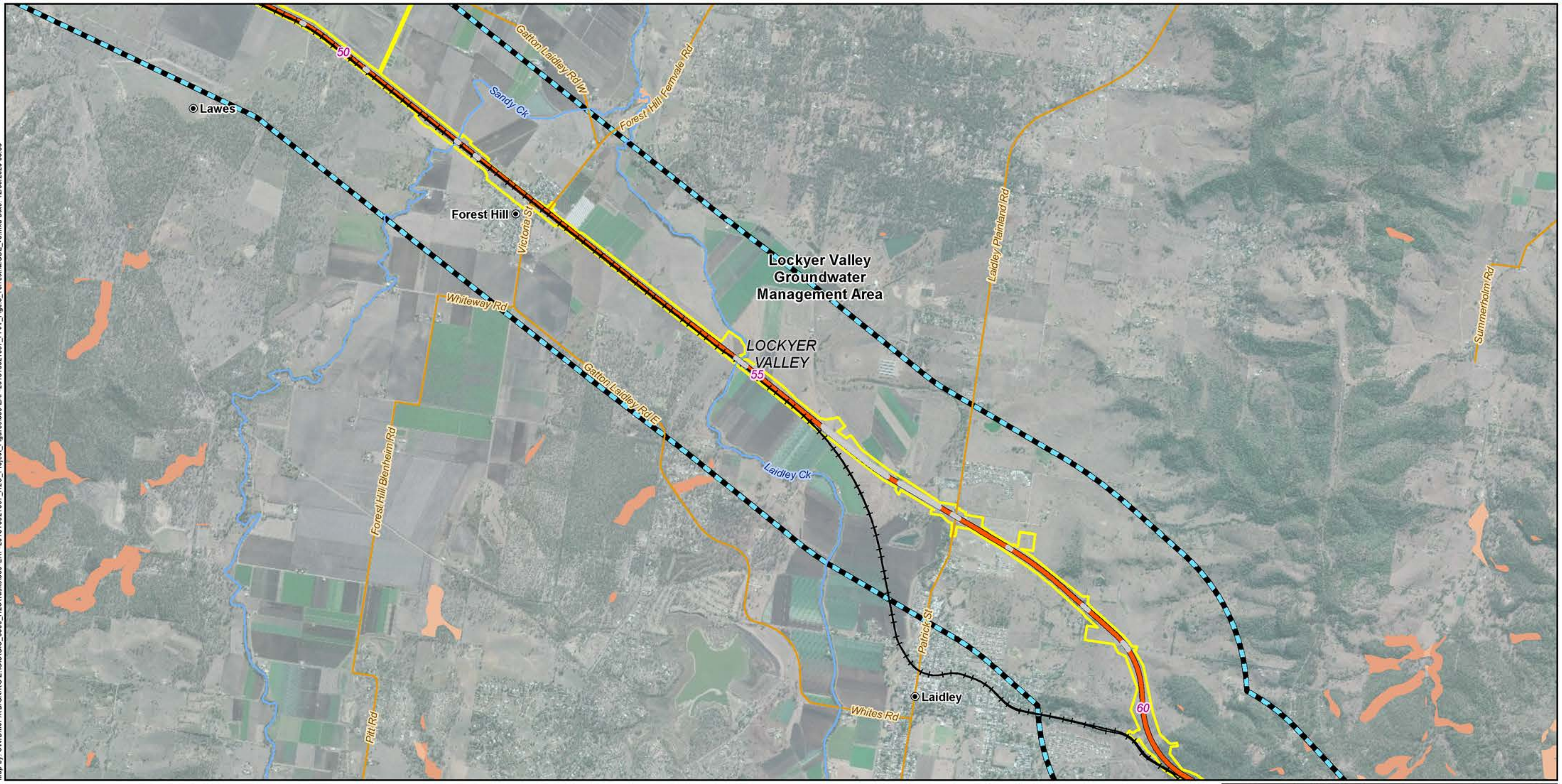
Helidon to Calvert

Figure 6.5b: Potential terrestrial GDEs

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



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Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- Watercourses
- Minor roads
- Bridges
- 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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Coordinate System: GDA 1994 MGA Zone 56

Helidon to Calvert

Figure 6.5c: Potential terrestrial GDEs

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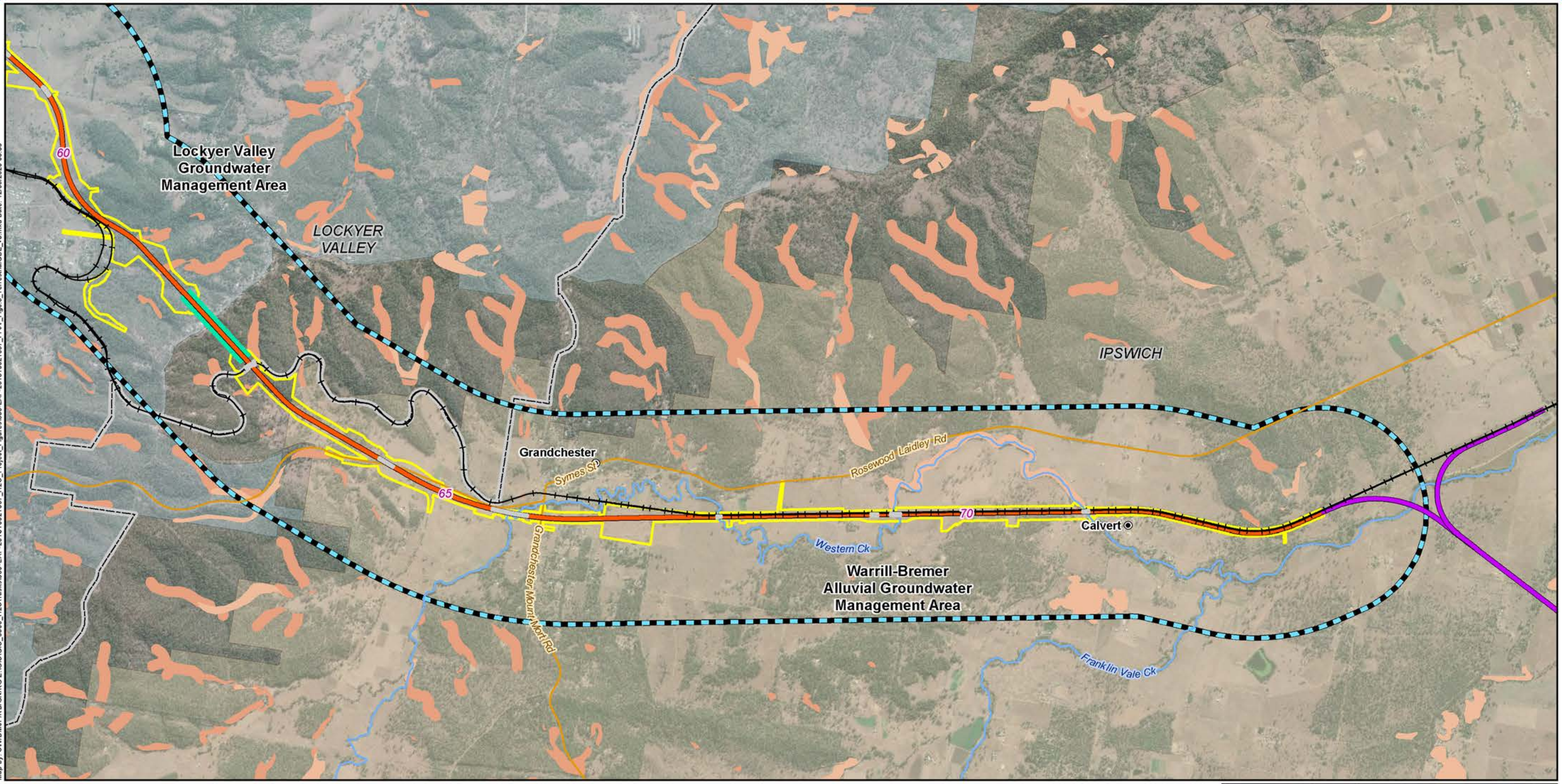

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Watercourses
- Minor roads
- Tunnel
- Bridges
- EIS disturbance footprint
- Groundwater study area
- Local Government Areas
- Lockyer Valley Groundwater Management Area
- Warrill-Bremer Alluvial 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 2.5 km

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Coordinate System: GDA 1994 MGA Zone 56

Helidon to Calvert

Figure 6.5d: Potential terrestrial GDEs

Map by: CW/DMcP/RB/GN/KG Z:\GIS\GIS_3300_H2C\Tasks\330-EAP-201810021057_H2C_Project_Figures\330-EAP-201810021057_FFJV_Fig6.5_TerrestrialGDE_v3.mxd Date: 12/05/2020 08:33

6.5.4 Surface water-groundwater interaction

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 is linked to leakage from the underlying sedimentary bedrock (Gatton Sandstone), which contains more-saline water (Raiber et al. 2017).

It is anticipated that there will be interaction between watercourses and shallow groundwater in the associated alluvial sediments at some locations; particularly where drainage channels are more deeply incised, and groundwater levels are shallow. Further, surface water-groundwater interaction is expected at locations being recharged under the Central Lockyer Water Supply Scheme (discussed in Section 6.2.3).

The degree of interconnection will vary 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).

An assessment of surface water-groundwater interaction for Laidley Creek (in the Lockyer Valley) was reported by Raiber et al (2016). The dynamic interaction during the drought (2007 data), post break of drought (2009) and subsequent flooding event (2011) can be seen in Figure 6.6.

During the drought, groundwater levels were low in the alluvial aquifer and generally below streambed elevation. The salinity of the alluvial aquifer groundwater increased over this period from increased contribution from the Gatton Sandstone due to higher groundwater elevations. Post break of the drought (2009) the alluvial groundwater levels increased, and Laidley Creek recharged the aquifer (i.e. the creek was considered to be a losing stream). Following the extensive 2011 floods groundwater levels from 2013 indicate that Laidley Creek became a gaining stream (i.e. groundwater entered the creek as baseflow).

The complex temporal pattern of surface water – groundwater interaction in mid-reaches of other streams in the Clarence-Moreton bioregion highlights the challenges in defining whether river reaches are gaining or losing, and the need for long-term time-series groundwater-monitoring data (Raiber et al 2016).

In areas of groundwater-surface water interaction, changes to groundwater levels, flow and/or quality that may occur due to the Project would therefore have the potential to affect environments including creeks, rivers, and GDEs.

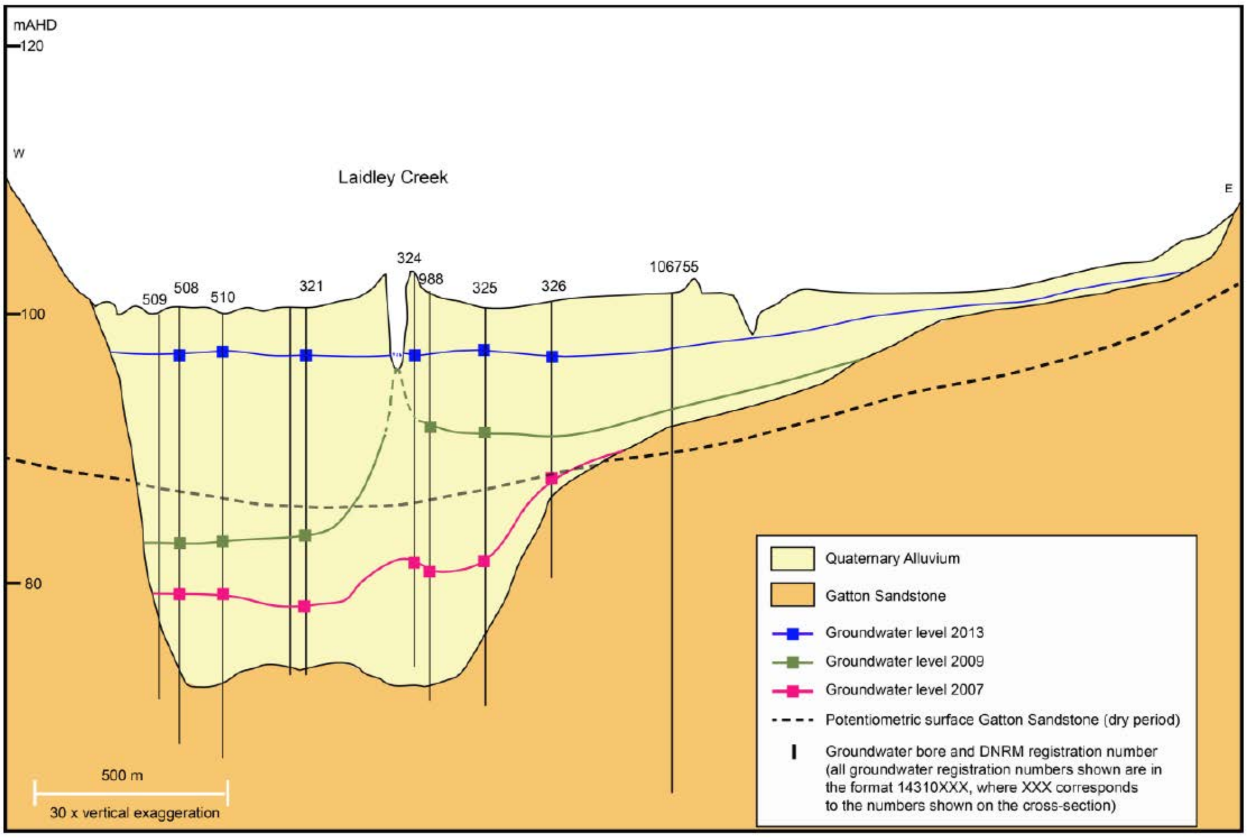


Figure 6.6 Cross section through Laidley Creek Catchment

Source: Raiber et al (2016)

7 Environmental values

QLD water quality (including water in rivers, streams, 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 QLD 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.

Relevant sub areas under the EPP (Water and Wetland Biodiversity) were identified in accordance with Schedule 1:

- The western part of the Project (approximately Ch 0.00 km to Ch 62.00 km): in the Lockyer Creek catchment (inclusive of Lockyer Creek, Laidley Creek and Sandy Creek), part of the Brisbane Basin. Relevant EVs and WQOs are described in the Department of Environment and Resource Management (DERM) (now Department of Environment and Science) document: *Lockyer Creek environmental values and water quality objectives* (DERM 2010a); and
- The eastern part of the Project (approximately Ch 62.00 km to Ch 73.00 km): in the Bremer River area, part of the Brisbane basin, with relevant EVs and WQOs described in the DERM document *Bremer River environmental values and water quality objectives* (DERM 2010b).

EVs for groundwater to be protected or enhanced in the groundwater study area are listed in Table 7.1 and discussed further below.

Table 7.1 Environmental values for groundwater relevant to the Lockyer Creek and Bremer River sub-catchments

EV	Definition
Aquatic ecosystems	'A community of organisms living within or adjacent to water, including riparian or foreshore area' (EPP (Water), schedule 2). The intrinsic value of aquatic ecosystems, habitat and wildlife in waterways 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. Waterways 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 waterways.
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.
Primary Contact Recreation	Primary recreational use of water means full body contact with the water, for example, diving, swimming, surfing, water skiing and windsurfing.
Drinking water supply	Suitability of raw drinking water supply. This assumes minimal treatment of water is required, for example, coarse screening and/or disinfection.

7.1 Aquatic ecosystems

There are no Wetlands of International Importance (Ramsar wetlands) within the groundwater study area. Two high ecological significance wetlands are located toward the eastern end of the groundwater study area, associated with the local hydrological catchment of Western Creek. The wetlands are located approximately 200 m north of Ch 72.40 km, and 400 m north of Ch 73.200 km) – as shown in Figure 6.4a-d and discussed in Section 6.5 (potential aquatic GDEs). Wetlands of high ecological value are within the groundwater study area between Ch 26.00 km and Ch 28.00 km, and several are intersected by the temporary construction disturbance footprint and permanent operational disturbance footprint Those wetlands considered to be potential GDEs (aquatic and/or terrestrial) are identified in Figure 6.4a-d and Figure 6.5a-d

Based on regional studies of potential GDEs discussed in Section 6.5, there are numerous moderate potential aquatic GDEs in the groundwater study area. These include Lockyer Creek, Laidley Creek and Western Creek (and their tributaries) (refer Figure 6.4a-d).

Numerous terrestrial GDEs of moderate to low potential are also present in the groundwater study area associated with the alluvial aquifers (refer Figure 6.5a-d). Such features can potentially be affected by changes to groundwater levels, flow and/or quality, and those relevant are considered in detail in Section 11.

No high potential GDEs are present within the groundwater study area.

7.2 Irrigation

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) states that the threshold salinity (refer to Section 6.2.5.1 for the definition of salinity) tolerances 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. Salinity values observed across DNRME (now Department of Regional Development, Manufacturing and Water) bores and Project bores within the groundwater study area (refer to Table 6.4 and Table 6.5) indicates all units are potentially suitable for irrigation.

7.3 Farm water supply/use

The salinity (refer to Section 6.2.5.1 for the definition of salinity) of the groundwater within the groundwater study area is variable, with TDS typically ranging from 1,000 to 6,000 mg/L TDS across the alluvial sediments and sedimentary bedrock. (refer Table 6.4 and Table 6.5), and generally precludes it 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 EV (i.e. Locker Creek, Sandy Creek and Western Creek).

7.4 Stock watering

In Section 6.2.5, the review of salinity in the DNRME groundwater database, regional groundwater reports and site investigation bores is presented in Table 6.4 and Table 6.5. The regional and site-specific salinity values indicate that groundwater is generally suitable for stock watering from the alluvium, Koukandowie Formation and the Woogaroo Subgroup (with TDS concentrations typically in the order of 1,000 to 6,000 mg/L as TDS). Refer to Section 6.2.5.1 for the definition of salinity.

The ANZG (2018) indicates that a loss of production and a decline in animal health occurs if stock are exposed to high salinity water for prolonged periods. Generally speaking a TDS value less than 4,000 mg/L is acceptable for livestock except for dairy cattle that require TDS less than 2,500 mg/L and poultry requiring less than 2,000 mg/L (**https://www.agric.wa.gov.au/livestock-biosecurity/water-quality-livestock**).

It is noted that in some instances values greater than 10,000 are present regionally in the alluvium, Koukandowie Formation and Gatton Sandstone (based on maximum TDS concentrations in Table 6.4), however such values have not been reported within the groundwater study area and site investigation monitoring bores (refer Table 6.4 and Table 6.5).

7.5 Primary recreation

This EV is not considered applicable to in-situ groundwater and more directly applicable to surface water. There are no registered groundwater springs within the groundwater study area that could be considered for recreational use. The nearest registered springs are located 4 km south of Ch 26.00 km (Helidon Spring) and 5 km north of Ch 26.00 km (Lockyer Creek Spring). Groundwater seepage from the alluvium or incised Clarence - Morton sedimentary units into water courses 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.

7.6 Drinking water

The suitability of water for human consumption (related to palatability) is defined in the Australian Drinking Water Guidelines where drinking water should not exceed a total dissolved solids (TDS) concentration of 600 mg/L (NHMRC and NRMMC 2011). Based on the salinity data presented in Section 6.2.5 (Table 6.5), the alluvium and sedimentary bedrock aquifer relevant to the study would be unsuitable for drinking water without treatment.

Note: Where only field electrical conductivity data is available at the Project and noting that EC is widely used as a surrogate for TDS, the water salinity recorded as EC (in µS/cm) can be converted to TDS in mg/L.

The conversion of these units is as follows: TDS (mg/L) = EC (µS/cm) x 0.64. Thus, the EC equivalent for TDS of 600 mg/L is 937.5 µS/cm

7.7 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 EVs.

A summary of the WQOs relevant to the Project is presented in Table 7.2 and are in accordance with the Lockyer Creek and Bremer River catchment guidance documents (DERM 2010a and 2010b respectively). The 20^{th} and 80^{th} percentiles of current conditions (i.e. July 2010) were adopted as guideline value by DERM.

Baseline groundwater quality data collected to date (October 2018) and the proposed ongoing baseline (background/pre-construction data) sampling will allow appropriate site specific WQO to be determined. These will be based on an assessment of the background groundwater quality data collected and with consideration to the DERM guideline values (refer Table 7.2).

Table 7.2 Groundwater Water Quality Objectives for the relevant catchments to the Project

Parameter	Percentiles	Lockyer Creek catchment			Bremer River catchment	
		Laidley Creek alluvium	Lockyer Creek alluvium	Sandy Creek alluvium	Western Creek	Franklin Vale Creek
EC (µS/cm)	20^{th}	760	1,050	1,120	1,330	1,300
	80^{th}	4,670	3,400	6,450	4,110	2,790
pH	20^{th}	7.7	7.7	7.5	7.4	7.4
	80^{th}	8.2	8.2	8.2	8	7.9
SiO_2 (mg/L)	20th	30	30	30	10	20
	80th	40	50	40	40	40
Total Ions (mg/L)	20th	600	730	680	960	1,040
	80th	2,740	2,160	3,700	2,380	1,540
TDS (mg/L)	20th	450	610	560	700	760
	80th	2,600	1,880	3,560	2,130	1,260
Na (mg/L)	20th	50	70	80	140	140
	80th	320	360	670	440	200
K (mg/L)	20th	0.8	1.5	1.3	0.5	0.5
	80th	2.6	3.8	3.5	3.3	3.7

Parameter	Percentiles	Lockyer Creek catchment			Bremer River catchment	
		Laidley Creek alluvium	Lockyer Creek alluvium	Sandy Creek alluvium	Western Creek	Franklin Vale Creek
Ca (mg/L)	20th	40	40	70	30	40
	80th	170	130	250	120	90
Mg (mg/L)	20th	40	45	50	50	60
	80th	210	160	300	150	120
Fe (mg/L)	20th	<0.01	<0.01	<0.01	<0.01	<0.01
	80th	0.03	0.04	0.04	0.01	0.01
HCO_3 (mg/L)	20th	320	320	300	210	520
	80th	540	650	510	610	710
Cl (mg/L)	20th	70	150	220	220	180
	80th	1,370	850	1,960	1,190	630
NO_3 (mg/L)	20th	0.2	0.5	0.3	<0.1	0.6
	80th	7.7	24.5	15.2	1.9	11.9
SO_4 (mg/L)	20th	5	10	5	4	<1
	80th	40	50	270	27	4
RAH (meq/L)	20th	-21.5	-13.4	-31.5	-13	-5.2
	80th	0.2	0.7	-1.8	0.7	1.7
SAR	20th	1.3	1.5	1.8	2.8	2.6
	80th	4.5	6.4	8.5	11.8	4.3
Hardness	20th	250	290	310	350	360
	80th	1170	860	1550	940	630

Source: Lockyer Creek and Bremer River catchment EV documents (DERM 2010a and 2010b).

Table notes:

meq/L = milliequivalents per litre
The 20th and 80th percentiles of current conditions are being used as a guideline value; RAH = residual alkali hazard; SAR = sodium absorption ratio.

7.8 Summary

Based on this review of EVs near the Project, the main groundwater EVs identified using available local and regional information and site investigation results include:

- Aquatic Ecosystems (moderate potential GDEs) in Lockyer Creek, Laidley Creek and Western Creek hydraulically connected to groundwater (primarily the alluvium)
- Irrigation (alluvium, Koukandowie Formation and Woogaroo Subgroup)
- Farm water (alluvium)
- Stock watering (alluvium, Koukandowie Formation and Woogaroo Subgroup).

8 Conceptual Hydrogeological Model

A conceptual model of the hydrogeological regime across the groundwater study area is summarised below and presented in Figure 8.1. The conceptualisation is a representation of the groundwater systems which incorporate an interpretation of the geological and hydrogeological conditions. Further, the conceptualisation consolidates the current understanding of the key processes of each groundwater system, including the influence of stresses, to assist in the understanding of potential changes/impacts on the systems from the Project.

8.1 Main hydrostratigraphic units

Most of the Project alignment (approximately 72 per cent) is underlain by unconsolidated Cenozoic to recent aged alluvium that is typically 20 to 35 m thick. These deposits display a distinct fining upwards sequence with gravels and coarse sands at the base and fine-grained floodplain sediments at the top (Rassam et al 2014). These alluvial beds occur mainly in the floodplains of Lockyer Valley (approximately Ch 40.00 km to Ch 60.00 km), and east of the Little Liverpool Range (approximately Ch 65.00 km to the end of the Project).

The main lithologies in the groundwater study area are sedimentary rocks of the Walloon Coal Measures (2 per cent of alignment), Gatton Sandstone (8 per cent of alignment), Koukandowie Formation (7 per cent of alignment) and Woogaroo Subgroup (11 per cent of alignment).

The Koukandowie Formation crops out as the Little Liverpool Ranges (approximately Ch 60.00 km to Ch 65.00 km), and the Woogaroo Subgroup crops out forming the Helidon Hills (approximately Ch 30.00 km to Ch 40.00 km). The Gatton Sandstone is predominantly overlain by alluvial sediments, with only minor areas where they crop out.

8.2 Groundwater levels and flow

Groundwater flow is typically controlled by topographic elevation i.e. flow occurs from topographic highs towards topographic lows. This relationship is evident in areas such as the Helidon Hills and Little Liverpool Range. A water table occurs in the alluvial sediments of Laidley Creek and Lockyer Creek through much of the central part of the groundwater study area, and Western Creek alluvium east of Little Liverpool Range. A water table aquifer is formed wherever the Woogaroo Subgroup (west), Gatton Sandstone (central) and Koukandowie Formation (east) crop out along limited sections of the groundwater study area.

Groundwater in the alluvial sediments occurs as baseflow beneath the main surface drainage channels. This is generally north and northeast in the central part of the groundwater study area, and east and northeast on the eastern side of the Little Liverpool Ranges. On a local scale, groundwater flow will be influenced by surface water-groundwater interaction and abstraction from water supply bores.

Regional groundwater in the shallow bedrock generally flows to the northeast, although local variations in flow directions are possible (for example due to groundwater abstraction). Mapping of Woogaroo Subgroup and Gatton Sandstone groundwater elevations indicate that groundwater flowpaths are influenced by the Lockyer Creek and Bremer River systems (Raiber et al 2016). On the eastern side of the Project alignment the Koukandowie Formation crops out in the Little Liverpool Range, and groundwater flow direction is locally controlled by a groundwater divide coinciding with the main ridge line.

8.3 Recharge

There is a net monthly and annual deficit of rainfall, with average evaporation exceeding average rainfall for all months (as discussed in Section 4.4.1). Recharge is likely to occur in response to higher or more continuous rainfall events, and overall net recharge rates in the groundwater study area are expected to be low.

Recharge to alluvial sediments is anticipated to be supplied by the following:

- Direct infiltration of rainfall (10.6 mm/year) and associated stream flow
- Seepage from ephemeral streams during periods of flow following rainfall
- Infiltration by surface water releases from Bill Gunn Dam (Lake Dyer) and Lake Clarendon Dam (off-stream storages that release water back into the creeks of the Central Lockyer as part of the Central Lockyer Water Supply Scheme)
- Sub-cropping rock below alluvium may also act as a source of recharge where upward vertical gradients and hydraulic connection occur, such as vertical discharge from the Gatton Sandstone into overlying alluvial sediments associated with watercourses (such as Lockyer Creek and Laidley Creek).

Recharge to the water table in rock formations occurs via direct infiltration of rainfall where the formations are exposed at the surface or blanketed by a thin layer of soil. For example, along ridgelines formed by the Woogaroo Subgroup (29.2 mm/year) and Koukandowie Formation (2.7 mm/year), and in lower lying areas where the Gatton Sandstone (3.7 mm/year) is not overlain by alluvial sediments. Recharge from overlying alluvial sediments may also occur where a downward hydraulic gradient occurs (i.e. where groundwater elevations in the alluvial sediments are higher than those in the underlying bedrock sediments).

8.4 Discharge

Discharge from alluvial sediments may occur as seepage to ephemeral streams and into underlying bedrock units during periods of higher groundwater levels - as seen in the Laidley Creek alluvial catchment (refer Figure 6.6). Discharge out of the groundwater study area will also occur as ‘underflow’ beneath creek channels. Evapotranspiration from vegetation growing in the creek beds and along the banks, and via pumping from the heavily utilised Lockyer Creek catchment are also primary discharge mechanisms from this unit.

Discharge mechanisms from the sedimentary 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. Discharge will also occur via evapotranspiration, typically along the ridgelines and in outcrop areas. Pumping bores also extract groundwater from the bedrock sediments within the groundwater study area (refer Section 6.4.1).

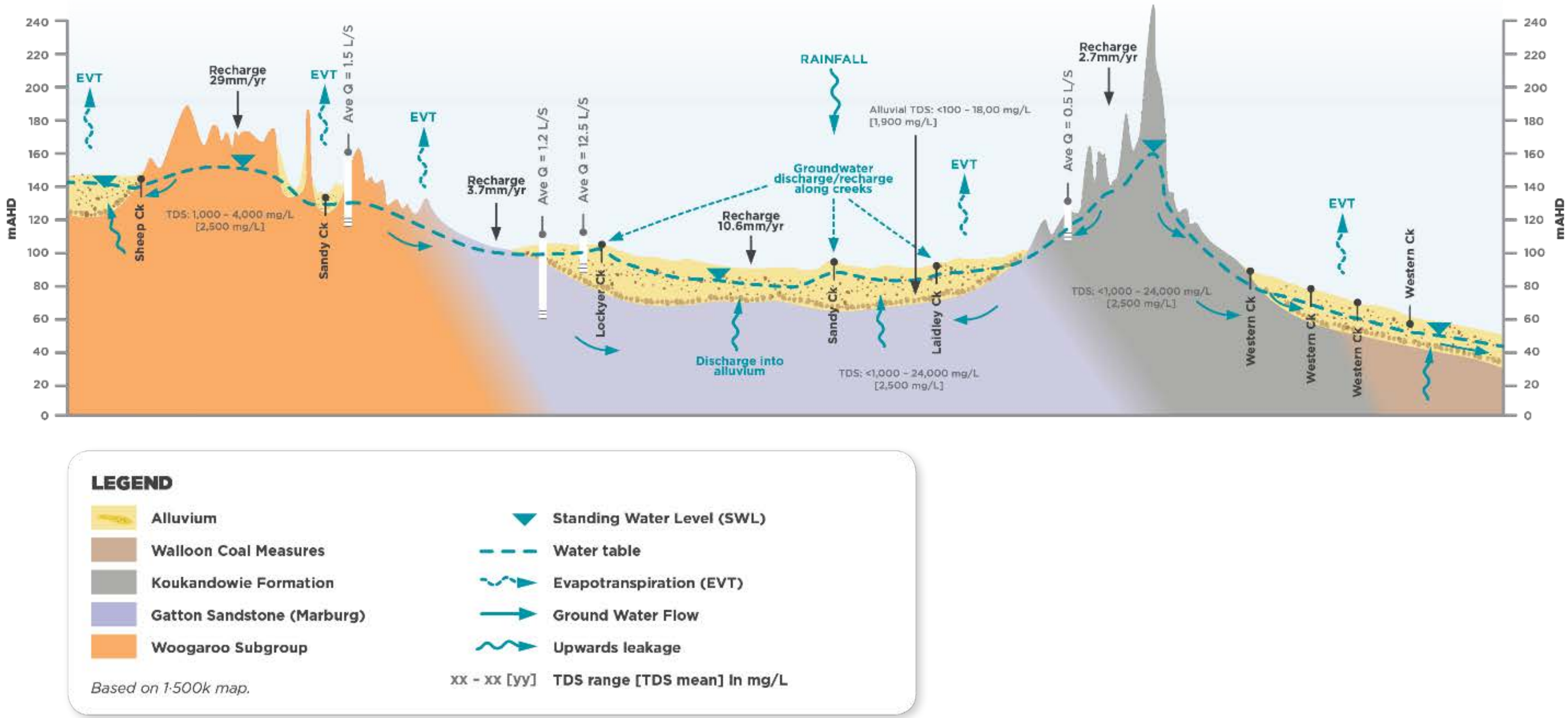


Figure 8.1 **Hydrogeological conceptual model for Helidon to Calvert**

9 Groundwater modelling

This section presents a summary of the preliminary inflow and drawdown modelling carried out as part of ongoing geotechnical investigations and hydrogeological interpretation (Golder 2019, 2020) (refer EIS Appendix W: Geotechnical factual report).

The results have been used to inform the significance-based impact assessment completed as part of this groundwater technical report.

9.1 Little Liverpool Tunnel and portal cuts

9.1.1 Objectives

The objective of the preliminary drawdown and inflow analysis by Golder (2020) was to inform an assessment of the potential to construct the Little Liverpool Tunnel and adjacent portal cuts as permanently drained structures.

9.1.2 Design assumptions

Preliminary estimate of groundwater inflows and drawdown associated with the drained tunnel and portal cuts included the following assumptions (from Golder 2020, refer Appendix A):

- Tunnel and portal cuts permanently drained and constructed entirely within the Koukandowie Formation
- Modelled portal cuts and tunnel alignment between Ch 61.60 km and Ch 62.80 km, with the tunnel itself located between Ch 61.84 km and Ch 62.66 km (a tunnel length of 820 m for the groundwater inflows and drawdown assessment)
- No lining or grouting works for higher permeability zones associated with faults or increased fracture intensity
- The Koukandowie Formation is permeable to a depth of 50 m. Below 50 m the rock was considered practically impermeable[2]
- Groundwater levels used in the model derived from correlation between topography and measured water level as shown in Figure 9.1.

The groundwater levels used in the model use a moving average applied over 300 m lengths to smooth the water level fluctuations that result from the direct application of the correlation to the topographic variations (visible on Figure 9.1). Note: actual water levels may differ locally due to variation in recharge and discharge, aquifer heterogeneity and anisotropy, as well as possible compartmentalisation within fractured rock.

[2] This relates to the vertical extent of the model being approximately 50 m below the tunnel, with no groundwater flow considered beyond this depth

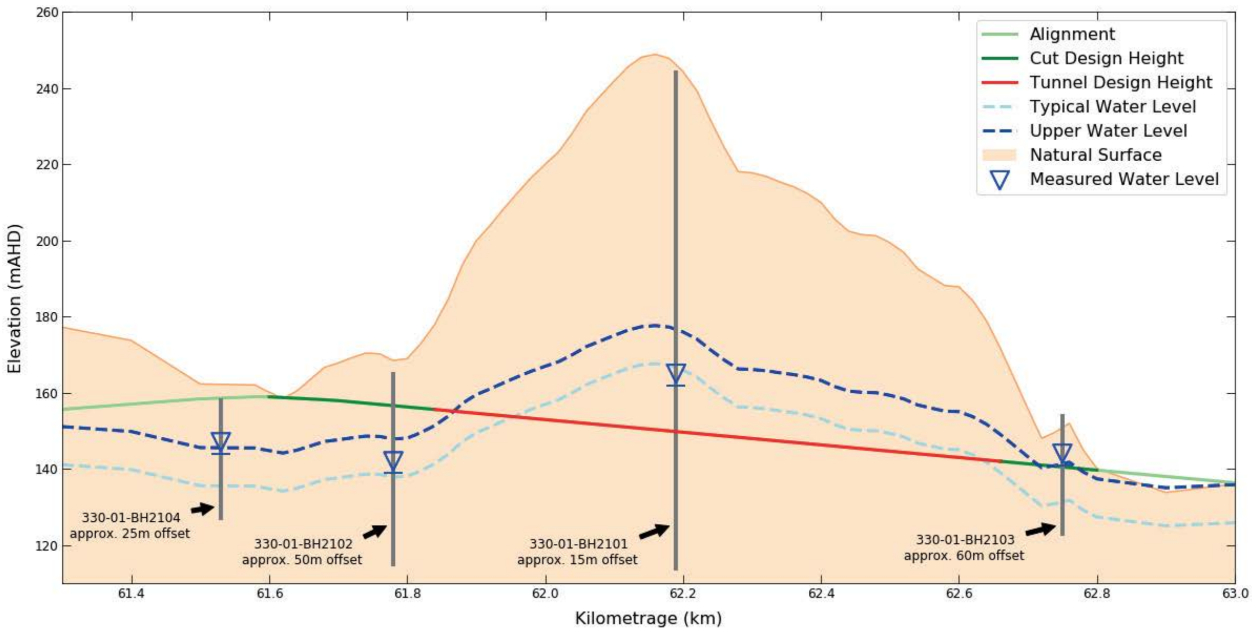


Figure 9.1 **Preliminary estimates of groundwater levels prior to tunnel construction '**

Source: Golder (2020)

9.1.3 Methodology

Groundwater inflows and drawdowns were estimated by Golder (2020) using the Perrochet analytical method (Marechal et al. 2014) and a steady-state numerical modelling approach using the finite element numerical modelling package SEEP/W model code (part of the GeoStudio software suite)[3].

The analytical method allowed simulation of transient discharge into the tunnel, and development of a cross-sectional steady-state numerical model using SEEP/W allowed comparison with results from the analytical method. Assumptions for each method are described in Golder (2020) and summarised below.

Inflow and drawdown analysis using the Perrochet method was based on assumptions including:

- Groundwater flows only horizontally within a plane perpendicular to the tunnel axis towards the tunnel
- Tunnel excavation will start from west to east at construction rate of 4 m per day over 205 days
- Water inflows to drained tunnel sections are along the entire length of the tunnel and the tunnel has been divided into 20 m intervals for the calculation
- The Koukandowie Formation is assumed to be homogeneous and isotropic above and below tunnel invert for
- Groundwater recharge occurs at a constant rate and does not change along the length of tunnel
- Horizontal hydraulic conductivity of 0.00864 m/day to represent the Koukandowie Formation
  - This is within the range of hydraulic conductivities estimated from regional and site-specific data (refer Section 6.3).

The inflow and drawdown analysis using the cross-sectional SEEP/W groundwater model. The modelling domain is shown in Figure 9.2 and was based on assumptions including:

- Modelled cross section at Ch 62.16 km, where rock thickness above tunnel crown is at its maximum
- Two geological units within the Koukandowie Formation have been included in the model: highly weathered rock with average 10 m thickness and underlying fresh rock[4]

[3] https://www.geoslope.com/products/seep-w
[4] Consistent with findings of the geotechnical drilling program at BH330-01-BH2101 to BH330-01-BH2104

- Constant head boundaries 5 km north (136.1 m AHD) and south (136.2 m AHD) of the tunnel based on correlation of groundwater depth and ground surface elevation
- Recharge applied to surface (top boundary) of the model, with rates adjusted to match inferred groundwater levels. Calibrated average recharge rate of 1.6 mm/year
  - Close to the lower estimate for regional recharge to the Koukandowie Formation reported in Section 6.2.3
- A regional groundwater flow directions have been interpreted from groundwater level contours estimated using the correlation between groundwater level and ground surface elevation. These contours indicate lateral flows along the tunnel alignment (i.e. perpendicular to the orientation of the cross-section model).
- Horizontal hydraulic conductivity of 0.08 m/day (adopting the upper hydraulic conductivity site-specific value, Table 6.7)
- Anisotropy ratio of 100 (horizontal to vertical).

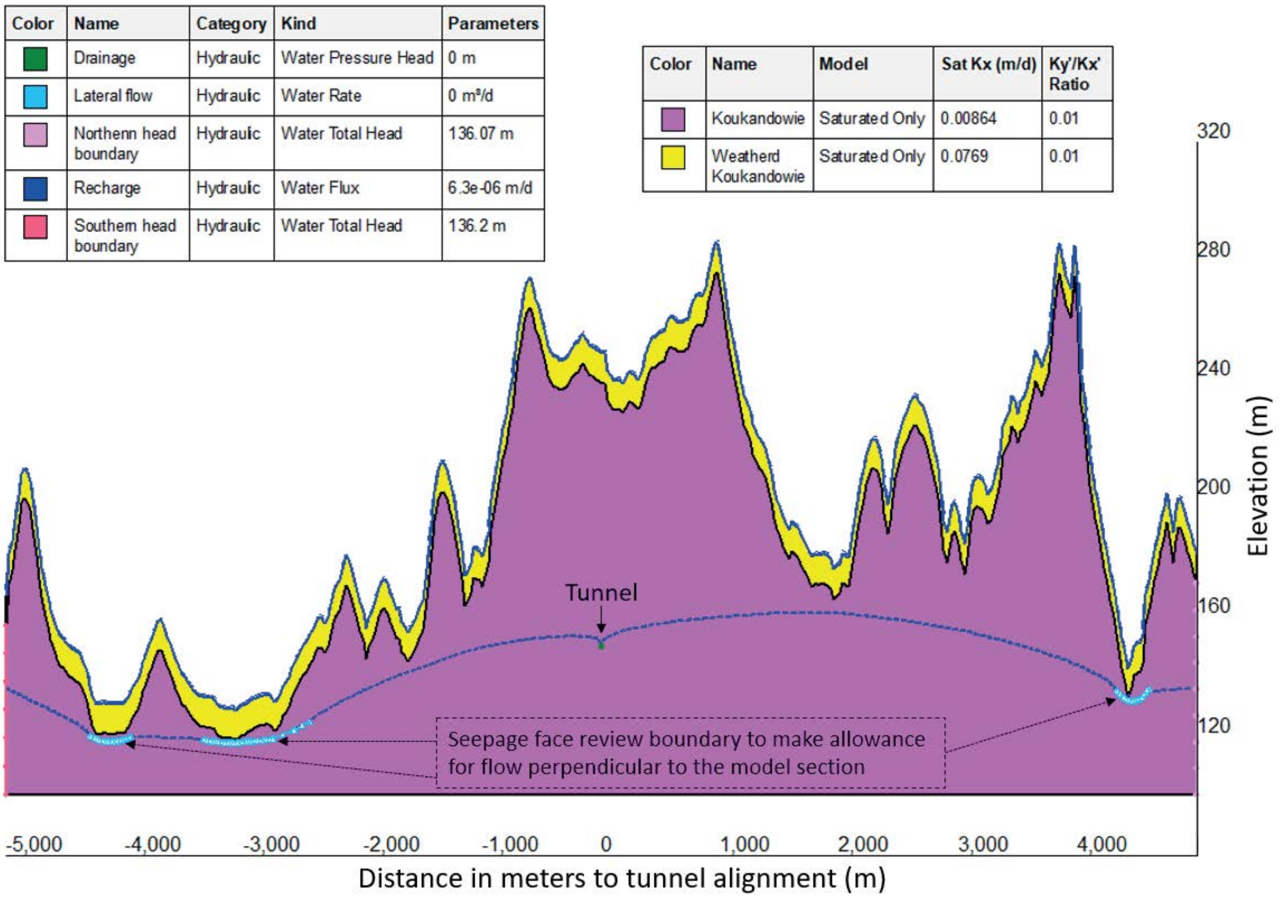


Figure 9.2 Little Liverpool Range tunnel SEEPW cross section model at Ch 62.16 km Golder (2020)

Calibration of the model and changes to model parameters (such as hydraulic conductivity and recharge) were based on matching inferred groundwater levels. It is noted that groundwater levels were estimated from limited site-specific groundwater data and relied on correlation between groundwater level and ground surface elevation.

Uncertainty analysis was also undertaken for predicted long-term drawdown. Potential effects of pre-existing groundwater levels 10 m higher than base case, and the presence of two higher permeability structural features were assessed.

Further details regarding calibration and sensitivity analysis are provided in Golder (2020) which is included in Appendix A.

Based on this methodology and the extent of available data it is considered that the models are Class 1 under the Australian Groundwater Modelling Guidelines (Barnett et al. 2012).

9.2 Cuts along the alignment

9.2.1 Assessment of cuts

The preliminary hydrogeological assessment (Golder 2020) included estimating potential groundwater inflows into slope cuts along the alignment. Five deep cuts were identified as potentially intersecting groundwater based on a comparison of cut floor elevations and groundwater levels along the alignment (with depth to groundwater inferred from topography and available groundwater level data). The cut locations are included in Table 10.2 and in Figure 6.3a and Figure 6.3c.

Estimates of drawdown due to cut inflows were not included in Golder (2020) but are considered in Section 10.2.2 as part of the groundwater technical report.

The potential implications of seepage water quality are described in Section 11.

9.2.2 Design assumptions and methodology

Preliminary analysis of potential groundwater inflows to cuts along the Project alignment was carried out by using the method described by Nguyen and Raudkivi (1983). Key assumptions are summarised below (from Golder 2020, refer Appendix A), and potential implications and limitations of the seepage rate assessment are provided in Section 10.3:

- Slope cuts are permanently drained
- Homogeneous and isotropic geological material
- Impermeable rock below bottom of slope cut (i.e. upward flow through cut floor is negligible compared to lateral flow[5])
- Groundwater recharge not considered in the analysis
- Analysis based on 'typical' hydrogeological parameters (included in Table 6.7)
- An average groundwater level was applied over the length of each cut (i.e. differences in groundwater elevation over length of cuts not included)
- Toe elevation of each cut is the level of discharge (i.e. no seepage face and hence conservative estimate of drawdown at cut and conservative estimate of lateral inflow).

The seepage associated with the deep cuts was estimated using the Dupuit-Forchheimer assumption (Nguyen and Raudkivi, 1983), holds that groundwater flows horizontally in an unconfined aquifer and that the groundwater discharge is proportional to the saturated aquifer thickness.

[5] Vertical hydraulic conductivity of formations is assumed to be 100th that of horizontal

10 Predictive simulations

10.1 Predictions of ingress

10.1.1 Little Liverpool Tunnel and portal cuts

A long-term inflow rate of approximately 0. 54 L/s was estimated for the Little Liverpool Tunnel, using the Perrochet analytical model. The long-term inflow into Ch 62.16 km (highest water level) was computed by the SEEP/W model to be less than 0.01 L/s per 100 m of tunnel. The predicted estimate of inflow using the analytical method for the 100 m section between Ch 62.14 and CH 62.24 was 0.19 L/s (refer Figure 9.1).

Higher inflows are predicted during construction, with a maximum short-term inflow rate of 2.56 L/s estimated. These short-term (weeks to a month) will need to be managed during the construction It is noted that the higher inflows would decline to rates similar to the long-term inflow rates over time (Golder 2020, refer Appendix A).

As part of an uncertainty analysis, to better assess inflow rates, a model scenario using elevated groundwater levels (+ 10 m higher than base case) was simulated. The estimated long-term inflow rate for the elevated water level scenario (as depicted in Figure 9.1) was 1.30 L/s, a total inflow rate calculated for the entire 820 m length of tunnel included in the modelling. Short term flow rates during construction were not considered under the uncertainty analysis scenarios.

The tunnel portal cuts were assumed not to intersect groundwater for modelling purposes. Subsequent groundwater level monitoring indicates that groundwater elevations at the western portal were approximately 143 m AHD at 330-01-BH2104 (Ch 61.50 km), and 140 m AHD at 330-01-BH2102 (Ch 61.75 km) in September/October 2018; approximately 15 m below the base of western portal (refer Figure 9.1). At the eastern portal the groundwater level was approximately 141 m AHD at 330-01-BH2103 (Ch 62.75 km) in September/October 2018 which is at or slightly above the base of the eastern portal (refer Figure 9.1). Continued baseline monitoring of groundwater levels near the portals and tunnel will inform seasonal variations and provide temporal groundwater level compared to base of portals and tunnel invert.

While the modelling has provided an estimate of tunnel inflows and allowed a groundwater impact assessment to be compiled, further investigations and modelling work during detailed design would refine estimated inflow rates to be managed during construction and operation of the free-draining Little Liverpool Tunnel and portal cuts (refer Section 10.3.3).

10.1.2 Cuts along the alignment

The hydrogeological interpretive report (Golder 2020, refer Appendix A) considered groundwater inflows into five deep cuts. Typical values for hydraulic properties were used (refer EIS Appendix W: Geotechnical factual report), and inferred groundwater elevations at cut locations was compared to base of cuts (although the initial depth of groundwater assumed in the cut prior to dewatering could not be verified).

Long-term inflows were less than 0.1 L/s at all locations, and short-term inflows ranged from less than 0.1 L/s to 0.2 L/s. The results are summarised in Table 10.1.

Based on the estimates of inflows (<0.1 to 0.2 L/s) to cuts along the alignment (Golder 2020), the annual volume of water seeping into a cut could be in the order 3,000 to 6,000 m^3 early post-construction (that is first year or so), reducing to less than 3,000 m^3/year in the longer-term.

Table 10.1 Estimated seepage rates for slope cuts

Location	Length (m)	Median cut elevation [GW elevation range] (m AHD)	Geology	Hydraulic properties[1]	Total seepage rate (L/s)	
					1 year post-construction	Long-term
Cut 330-C04: Ch 28.26 km – Ch 29.44 km (Figure 6.3a)	1,180	165 [167.7–178.1]	Gatton Sandstone	K = 0.00864 m/day Specific Yield = 0.05	0.1	< 0.1
Cut 330-C07: Ch 33.01 km – Ch 33.21 km (Figure 6.3a)	200	165.7 [176.8–185.8]	Woogaroo Subgroup	K = 0.432 m/day Specific Yield = 0.05	0.2	< 0.1
Cut 330-C08: Ch 34.53 km – Ch 35.07 km (Figure 6.3a)	540	148.4 [147.9-155.5]	Woogaroo Subgroup	K = 0.432 m/day Specific Yield = 0.05	0.1	< 0.1
Cut 330-C15: Ch 59.83 km – Ch 60.66 km (Figure 6.3c)	830	141.3 [151.5-156.2]	Koukandowie Formation and Gatton Sandstone	K = 0.00864 m/day Specific Yield = 0.05	0.1	< 0.1
Cut 330-C16: Ch 61.17 km – Ch 61.64 km (Figure 6.3c)	470	157.2 [159.8-185.5]	Koukandowie Formation	K = 0.00864 m/day Specific Yield = 0.05	< 0.1	< 0.1

Source: Golder (2020)

Table note:

1 Values from Table 5 of Golder (2020)

10.2 Predictive drawdown

10.2.1 Little Liverpool Tunnel and portal cuts

Under the base-case scenario (in which ‘typical groundwater levels’ are assumed at the tunnel – refer Figure 9.1), the Perrochet analytical method estimated a maximum long-term drawdown along the proposed tunnel to be up to 15 m, with drawdown of up to 5 m extending to around 400 m along the tunnel alignment, and to 50 m from the tunnel (refer Figure 10.1). It is noted that the drawdown mainly extents along the tunnel alignment. This is due to the tunnel construction effects with the inferred water table in the area.

Uncertainty analysis was undertaken to assess predicted long-term drawdown for three model scenarios. These considered higher than ‘typical’ groundwater levels, and the presence of two higher permeability structural features over the length of tunnel. The faults were not observed in the field, but the uncertainty scenarios were based on occasional faults being interpreted in the Little Liverpool Range strata. The modelled faults were nominally placed at Ch 62.16 km (highest groundwater level) and Ch 62.39 km (mid-point between eastern portal and Ch 62.16 km) and oriented perpendicular to the tunnel. The width of the structurally affected zones was modelled to a wide 10 m zone and a higher hydraulic conductivity was applied (0.08 m/day) based on the upper value in Table 6.7.

The three model scenarios considered were:

- Scenario 1: Elevated groundwater levels (+10 m), no structural feature - 5 m drawdown contour extends to approximately 750 m along the tunnel and 65 m from the tunnel
- Scenario 2: Base case groundwater levels, two structural features – 5 m drawdown contour extends to approximately 400 m along the tunnel alignment and 120 m from the tunnel
- Scenario 3: Elevated groundwater levels (+10 m), two structural features - 5 m drawdown contour extends to approximately 760 m along the tunnel alignment and 170 m from the tunnel. This scenario is considered the "worst case" for predicted drawdown extents.

There are currently limited site-specific temporal data to inform 'typical' versus 'upper' groundwater levels near the Little Liverpool Tunnel. However, groundwater level monitoring results from October 2018 were closer to those described in Scenario 1 where groundwater levels are 10 m higher than the base case of 'typical' water levels. The results from the uncertainty analysis for Scenarios 1 and 3 (with structural features), and in lieu of additional temporal data, are conservatively considered for assessing potential impacts to groundwater levels (refer Section 11).

While the model has allowed an assessment of potential impacts to groundwater users to be completed, further modelling work would refine drawdown predictions associated with a free draining Little Liverpool Tunnel, and better inform assessment of potential impacts due to changes in groundwater levels and flow patterns (refer Section 10.3.3).

'Predicted long-term drawdown extents are shown in Figure 10.2, Figure 10.3 and Figure 10.4.

Figure 10.1 Base case - Estimated long-term drawdown at Little Liverpool Range tunnel

Source: Golder (2020)

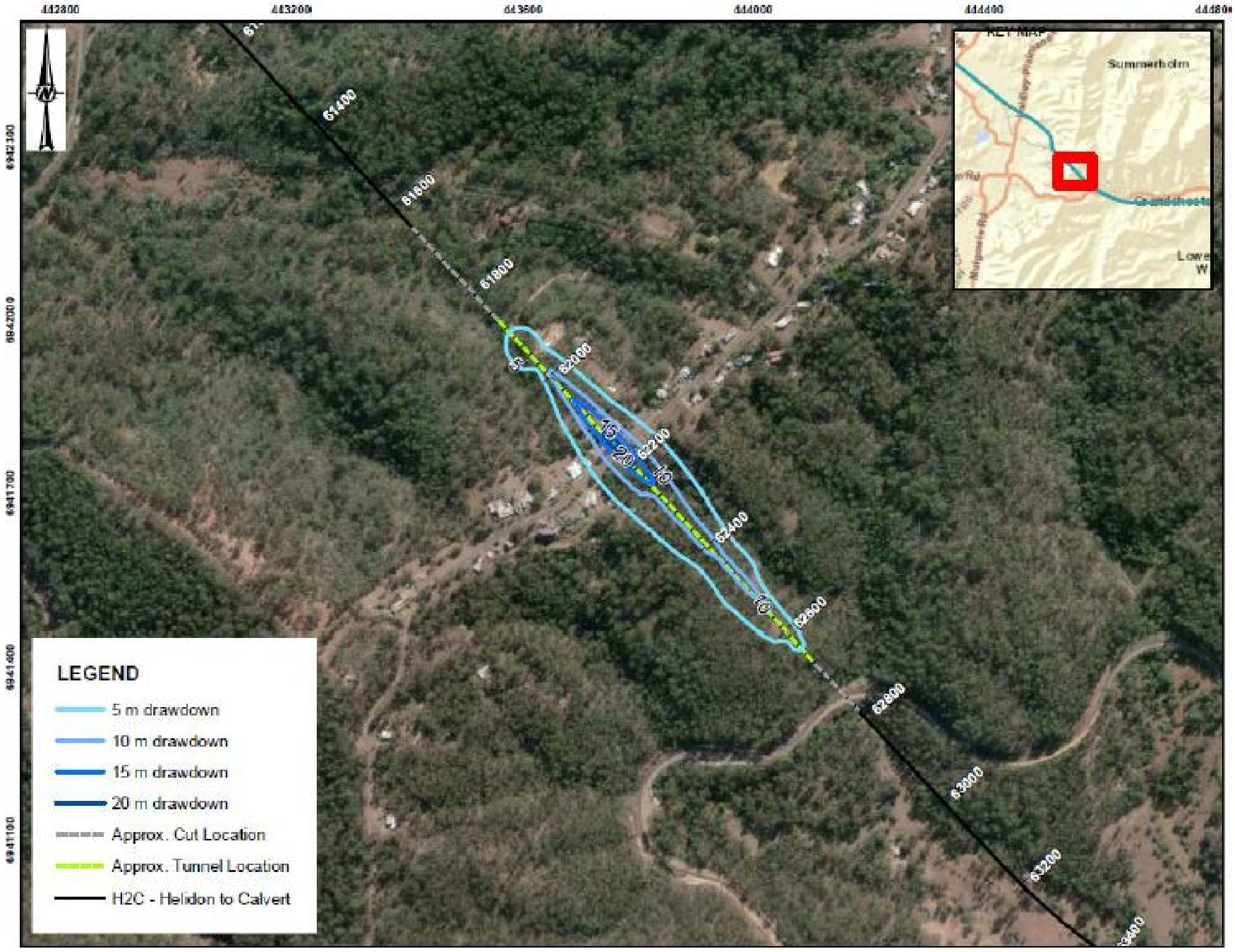


Figure 10.2 **Scenario 1 (Elevated groundwater levels): Predicted long-term drawdown extent**

Source: Golder (2020)

Figure 10.3 **Scenario 2 (Base case with faults): Predicted long-term drawdown extent**

Source: Golder (2020)

Figure 10.4 **Scenario 3 (Elevated levels with faults): Predicted long-term drawdown extent**

Source: Golder (2020)

10.2.2 Cuts along the alignment

Estimates of drawdown associated with drained cuts were not provided for the five deep cuts assessed in Golder (2020), however, long-term inflow rates in to the cuts were estimated to be less than 0.1 L/s (3,000 m^3/year) as discussed in Section 10.1.2.

A preliminary estimate of drawdown has been produced as part of this groundwater technical report, using this cut inflow estimate, based on a simple steady state mass balance approach.

The annual recharge volume required to balance the cut inflows can be calculated based on a 'recharge area' and a steady-state long-term net recharge, in this case 2.7 mm/year has conservatively been assumed (from Table 6.3). A buffer distance can then be estimated around each cut based on the required recharge area and length of cut, such that annual recharge meets annual inflows into the cut. The buffer distance is then used as an estimate of the long-term drawdown extent (that is, under steady-state / long-term conditions when drawdown has stabilised).

Table 10.2 summarises the estimated extent of steady state drawdown (i.e. buffer distance) for each of the five cuts considered in Golder (2020). The inflow rate of 0.1 L/s has been used based on Golder (2020).

This mass balance approach provides a conservative estimate for a zero-drawdown extent, that is, the distance at which no reduction in groundwater levels is anticipated. Moderate drawdowns in the order of 0.1 to 0.5 m would therefore occur closer to the cuts (possibly in the order of 300 to 500 m from the cuts) - due to the steep shape of the drawdown curve away from the cuts based on aquifer hydraulic properties of the rock formations being cut through.

Table 10.2 Estimated extent of drawdowns at cuts

Cut location	Cut length (m)	Annual inflow[a] (m^3/year)	Equivalent recharge area (m^2)	Drawdown extent[b] (m from cut)
Ch 28.26 km to Ch 29.44 km	1,180	3,200	1,066,667	300
Ch 33.01 km to Ch 33.21 km	200			470
Ch 34.53 km to Ch 35.07 km	540			400
Ch 59.83 km to Ch 60.66 km	830			350
Ch 61.17 km to Ch 61.64 km	470			420

Table notes:

a Based on inflow of 0.1 L/s from Golder (2020)

b Drawdown extent assumed same in all directions from edge cut

The estimates of drawdown extent are used in Section 11 when considering the potential for groundwater users (that is, bores and potential GDEs) to be impacted by reduced groundwater levels due to seepage into drained cuts.

10.3 Model limitations

10.3.1 Little Liverpool Tunnel and portal cuts

The preliminary hydrogeological interpretative report (Golder 2020) described the following limitations:

- The Perrochet method does not allow for anisotropy of models, although vertical hydraulic conductivities are expected to be considerably lower than horizontal hydraulic conductivity values used
- No account for groundwater recharge parallel to the tunnel alignment, limiting spatial extent of recharge zones and therefore potential overestimate of groundwater drawdown zone
- Materials assumed to be saturated only, with effects of variable saturation on groundwater flow and recharge not considered

Information regarding the extent and location of structurally affected zones is limited, and uncertainty analysis indicated such zones could significantly affect inflow and drawdown associated with the tunnel.

10.3.2 Cuts along the alignment

The following limitations were noted in Golder (2020):

- Impervious base to cuts may have resulted in underestimates of flow rates
- Rainfall effects on seepage rates not considered
- Structural features not included
- Seepage from perched groundwater not included in analysis

10.3.3 Model risks and mitigation

Groundwater related risks and proposed mitigation measures were identified by Golder (2020) and are summarised in Table 10.3.

Table 10.3 Model risks and mitigation measures

Risk	Mitigation measure
Higher groundwater levels in Koukandowie Formation leading to higher than predicted inflows to tunnel and portals	Proposed installation of monitoring bores every 200 m along tunnel alignment and all cuts anticipated to intersect groundwater table and installation of data loggers. To establish groundwater levels and inform final design and construction.
Preferential groundwater flow (i.e. fault structures, dykes) leading to greater than predicted tunnel inflows	Proposed additional geophysical investigations, installation of piezometers and borehole permeability testing. To identify location, extent and characteristics of geological structures along tunnel alignment prior to final design and construction.
Higher or lower hydraulic conductivity values of formations leading to current estimates being under or overestimates of tunnel and/or cut drainage	Proposed additional permeability testing of formations to establish hydrogeological characteristics of the aquifer systems along the tunnel alignment and cut locations
Higher recharge than anticipated and therefore higher inflows than expected to tunnel and portal cuts	Proposed continuous groundwater level measurements at monitoring bores along tunnel alignment and cuts

It is noted however that proposed cuttings and tunnel are through topographic highs to achieve an acceptable grade. Based on the hydrogeological conditions described in Section 6, and in particular the depth to groundwater, low hydraulic conductivity and proximity of groundwater users (i.e. bores and potential GDEs), the preliminary modelling is sufficient to allow an assessment of potential groundwater impacts to be completed. Potential impacts to groundwater and groundwater users due to drained cuts and tunnel are detailed in Section 11.

Of course, findings from additional investigations and assessments that may take place, and subsequent revised estimates of drawdowns and inflow rates to the tunnel and cuts would allow refinement of the current groundwater impact assessment.

11 Potential impacts

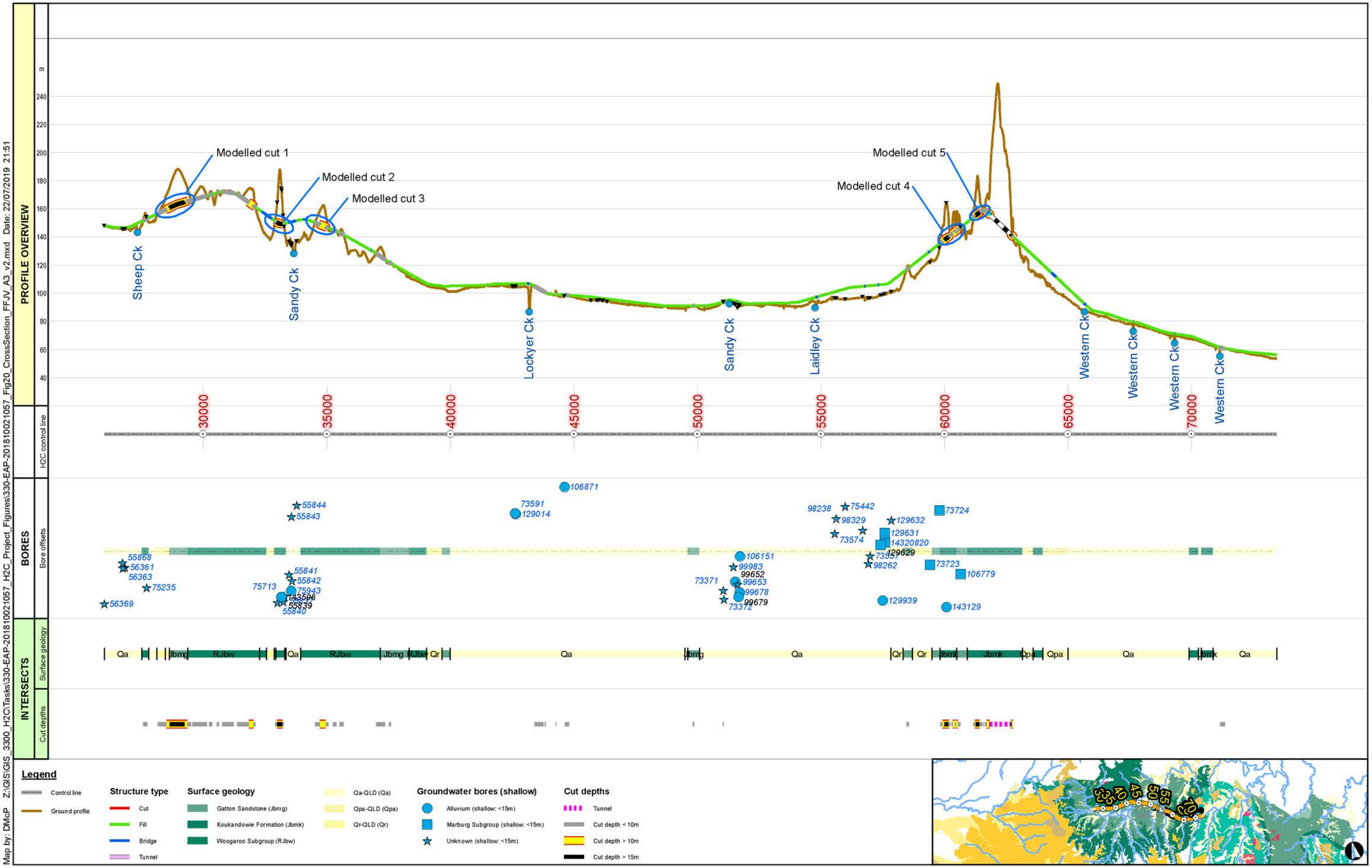
11.1 Design elements relevant to potential groundwater impacts

The proposed 47 km length of new dual-gauge rail line will be constructed across the landscape using a combination of cuttings, embankments, bridges and a tunnel through the Little Liverpool Range (refer Figure 11.1).

Although final design details may change, the current general design elements most relevant to the groundwater study are summarised in Table 11.1. These elements, and additional design and construction elements that may also impact on groundwater, are described further in the following sections.

Table 11.1 Summary of key elements with potential to impact on groundwater

Design element	Description	Assumptions
Embankments	Approximately 34 km embankments will be required along the alignment, and maximum height of bank 23 m (at Ch 33.40 km) Total volume of fill 2,450,540 m^3.	Bridges used to span significant creeks and adjacent alluvial sediments. 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 and groundwater flow patterns and ii) changes in groundwater quality.
Cuts	Cuttings will be required along the alignment to maintain grade. Total length of cut 7.6 km Approximately 9 sections of cut will be greater than 10 m, with four of these being greater than 20 m (from GIS analysis – refer Figure 11.1). Maximum depth of cut 38.8 m at Ch 60.00 km Large scale cut batters at tunnel portals.	Cuts typically through sedimentary rocks. Limited number and depth of cuts in alluvial sediments, none greater than 10 m. Significant dewatering of alluvial sediments not anticipated Cuttings less than 10 m deep unlikely to intersect significant depth below water table. Preliminary inflow estimates (Golder 2020, refer Appendix A) typically < 0.1L/s in five deep cut sections anticipated to intersect groundwater. Shallow perched groundwater may be intersected but result in relatively small and temporary inflows.
Tunnelling	Approximately 850 m long. Drill and blast or road-header construction. Maximum rock thickness above tunnel crown approximately 90 m.	Constructed through Koukandowie Formation. Free draining tunnel. Approximately 80% of tunnel length below water table, and up to around 10 m water above invert level (at Ch 62.14 to Ch 62.24). Portals will potentially intersect groundwater (refer Section 10.1.1). Current modelling assumes the tunnel will not intersect groundwater however further investigations and modelling work during detailed design would refine estimated inflow rates to be managed during construction and operation of the free-draining Little Liverpool Tunnel and portal cuts



Map by: DMcP Z:\GIS\GIS_3300_H2C\Tasks\330-EAP-201810021057_H2C_Project_Figures\330-EAP-201810021057_Fig20_CrossSection_FFJV_A3_v2.mxd Date: 22/07/2019 21:51

Horizontal lateral scale for borehole offsets: 1:60,000

Horizontal longitudinal scale as determined by chainage markers on C/L

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Package 330: Helidon to Calvert

Figure 11.1: Alignment Profile Schematic

11.1.1 Site clearing and grading

The Project site clearing includes removal of vegetation and debris. Site clearing will begin prior to the main earthworks' construction teams arriving. Where required, ARTC will seek vegetation clearing permits and implement management measures to minimise impacts to EVs (i.e. native fauna and water quality).

All turf, topsoil and other organic and unsuitable material will be stripped from the site. Wherever practical and appropriate, such material will be stockpiled and recycled within the Project disturbance footprint.

Access roads will be required along the alignment to allow drainage, earthworks, and bridge 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 waterways, and disturbance to the water quality of existing waterways.

11.1.2 Embankments

Approximately 70 per cent of the alignment will require embankments to attain the required grade. Some of these are significant with heights in the order of 15 to 20 m, such as near Sandy Creek (Ch 33.80 km) and east of Laidley Creek to the western flanks of the Little Liverpool Range (that is, from Ch 55.00 km to Ch 60.00 km), as seen in Figure 11.1. The anticipated subgrade for most embankments is Quaternary age alluvium. Embankments may also be constructed on subgrade consisting of sediments of the Woogarroo Subgroup in the west of the groundwater study area (between Helidon and Gatton).

11.1.3 Bridge and piling sections

The Project requires new bridge structures with the majority of bridges span Quaternary Age alluvium subgrade. The bridges would typically be founded on driven precast or bored in-situ piled foundations supporting in-situ reinforced concrete substructures. Cast-in-Place (CIP) piling technique with concrete emplaced via a tremmie line or other pumping method allows for the removal of augered soil/rock while pumping concrete or grout through the hollow stem to stabilise the ground.

11.1.4 Cut sections

The limited groundwater level data available (discussed in Section 6.2.1) indicate depths to regional groundwater may be in the order of 15 m below ground surface in areas of high relief where deep cuttings are proposed. Five cut sections were highlighted in Golder (2020) as potentially intersecting groundwater (refer Section 9.2) with long-term inflow rates in the order of less than 0.1 L/s at those locations.

Sections of deep cut (10 to 15 m and > 15 m) are indicated on Figure 11.1. Overall, cut sections between 10 and 15 m account for approximately 2 per cent (1.14 km) of the rail line, and cuts greater 15 m deep account for a further 2 per cent (1.15 km) of the alignment.

11.1.5 Tunnelling

The Project proposes a tunnel through the Little Liverpool Range to facilitate the required gradients for this area due to the undulating terrain. The current tunnel drive length is approximately 850 m, with a maximum cover of approximately 90 m. It is anticipated that groundwater will be encountered along parts of the tunnel, up to depths of around 10 m.

Stormwater runoff at the western portal area would either be collected in a portal stormwater sump to prevent it running the length of the tunnel or redirected by design of adjacent earthworks. The resulting water would then be pumped/drained to a nearby drain. Surface water will not be permitted to flow from the western portal, through the tunnel to the eastern portal. Any water collected inside the tunnel (e.g. groundwater, carry-through, washdown, firefighting) will be collected at the tunnel low end sump at the eastern portal. This water will likely be processed through a water treatment plant including hydrocarbon separation.

Regardless of the construction methodology, it is likely a flexible sheet type membrane would be used to waterproof the tunnel. For a drained tunnel, the purpose of this waterproof membrane is to control groundwater inflows over the crown and walls of the driven tunnel down to invert level, where the water would be collected in an appropriate groundwater drainage system. The other 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.

11.1.6 Construction water supply

Water will be required for construction activities including dust control, site compaction and reinstatement during construction. It is estimated that up to 564 ML of principally non-potable water will be required for the duration of construction. ARTC recognises water sourcing and availability is critical to supporting the construction program for the Project. Sources of construction water will be finalised as the construction approach is refined during the detailed design of the Project (post-EIS) and will be dependent on:

- Climatic conditions in the lead up to, and during, 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) Commercial water supplies where capacity exists: existing infrastructure, well understood water systems, available water volumes known, existing (in place) licensing

b) Public surface water storages (e.g. dams and weirs)

c) Permanently flowing watercourses

d) Privately held water storages (e.g. dams or ring tanks, under private agreement)

e) Existing registered and licenced bores

f) Treated water (e.g. from wastewater treatment plants, CSG fields, or desalination plants)

g) Drilling of new bores (least preferred option).

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
- Water quality requirement for the activity
- Source location relative to the location of need.

The buying or sharing of groundwater from existing water licence/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 two 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.

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 licenced 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.

11.1.7 Quarries

Potential quarries to be utilised by the Project have been identified and investigated with a focus on the required properties of the construction material and the haul distances from the quarries to the work fronts. Any material sourced from an existing operational quarry would be in accordance with the relevant facilities operational conditions.

These are not expected to have an impact on groundwater values within the groundwater study area.

11.1.8 Drainage infrastructure

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 the 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.

11.2 Construction phase potential impacts

Construction activities for the Project include a variety of activities which have the potential to impact on groundwater resources. These activities include earthworks (cut-and-fill sections), drainage construction, haul-road and access-track construction, track laying and bridge pilings.

11.2.1 Water resources

11.2.1.1 Loss or damage to registered groundwater bores

Registered bores within, or near, the temporary construction and/or permanent operational disturbance footprints have the potential to be damaged or lost during construction, or to become inaccessible during construction (refer Figure 6.3a-d). Liaison will occur with all potentially affected landowners to ensure that potential damage to/destruction of, or loss of access to, all bores is identified (ground truthing). Once detailed design has been undertaken and ground truthing of registered bores has occurred, potential risks can be refined, and mitigation determined.

11.2.1.2 Embankments

Surface loading from embankments can cause compaction of compressible materials (that is, alluvial sediments) leading to increased groundwater levels (i.e. mounding) upstream of the embankment and reduction in groundwater levels downstream of the embankment. Compaction will also reduce the ability of the aquifer material to transmit shallow groundwater (i.e. reduction in aquifer's hydraulic properties and damming effect). This can result in more frequent and prolonged inundation of low-lying ground, particularly during times of higher groundwater levels (for example, following significant rainfall recharge events).

The potential significance of impact is dependent on the embankment characteristics (i.e. height), compressibility of the underlying materials (i.e. clay, silt and sand content of the alluvial sediments) and depths to groundwater.

Depths to groundwater in the alluvial sediments are typically greater than 5 m and therefore the potential for impacts is reduced. The potential for mounding and damming of groundwater may be greater in areas of shallower groundwater in alluvial sediments local to active channels (such as Lockyer Creek, Laidley Creek and Western Creek).

As seen in Figure 11.1 the anticipated embankment heights are typically less than 5 m across the floodplains of Lockyer, Sandy and Laidley Creek (Ch 40.00 km to Ch 55.00 km). Embankment heights in the order of 10 to 15 m are proposed on alluvial sediments near Sandy Creek (Ch 33.80 km) and east of Laidley Creek to the western flanks of the Little Liverpool Range (that is, from Ch 55.00 km to Ch 60.00 km). These areas may present a greater potential to impact groundwater levels and flow.

As part of ongoing geotechnical investigations, an assessment of embankments, including critical sections (typically greater than 10 m, floodplains and poor ground conditions) have been reviewed in terms of stability of proposed geometry with respect to anticipated geological profile and groundwater levels. Assessment of anticipated subgrade conditions has also been undertaken for the alignment. The type and extent of subgrade treatment has been defined based on the expected ground conditions. Areas identified to likely require treatment include soft subgrades, reactive soils; where global stability or settlement has been identified to be a potential issue, and where drainage blankets are required.

Overall, there is the potential for embankments to effect groundwater levels and/or the hydraulic properties of the aquifer(s) locally across some section of the alignment (as described above). This will be confirmed as part of further geotechnical investigations which propose additional investigation and monitoring of groundwater levels in low lying floodplain areas to inform final design.

11.2.1.3 Subsidence/settlement

Early drawdown of groundwater levels 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.

The greatest potential occurs where groundwater is shallow, soils are compressible, and buildings/structures are nearby. In such locations either embankments or bridges are typically proposed.

Further, there are a limited number of cuttings anticipated to be significantly below water table, with five identified in Golder (2020). These deep cuttings in high relief areas are typically in more competent rock with depths to groundwater in the order of 20 m, and so the risk of settlement is reduced. Reduced groundwater levels due to dewatering and/or seepage into the tunnel are not considered to present a risk of settlement due to the competent sedimentary bedrock material being tunnelled (that is, Koukandowie Formation).

Overall, the potential for settlement and damage to buildings and properties due to subsidence from drained cuttings and the tunnel appears to low. It is anticipated that the potential for settlement will be confirmed as part of ongoing geotechnical investigations and will inform final design.

11.2.1.4 Dewatering/seepage to cuts and tunnel

Reduced groundwater levels during construction due to dewatering and/or seepage to cuts and the tunnel has the potential to impact groundwater users (e.g. registered bores and GDEs).

The maximum steady state extents of drawdown (i.e. reduced groundwater levels) due to long-term (that is, ongoing) seepage into cuts were estimated in Section 10.2.2, based on inflow rates for the five deep cut sections considered in Golder (2020). The long-term drawdown extents were between 300 m and 470 m from the cuts and can be used as conservative estimates for the construction phase.

There are only two registered bores within the predicted drawdown extents estimated in Section 10.2.2 for the five cuts considered in Golder (2020). The use of these registered bores is unknown, however, both are deep bores, constructed to 70 m (RN75520) and 102 m (RN106088), and are located approximately 250 m north of the cut at Ch 28.26 km to Ch 29.44 km (refer Figure 6.3a). The base of cut at this location is approximately 165 m AHD, which is around 15 m below the surface elevation at the deep bores (approximately 180 m AHD). Given that the depth to groundwater in this area of higher relief is anticipated to be in the order of 15 to 20 m, the water levels at the registered bores are not expected to be adversely affected by cut seepage. The location and use of the bores have not yet been physically confirmed. Further, the static water level, pump depth and pumping water level is also currently unknown. This information will be collected through liaison with the bore owners prior to the construction phase to allow for a detailed assessment of the potential for material impact (deemed a drawdown of 5 m below current water level) at these bores.

Overall, long-term seepage into the five cuts, based on the aquifer hydraulic properties, is considered to not adversely impact on groundwater levels in these registered bores.

There are potential aquatic GDEs (refer Figure 6.4) within the estimated extents of drawdown at four of the five cuts considered in Section 10.2.2 (after Golder 2020). Most of these features are described as wetlands associated with alluvial aquifers (from the BoM GDE Atlas). These are in lower lying parts of the landscape and below the elevation of the base of cut (refer Figure 11.1). Reduced groundwater levels in the bedrock due to long-term seepage into the cuts would therefore not be expected to adversely impact those potential aquatic GDEs. The exceptions are potential aquatic GDEs described as wetlands associated with flow from sedimentary rock that are close to the cuts at Ch 29.00 km (approximately 100 m south) and Ch 61.00 km (immediately adjacent). It is possible that if groundwater levels and/or flows are reduced then adverse impacts may occur to these potential terrestrial GDEs. These features have not been ground-truthed and are potential GDEs only, based on BoM GDE Atlas.

Potential terrestrial GDEs (refer Figure 6.5) are within the estimated extent of drawdown for two of the five cuts considered in Section 10.2.2 (after Golder 2020). Several moderate potential terrestrial GDEs (from regional studies) are present immediately adjacent to the cut located at Ch 29.00 km. These features are described as wetlands associated with alluvial aquifers (from the BoM GDE Atlas). They occur in lower lying parts of the landscape and below the elevation of the base of cut (refer Figure 11.1). Reduced groundwater levels in the bedrock due to long-term seepage into the cuts would therefore not be expected to adversely impact those potential aquatic GDEs. The low potential terrestrial GDEs (from regional studies) immediately adjacent to cut at Ch 61.00 km are described as wetlands associated with saline flow from sedimentary rock. It is possible that if groundwater levels and flow are reduced then adverse impacts may occur to these potential terrestrial GDEs. These features have not been ground-truthed and are potential GDEs only, based on BoM GDE Atlas.

Preliminary modelling of a drained tunnel through the Little Liverpool Ranges was carried out to estimate potential drawdown impacts (Sections 9 and 10). Under the base case scenario (estimated typical groundwater levels and no structural features) drawdown impacts were limited and no registered bores or potential GDEs were within the predicted 1 m drawdown extent and no unacceptable adverse impacts would be anticipated.

The nearest registered bore (RN106453) to the proposed tunnel is located approximately 240 m southwest of Ch 62.20 km. This registered bore is not located within the modelled 5 m drawdown extent for any of the three modelling scenarios. The use and characteristics of the bore will be confirmed post-EIS. Further, the static water level, pump depth and pumping water level is also currently unknown, however, the total depth of the bore is reported as being 91.5 m. This information will be collected through liaison with the bore owner prior to the construction phase to ensure there are no potential implications of tunnel construction related drawdown at this bore.

The existing low to moderate potential aquatic GDEs located 1 km to the northeast (refer Figure 6.5d) are not predicted to intersect with the modelled 5 m drawdown extent (refer Section 10.2). However, under this modelled scenario, there are several groundwater that may be impacted by the free draining tunnel.

11.2.1.5 Vegetation removal and surface disturbance

Increased groundwater levels (if any) due to vegetation removal across the groundwater study area will be localised and temporary; assuming revegetation across much of the disturbed area post-construction.

Construction and rehabilitation will be carried out progressively and therefore the total area of cleared vegetation will be minimised. Potential impacts to groundwater are likely to be minor only with disturbed area footprints small relative to regional scale groundwater systems.

11.2.1.6 Bridge 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).

11.2.1.7 Construction water supply

Water will be required for dust control, site compaction and reinstatement during construction and for tunnelling works. A number of potential water sources have been investigated, including extraction of groundwater and/or surface water, private bores, and watercourses. This will be further explored prior to construction in consultation with relevant stakeholders including regulatory agencies, local councils, and landowners. Where water is not available, it will be transported to the site via tanker truck and stored in temporary storage tanks.

11.2.2 Water quality

11.2.2.1 Spills and uncontrolled releases

During construction there is the potential for pollutants to reach groundwater from activities including accidental spills and leaks, and runoff from washdown areas. In areas of low relief where groundwater is shallower and hence more vulnerable, the flood plain alluvial sediments are typically dominated by clays and silty clays, which will impede vertical infiltration to groundwater.

11.2.2.2 Contamination

Leaching of contaminated embankment fill could also impact groundwater quality and affect EVs. It is anticipated that the Project will source embankment fill from cut volumes where possible. Any impacts would be local to embankments and limited in extent due to the linear footprint of these features. In areas of low relief where groundwater is shallower and hence more vulnerable, the flood plain alluvial sediments are typically dominated by clays and silty clays which will impede vertical infiltration to groundwater.

11.2.2.3 Bridge pilings

Changes to groundwater quality (for example pH and salinity) may occur during installation of pilings for bridge construction. Such changes (if any) will be temporary, localised and minor.

11.2.2.4 Acid rock drainage/acid sulfate soils

The intersection of sulphide-bearing rocks in cuts or tunnel or use of sulphide-bearing materials in embankment fill could present an acid rock drainage (ARD) risk following exposure of the rocks to oxygen and subsequent runoff which could impact on EVs, i.e. aquatic GDEs and groundwater users. ARD occurs naturally when sulphide minerals are exposed to air and water. This process is accelerated through excavation activities which increase rock exposure to air, water, and microorganisms. The resulting drainage may be neutral to acidic with dissolved heavy metals and significant sulfate levels. Potential acid sulfate soils also present a risk though excavation of cuts in soils susceptible to acid forming conditions.

Based on the surface geology traversed by the Project alignment, the following is noted:

- Alluvium – generally low risk due to young age and lack of sulphide minerals
- Sedimentary units – the Woogaroo Subgroup and Koukandowie Formation, in which cuts and tunnel are proposed, may host disseminated sulphide minerals (i.e. pyrite), particularly within shale and mudstone units.

Rainfall infiltration into cuttings and tunnel with sulphide-bearing minerals above the saturated zone may also pose an acid rock drainage risk even if the entire cut is in the unsaturated zone (above groundwater).

11.3 Operational phase potential impacts

Construction and operation of the proposed rail line has the potential to have long-term impacts on groundwater resources or groundwater quality are discussed below.

11.3.1 Water resources

11.3.1.1 Access to registered groundwater bores

Registered bores located within, or near to, the permanent operational disturbance footprint may become inaccessible or difficult to access due to rail corridor restrictions following construction (refer Figure 6.3a-d). Liaison with affected landowners will be undertaken to determine potential impacts.

11.3.1.2 Embankments

As discussed in Section 11.1.2, surface loading from embankments can cause compaction of compressible materials (that is, alluvial sediments) leading to increased groundwater levels (i.e. mounding) upstream of the embankment and reduction in groundwater levels downstream of the embankment. Compaction will also reduce the ability of the aquifer material to transmit shallow groundwater (i.e. reduction in aquifer's hydraulic properties and damming effect). This can result in more frequent and prolonged inundation of low-lying ground, particularly during times of higher groundwater levels (for example, following significant rainfall recharge events).

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.

Depths to groundwater in the alluvial sediments are typically greater than 5 m and therefore the potential for impacts is reduced. The potential for mounding and damming of groundwater may be greater in areas of shallower groundwater in alluvial sediments local to active channels (such as Lockyer Creek, Laidley Creek and Western Creek).

As seen in Figure 11.1 the anticipated embankment heights are typically less than 5 m across the floodplains of Lockyer, Sandy and Laidley Creek (Ch 40.00 km to Ch 55.00 km). Embankment heights in the order of 10 to 15 m are proposed on alluvial sediments near Sandy Creek (Ch 33.80 km) and east of Laidley Creek to the western flanks of the Little Liverpool Range (that is, from Ch 55.00 km to Ch 60.00 km). These areas may present a greater potential to impact groundwater levels and flow.

As part of ongoing geotechnical investigations, an assessment of embankments, including critical sections (typically greater than 10 m, floodplains and poor ground conditions) have been reviewed in terms of stability of proposed geometry with respect to anticipated geological profile and groundwater levels. Assessment of anticipated subgrade conditions has also been undertaken for the alignment. The type and extent of subgrade treatment has been defined based on the expected ground conditions. Areas identified to likely require treatment include soft subgrades, reactive soils; where global stability or settlement has been identified to be a potential issue, and where drainage blankets are required (FFJV 2019).

Overall the potential for embankments to significantly affect groundwater levels and/or the hydraulic properties of the aquifer(s) is considered to be low. This will be confirmed as part of further geotechnical investigations have been proposed that will include additional investigation and monitoring of groundwater levels in low lying floodplain areas to inform final design (FFJV 2019).

11.3.1.3 Seepage to cuts and tunnel

Lowered groundwater levels due to long-term seepage into cuts and the Little Liverpool Tunnel has the potential to impact groundwater users (including registered bores and surface water flows). Long-term dewatering may also have the potential to impact vegetation (GDEs) such as deep-rooted trees.

The maximum steady state extents of drawdown (i.e. reduced groundwater levels) due to long-term seepage into cuts were estimated in Section 10.2.2, based on inflow rates for the five deep cut sections considered in Golder (2020). The long-term drawdown extents were predicted between 300 m and 470 m from the cuts and can be used to consider potential to impact groundwater users during operational phase.

There are only two registered bores within the drawdown extents estimated for the five cuts considered in Section 10.2.2 (after Golder 2020). The use of the bores is unknown however both are deep bores, constructed to 70 m (RN75520) and 102 m (RN106088), and are located approximately 250 m north of the cut at Ch 28.26 km to Ch 29.44 km (refer Figure 6.3a). The base of cut at this location is approximately 165 m AHD, which is around 15 m below the surface elevation at the deep bores (approximately 180 m AHD). Given that the depth to groundwater in this area of higher relief is also anticipated to be in the order of 20 m, the water levels at the registered bores are not expected to be adversely affected by cut seepage. The location and use of the bores have not yet been physically confirmed. Further, the static water level, pump depth and pumping water level is also currently unknown. This information will be collected through liaison with the bore owners prior to the construction phase to allow for a detailed assessment of the potential for material drawdown impact at these bores.

Overall, long-term seepage into the five cuts considered are not anticipated to adversely impact groundwater levels in registered bores.

There are potential aquatic GDEs (refer Figure 6.4) within the estimated extents of drawdown at four of the five cuts considered Section 10.2.2 (after Golder 2020). Most of these features are described as wetlands associated with alluvial aquifers (from the BoM GDE Atlas). These are in lower lying parts of the landscape and below the elevation of the base of cut (refer Figure 11.1). Reduced groundwater levels in the bedrock due to long-term seepage into the cuts would therefore not be expected to adversely impact those potential aquatic GDEs. The exceptions are potential aquatic GDEs described as wetlands associated with flow from sedimentary rock that are close to the cuts at Ch 29.00 km (approximately 100 m south) and Ch 61.00 km (immediately adjacent). It is possible that if groundwater levels and/or flows are reduced then adverse impacts may occur to these potential terrestrial GDEs. These features have not been ground-truthed and are potential GDEs only, based on BoM GDE Atlas.

Potential terrestrial GDEs (refer Figure 6.5) are within the estimated extent of drawdown for two of the five cuts considered in Section 10.2.2 (after Golder 2020). Several moderate potential terrestrial GDEs (from regional studies) are present immediately adjacent to the cut located at Ch 29.00 km. These features are described as wetlands associated with alluvial aquifers (from the BoM GDE Atlas). They occur in lower lying parts of the landscape and below the elevation of the base of cut (refer Figure 11.1). Reduced groundwater levels in the bedrock due to long-term seepage into the cuts would therefore not be expected to adversely impact those potential aquatic GDEs. The low potential terrestrial GDEs (from regional studies) immediately adjacent to cut at Ch 61.00 km are described as wetlands associated with saline flow from sedimentary rock. It is possible that if groundwater levels and flow are reduced then adverse impacts may occur to these potential terrestrial GDEs. These features have not been ground-truthed and are potential GDEs only, based on BoM GDE Atlas.

Preliminary modelling of a drained tunnel through the Little Liverpool Ranges was carried out to estimate potential drawdown impacts (Sections 9 and 10). Under the base case scenario (estimated typical groundwater levels and no structural features) drawdown impacts were limited in magnitude and lateral extent, and no registered bores or potential GDEs were within the predicted 1 m drawdown extent and no unacceptable adverse impacts would be anticipated.

The nearest registered bore (RN106453) to the proposed tunnel is located approximately 240 m southwest of Ch 62.20 km. This is not located within the modelled 5 m drawdown extent for any modelling scenario. The use and characteristics of the bore will be confirmed post-EIS. Further, the static water level, pump depth and pumping water level is also currently unknown, however the total depth of the bore is reported as being 91.5 m. This information will be collected through liaison with the bore owner prior to the construction phase to ensure there are no potential implications of any drawdown at this bore.

The existing low to moderate potential terrestrial GDEs located 1 km to the northeast (refer Figure 6.5d) are not predicted to intersect with the modelled 5 m drawdown extent (refer Figure 10.2). However, under this modelled scenario, there are a number of groundwater users that may be potentially impacted by the free draining tunnel.

It is currently assumed that cuttings, portals and Little Liverpool Tunnel will be free draining and dewatering effects will be ongoing/long-term. Final design construction techniques could consider mitigation of groundwater inflows and reduce the lateral extent of dewatering effects and volume of groundwater to manage/discharge.

11.3.1.4 Bridge 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.

11.3.2 Water quality

11.3.2.1 Spills and uncontrolled releases

Water quality impacts, as a result of contamination from unintended spills and leaks of hydrocarbons (oils, fuels and lubricants) and other chemicals related to use of heavy plant and equipment and water mixtures and emulsions related to washdown areas, are not anticipated after the construction phase.

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.

Derailments and tunnel fires also have the potential to impact groundwater quality. The development and implementation of an *Incident Management Plan* will effectively address these types of rare events.

11.3.2.2 Embankments

Surface loading from embankments can cause compaction of compressible materials (that is, alluvial sediments) leading to increased groundwater levels (mounding) and the potential for increased salinity in shallow groundwater from evaporative effects. Depths to groundwater in the alluvial sediments are typically greater than 5 m and therefore the potential for impacts are reduced, however in areas of shallower groundwater such as alluvial sediments local to active channels (such as Lockyer Creek, Laidley Creek and Western Creek) the potential for impacts may be greater.

Further geotechnical investigations have been proposed that will include additional investigation and monitoring of groundwater levels in low lying floodplain areas to inform final design (FFJV 2019).

12 Mitigation measures

12.1 Design considerations

The mitigation measures presented in Table 12.1 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 12.1 Initial mitigation - design

Aspect	Design measures
Water resources	The Project is generally located within the existing West Moreton System rail corridor. The design has been developed to utilise the existing rail corridor protection and minimise land severance and impacts to natural and rural landscapes to the greatest extent possible. 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). The design of culverts and embankment have developed to minimise pre-loading and compaction of alluvial sediments. This will reduce the risk of altering shallow groundwater levels and recharge patterns. The current embankment designs allow for openings (i.e. culverts and bridge spans) near creeks and rivers to assist with flow.
Water quality	The disturbance footprint defined in Project design has aimed to minimise clearing extents to that required to construct and operate the works.

12.2 Proposed mitigation measures

To manage Project risks during construction mitigation measures have been proposed, as presented in Table 12.2. These proposed mitigation measures have been identified to address Project specific issues and opportunities, legislative requirements, accepted government plans, policy and practice.

Table 12.2 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 13.1.

Table 12.2 Groundwater mitigation measures

Delivery phase	Aspect	Proposed mitigation measures
Detailed design	Water resources	Undertake additional investigations and assessment of potential drainage/dewatering impacts associated with the Little Liverpool Tunnel, portals, and deep cut sections to refine current understanding and inform detail design, verify potential impacts and ensure implemented mitigation measures are appropriate. Refine seepage analysis for deep cuts to inform detail design (for example drainage blanket specifications, shotcrete and weep hole specifications). Review the proposed groundwater monitoring network (refer Table 12.3) to ensure locations are accessible during pre-construction, construction, and commissioning and operation of the Project. Continue collection of baseline groundwater monitoring data (levels and quality) to confirm seasonal variation and inform detail design and the development of a final Groundwater Management and Monitoring Program (GMMP). Include monitoring at any additional bores identified during the development of the GMMP prior to construction and operation. Engage with relevant landholders to confirm the location of existing bores, identification/confirmation of new monitoring bore locations and/or unregistered bores, and procure access agreements to existing registered groundwater bores included in the GMMP (refer Table 12.3). Confirm (i.e. physical survey or ground truth) the location of registered and unregistered bores that may be lost due to construction or operation of the Project. Where a groundwater bore is expected to be decommissioned or have access to it impaired as result of the Project, reasonable options and potential 'make good' arrangements will be agreed, where feasible, in consultation with the potentially affected landowner. Undertake field 'truthing' of identified potential aquatic and terrestrial GDEs within the groundwater study area that can potentially be impacted by the Project and confirm their status.
	Water quality	Undertake detailed geotechnical investigations at deep cut sections to inform design and location-specific construction management of groundwater. Risks associated with dewatering (i.e. water table lowering) and environmental management requirements during construction are identified through appropriate groundwater monitoring, modelling, and analysis.
Pre-construction	Water resources	Confirm source(s) for construction water requirements via consultation with relevant stakeholders (including landowners/occupants) prior to construction. Appropriate approvals and agreements will be sought for the extraction of water. Where private water sources are utilised for construction, monitoring will be undertaken during extraction to ensure volumes and conditions stipulated by licence requirements and/or private landholder agreements are met. Continue collection of groundwater monitoring data (levels and quality) to confirm seasonal variation and inform detail design and the development of the GMMP. Include monitoring at any additional bores identified during the development of the GMMP to establish a comprehensive monitoring regime prior to construction and operation.
	Water quality	Undertake site inspections prior to the construction of cuts, including visual examination of surface outcrops for sulphide minerals or evidence of sulphide mineralisation. Utilise the information from these inspections to inform the management of potential ARD from cuttings prior to construction works. Any excavated material which is suspected to contain sulphides will be stockpiled, lined and covered (as appropriate) to manage and minimise rainfall infiltration and potential leaching. Where possible, treatment and onsite reuse are preferred to off-site disposal. A case-by-case assessment of the suitability of material for treatment and reuse will be required. Routine sampling of discharge waters from the deep cuts intersecting groundwater will be undertaken to assess the potential for ARD processes taking place. Screening of the seepage water onsite for pH (trending down) and electrical conductance (EC) (trending up) and comparison to the baseline groundwater monitoring program results/trends will allow for indication of ARD processes. Further laboratory analyses for the key analytes pH, total dissolved solids (TDS), EC, total suspended solids (TSS), alkalinity, and dissolved metals will validate the presence or absence of ARD.

Delivery phase	Aspect	Proposed mitigation measures
		If ARD-contaminated discharge water is found to be generated from the deep cuts, this water will need to be impounded in ponds and neutralised via treatment (hydrated lime or dilution or similar) prior to release into the surrounding catchment or other discharge mechanism. Identification and/or reuse of contaminated, hazardous or potentially contaminated material on site (i.e. soil, ballast) will be subject to a risk assessment and managed accordingly.
Construction and commissioning	Water resources	Implement the Construction Environmental Management Plan (CEMP) and the construction phase GMMP with appropriate groundwater level and quality monitoring criteria based on groundwater monitoring, modelling, analysis, and regulatory requirements; with make-good arrangements with the owners of groundwater bores as necessary. Opportunities to re-use/ recycle groundwater resultant from tunnel and cuttings, where encountered, are identified and implemented where feasible during construction.
	Water quality	Vehicle and plant maintenance will be undertaken in suitable bunded hardstand areas, to minimise the risk of contaminants from incidental spills or leaks from entering aquifers via infiltration or surface runoff. 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. Personnel involved in ground-disturbing works are familiar with hazardous spill management procedures. 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. Chemical and dangerous goods storage areas will be located in appropriately designed facilities, such as bunded areas, sealed or lined surfaces, hardstand areas, or storage within containers. Storage of chemicals, oils, fluids and other hazardous substances will be in accordance with the appropriate safety data sheets and relevant Australian Standards. These measures would minimise the risk of contaminants from incidental spills or leaks from entering aquifers via infiltration or surface runoff. Where possible, laydown areas and storage areas will be located away from creeks, rivers and sensitive receptors such as existing groundwater bores or known GDEs. Imported fill material will be clean, certified contaminant free and be required to comply with regulatory guidelines for the intended use. Material won from site will be tested and assessed for suitability prior to use within proximity to potential groundwater infiltration sites. Any 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 are preferred to off-site disposal. A case-by-case assessment of the suitability of material for treatment and reuse will be required. Routine sampling of discharge waters from the deep cuts intersecting groundwater will be undertaken to assess the potential for ARD processes taking place. Screening of the seepage water onsite for pH (trending down) and EC (trending up) and comparison to the baseline groundwater monitoring program results/trends will allow for indication of ARD processes. Further laboratory analyses for the key analytes pH, TDS, EC, TSS, alkalinity, and dissolved metals will validate the presence or absence of ARD potential. If ARD-contaminated discharge water is found to be generated from the deep cuts, this water will need to be impounded in ponds and neutralised via treatment with hydrated lime or dilution prior to release into the surrounding catchment or other discharge mechanism. Implement the GMMP. Any groundwater supply and/or monitoring bores that are decommissioned will be undertaken in accordance with the *Minimum Construction Requirements for Water Bores in Australia – Edition 3* (Feb 2012).

Delivery phase	Aspect	Proposed mitigation measures
Operation	Water resources	Implement the operations phase GMMP. Groundwater levels at the Little Liverpool Tunnel will be monitored in accordance with the GMMP, or as required under the tunnel operational requirements.
	Water quality	Operators will notify their employee(s) of the storage, handling, or transport of hazardous substances or dangerous goods to raise awareness and reduce potential of associated incidents. Operators will ensure appropriate controls are 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. In the event of a spill, all necessary actions will be taken to contain the spill and follow ARTC emergency response protocols. Little Liverpool Tunnel and potential deep cut seepage water will be monitored and discharged in accordance with the water management plan, as confirmed during detailed design. Groundwater quality will be monitored in accordance with the GMMP, assessed against trigger levels and contingency measures followed (as required). Any groundwater supply and/or monitoring bores that are decommissioned will be undertaken in accordance with the *Minimum Construction Requirements for Water Bores in Australia – Edition 3 (Feb 2012*).

12.3 Groundwater monitoring and management program

A groundwater management and monitoring program (GMMP) is proposed to assist with Project environmental management and compliance requirements. The program will be conducted before, during, and after the construction works to ensure a suitable groundwater dataset is established before starting any construction activities, with continued monitoring to confirm that construction and operation are not impacting on the groundwater resources.

An indicative minimum network of three existing landholder bores and nine existing design phase investigation bores is summarised in Table 12.3. Landholder approval will be procured prior to inclusion of landholder bores in the network. The focus of the groundwater network is to monitor groundwater levels and quality at or near cuts and the tunnel.

It would be beneficial to install dedicated environmental monitoring wells in these existing locations and refine the network after the detail design is complete. The additional environmental monitoring bores could be sited in areas where storage of potentially contaminating materials is proposed, or in locations to provide adequate coverage up and down hydraulic gradient in areas of potential groundwater impact (for example at other deep cuts and significant embankments on compressible alluvial sediments). In particular, it is noted that additional monitoring bores screened in the alluvial sediment will be considered. Approximately 72 per cent of the alignment is underlain by alluvial sediments, with one monitoring well (330-01-BH2203) constructed in these sediments to date as part of geotechnical site investigations.

Table 12.3 Indicative minimum groundwater monitoring network

Chainage (km)	Bore ID	Easting[1]	Northing[1]	Aquifer[2]	Monitoring type	Rational
28.8	RN106088	414745	6953654	Woogaroo Subgroup[3]	Water level only Data logger	Registered bore within estimated extent of drawdown for cut at Ch 28.20 km – Ch 29.40 km
29.0	330-01-BH2301	414866	6953376	Gatton Sandstone	Water levels and quality Data logger	Background water levels and quality at cut location Ch 28.20 km – Ch 29.40 km
29.4	RN75520	415336	6953557	Woogaroo Subgroup[3]	Water level only Data logger	Registered bore within estimated extent of drawdown for cut at Ch 28.20 km – Ch 29.40 km
32.0	330-01-BH2303	417589	6952572	Woogaroo Subgroup	Water levels and quality Data logger	Background water levels and quality at cut section.
33.5	330-01-BH2203	419239	6952190	Alluvium	Water levels and quality Data logger	Background water levels and quality in floodplain near bridge and fill sections.
34.5	330-01-BH2207	420000	6951909	Woogaroo Subgroup	Water levels and quality	Background water levels and quality along alignment and cut at Ch 35.00 km
51.5	330-01-BH2212	436009	6948601	Gatton Sandstone	Water levels and quality	Background water levels and quality along alignment.
61.5	330-01-BH2104	443345	6942248	Koukandowie Formation	Water levels and quality Data logger	Monitor water levels and quality at west portal

Chainage (km)	Bore ID	Easting[1]	Northing[1]	Aquifer[2]	Monitoring type	Rational
61.8	330-01-BH2102	443525	6942102	Koukandowie Formation	Water levels and quality Data logger	Monitor water levels and quality at west portal
62.2	330-01-BH2101	443843	6941833	Koukandowie Formation	Water levels and quality Data logger	Monitor water levels and quality at tunnel.
62.6	RN106453	443535	6941700	Koukandowie Formation[3]	Water levels only Data logger	Registered bore closest to drained tunnel.
62.8	330-01-BH2103	444151	6941339	Koukandowie Formation	Water levels and quality Data logger	Monitor water levels and quality near east portal.

Table notes:

1 MGA94 Z56;
2 From Golder (2020)
3 From surface geology mapping (refer Figure 5.2)

After completion of baseline monitoring program, and with consideration to the detailed design, the frequency and location of level measurements will be reviewed and amended for suitability to achieve GMPP objectives.

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 study areas.

12.3.1 Groundwater level monitoring

Manual measurements on all bores is proposed during establishment of the baseline groundwater dataset as this will be the basis of comparison for the Project.

Automated pressure transducers/level loggers, to be installed in selected bores, with proposed locations indicated in Table 12.3. The monitoring across 12 existing reference design phase investigation bores (refer Section 3.2.2.2) will continue and data recorded after October 2018 will be incorporated in the detailed design phase.

Ideally, the baseline groundwater monitoring program will comprise a sufficient period to account for natural (seasonal) or anthropogenic fluctuations of groundwater levels prior to construction.

12.3.2 Groundwater quality monitoring

The baseline groundwater monitoring program is to include the bores included in Table 12.3 at a minimum to characterise the local groundwater quality prior to construction activities. The data collected during the baseline program will be used to assess potential impacts of the Project on local groundwater resources and inform likely discharge quality from cut and tunnel seepage.

Groundwater quality samples are to be collected in accordance with the agreed GMMP, ideally for a period sufficient to account for and allow characterisation of natural (seasonal) and/or anthropogenic variation. 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 suitability for construction water purposes.

Field parameters to be collected during sampling should include pH, EC, temperature, redox potential, and DO.

The analytical suite used in previous baseline sampling (conducted in October 2018) is proposed for laboratory analyses for continued baseline groundwater sampling:

- pH, EC and TDS
- Major anions (HCO_3^-, Cl^-, SO_4^{2-})
- Major cations (Ca^{2+}, Mg^{2+}, Na^+, K^+)
- Dissolved and Total Metals (Al, As, B, Cd, Cr, Cu, Mn, Pb, Ni, Se, Mo, Ag, Zn, B, Fe, Hg)
- Nutrients (ammonia, nitrite, nitrate, total nitrogen, total phosphorus).

In addition to the analytical suite in the October 2018 groundwater monitoring event, the following will be considered for future baseline groundwater monitoring:

- Hydrocarbons (BTEX, TPH/TRH, naphthalene)
- Pesticides/herbicides.

Groundwater quality data (post-EIS) 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 2018) and *Groundwater Sampling and Analysis – A Field Guide* (Geoscience Australia 2009) unless an updated version is available prior to commencement of the monitoring program.

Any trigger levels derived for the Project will be developed with reference to the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2018 edition).

12.3.3 Data management and reporting

The following data and reporting are proposed:

- All groundwater data will be validated with suitable QA/QC controls applied
- Monitoring data will be assessed to identify trends and compare to trigger levels (pre-construction).
- After baseline monitoring, data will be assessed on an annual basis to identify monitoring data trends. Where consecutive data points for the same bore(s) indicate divergence from the baseline trends or previous data, the bore data will be further investigated to determine appropriate actions. This may include more rigorous monitoring or trigger a re-assessment of impacts and/or mitigation measures.
- Relevant reporting will be completed on an annual basis and present the assessment of water levels and water quality trends, including hydrographs and hydrochemical trilinear plots. The annual assessment will recommend if the location and frequency of monitoring will be modified and recommend whether monitoring will cease.

13 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 11.

For each of the potential impacts discussed in Section 11, the initial significance assessment was undertaken on the assumption that the design considerations (or initial mitigation) factored into the reference design phase (refer Table 12.1) have been implemented.

Proposed mitigation measures (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 12 (refer Table 12.2).

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.

A summary of the significance assessment is provided in Table 13.1.

13.1 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 low.

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 Little Liverpool Tunnel and deep cut sections are proposed to further refine current understanding (as described in this groundwater technical report) and inform detailed design.

13.2 Long-term impacts

The main potential long-term impacts identified beyond the construction stage are:

- Changes to groundwater levels and flow associated with loading from embankments and ongoing dewatering/draining of the Little Liverpool Tunnel and deep cuts
- Management of discharge from dewatering/drainage of the tunnel and deep cuts.

Final construction 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 potential drainage/dewatering impacts of the tunnel and deep cuts, and potential loading impacts near significant embankments.

Table 13.1 Significance assessment summary for groundwater

Potential impact	Phase	Pre-mitigated significance			Application of proposed mitigation measures presented in Table 12.1 by aspect	Residual significance	
		Sensitivity	Magnitude	Significance		Magnitude	Significance
Loss of registered bores (through damage, destruction or loss of access)	Construction	Moderate	Moderate	Moderate	Water resources (pre-construction)	Low	Low
	Operations		Moderate	Moderate		Low	Low
Embankments – increased groundwater levels leading to surface inundation and/or increased groundwater salinity	Construction	Moderate	Low	Moderate	Water resources (detailed design) Water quality (detailed design)	Low	Low
	Operations		Moderate	Moderate		Low	Low
Ground movement due to reduction in groundwater levels (from dewatering/seepage to cuts and tunnel)	Construction	Moderate	Moderate	Low	-	Low	Low
	Operations		Low	Low	-	Low	Low
Reduced groundwater levels affecting groundwater users (bores and GDEs) due to seepage into cuts and groundwater extraction for construction water supply (if required)	Construction	Moderate	Moderate	Moderate	Water resources (detailed design, pre-construction, construction and operation)	Low	Low
	Operations		Moderate	Moderate		Low	Low
Reduced groundwater levels affecting groundwater users (bores and GDEs) – due to drained tunnel	Construction	Moderate	High	High	Water resources (detailed design, pre-construction, construction and operation)	Moderate	Moderate
	Operations		High	High		Moderate	Moderate
Contamination or water quality degradation of groundwater resources requiring remediation (including leaks and spills, flow between aquifers due to borehole intersections, contaminated spoil)	Construction	Moderate	Moderate	Moderate	Water quality (pre-construction, construction and operation)	Low	Low
	Operations		Low	Low		Low	Low
Acid rock drainage (ARD) from cuts and/or tunnel impacts on EVs (i.e. GDEs)	Construction	Moderate	Moderate	Moderate	Water quality (pre-construction, construction and operation)	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 (pre-construction and construction)	Low	Low
	Operations		Low	Low	-	Low	Low

13.3 Cumulative impacts

A CIA was required in the ToR *for an environmental impact statement: Inland Rail – Helidon to Calvert Project October 2017* (DSDMIP 2017).

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 alignment, 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.

ARTC propose to access construction water from existing Water Plans issued under the Queensland Water Act. Surface water and groundwater sources and associated Water Plans have been identified along the alignment (refer Section 2.3.2). ARTC may also elect to source water from a commercial water provider. Individual water supply plans will be prepared for each Inland Rail project in consultation with regulatory agencies, local government authorities and other stakeholders. These individual plans will identify specific water supply options applicable to each project, including relevant approval requirements. ARTC propose to consult with DNRME (now Department of Regional Development, Manufacturing and Water) to discuss the overall water demand for the Inland Rail projects, to highlight the relevant options that are being considered and discuss how any stakeholder concerns can be mitigated.

13.3.1 Surrounding projects and timeline relationships

Projects and operations surrounding the groundwater study area are summarised in Table 13.3 and shown on Figure 13.1.

Table 13.2 Projects and operations surrounding the groundwater study area

Project and proponent	Location	Description	Relationship to the Project
Gowrie to Helidon (ARTC)	Rail alignment from Gowrie to Helidon	26 km single-track dual-gauge freight railway as part of Inland Rail.	Potential overlap of construction with The Project H2C and G2H
Calvert to Kagaru (ARTC)	Rail alignment from Calvert to Kagaru	53 km single-track dual-gauge freight railway as part of Inland Rail.	Potential overlap of construction with the Project and C2K
Bromelton State Development Area (SDA)	Bromelton, Qld	Delivery of critical infrastructure within the Bromelton SDA will support future development and economic growth. This includes a trunk water main and the Beaudesert Town Centre Bypass. This infrastructure provides opportunities to build on the momentum of current development activities by major landowners in the SDA.	Ongoing development approximately 55 km at the Bromelton SDA could require deconfliction of construction resources. There may also be an increase of heavy vehicles using the surrounding highways
Ipswich Motorway Upgrade Rocklea to Darra (Remaining sections)	Western Brisbane, Qld	Addressing of congestion and extensive delays in the Ipswich Motorway corridor by a range of road upgrades along 7km of Ipswich Motorway between Rocklea and Darra.	Construction periods may overlap resulting in conflict in demand for construction resources and additional traffic on arterial roads
RAAF Base Amberley future works	RAAF Base Amberley	White paper dedicated future upgrades to RAAF Base Amberley at a cost of $1 B	Ongoing development at RAAF Base Amberley may see increase in road traffic with heavy vehicles and further increase as the Project construction occurs
Gatton West Industrial Zone (GWIZ)	3 km north west Gatton	Industrial development including a transport and logistics hub on the Warrego Highway	May increase road traffic and increase need for rail resources.

Project and proponent	Location	Description	Relationship to the Project
InterlinkSQ	13 km west of Toowoomba	200 ha of new transport, logistics and business hubs. Located on the narrow gauge, regional rail network and interstate network. Located at the junction of the Gore, Warrego and New England Highways.	Ongoing development could require deconfliction of construction resources. There may also be an increase in heavy vehicles using the surrounding highways

Only the adjacent ARTC projects have been considered in the CIA for groundwater (refer Table 13.3). Other projects are considered too far from the Project alignment 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 13.3 Applicable projects and operations considered for the groundwater cumulative impact assessment

Project and proponent	Location	Description	EIS status	Timeline	Relationship to the Project
Gowrie to Helidon (ARTC)	Rail alignment from Gowrie to Helidon	26 km single-track dual-gauge freight railway as part of the ARTC Inland Rail Project	Draft EIS being prepared by ARTC	Construction: 2021 – 2026 Operation: >50 years	Potential overlap of construction for the Project and G2H
Calvert to Kagaru (ARTC)	Rail alignment from Calvert to Kagaru	53 km single-track dual-gauge freight railway as part of the ARTC Inland Rail Project	Draft EIS being prepared by ARTC	Construction: 2021 – 2026 Operation: >50 years	Potential overlap of construction for the Project and C2K

The timeline relationships for projects are provided in Table 13.4. As a worst case it has been assumed the construction phase of all three ARTC projects will be run concurrently.

Table 13.4 Project relationship timeline for Helidon to Calvert Project

Project	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Gowrie to Helidon (ARTC)										
Helidon to Calvert (ARTC)										
Calvert to Kagaru (ARTC)										

Legend **Construction** **Operation**

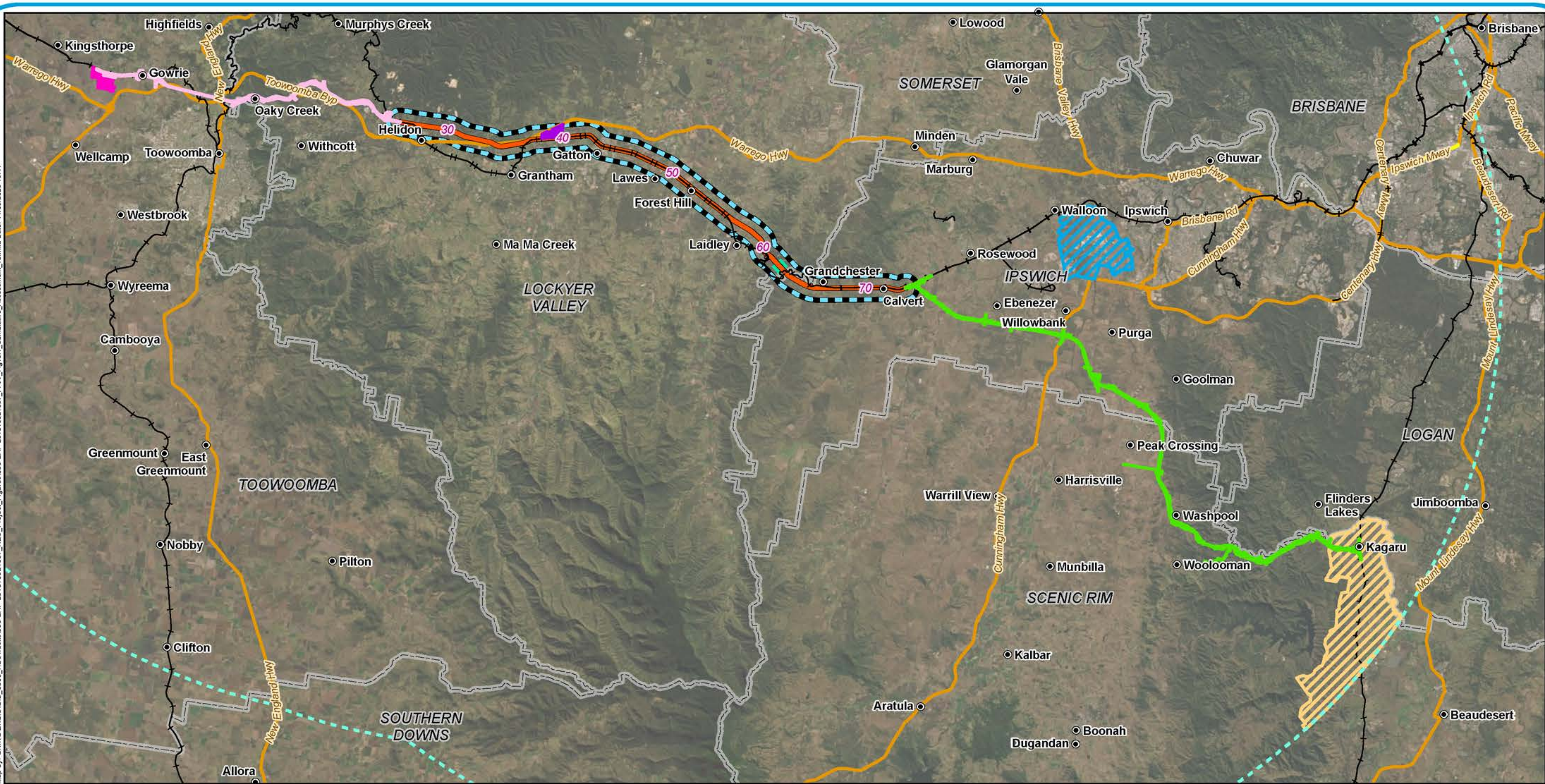
13.3.2 Assessment of potential cumulative impacts

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 13.5.

Table 13.5 Summary of potential cumulative impacts

Project	Potential cumulative impact	
	Groundwater levels	Groundwater quality/contamination
Gowrie to Helidon (ARTC) Calvert to Kagaru (ARTC)	Potential overlap of impacts from reduced groundwater levels due to seepage to tunnels and cuttings, groundwater supply (if required). Potential primarily at the start and end of alignment where the Project abuts these other ARTC projects. Possible subsequent impacts on groundwater users.	Potential cumulative impacts on groundwater quality in shallow aquifers from derailments and tunnel incidents, spills/leaks from heavy machinery, drill rigs and storage of fuels.

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



Map by: GN/KG Z:\GIS\GIS_3300_H2C\Tasks\330-EAP-201810021057_H2C_Project_Figures\330-EAP-201810021057_FFJV_Fig13.1_Cumulative_Assessment_v3.mxd Date: 11/05/2020 15:41

Legend

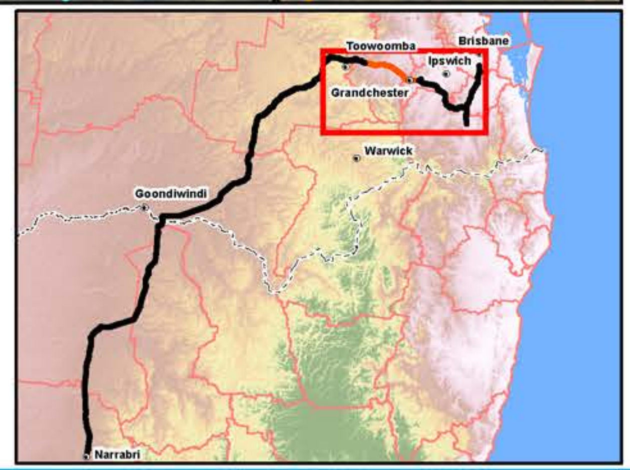
- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- Tunnel
- Major roads
- Minor roads
- Cumulative impact study area
- Local Government Areas
- Groundwater study area

Projects

- Bromelton State Development Area
- Calvert to Kagaru
- Gatton West Industrial Zone (GWIZ)
- Gowrie to Helidon
- Interlink SQ - Global Logistics Centre
- Ipswich Motorway Upgrade
- RAAF Amberley

A3 scale: 1:350,000

0 3 6 9 12 15 km



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Coordinate System: GDA 1994 MGA Zone 56

Helidon to Calvert

Figure 13.1: Projects surrounding the proposal - cumulative assessment

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 will 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 will 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 13.6.

Table 13.6 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 at ends of the Project alignment with either ARTC projects. Overlap of construction activities at the ends of the Project alignment with either ARTC projects.	Adherence to dewatering and water supply mitigation measures discussed in Section 12. Adherence to the draft Outline Environmental Management Plan (draft Outline EMP) to respond effectively to groundwater level drawdown.
	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. Overlap of construction activities at the ends of the Project alignment with either ARTC projects.	Implementation of the groundwater monitoring program to identify and respond to issues. Adherence to the draft Outline EMP 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				

14 Conclusion

To meet the study scope and objectives outlined in the ToR, 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 assessed and a significance assessment carried out with the key conclusions being:

- A moderate residual significance risk was identified for the potential of reduced groundwater levels to impact groundwater users (registered bores and potential GDEs) due a drained Little Liverpool Tunnel under model Scenario 1. Under this scenario groundwater levels were modelled as being 10 m higher than the anticipated base case model of 'typical groundwater levels. Additional groundwater level monitoring data have since indicated that the higher groundwater level Scenario 1 can occur in response to wet season and provides a representative simulation of seasonal groundwater fluctuation and impact assessment.

  Continued groundwater level monitoring will confirm groundwater levels at the tunnel and inform additional design investigations and modelling
- Residual significance risks were identified as being low for all other potential impacts including loss of registered bores through destruction or loss of access, reduced groundwater levels from seepage to cuttings impacting groundwater users (bores and GDEs) and changes to groundwater levels due to loading from embankments (i.e. upstream mounding and damming, and downstream groundwater level reductions)

  Proposed additional geotechnical works, including investigation and monitoring of groundwater levels at deep cuttings and areas of foundation treatment in low lying floodplain areas will further inform detail design.

An indicative GMMP is proposed to provide an on-going assessment of the potential impacts of the Project on the identified groundwater EVs. The program includes an indicative monitoring well network for periodic water level and groundwater quality monitoring.

A CIA was undertaken that considered the adjoining ARTC projects. The CIA identified a low significance due to the physical distance of each Project from the Project and via adoption and implementation of mitigation measures.

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APPENDIX N

Groundwater Technical Report

Appendix A Preliminary Hydrogeological Interpretive Report

HELIDON TO CALVERT ENVIRONMENTAL IMPACT STATEMENT

IR_1381

GOLDER

REPORT

Inland Rail Section 330 - Helidon to Calvert Preliminary Hydrogeological Interpretive Report

Feasibility Design Stage

Submitted to:

Future Freight Joint Venture

Submitted by:

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1893802-022-R-Rev2

09 March 2020

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1.0 INTRODUCTION

1.1 Background

Inland Rail is a freight transport project connecting Melbourne with Brisbane via regional Victoria, New South Wales and Queensland.

Inland Rail has been divided into 13 projects to deliver the 1 700-kilometre rail line by 2024/25. The Helidon to Calvert (H2C) section (Section 330 between Kilometrage 26.000 to 73.440 km) comprises approximately 47 kilometres of new dual gauge rail line connecting Helidon with Calvert, via Placid Hills, Gatton, Forest Hill, Laidley and Grandchester.

1.2 Objective

This report provides 70% Feasibility Design advice regarding estimated inflows and drawdown associated with the drained tunnel and cuts and an assessment of water quality parameters to inform feasibility design for earthworks, bridges and tunnelling along the H2C Section 330 of the works.

1.3 Alignment

The Helidon to Calvert project area consists of an approximately 47-kilometre route that extends in an east-south-easterly direction between Helidon (western terminus) and Calvert (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 320 – Gowrie to Helidon to the west and Section 340 – Calvert to Kagaru to the east. The project includes in its current design

- 47.440 km of new dual gauge track
- 820 m long tunnel referred to as the Little Liverpool Tunnel
- 22 bridges (including 3 road and 19 rail)19 slope cuts and
- 17 embankments.

2.0 REVIEWED INFORMATION

For the Feasibility Study of the H2C section ARTC has undertaken a geotechnical investigation (the H2C FS SI) to gain an understanding of the ground conditions along the alignment. Work completed at the time of reporting includes:

- Rotary and core drilling at:
  - 6 bridge locations
  - 1 culvert location
  - 2 cut locations and
  - 4 location near the Little Liverpool Tunnel
- Installation of 13 groundwater monitoring bores equipped with standpipe piezometers and automatic water level probes recording groundwater level at hourly intervals
- Borehole permeability testing including falling head/slug testing in 9 monitoring bores
- Groundwater sampling for water chemistry analysis

Data records and information gained from the investigation are reported in the H2C Geotechnical Site Investigation Report (Golder, 2018c) and were used to inform the hydrogeological assessment. Selected results from the site investigation are presented in this report.

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.
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.
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 for registered groundwater bores (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.

The “University of Queensland Gatton” BoM weather station (040082) is the nearest station to the Section 330 alignment with long-term statistical climate data (1965 to 2018). For this station, the mean maximum and minimum daily temperatures are 26.9 and 13.0 degrees Celsius respectively (calculated as annual statistics). The monthly mean maximum daily temperatures range from 20.8 degrees Celsius in July to 31.6 degrees Celsius in January. The monthly mean minimum daily temperatures range from 6.2 degrees Celsius in July to 19.1 degrees Celsius in January.

Table 1 provide long-term mean monthly rainfall summary statistics for the University of Queensland Gatton BoM station, a mean annual rainfall of 772.4 mm and a median annual rainfall of 774.4 mm are reported.

Table 1: Long-term mean monthly rainfall summary statistics for ‘University of Queensland Gatton’ Australian Bureau of Meteorology station number 040082 for the years between 1897 and 2018. Source: Bureau of Meteorology (2018).

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	111.1	100.2	79.3	48.6	45.4	41.7	36.4	26.7	34.8	65.0	79.0	99.7	772.4
Lowest	2.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	1.3	354.5
10th %ile	36.1	21.2	9.8	5.3	5.3	3.9	2.4	3.8	3.9	15.3	19.3	34.7	536.0
Median	95.0	85.0	72.0	35.9	27.2	25.7	26.2	21.1	27.4	51.8	72.4	84.2	774.4
90th %ile	194.8	185.0	143.4	115.8	102.4	95.3	72.6	55.8	72.4	136.0	134.0	184.1	1022.1
Highest	452.9	307.3	323.4	324.1	443.5	319.6	306.4	94.8	190.5	269.0	321.2	317.0	1241.4

Note: Lowest and highest monthly values are in blue and red, respectively

The University of Queensland Gatton weather station (040082) has rainfall records available from 1897 to 2018. Records from this station have been used to assess the Cumulative Rainfall Deficit (CRD). Figure 1 shows the pattern of average monthly rainfall for the period of record. While the University of Queensland Gatton weather station (040082) reports mean daily evaporation for each month from 1968 to 2002, the Gatton DAFF Research weather station (040436) has more recent data from 1992 to 2014. Evaporation from the Gatton DAFF Research station has been reported on Figure 1.

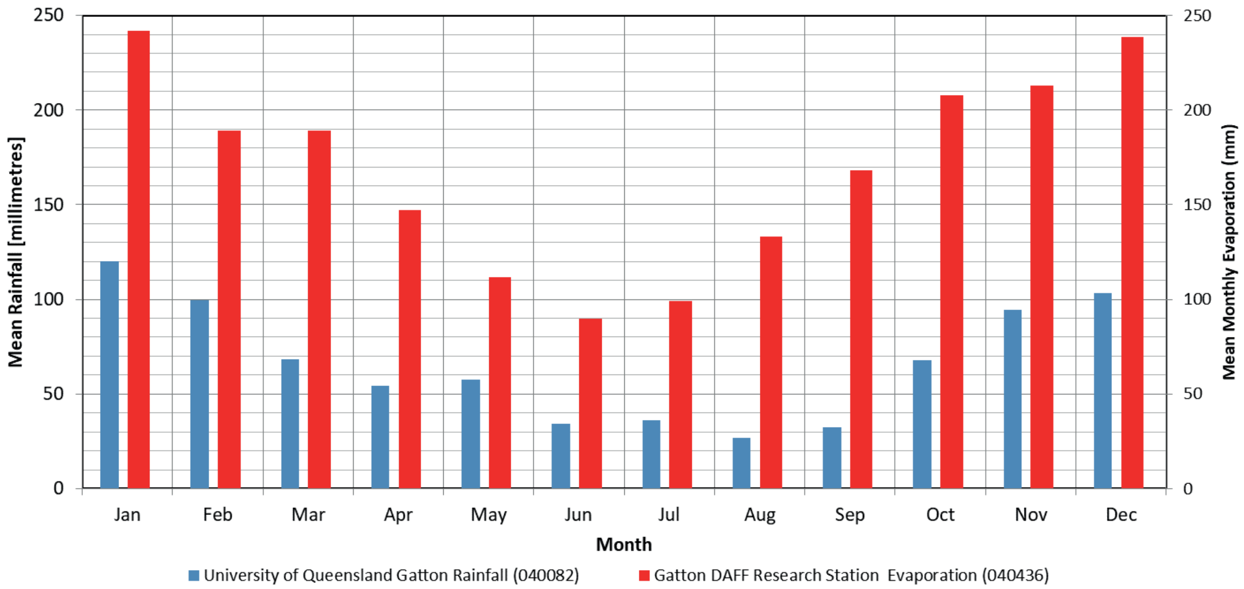


Figure 1: Monthly rainfall statistics for 'University of Queensland Gatton ' Australian Bureau of Meteorology station number 040082 and mean daily evaporation for each month from the Gatton DAFF Research station number 040436.

Annual rainfall records were used to calculate rainfall residuals and the CRD, for the 'University of Queensland Gatton' BoM station (Figure 2). It should be noted that rainfall data for three data points from January 2002, January 2011 and June 2016 were used from the Gatton DAFF Research station to fill in missing monthly rainfall data from the University of Queensland Gatton station for the CRD analysis.

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.

Clear long-term trends occur at Gatton and likely along the entire H2C rail corridor. The CRD underwent multiple cycles, generally increasing from 1922 to 1976 and then generally decreased until 2007 with several wetter than average periods during this time. Negative CRD was experienced between 1998 until 2008 resulting in drought conditions. From 2008, the CRD graph shows a positive trend until 2014.

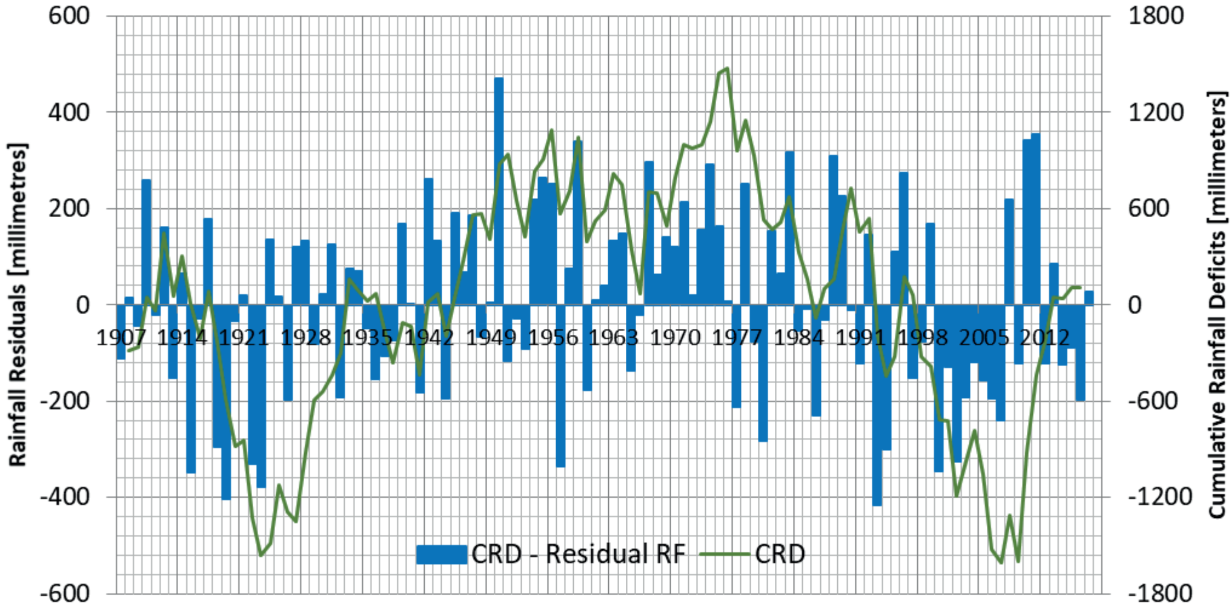


Figure 2: Annual residual rainfall and cumulative residual deficit (cumulative deviation from average) for 'University of Queensland Gatton' Australian Bureau of Meteorology station number 040082, record period between 1894 and 2018.

3.2 Topography and Drainage

The rail alignment runs from a point close to the base of Toowoomba Range to the west of Helidon, to the east of the Little Liverpool Range near Calvert. The area is dominated by the alluvial floodplain of the Lockyer Creek and its tributaries, which is a relatively flat to slightly undulating broad flood plain truncated by a series of meandering watercourses with localised slopes. To the east of the Little Liverpool Range where elevations rise to over 250 m AHD, the Bremer River floodplain and a tributary, Western Creek, are encountered along the alignment.

Lockyer Creek is a major regional drainage system in the Lockyer Valley which flows to the northeast where it reaches confluence with the Brisbane River to the south (i.e. downstream) of Wivenhoe Dam. The primary tributaries of Lockyer Creek include Flagstone Creek, Sandy Creek, Alice Creek, Laidley Creek, Tenthill Creek, Murphy's Creek and Ma Ma Creek. These watercourses drain the Main Range National Park and the western Scenic Rim. The watercourses in the valley are generally slow flowing, meandering channels which have generated fluvial terrace complexes with localised slopes or stepped slopes. However, due to the size of the catchments of the tributaries which drain into the Lockyer Creek, the watercourses are prone to flooding during the wet season. The Lockyer Creek is most notable for the destructive flooding event which occurred in January 2011 following a 1 in 1000-year rainfall event.

3.3 Land Use and Cover

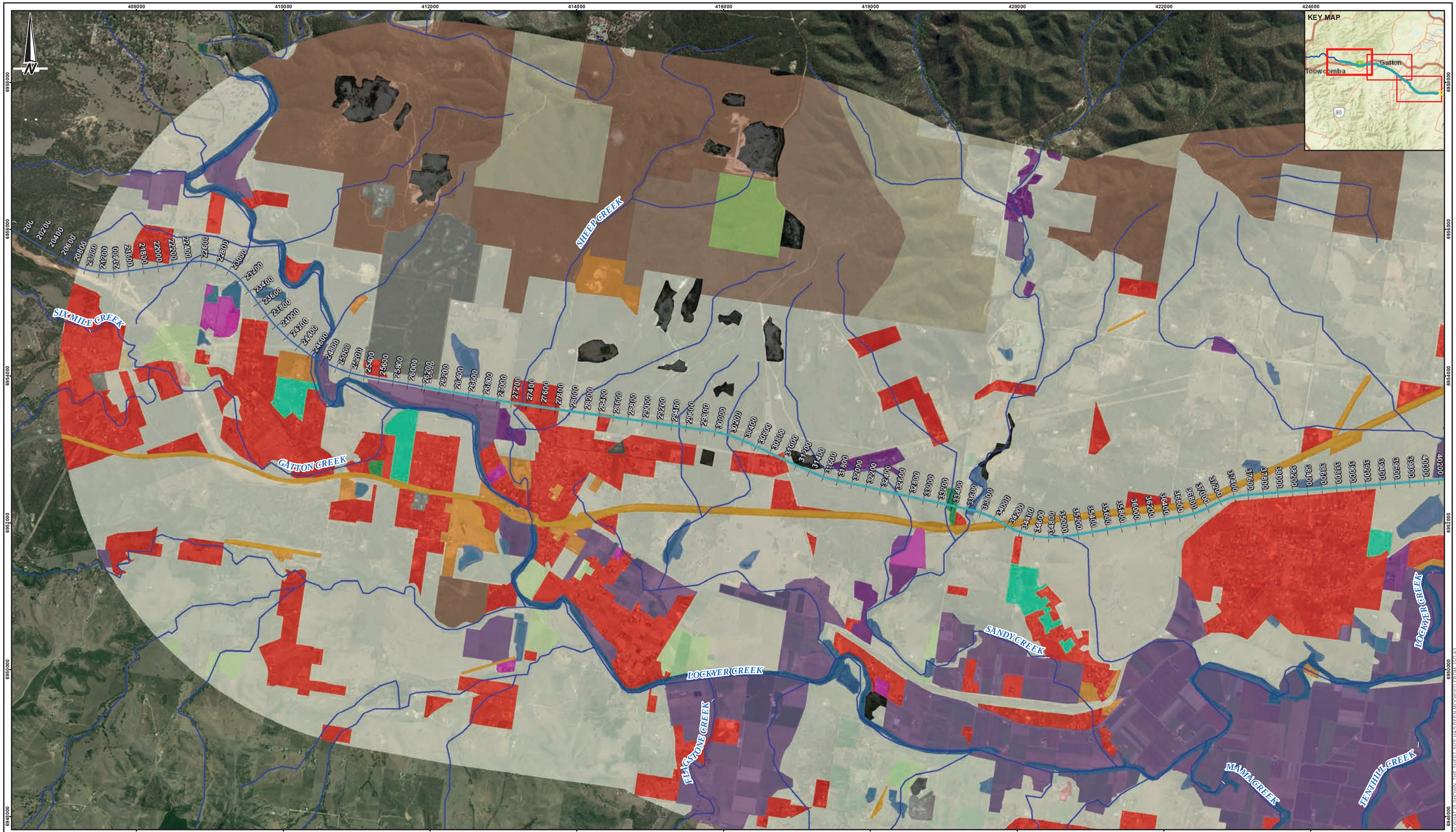
The H2C rail corridor extends west to east through the northern portion of the Clarence-Moreton Bioregion.

The H2C rail corridor is traversed by a number of perennial river systems (e.g. the Lockyer Creek and its primary tributaries and the Bremer River to the east of the Little Liverpool range). At drought times, watercourses of some of these tributaries may temporary be dry (e.g. Laidley Creek during the drought of 2007). The primary land use within 5 kilometres of the rail alignment comprises grazing native vegetation (58.3% of the total area). Irrigated areas occur in close proximity to river systems and comprise approximately 14.7% of the total area within a 5-kilometre corridor. Irrigated areas may contribute to excess recharge along river systems or groundwater level drawdown when irrigation water is sourced from groundwater bores. Elevated areas within the project corridor are typically vegetated with scattered woody vegetation including native shrubs and trees.

Land use types within the 5-kilometre corridor are listed in Table 2 and shown on Figure 3.

Table 2: Percent land use by area (within 5-kilometre corridor of H2C alignment)

Land Use Type (Secondary)	Sum Area (Square Metres)	Percent of Total
Grazing native vegetation	321 401 442.6	58.3
Irrigated Areas (inc. Irrigated modified pastures, cropping, perennial and seasonal horticulture and land in transition)	81 085 975.5	14.7
Residential	64 942 536.0	11.8
Other minimal use	26 472 708.0	4.8
Intensive uses (inc. Services, Utilities, Transport and Communication, and Waste Treatment and Disposal)	16 751 947.4	3.0
Water (inc. Reservoir/dam, Marsh/Wetland, River, Channel/aqueduct)	11 825 030.8	2.1
Nature conservation	9 830 559.8	1.8
Grazing modified pastures	2 420 793.8	0.4
Mining	2 128 424.7	0.4
Land in transition	2 038 358.0	0.4
Forestry (Plantation and Production)	1 263 543.7	0.2
Others (incl. Cropping, Managed Resource Protection, perennial horticulture, Perennial and Intensive Horticulture, Intensive animal production and Manufacturing and Industrial)	11 283 347.9	2.0



LEGEND

Inland Rail Alignment Section

- H2C - Helidon to Calvert
- G2H - Gowrie to Helidon
- Watercourse

Land use (5km Buffer of Alignment)

- Nature conservation
- Managed resource protection
- Other minimal use
- Grazing native vegetation
- Production forestry
- Grazing modified pastures
- Cropping
- 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

FOR DISCUSSION PURPOSE ONLY

DRAFT

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)

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REFERENCE(S)

1. **Watercourses:** Geoscience Australia
2. **G2H, H2C and C2K Alignment:** Provided by FFJV on 31st July 2018, 6th Nov 2018 and 5th Nov 2018 respectively.
3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

PROJECT
INLAND RAIL SECTION 330 H2C

CONSULTANT
GOLDER

DD-MMM-YY	12/12/2018
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

TITLE
LANDUSE OF THE HELIDON TO CALVERT CORRIDOR

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	1	3-1

PATH: B:\INLAND_RAIL\Hydrogeology Folder\99_PROJECTS\Package_1\21893802-022-CT-F003-Rev1-Landuse.mxd PRINTED ON: 2018-12-12 AT: 10:46:20 AM

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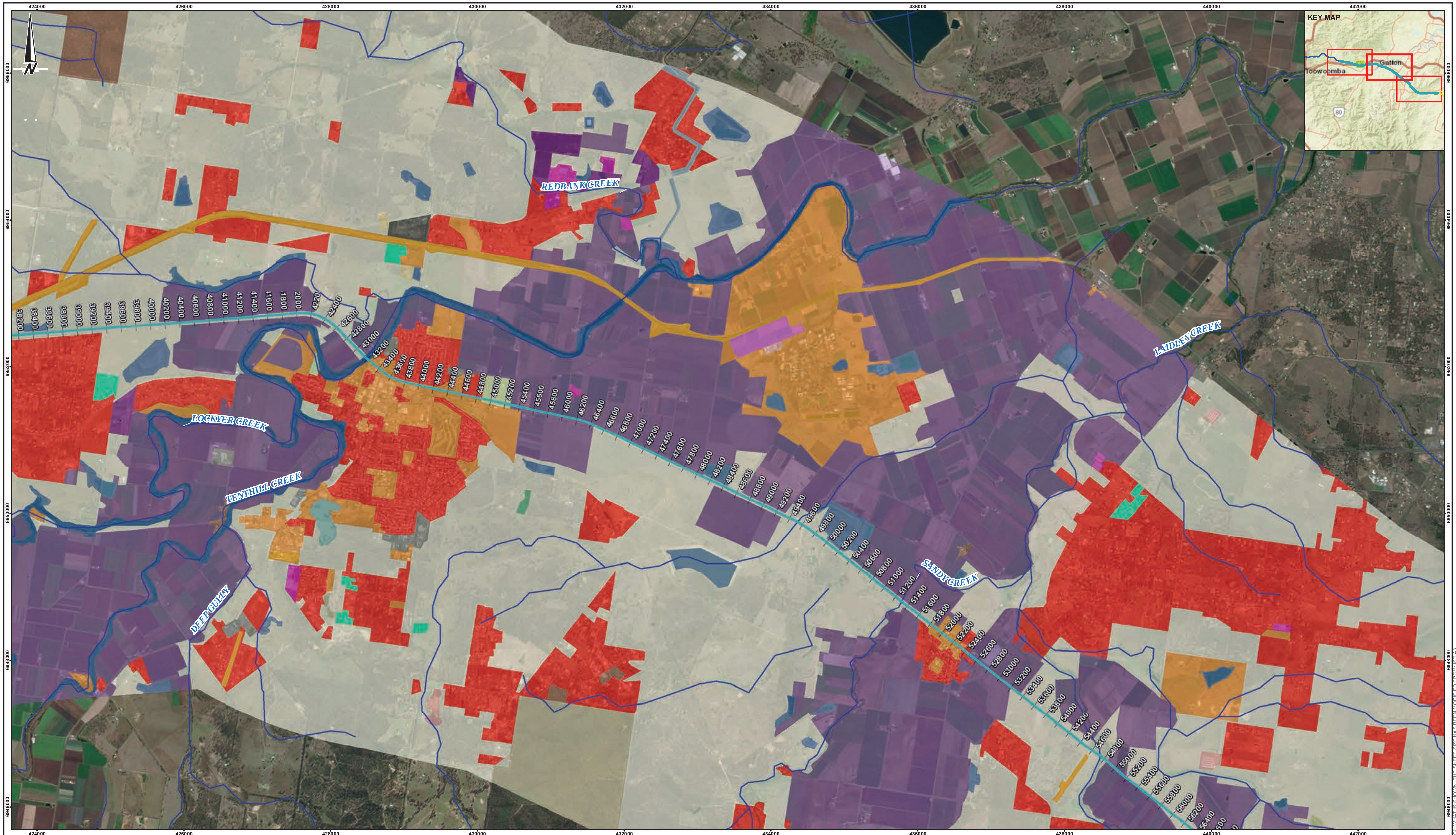

LEGEND

Inland Rail Alignment Section

- H2C - Helidon to Calvert
- Watercourse

Land use (5km Buffer of Alignment)

- Nature conservation
- Other minimal use
- Grazing native vegetation
- Grazing modified pastures
- Perennial horticulture
- Land in transition
- Irrigated modified pastures
- Irrigated perennial horticulture
- Irrigated seasonal horticulture
- Irrigated land in transition
- Intensive horticulture
- Intensive animal husbandry
- Manufacturing and industrial
- Residential
- Services
- Utilities
- Transport and communication
- Waste treatment and disposal
- Reservoir/dam
- River
- Channel/aqueduct
- Marsh/wetland

FOR DISCUSSION PURPOSE ONLY

DRAFT

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 500 1,000 1,500 2,000
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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

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3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

PROJECT
INLAND RAIL SECTION 330 H2C

CONSULTANT
GOLDER

DD-MMM-YY	12/12/2018
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

TITLE
LANDUSE OF THE HELIDON TO CALVERT CORRIDOR

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	1	3-2

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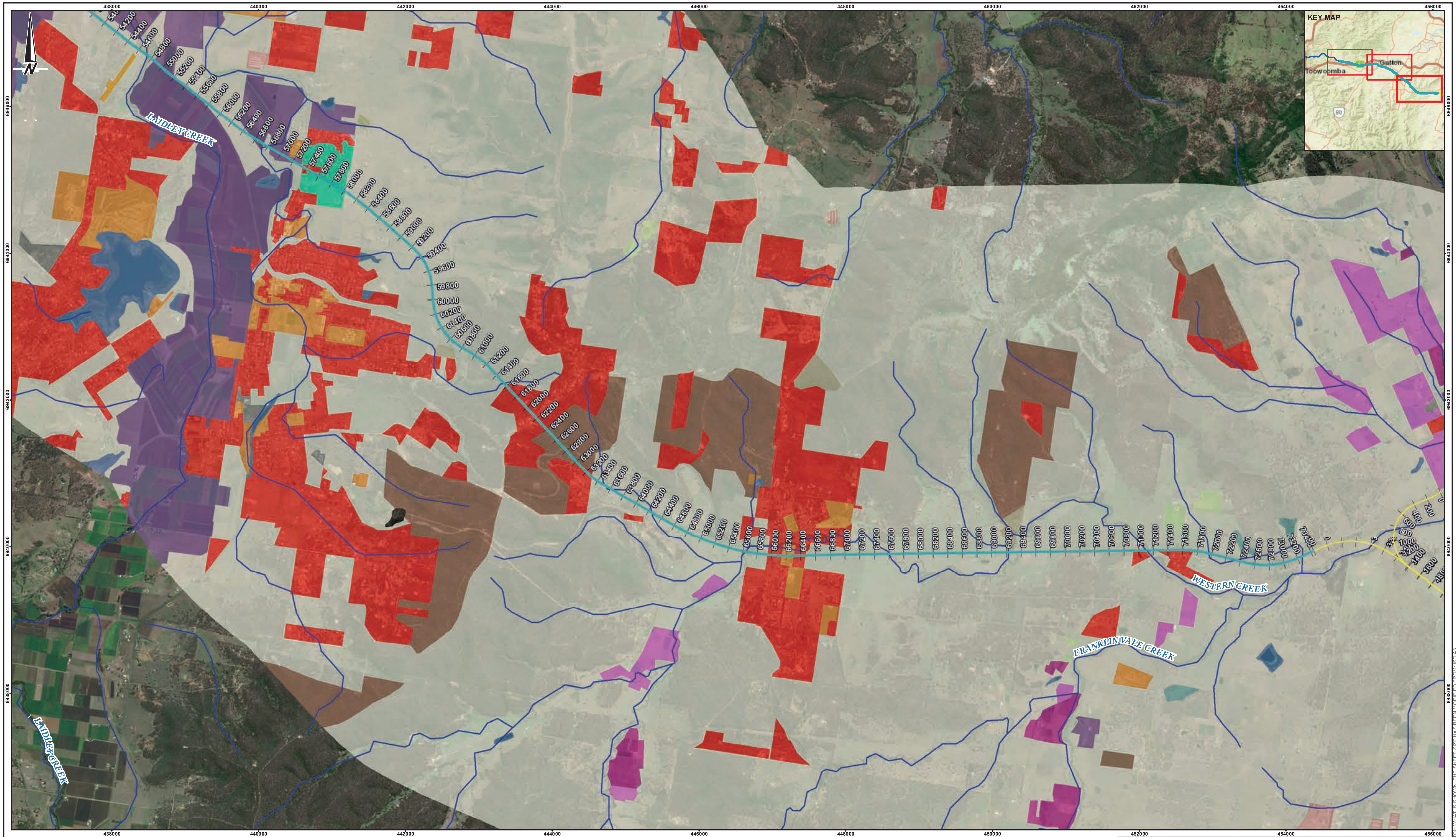

LEGEND

Inland Rail Alignment Section

- H2C - Helidon to Calvert
- C2K - Calvert to Kagaru
- Watercourse

Land use (5km Buffer of Alignment)

- Nature conservation
- Other minimal use
- Grazing native vegetation
- Grazing modified pastures
- Land in transition
- Irrigated modified pastures
- Irrigated cropping
- Irrigated seasonal horticulture
- Intensive animal husbandry
- Manufacturing and industrial
- Residential
- Services
- Utilities
- Transport and communication
- Mining
- Reservoir/dam
- Marsh/wetland

FOR DISCUSSION PURPOSE ONLY

DRAFT

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 500 1,000 1,500 2,000
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NOTE(S)

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3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

PROJECT
INLAND RAIL SECTION 330 H2C

CONSULTANT
GOLDER

DD-MMM-YY	12/12/2018
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

TITLE
LANDUSE OF THE HELIDON TO CALVERT CORRIDOR

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	1	3-3

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

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4.0 STRATIGRAPHY AND GEOLOGICAL PROCESSES

The stratigraphic units encountered within the H2C rail corridor are described below from oldest to youngest and are reported on Figure 4.

The H2C alignment is anticipated to encounter the following units in various areas:

- Woogaroo Subgroup in more elevated areas between Kilometrage 29.100 to 39.000 km
- Marburg Subgroup – comprising the Koukandowie Formation (including the Heifer Creek Sandstone Member) and the Gatton Sandstone exposed at surface or blanketed by a thin layer of red and yellow podosols, lithosols and, potentially, sodosols soil types in the Little Liverpool Range between Kilometrage 59.400 and 65.000 km
- Walloon Coal Measures and alluvium between Kilometrage 65.000 and 73.400 km
- Quaternary age alluvium in low lying areas between Kilometrage 26.000 and 59.400 km

Woogaroo Subgroup

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.

These sedimentary rocks originated from terrestrial stream and overbank flood wetland (‘backswamp’) deposition that created a series of coarse-grained rising through to fine-grained rocks (sandstones and mudstones) potentially incorporating organic materials that are preserved as wispy coal.

The Woogaroo Subgroup that forms the lower part of the Bundamba Group has a thickness of 1000 m to 1200 m. The upper unit (the Ripley Road Sandstone) is equivalent to a facies variant within the Woogaroo Subgroup that was formerly referred as the Helidon Sandstone. This is observed in outcrop on the alignment where it crosses to the north of the Warrego Highway. It comprises a coarse grained and predominantly clean quartz rich sandstone as well as quartz rich granule conglomerate. It is equivalent to the Precipice Sandstone of the Surat Basin.

The lithology is typically expressed as the low to moderately undulating country of the Helidon Hills foothills that is crossed by the alignment between Helidon Spa and the Placid Hills north of the Warrego Highway.

Gatton Sandstone (Marburg Subgroup)

Gatton Sandstone is the lower member of the Marburg Subgroup and the principal rock types in the Gatton Sandstone are cross bedded quartz lithic to lithic sandstone medium to very coarse grained, with pebble and cobble conglomerate at the base of channel sands, and dark grey to black siltstone and shale. There are some thin coal laminae in the siltstone. Pebble beds, carbonised wood fragments and large-scale planar and cross-bedding are characteristic of this formation. The sandstone is predominantly fine grained, grey in colour and high strength when fresh. When weathered, the sandstone is typically pale brown. It may be possible to differentiate the Gatton Sandstone into its constituent Calamia and the Koreelah Conglomerate Members. The lower (Koreelah Conglomerate) Member tends to be predominantly coarser grained.

The Gatton Sandstone conformably underlies the Ma Ma Creek Member of the Koukandowie Formation at a conformable, sharp contact between siltstones of the Ma Ma Creek Member and the Gatton Sandstone. This formation is described by McTaggart (1963) to contain cements rich in sodium, calcium and magnesium carbonates (McTaggart, 1963).

Koukandowie Formation (Marburg Subgroup)

The Marburg Subgroup bedrock in the area of the Little Liverpool Range section between CH 59.400 to 66.400 km, is thought to include a significant proportion of the Koukandowie Formation. The proposed Section 330 tunnel is within the Koukandowie Formation within the Little Liverpool Ranges. The Gatton Sandstone underlies the Koukandowie Formation and may be exposed in some portions of the Little Liverpool Range.

This Koukandowie Formation commonly forms prominent topographic features with steep slopes and is often exposed in cliffs, benches and cuttings (Wells and O'Brien, 1994). The Koukandowie Formation is reportedly the equivalent to the Hutton Sandstone of the Surat basin west of the Toowoomba Range (IESC, 2014).

The Koukandowie Formation is divided into the basal Ma Ma Creek member, undifferentiated Koukandowie Formation and the Heifer Creek Sandstone near the top of the unit.

In the type section in GSQ Ipswich 24 the Koukandowie Formation contains about 67% sandstone. The Ma Ma Creek Member contains 54% shale and siltstone whereas sections of the Koukandowie Formation that are undifferentiated into Members contain 80% sandstone. The sandstone is typically fine to coarse grained, cross laminated and rippled. Thin pebble conglomerates occur at the base of channel sands. Interbedded mudstone intervals are 10 to 12 m thick with fine grained sandstone laminae, cross laminae and rootlets. In places, the mudstone exhibits brecciated soil textures. The Formation is about 260 m thick in GSQ Ipswich 24.

The Heifer Creek Sandstone is commonly cliff forming with interbedded weaker units that form benches. Colluvium, comprising large blocks from the competent strata and clayey fines from the weaker layers frequently accumulates on the benches corresponding to the finer grained weathered rock horizons (Willmott, 1984).

The lower boundary of the Koukandowie Formation is defined as the change from predominantly mudrocks to very coarse grained, quartz-lithic to lithic sandstone bodies of the Gatton Sandstone ‘Formation’.

Walloon Coal Measures

The Walloon Coal Measures (WCM) overlies the Koukandowie Formation and the Gatton Sandstone. The Walloon Coal Measures is variable in composition and typically includes sandstone, siltstone, mudstone and coal in the upper half to two-thirds of the formation 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 and the upper part of the unit was deposited as coal swamps. The Walloon Coal Measure rocks form gently undulating terrain.

Tertiary Age Volcanics

From reference to the published geological data, it appears that the mainly alkali basaltic volcanics occur over 2 km to the north from the proposed Little Liverpool Range tunnel. This unit is not anticipated to be encountered along the Section 330 alignment based on a review of published geological data.

Alluvium and Colluvium

The alignment is within the alluvial plains of the Lockyer Creek and its tributaries, while to the east of the Little Liverpool Range is within the alluvial plains of the Bremer River valley. The alluvial plains overlie 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.

Colluvium deposits may be located at the base of the Little Liverpool Range, Lockyer National Park and along drainage lines in the more elevated parts of the alignment. These deposits are conceptualised to consist of a wide range of grain sizes.

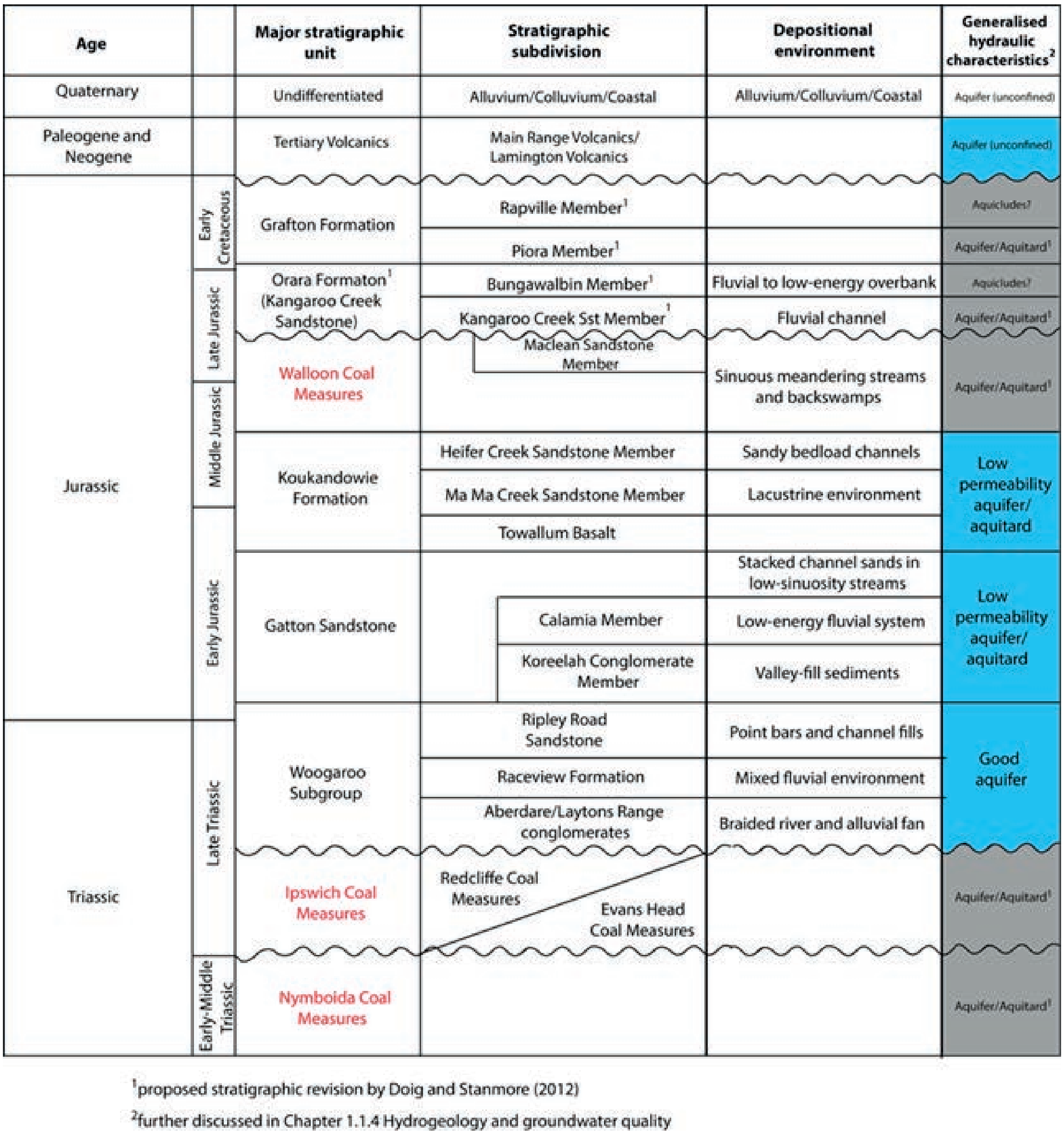

Figure 4: Stratigraphy of the Clarence-Moreton sedimentary basin (Rassam et. al., 2014)

4.1 Geological Structures

The Clarence-Moreton Basin and the Laidley Sub-Basin in its north developed between fault guided blocks in the basement rocks that were mobilised during the ancient (Palaeozoic Era) New England Orogen (mountain building period). The Basin subsided and infilled with sediments throughout the Mesozoic Era.

Tectonic compression created crustal doming (uplift) of the Great Dividing Range during relatively recent geological times from the mid Cretaceous Period and into the Caenozoic Era (principally Tertiary Period). This uplift instigated a westward migration of the Great Escarpment as retrograde fluvial (river) erosion extended back from the coastal plains.

The sedimentary rocks of the Clarence Moreton Basin are gently folded, with a series of north west to south east trending axial planes and regional faults being mapped. The Gatton Arch is a structural high in the underlying Palaeozoic basement rocks that developed during the general trend of a regional basin sag. It is likely to have formed as an intrabasinal bulge during deposition into the Laidley and (west of the Arch) Cecil Plains sub-basins. The Arch has a north to south trending axis, across which the sedimentary rocks of the Clarence Moreton Basin are relatively thin.

There is some slight folding in the strata, typically about the regional structural NNE to SSW trend, though dip of strata may typically be just 5˚ to 10˚ towards the southeast and southwest across southerly plunging broad synclines and anticlines. The ‘dip and scarp’ slopes of cuestas reflect the folding (dip orientation) of the bedded strata in the region. Strata within the Little Liverpool Range section of the alignment have a broad-scale shallow dip towards the south east, creating the Cunningham’s Ridge escarpment. The strata are not heavily faulted. Occasional (also NNW to SSE trending) faults have been interpreted; no record of their type/ throw has been noted. For the purpose of modelling we have considered the frequency of two major faults within the Koukandowie Formation to be present over each kilometre tunnel length.

5.0 REGIONAL HYDROGEOLOGY

5.1 Hydrostratigraphy

A hydrostratigraphic sequence of the Clarence-Moreton sedimentary basin is presented in Figure 4 (Rassam et. al., 2014).

To the west of Little Liverpool Range, the alignment is located within the alluvial plains of the Lockyer Creek and its tributaries, while to the east of Little Liverpool Range it is within the alluvial plains of the Bremer River valley. The alluvial plains have infilled valleys with gravels, sands, loams and clays carrying large supplies of fresh to slightly brackish groundwater. The 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 be thicker and contain larger grain sizes such as sand and gravel near the existing watercourses and along palaeochannels and will be more conductive to groundwater flow. The area surrounding the watercourse which are floodplains of the watercourses are conceptualised to possess sediment deposits containing smaller particle sizes such as fine sand, silt and clay sediments and will constrain groundwater flow within the subsurface.

Colluvium deposit may be located at the base of the Little Liverpool Range and Lockyer National Park as well as along drainage lines in the more elevated parts of the alignment. These deposits are conceptualised to consist of a wide range of grain sizes. Most colluvium is anticipated to be located above the water table and is likely to contain higher proportions of fine materials due to weathering. Inflows to cuts through colluvium may occur intermittently following rainfall.

Within the project alignment, Walloon Coal Measures (WCM) overlie the Koukandowie Formation and the Gatton Sandstone. The WCM 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, locally, coal seams and geological structures such as faulting may increase the potential for groundwater movement and storage. The WCM are considered a Great Artesian Basin (GAB) aquifer in the Water Resource GAB Plan (2006) despite low permeabilities as there are localised groundwater aquifers within this formation. Seepage into deep cuts from this unit is anticipated to be low except where local permeability is increased by weathering, fracturing or coal seams. Storage of this unit is anticipated to be low and may result in low long-term seepage rates.

Rocks of the Koukandowie Formation are generally described as low permeability aquifers and aquitards. The member is of highly variable permeability, but mostly 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. Groundwater in the Koukandowie Formation is typically unconfined below ridges and mostly unconfined elsewhere. The Koukandowie Formation is reportedly the equivalent to the Hutton Sandstone (IESC, 2014); therefore, where information was unavailable on the Koukandowie Formation, literature values for the Hutton Sandstone were used. The Little Liverpool Tunnel is within the Koukandowie Formation.

The Gatton Sandstone contains water, but overall, is of low to moderate permeability and the water is of poor quality; in places, water is saline at depth. 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). Groundwater in the Gatton Sandstone is typically unconfined below ridges and mostly unconfined elsewhere.

The Helidon Sandstone of the Woogaroo Subgroup is the equivalent of the Precipice Sandstone to the west of the Toowoomba Ranges in the Surat Basin. The Precipice Sandstone is a regional sandstone unit which is a major aquifer which is heavily utilised for water supply owing to its high conductivity and fresh water supply. Seepage into deep cuts from this unit is anticipated to be relatively high. Storage of this unit is anticipated to be high and may result in moderate long-term seepage rates.

5.2 Groundwater Level and Flow

Regional groundwater flow in the Lockyer Creek valley has been assessed by CSIRO (Cui *et. al,* 2018) and the mean groundwater level in shallow bedrock aquifers during the period between 2000 to 2007 is reported on Figure 5. The figure illustrates a generally northeast flow direction for groundwater within the sub-basin. It should be noted that groundwater abstraction may lead to localised variations in groundwater flow direction; however, the dominant regional flow direction will be to the northeast.

Groundwater in the shallow bedrock, including the Woogaroo Subgroup, is reported by CSIRO (Cui *et. al,* 2018) to generally reflect topographic elevations and experience a decrease in hydraulic head from dividing ridges between catchments toward the alluvial plains. This may result in local variations to flow direction. For example, Cui *et. al,* 2018 reports that groundwater in the Woogaroo Subgroup flows in a south-easterly direction in the northern portion of the Lockyer Valley but changes to a north-easterly direction in the central alluvial channel. Groundwater depths of the Woogaroo Subgroup in the northern Lockyer Valley range in mean depth from 33.2 m depth up to a maximum of 92.5 m depth (Cui *et. al,* 2018) which are reportedly deeper in the Woogaroo Subgroup than other sedimentary units in the Lockyer Valley.

The locations of groundwater level bores from the 8 H2C FS site investigation bores and registered groundwater bores (DNRME, 2018) within 500 m of the alignment and with recorded groundwater levels are reported in Figure 6. Registered groundwater bores with water quality data within 5 km of the alignment is also reported on Figure 6.

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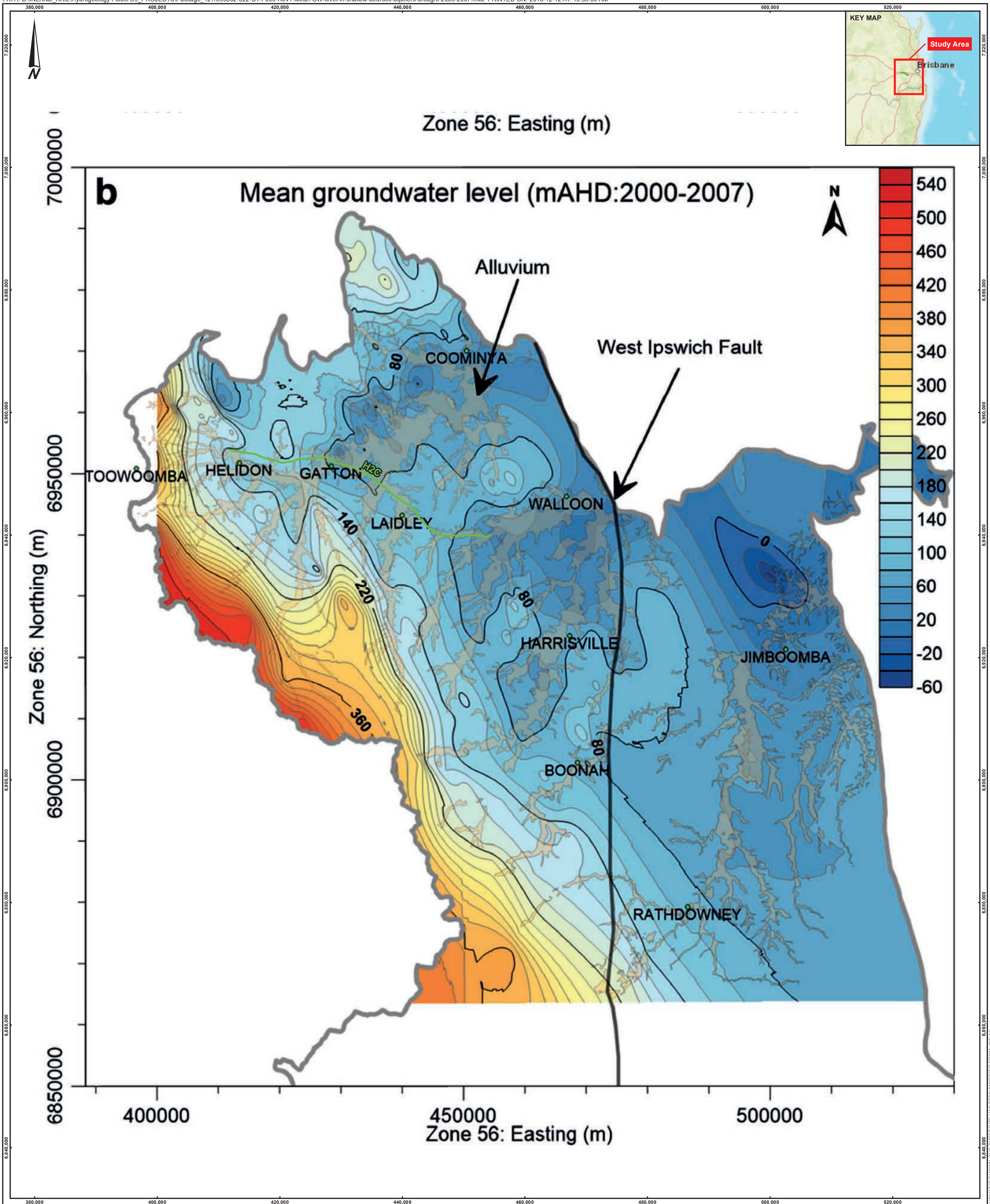

LEGEND

Inland Rail Alignment Section

H2C - Helidon to Calvert

FOR DISCUSSION PURPOSES ONLY

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Projection: Transverse Mercator
Datum: GDA 1994

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CLIENT
FUTURE FREIGHT JOINT VENTURE

CONSULTANT
GOLDER

YYYY-MM-DD	12/12/2018
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

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REFERENCE(S)

1. **Alignment:** Provided by FFJV on 6th Nov 2018 ,
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 SECTION 330 H2C

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
1893802	022	1	5

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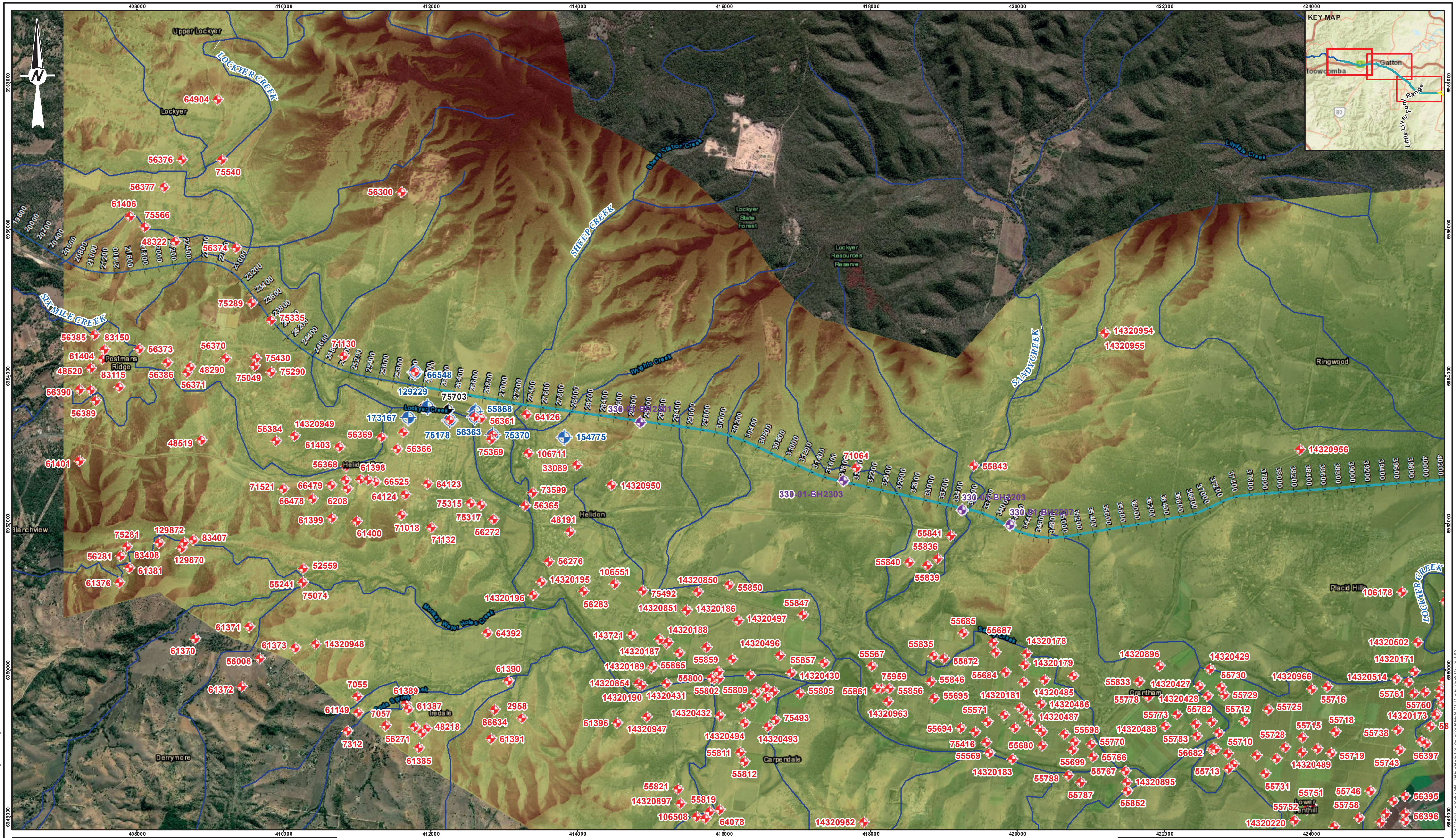

LEGEND

- FFJV/Golder Site Investigation Boreholes
- Registered Bores within 5km of proposed alignment with Water Quality Data
- Registered Bores within 500m of proposed alignment with recorded grounwater levels
- Registered Water Supply Bores within 500m of proposed alignment with recorded grounwater levels
- Watercourse

Inland Rail Alignment Section

- H2C - Helidon to Calvert
- G2H - Gowrie to Helidon

H2C Digitial Elevation Model 1 meter

High : 435.792 m

Low : 33.3232 m

FOR DISCUSSION PURPOSE ONLY

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Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

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1:50,000 @A3 METRES

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REFERENCE(S)

1. **G2H, H2C and C2K Alignment, 1m DEM:** Provided by FFJV on 31st July 2018, 6th Nov 2018, 5th Nov 2018 and derived from LiDAR data provided by FFJV respectively.
2. **Registered Bores:** Queensland Groundwater Database (2018)
3. **ARTC Geotech and Groundwater Bores:** Retrieved from ARTC's 01-3400-PD-P00-DE-0009_2 C2K Concept Geotechnical Factual Report Aug 2016
4. **Watercourse:** Geoscience Australia

CLIENT

FUTURE FREIGHT JOINT VENTURE

PROJECT

INLAND RAIL SECTION 330 H2C

CONSULTANT

GOLDER

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DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

TITLE

SECTION 330 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	2	6-1

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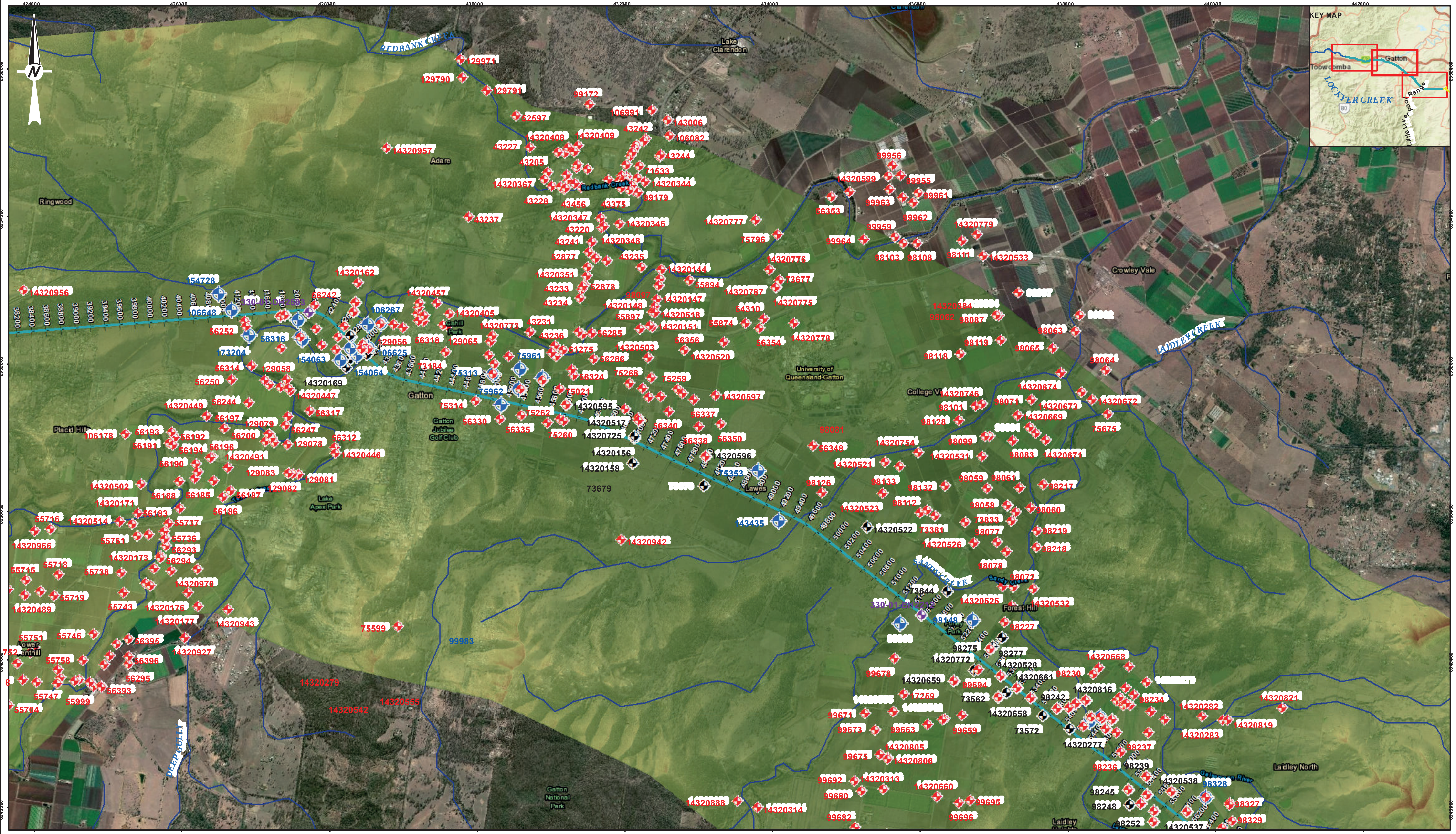

LEGEND

- FFJV/Golder Site Investigation Boreholes
- Registered Bores within 5km of proposed alignment with Water Quality Data
- Registered Bores within 500m of proposed alignment with recorded grounwater levels
- Registered Water Supply Bores within 500m of proposed alignment with recorded grounwater levels
- Watercourse

Inland Rail Alignment Section

- H2C - Helidon to Calvert

H2C Digitial Elevation Model 1 meter

High : 435.792 m

Low : 33.3232 m

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Projection: Transverse Mercator
Datum: GDA 1994

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3. **ARTC Geotech and Groundwater Bores:** Retrieved from ARTC's 01-3400-PD-P00-DE-0009_2 C2K Concept Geotechnical Factual Report Aug 2016
4. **Watercourse:** Geoscience Australia

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FUTURE FREIGHT JOINT VENTURE

PROJECT
INLAND RAIL SECTION 330 H2C

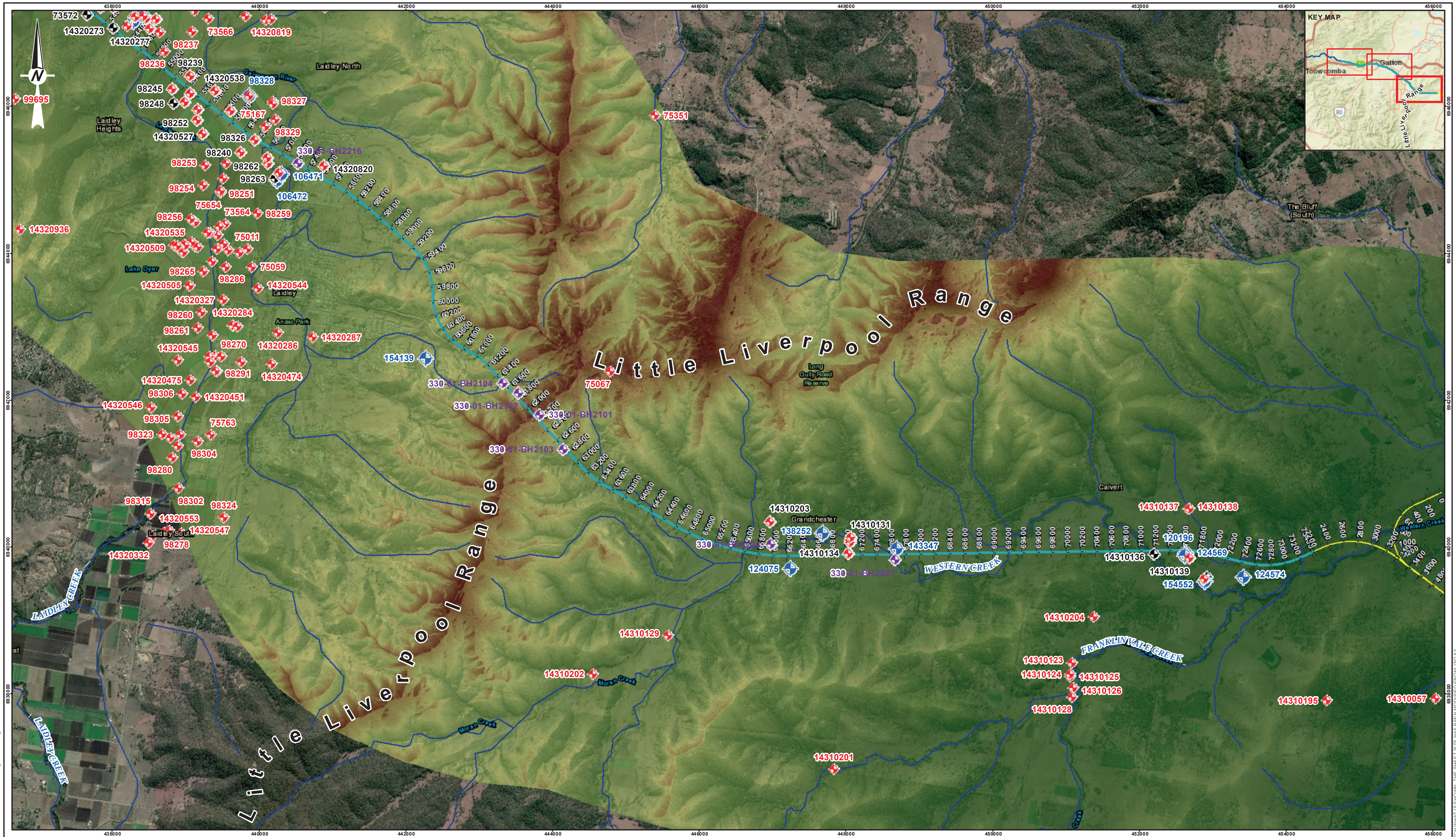
CONSULTANT

GOLDER

YYYY-MM-DD	5/03/2020
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

TITLE
SECTION 330 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	2	6-2



LEGEND

- FFJV/Golder Site Investigation Boreholes
- Registered Bores within 5km of proposed alignment with Water Quality Data
- Registered Bores within 500m of proposed alignment with recorded grounwater levels
- Registered Water Supply Bores within 500m of proposed alignment with recorded grounwater levels
- Watercourse

Inland Rail Alignment Section

- H2C - Helidon to Calvert
- C2K - Calvert to Kagaru

H2C Digitial Elevation Model 1 meter

High : 435.792 m

Low : 33.3232 m

FOR DISCUSSION PURPOSE ONLY

DRAFT

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. **G2H, H2C and C2K Alignment, 1m DEM:** Provided by FFJV on 31st July 2018, 6th Nov 2018, 5th Nov 2018 and derived from LiDAR data provided by FFJV respectively.
2. **Registered Bores:** Queensland Groundwater Database (2018)
3. **ARTC Geotech and Groundwater Bores:** Retrieved from ARTC's 01-3400-PD-P00-DE-0009_2 C2K Concept Geotechnical Factual Report Aug 2016
4. **Watercourse:** Geoscience Australia

CLIENT
FUTURE FREIGHT JOINT VENTURE

PROJECT
INLAND RAIL SECTION 330 H2C

CONSULTANT

GOLDER

YYYY-MM-DD	5/03/2020
DESIGNED	BG
PREPARED	BG
REVIEWED	NMC
APPROVED	DB

TITLE
SECTION 330 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	2	6-3

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

PATH: B:\INLAND_RAIL\Hydrogeology Folder\99_PROJECTS\Package_1\1893802-022-CT-F007-Rev2-FFJV-Investigation-and-Registered-Bore-Locations.mxd PRINTED ON: 2020-03-05 AT: 2:27:24 PM

A total of 10 groundwater monitoring bores were installed during investigations to date. Pressure transducers (water level data loggers) were installed in the H2C FS site investigation groundwater monitoring bores to continuously monitor groundwater levels at hourly intervals with a barometric pressure correction applied to monitored data. Available hydrographs for bores installed during H2C FS site investigation investigations are reported in APPENDIX A.

Basic groundwater level statistics from all available groundwater bores are reported in APPENDIX B.

From the DNRME (2018) registered groundwater bore database, 302 bores are located within 500 m of the alignment. Of these 47 have at least one groundwater level measurement since the year 2000 and an assigned aquifer unit, with 38 screened in various alluvium units and 9 bores screened in rock. Bores with data since the year 2000 have been the focus in order to allow comparisons between the rock and alluvial units.

Hydrographs for registered bores constructed within the alluvium are reported on Figure 7 and Figure 8, while bores completed in the Marburg Subgroup (undifferentiated) are reported on Figure 9. It should be noted that time series data is plotted for 15 alluvium and 2 rock bores only because the remainder of the data points were typically single point measurements. The timing of high rainfall climatic events since 2008 is indicated on Figure 7 through Figure 9 to indicate groundwater responses to these events. Rainfall depth has not been reported on the registered bore hydrographs due to the limited resolution of the measurements. Changes in water levels of up to 10 m in response to storm and flood events between 2008 and 2012 are apparent from the hydrographs in Figure 7 and Figure 8 and suggesting potential for significant groundwater level rise to occur along the rail alignment crossing low ground flood plains. Groundwater level records of boreholes located at high ground in rock show less significant level rise between 2008 and 2012 (Figure 9). From these limited records a level rise of up to 5 m is inferred during years with rainfalls well above long-term average.

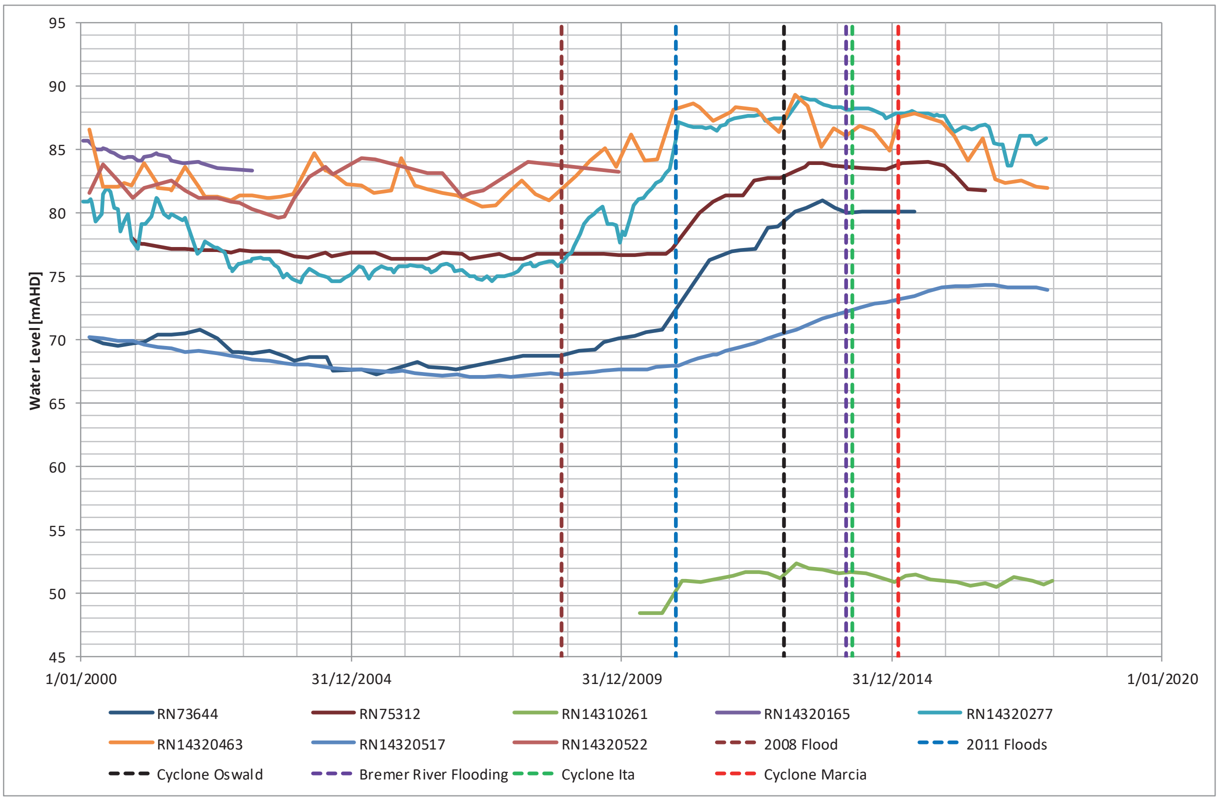


Figure 7: Water levels of registered groundwater bores completed in alluvium within 500 m of the rail alignment (DNRME, 2018) from 2000 until 2017 and climatic events since 2008 flooding

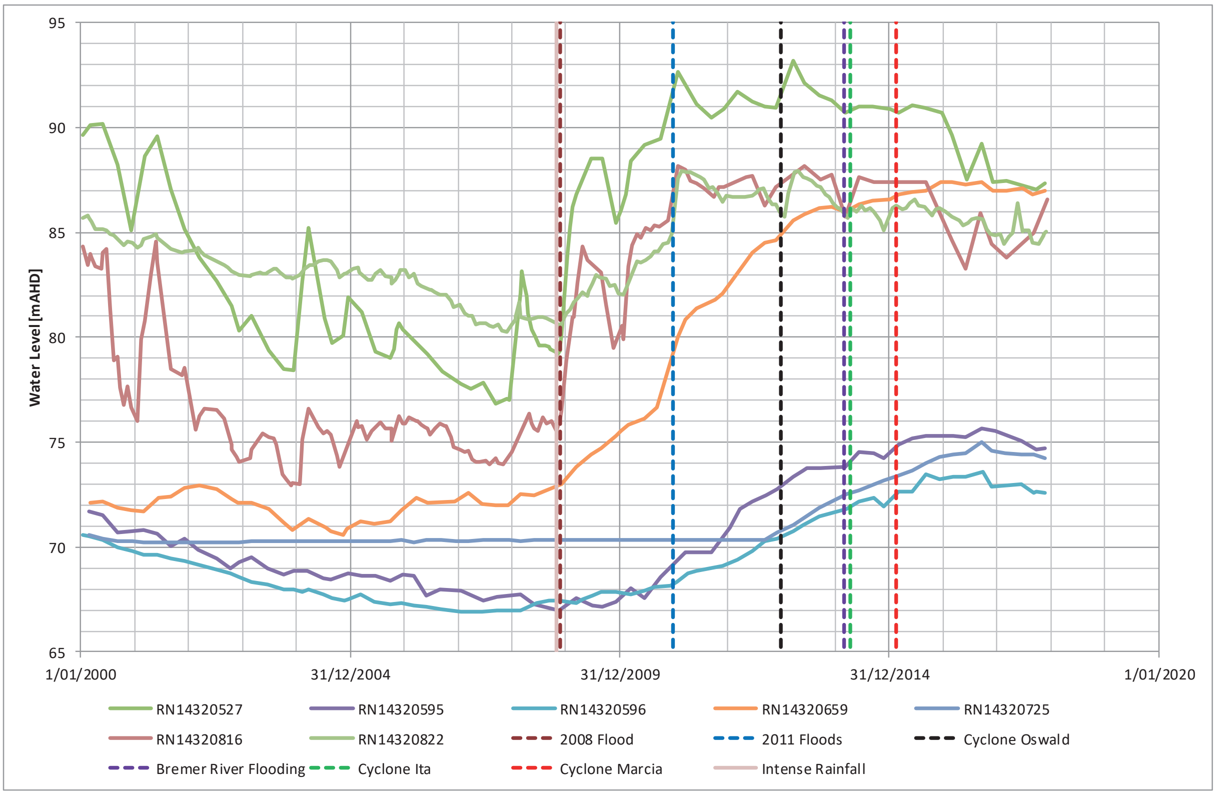


Figure 8: Water levels of registered groundwater bores completed in alluvium within 500 m of the rail alignment (DNRME, 2018) from 2000 until 2017 and climatic events since 2008 flooding

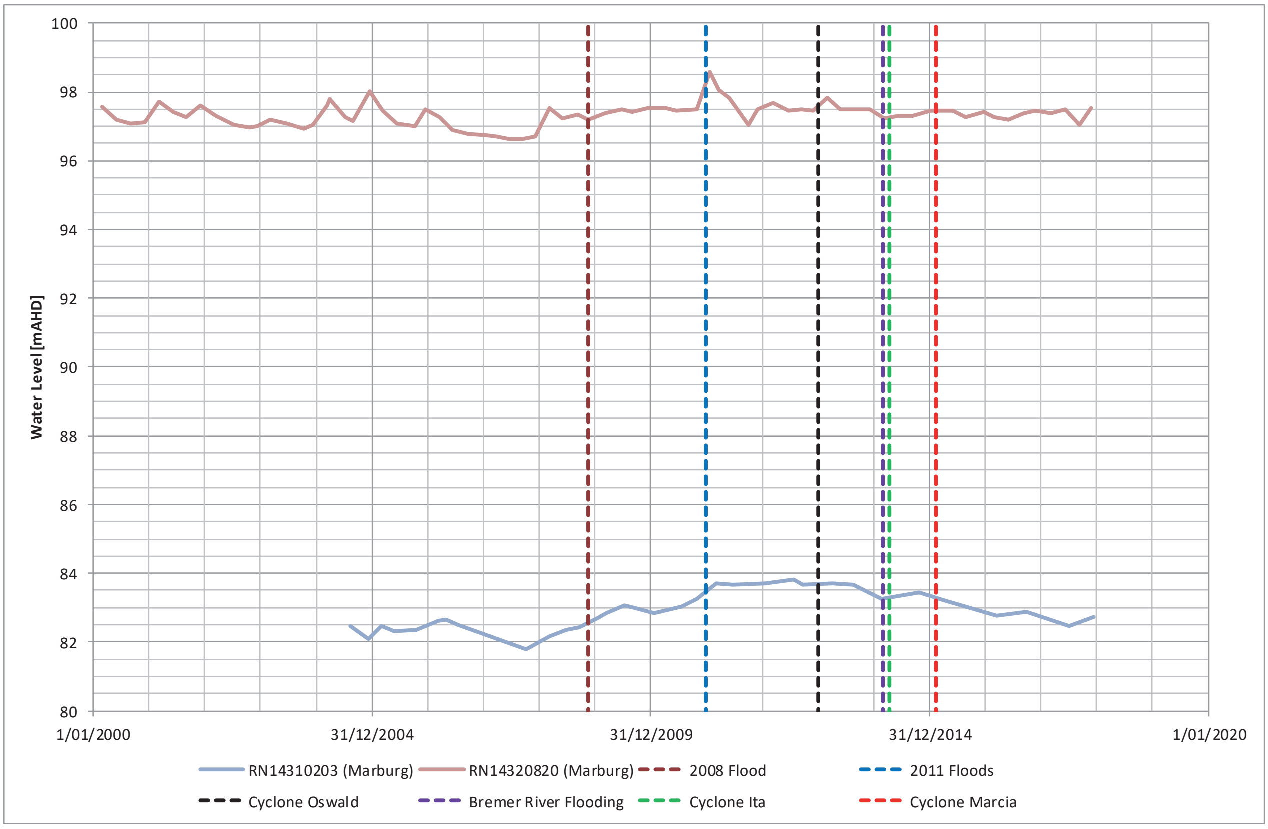


Figure 9: Time series water levels of registered groundwater bores completed in rock within 500 m of the rail alignment (DNRME, 2018) from 2000 until 2017 and climatic events since 2011 flooding

5.3 Groundwater Recharge

In areas with alluvial or colluvial materials, recharge is anticipated to be supplied by direct infiltration of rainfall, by seepage from ephemeral streams during periods of flow following rainfalls, and to a lesser extent in response to releases from Bill Gunn Dam (DNRME 2000). Sub-cropping rock below permeable alluvium may also act as a source of recharge. Recharge to the water table in rock formations along ridgelines is believed to occur via direct infiltration of rainfall across the ridge where the formations are exposed at the surface or blanketed by a thin layer of soil. Locally perched groundwater may exist where more permeable weathered rock or soils are underlain by low permeable rocks.

There is a net deficit of rainfall on average (annual evaporation exceeds annual rainfall), and on average a deficit for each month of the year (Figure 1). 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 occur in response to higher or more continuous rainfall events, and the overall net recharge rates at the site are expected to be low.

During the periods of low rainfall, the groundwater levels of the alluvium was determined to reduce by a median of 0.7 m/year, while during wet periods, the alluvial bores increased by a median rate of 2.1 m/year.

A response of historical groundwater levels in alluvium to climate variability was reported by Cui *et. al.,* 2018 for alluvium in the Lockyer Valley, indicating a decrease in the median of 0.7 m/year during drought conditions and an increase of 2.1 m/year during wet periods, though the results for the wet period may have been influenced by the extreme conditions from the 2008 and 2011 floods. These rates are less pronounced in sedimentary rock units with the median of the WCM decreasing by 0.1 m/year and increasing by 0.3 m/year during drought and wet periods, respectively, while the median of the water levels in the Gatton Sandstone may experience a median increase of as much as 0.7 m/year during wet periods.

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 alluvial units, Walloon Coal Measures, Koukandowie Formation, Gatton Sandstone and Woogaroo Subgroup, was estimated using chloride mass balance. Statistical parameters for groundwater recharge are reported in **Table 3**.

Table 3: Clarence-Moreton bioregion rainfall recharge estimates (Australian Government, 2014)

Formation	Number of Samples/ Tests	Lower (mm/year)	Typical (mm/year)	Upper (mm/year)
Alluvium	2594	3.9	10.6	32.0
Walloon Coal Measures	52	1.1	2.9	6.0
Koukandowie Formation	21	1.6	2.7	5.9
Gatton Sandstone	242	1.1	3.7	10.2
Woogaroo Subgroup	242	12.2	29.2	68.9

Note: Values are obtained from ranges presented in reviewed literature. The limits are the minimum and maximum from the ranges presented, with the median value of this range presented as the typical value.

5.4 Groundwater Chemistry

There are a total of 1932 samples from 787 groundwater monitoring bores within 5 km of the proposed rail alignment. Collected samples span a range of 99 years, with the earliest samples collected in 1919 and the most recent collected as part of the H2C FS site investigation. Water chemistry data has been collected from the QLD registered bores database, reviewed documents and in the H2C Geotechnical Site Investigation Report (Golder 2018c). Water chemistry data is summarised in APPENDIX C.

Of these monitoring bores, 381 contain a complete set of cation and anion analytical records, 298 of which are screened in the Quaternary alluvium, 26 in the Gatton Sandstone, 42 in the Marburg Subgroup (undifferentiated), two in the WCM and six in the Woogaroo Subgroup. A Piper Diagram was generated to determine hydrogeochemical classification of the tested formations. The Piper Diagram for groundwater sampled from the Quaternary alluvium is shown in Figure 10, while samples from the remaining formations are shown in Figure 11. 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 overall character of the water.

Groundwater sampling data from the H2C FS site investigation is available from 7 groundwater monitoring bores at the time of reporting.

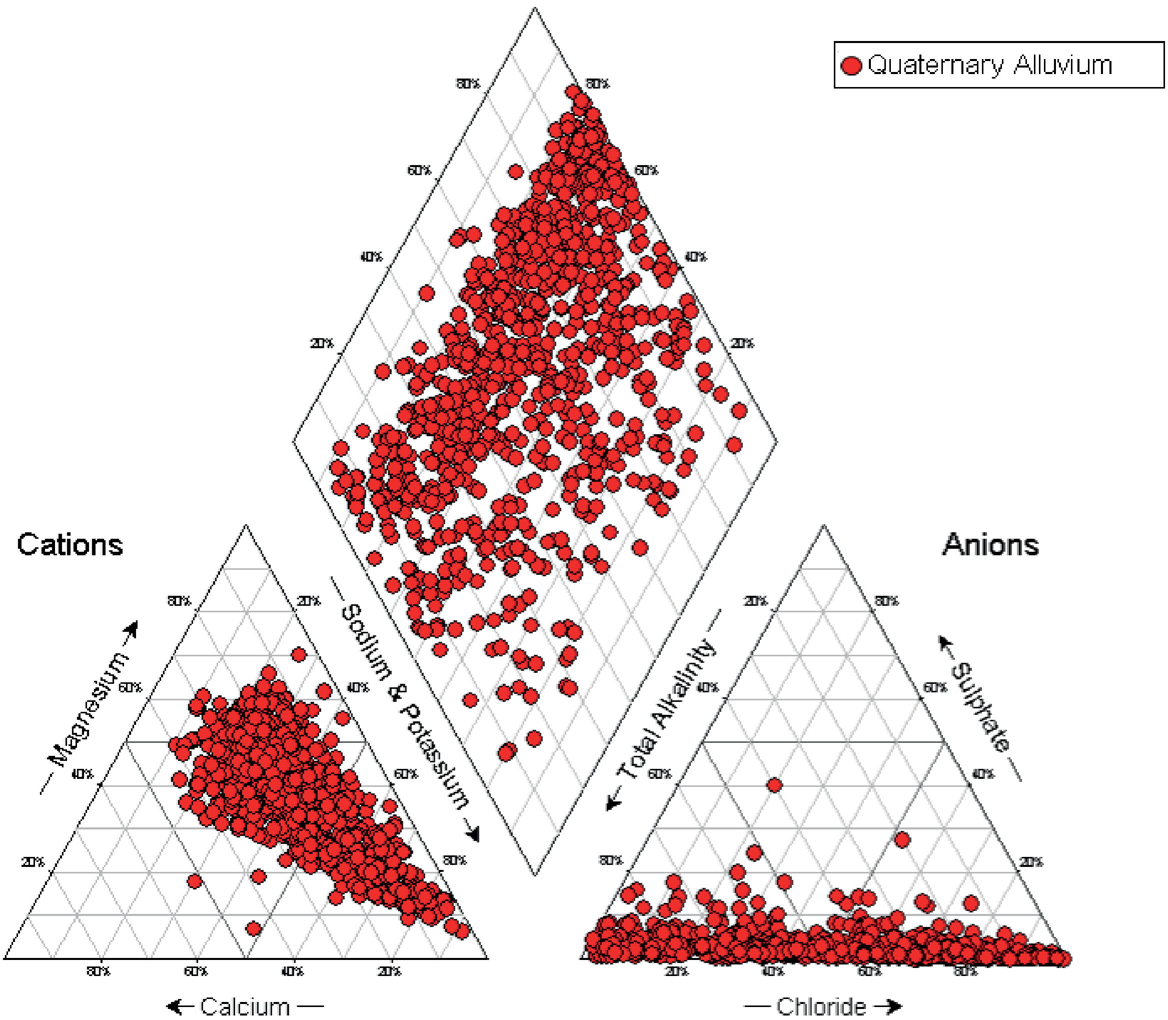


Figure 10: Piper Diagram of groundwater of Quaternary alluvium

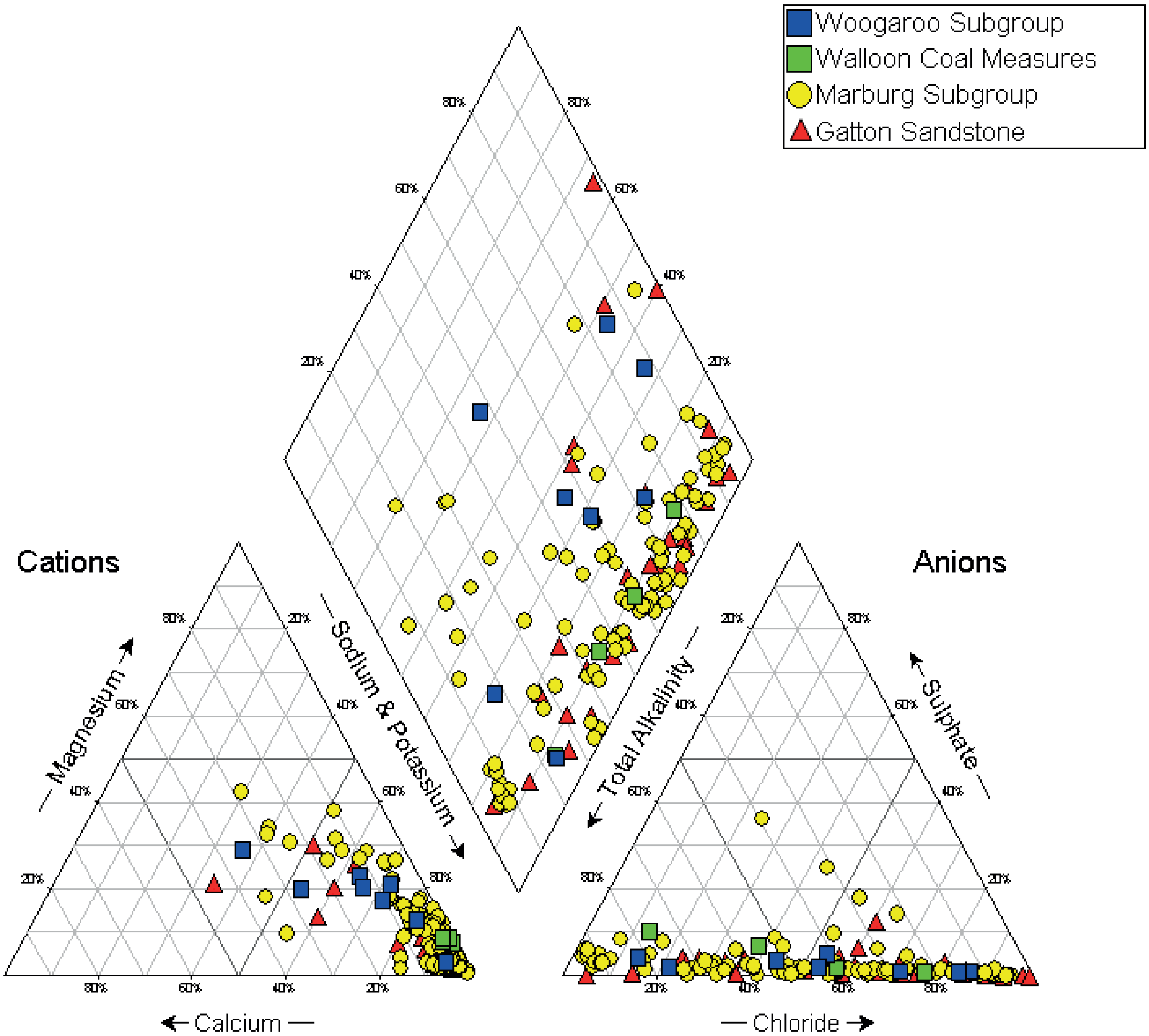


Figure 11: Piper Diagram of groundwater of hydrostratigraphic rock units (excluding the Quaternary alluvium)

Water in the Quaternary alluvium is 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 or topographic influences. Groundwater in the Marburg Subgroup (undifferentiated) and WCM is primarily of Na-Cl-HCO_3 type, while groundwater in the Woogaroo Subgroup and Gatton Sandstone varies between Na-CL-HCO_3 and Mg-SO_4 water types. Variation of water types may be attributed to water bores screened across formations, geological structures separating formations or general variability over time.

Further information on the potential effects of groundwater characteristics on durability is provided in Section 8.0.

5.5 Groundwater Use

Reflecting the land use and cover discussed in Section 3.3 and reported on Figure 3, the groundwater use in the area is primarily for pastoral and intense agricultural uses such as irrigation or water supply. Large areas used for cropping and grazing land typically occur along the flatter river valley with water supply generally being obtained from shallow alluvial aquifers in the Lockyer and Bremer River valleys. There are multiple irrigation areas near the alignment in Lockyer Valley and Bremer River valley as reported on Figure 3 with bores classified as water supply reported in nearby areas on Figure 6. The water supply bores are typically located near watercourses and likely target alluvial aquifer units. There is no groundwater use anticipated in the Little Liverpool Range near the proposed tunnel alignment based on the registered bore database

(Figure 6). The Environmental Impact Assessment (H2C – 2-0001-330-EAP-10-RP-0114) will develop further detail on groundwater use.

6.0 CONCEPTUAL HYDROGEOLOGICAL MODELS

Conceptualisations for the Little Liverpool Tunnel, portal cuts, slope cuts and bridge 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 site investigation along the proposed H2C alignment (Golder, 2018c) and the Clarence-Moreton Bioregional Assessment database (Australian Government, 2018), and DNRME (2008). 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 Gatton Sandstone, Koukandowie Formation, Walloon Coal Measures (WCM) and alluvial sediment deposits. Hydraulic conductivity values for the Woogaroo Subgroup were insufficient in number to complete a meaningful statistical analysis.

Where not explicitly stated otherwise, hydraulic conductivity refers to the saturated hydraulic conductivity in this report.

Slug tests are scheduled to be conducted in all groundwater bores installed as part of the H2C FS site investigation. At the time of this report, slug test results for 8 bores are available. These tests are reported in Golder, 2018c.

Hydraulic conductivity values from testing carried out for the project are summarised in Table 4. Two tests were conducted at piezometers installed in the Woogaroo Subgroup (330-01-BH2207 and 330-01-BH2303), reporting a range in hydraulic conductivity between 1.3 x 10^{-8} and 5.7 x 10^{-6} m/s.

Four tests were conducted at piezometers installed in the Gatton Sandstone (330-01-BH2212, 330-01-BH2216, 330-01-BH2224 and 330-01-BH2503), reporting a range in hydraulic conductivity between 2.2 x 10^{-9} and 1.4 x 10^{-5} m/s.

Boreholes 330-01-BH2101 to 330-01-BH2104 were drilled in the Koukandowie Formation along the Little Liverpool tunnel alignment. Results are only available for 330-01-BH2102 at a depth of 25.0 to 50.0 m. A falling head test was conducted in the borehole and indicating a hydraulic conductivity value of 2.9 x 10^{-6} m/s.

One test was conducted in a piezometer installed in alluvium at a depth of 6.0 to 12.0 m, indicating a hydraulic conductivity value of 3.3 x 10^{-6} m/s.

Hydraulic borehole testing has not been conducted in 33001BH2101, 33001BH2103, 33001BH2301 or 33001BH2227 at the time of this report.

Table 4: Hydraulic test results summary from H2H Feasibility Study site investigations (Golder, 2018c)

Bore	Test Interval (m bgl)	Test Method	Formation	Analytical Method	Hydraulic Conductivity (m/s)
330-01-BH2101	100.0 to 129.0	Not tested	Koukandowie Formation	Not tested	Not tested
330-01-BH2102	25.0 to 50.0	Falling Head Test	Koukandowie Formation	Hvorslev and KGS	2.9×10^{-6}
330-01-BH2103	16.0 to 30.0	Not tested	Koukandowie Formation	Not tested	Not tested
330-01-BH2104	15.0 to 31.0	Slug test	Koukandowie Formation	NA	Not analysed [A]
330-01-BH2203	6.0 to 12.2	Rising head test	Alluvium	Hvorslev and KGS	3.3×10^{-6}
330-01-BH2207	11.5 to 20.5	Slug test	Woogaroo Subgroup	Hvorslev and KGS	5.7×10^{-6}
330-01-BH2212	23.0 to 27.0	Slug test	Gatton Sandstone	Hvorslev and KGS	1.4×10^{-5}
330-01-BH2216	18.5 to 25.5	Slug test	Gatton Sandstone	Hvorslev and KGS	1.4×10^{-6}
330-01-BH2224	8.5 to 21.5	Slug test	Gatton Sandstone	Hvorslev and KGS	3.6×10^{-6}
330-01-BH2227	16.0 to 20.0	Not tested	Koukandowie Formation	Not 7HVWHG	Not tested
330-01-BH2301	12.0 to 30.0	Not tested	Gatton Sandstone	Not 7HVWHG	Not tested
330-01-BH2303	15.0 to 30.0	Falling head test	Woogaroo Subgroup	Hvorslev and KGS	1.3×10^{-8}
330-01-DH2503	8.0 to 15.0	Rising head test/ Falling head test	Gatton Sandstone	Hvorslev and KGS	2.2×10^{-9}

Note: A – Test not analysed because bore was still recovering at the time the test was conducted.

Not yet tested – Testing not completed at the time of reporting.

Woogaroo Subgroup

Hydraulic conductivity of the Woogaroo Subgroup range between an estimate of 5.0×10^{-7} and 6.9×10^{-5} m/s based primarily on literature records summarised by the University of Southern Queensland (2011), DNRME (2008) and considering results of site-specific tests. Based on considerations of the site-specific test results (refer above) and regional hydraulic conductivity data, a value of 5.0×10^{-6} m/s has been adopted as the typical value for the Woogaroo Subgroup for modelling inflow to cuts.

There are no specific yield values available for the Woogaroo Subgroup from either project specific testing or from other data sources. Resulting from these data limitations, the range of hydraulic conductivity and specific yield values has been estimated from values adopted for similar sandstones (Precipice Sandstone) in previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011). The Precipice Sandstone is equivalent to the Helidon Sandstone (Woogaroo Subgroup) and is known to be a highly productive regional aquifer with high potential for water supply. Lower, typical and upper specific yield estimates are provided in Table 5.

Gatton Sandstone

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.

In addition to the four tests carried out in 330-01-BH2212, 330-01-BH2216, 330-01-BH2224 and 330-01-DH2503 as discussed above, a total of 88 test results are available for the Gatton Sandstone for locations across the Clarence-Moreton basin, with results ranging between 5×10^{-10} to 2×10^{-5} m/s. Of these 88 permeability test records, 46 are above 1×10^{-7} m/s and 25 are above 1×10^{-6} m/s. A statistical distribution of permeability test results for the Gatton Sandstone including all 88 tests is shown in Figure 12 and statistical parameters for the test records are summarised in Table 5. The test records indicate that the hydraulic conductivity of the Gatton Sandstone is highly variable, reflecting the fractured nature of the aquifer and the variability in hydraulic conductivity of the sandstone with depth across the weathering profile.

Based on considerations of the site-specific test results and regional hydraulic conductivity data, a value of 1×10^{-7} m/s has been used as a typical value for the Gatton Sandstone for modelling to assess inflow to cuts. This value reflects both the regional data and the site specific data, with a higher weighting placed on the site data to derive a value that is more likely to represent local conditions.

Hydraulic conductivity of the Gatton Sandstone is expected to be transversely isotropic with interbedding of sandstone and siltstone/mudstone resulting in a higher resistance to flow in the vertical than in the horizontal direction. In the absence of any test records for vertical hydraulic conductivity of the Gatton Sandstone literature values of anisotropy (IESC, 2014) were adopted for this assessment. Anisotropy ratios adopted for this assessment are reported in Table 5.

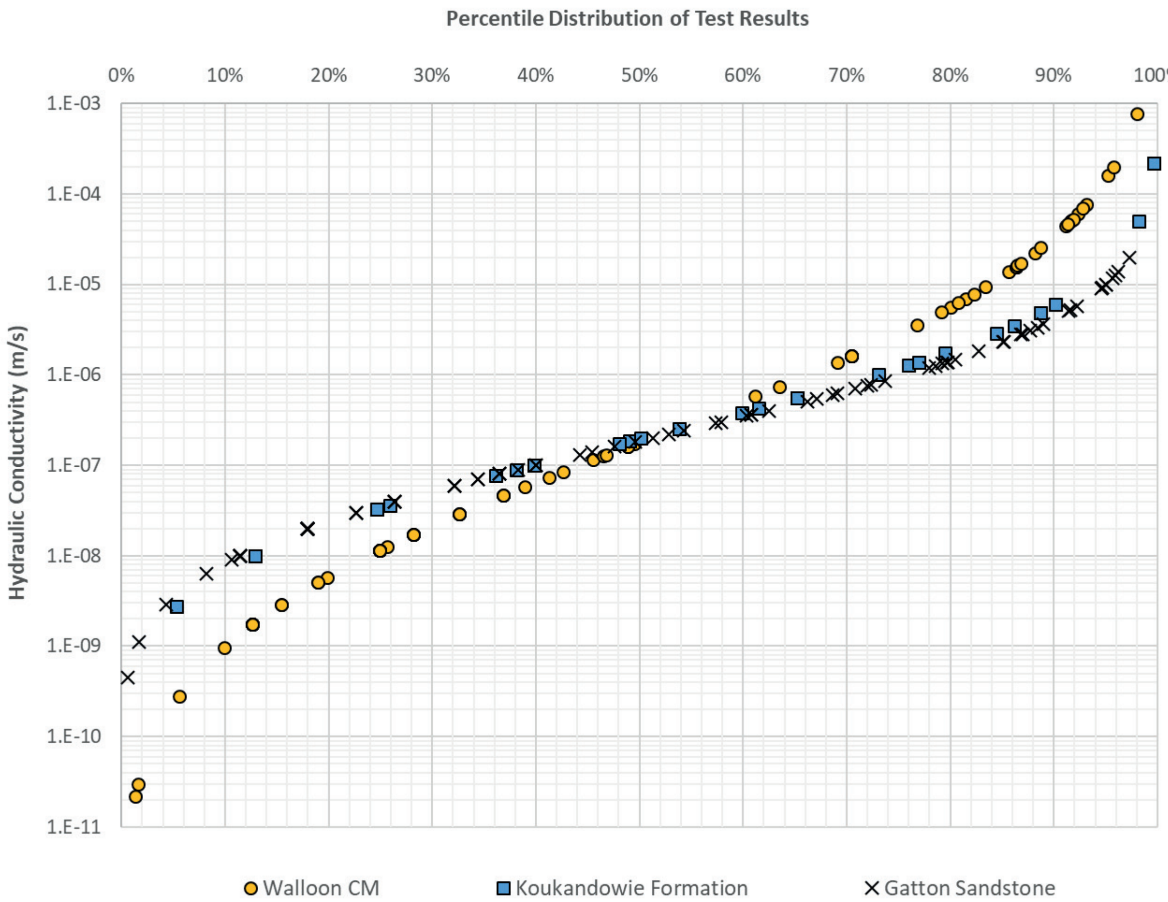


Figure 12: Statistical distribution of permeability test results for selected hydrostratigraphic units of the Clarence Moreton Basin.

Koukandowie Formation

A total of 61 test results are available for the Koukandowie Formation for locations across the Clarence-Moreton basin and literature, with results ranging between 2.8 x 10^{-9} and 2.2 x 10^{-4} m/s. Of these 60 permeability test records, 26 are above 1 x 10^{-7} m/s and 14 are above 1 x 10^{-6} m/s. A statistical distribution of permeability test results for the Koukandowie Formation, including all 61 tests is shown in Figure 12 and statistical parameters for the test records are summarised in Table 5.

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. Based on considerations of the site-specific test results and regional hydraulic conductivity data, a value of 1 x 10^{-7} m/s has been used as a typical value for the Koukandowie Formation for modelling to assess tunnel inflow and cut seepage rates.

Hydraulic conductivity of the Koukandowie Formation is expected to be transversely isotropic with interbedding of sandstone and siltstone/mudstone resulting in a higher resistance to flow in the vertical than in the horizontal direction. In the absence of any test records for vertical hydraulic conductivity of the Koukandowie Formation, literature values of anisotropy (IESC, 2014) were adopted for this assessment. Anisotropy ratios adopted for this assessment are reported in Table 5.

There are no specific yield values available for the Koukandowie Formation from either project specific testing or from other data sources. A range of specific yield values has been estimated from values adopted for similar sandstones (Hutton Sandstone) in previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011). Lower, typical and upper specific yield estimates are provided in Table 5.

Walloon Coal Measures

No project site specific testing has been conducted in the Walloon Coal Measures. A total of 79 test results are available for the Walloon Coal Measures for locations across the Clarence-Moreton basin and from literature,-with results ranging between 2.2×10^{-11} and 7.8×10^{-4} m/s. Of these 79 permeability test records, 39 are above 1×10^{-7} m/s and 31 are above 1×10^{-6} m/s. A statistical distribution of permeability test results for the Walloon Coal Measures, including all 79 tests is shown in Figure 12 and statistical parameters for the test records are summarised in Table 5. The test records indicate that the hydraulic conductivity of the Walloon Coal Measures 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. The occurrence of higher permeable coal seams in the upper part of the WCM may have also contributed to the variability in the test results.

Based on considerations of the site-specific test results and regional hydraulic conductivity data, a value of 1×10^{-7} m/s has been used as a typical value for the Walloon Coal Measures for modelling to assess inflow into cuts.

There are no specific yield values available for the Walloon Coal Measure from either project specific testing or from other test data sources. A range of specific yield values has been estimated from values adopted in previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011). Lower, typical and upper specific yield estimates are provided in Table 5.

Hydraulic conductivity of the Walloon Coal Measure is expected to be transversely isotropic with interbedding of sandstone, siltstone/mudstone and coal, resulting in a much higher resistance to flow in the vertical than in the horizontal direction. Due to the low vertical hydraulic conductivity of the WCM this formation is generally thought to act as a confining layer to the underlying aquifers of the Koukandowie Formation. In the absence of any test records for vertical hydraulic conductivity of the Walloon Coal Measure literature values of anisotropy (IESC, 2014) were adopted for this assessment. Anisotropy ratios adopted for this assessment are reported in Table 5.

Alluvium

A total of 107 test records are available for the alluvium with horizontal hydraulic conductivity values ranging between 1×10^{-6} and 1.7×10^{-2} m/s. Test records are considered to be strongly biased towards the high end of the conductivity range since tested bores were mostly drilled for irrigation purposes and therefore, targeted the high yielding alluvial gravel and sand aquifers. The alluvial sediment deposits are likely transversely isotropic due to interbedding of more sandy layers with beds of silt and clay. Specific yield data were unavailable for the rail corridor and a range of specific yield values reported in literature for similar materials has been adopted or design purpose.

Table 5: Preliminary hydrogeological design parameters

Formation	Hydraulic Property/year	Number of Samples/Tests	Lower	Typical	Upper
Woogaroo Subgroup	Hydraulic Conductivity (m/s) A	Estimate	5×10^{-7}	5×10^{-6}	5×10^{-5}
	K_h/K_v B	Estimate	20	100	500
	Specific Yield C	Estimate	0.015	0.05	0.10
	Rainfall Recharge (mm/year) D	242	12.2	29.2	68.9
Gatton Sandstone	Hydraulic Conductivity (m/s) A	88	2×10^{-8}	1×10^{-7}	1.4×10^{-6}
	K_h/K_v B	Estimate	20	100	500
	Specific Yield C	Estimate	0.015	0.05	0.10
	Rainfall Recharge (mm/year) D	242	1.1	3.7	10.2
Koukandowie Formation	Hydraulic Conductivity (m/s) A	61	3.2×10^{-8}	1×10^{-7}	8.9×10^{-7}
	K_h/K_v B	Estimate	20	100	500
	Specific Yield C	Estimate	0.015	0.05	0.10
	Rainfall Recharge (mm/year) D	6	1.7	2.3	25.7
Walloon Coal Measures	Hydraulic Conductivity (m/s) A	82	1.2×10^{-8}	1×10^{-7}	9.1×10^{-6}
	K_h/K_v B	Estimate	20	100	500
	Specific Yield C	Estimate	0.005	0.035	0.05
	Rainfall Recharge (mm/year) D	52	1.1	2.9	6.0
Alluvium	Hydraulic Conductivity (m/s) A	Estimate	1×10^{-6}	1×10^{-5}	3.2×10^{-3}
	K_h/K_v	Estimate	1	10	100
	Specific Yield C	Estimate	0.05	0.10	0.15
	Rainfall Recharge (mm/year) D	2594	3.9	10.6	32.0

Note: [A] Lower, typical and upper values are estimates based on $\mu - \sigma$, μ, $\mu + \sigma$ of hydraulic test records with μ, median, and σ, standard deviation, of the logarithmized test values.

[B] K_h/K_v – Ratio between horizontal and vertical hydraulic conductivity, estimates are based on lithological characteristic of the Gatton Sandstone, Koukandowie Formation, Walloon Coal Measures and experience with formation of similar lithology.

[C] Estimates based on model calibration results of sandstone in the Surat Basin. Judgement was applied to adjust literature values considering textural features of the Gatton Sandstone., Koukandowie Formation, Walloon Coal Measures and alluvial sediment deposits

[D] Lower, typical and upper values are represented by 25th, 50th (median) and 75th percentiles of recharge estimates for locations across the Clarence-Moreton bioregion. Actual recharge values may vary depending on relief, soil and vegetation cover between Kilometrage 39.500 and 41.280 km. Data source: Raiber et al., 2016.

6.2 Observed and Inferred Groundwater Levels

Groundwater monitoring bores equipped with standpipe piezometers and automated water level probes were constructed along the proposed alignment as part of the H2C FS site investigation. Water level measurements available at the time of reporting are summarised in Table 6.

Table 6: Depth to groundwater table and groundwater level records for H2C monitoring bore locations along the proposed H2C alignment

Bore	Screen Interval (m bgl)	Formation	Date of Observation	Depth to Water (m bgl)	SWL RL (m AHD)
330-01-BH2101	100.0 to 129.0	Koukandowie Formation	30/11/2018	82.5	162.5
330-01-BH2102	25.0 to 50.0	Koukandowie Formation	23/10/2018	26.4	138.6
330-01-BH2103	15.0 to 30.0	Koukandowie Formation	20/11/2018	13.1	140.9
330-01-BH2104	15.0 to 31.0	Koukandowie Formation	22/10/2018	15.6	142.4
330-01-BH2203	6.0 to 12.2	Alluvium	24/10/2018	14.4	124.6
330-01-BH2207	11.5 to 20.5	Woogaroo Subgroup	25/10/2018	9.7	131.4
330-01-BH2212	23.0 to 27.0	Gatton Sandstone	23/10/2018	NR	NR
330-01-BH2216	18.5 to 25.5	Gatton Sandstone	23/10/2018	2.9	94.1
330-01-BH2224	8.5 to 21.5	Gatton Sandstone	25/10/2018	NR	NR
330-01-BH2227	16.0 to 20.0	Koukandowie Formation	NR	NR	NR
330-01-BH2301	12.0 to 30.0	Gatton Sandstone	25/10/2018	28.3	159.7
330-01-BH2303	15.0 to 30.0	Woogaroo Subgroup	25/10/2018	24.3	150.7
330-01-DH2503	8.0 to 15.0	Gatton Sandstone	25/10/2018	13.0	92.0

NR - No measurements were available at the time of reporting.

Groundwater levels along the Little Liverpool Tunnel alignment, earthworks and bridge locations were estimated based on available water level data within the same rock formation, similar ground relief and land use. Estimates were derived using statistical methods and are based on the correlation between static water level and ground surface elevation of groundwater monitoring locations. These estimated groundwater levels in various parts of the alignment are discussed below.

Little Liverpool Range Tunnel

The Little Liverpool Range Tunnel is within the Koukandowie Formation under the Little Liverpool Ranges. Groundwater monitoring bores 330-01-BH2101, 330-01-BH2102, 330-01-BH2103 and 330-01-BH2104 were constructed along the ridge following the H2C tunnel alignment (refer to Figure 14). These monitoring bores were equipped with standpipe piezometers installed in the Koukandowie Formation . Water level results from these bores are reported in Table 6. Water levels in these 4 bores have stabilised as follows: 330-01-BH2101 162.5 m AHD (30/11/2018), 330-01-BH2102 138.6 m AHD (23/10/2018) 330-01-BH2103 140.9 m AHD (20/11/2018) and 330-01-BH2104 142.4 m AHD (22/10/2018) respectively. Hydrographs for these monitoring bores are reported in APPENDIX A (Figures A1, A2, A3 & A4).

A preliminary estimate of natural groundwater level along the tunnel alignment and slope cuts at the portals prior to tunnel construction is reported in Figure 13. Actual water levels may differ locally due to local variation of recharge and discharge across the ridge and compartmentalisation of groundwater in the fractured rock.

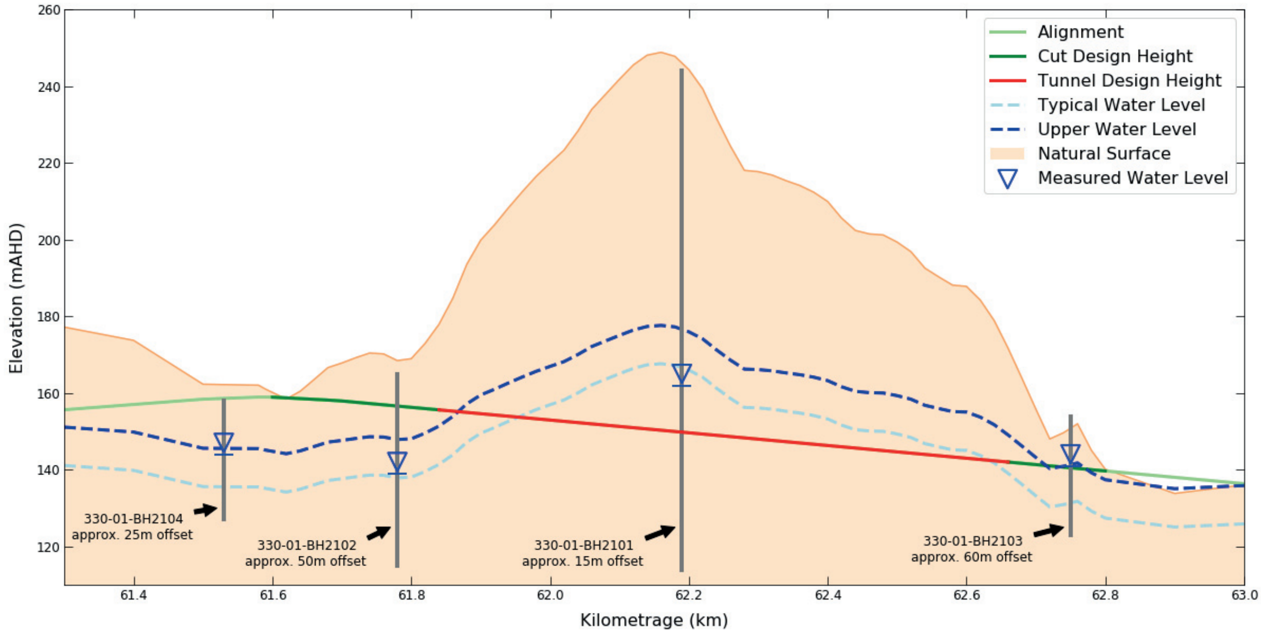


Figure 13: Preliminary estimate of pre-development groundwater level along the alignment between Kilometrage 61.300 to 63.000 km prior to tunnel construction

A summary of estimated typical and upper groundwater levels within the Koukandowie Formation along the tunnel alignment is provided in Table 7 below. Upper estimates are based on judgement from considering the available and limited data and require further refinement through groundwater level monitoring.

LEGEND

FFJV/Golder Site Investigation Boreholes (Drilled to Date)

Approx. Cut Location

Approx. Tunnel Location

H2C - Helidon to Calvert

FOR DISCUSSION PURPOSES ONLY

DRAFT

Coordinate System: GDA 1994 MGA Zone 56
Projection: Transverse Mercator
Datum: GDA 1994

0 150 300

1:10,000 A4 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

REFERENCE(S)

1. **G2H, H2C and C2K Alignment, 1m DEM:** Provided by FFJV on 31st July 2018, 6th Nov 2018, 5th Nov 2018 and derived from LiDAR data provided by FFJV respectively.
2. **ARTC Geotech and Groundwater Bores:** Retrieved from ARTC's 01-3400-PD-P00-DE-0009_2 C2K Concept Geotechnical Factual Report Aug 2016

CLIENT
FUTURE FREIGHT JOINT VENTURE

PROJECT
INLAND RAIL SECTION 330 H2C

TITLE
LITTLE LIVERPOOL RANGE TUNNEL PLAN VIEW

CONSULTANT

GOLDER

DD-MM-YYYY	6/03/2020
DESIGNED	DW
PREPARED	DW
REVIEWED	AT
APPROVED	AT

PROJECT NO.	CONTROL	REV.	FIGURE
1893802	022	2	14

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Table 7: Summary of preliminary estimates of groundwater level along the alignment between Kilometrage 61.300 to 63.000 km prior to tunnel construction

Kilometrage (km)	Estimated Groundwater Level	
	Typical Level (m AHD)	Upper Level (m AHD)
61.300	141	151
61.400	140	150
61.500	136	146
61.600	135	145
61.700	138	148
61.800	138	148
61.900	150	160
62.000	157	167
62.100	165	175
62.200	166	176
62.300	156	166
62.400	153	163
62.500	149	159
62.600	146	156
62.700	134	144
62.800	126	136
62.900	125	135
63.000	126	136

Slope Cuts

Registered bores with historical water level records are typically located in low lying areas near creeks and rivers with limited data available at higher elevations. For two cut locations along the H2C alignment, groundwater level records are available for the period between September 2018 to October 2018 (Table 6). 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 water level data with ground surface elevation. A summary of preliminary estimates of groundwater level at deep cuts relative to cut elevations is presented in Table 8.

Based on a review of available information, groundwater is anticipated to be encountered in at least 5 of the 19 deep cut locations. Locally perched groundwater may exist which will require further assessment after more detailed site investigations have been conducted for Detailed Design.

Table 8: Locations where cuts are anticipated to encounter the water table

Name	Start (km)	End (km)	Length (km)	Median CL Elevation at Cut (mAHD)	Median GW Level at Cut (mAHD)	Maximum GW Level at Cut (mAHD)
330-C04	28.260	29.440	1.180	165.0	167.7	178.1
330-C07	33.010	33.210	0.200	165.7	176.8	185.8
330-C08	34.530	35.070	0.540	148.4	147.9	155.5
330-C15	59.830	60.660	0.830	141.3	151.5	156.2
330-C16	61.170	61.640	0.470	157.2	159.8	185.5

Note: CL= Cut Level

7.0 GROUNDWATER DRAWDOWN AND INFLW MODELLING

7.1 Little Liverpool Tunnel and Portal Cuts

Preliminary analysis of groundwater inflows and drawdown associated with a drained tunnel and portal cuts has been carried out to inform an assessment of the potential to construct the Little Liverpool Tunnel and adjacent cuts as permanently drained structures. The analysis has been based on the alignment X_IR_3310000_D_RAI_3D_DESIGN_12D in the version as of 23 October 2018, preliminary hydrogeological parameters listed above and preliminary groundwater levels provided in Table 7.

7.1.1 Design Assumptions

The Little Liverpool Tunnel alignment for Section 330 H2C is located between Kilometrage 61.840 km and 62.660 km (Kilometrages of the tunnel design portals) in the Koukandowie Formation. The approximate length of the single-track tunnel is 820 m. The tunnel invert elevation varies between 142.0 m AHD and 155.6 m AHD and design height of the tunnel is 10 m throughout the alignment. Maximum rock thickness above tunnel crown is approximately 98 m at Kilometrage 62.160 km.

On either side of the tunnel the design rail track is incised into a slope with large-scale cut batters at the tunnel portals. The cut at the western portal has a length of approximately 220 m and a depth of up to approximately 17 m. At the eastern tunnel portal, the cut has a depth of up to approximately 22 m and extends in length for approximately 120 m to the east.

In general, the groundwater models are based on the following assumptions:

- Tunnel and portal cuts are assumed to be permanently drained;
- Tunnel and portal cuts are assumed to be within the Koukandowie Formation;
- The modelled tunnel alignment and portal cuts is between Kilometrage 61.600 to 62.800 km with the tunnel itself located between Kilometrage 61.840 to 62.660 km;
- There will be no lining or grouting work undertaken for zones of higher permeability associated with faults or locally increased fracture intensity;
- The rock below the tunnel invert is permeable Koukandowie Formation to a depth of approximately 50 m. Below a depth of 50 m, the rock is assumed to be practically impermeable;
- The groundwater level used in the model is derived from the correlation between topography and water level as shown in Figure 13, with a moving average applied over 300 m lengths to smooth the water level fluctuations that result from direct application of the correlation to the topographic variations[1].

7.1.2 Methodology

The estimates of groundwater inflows and drawdown were derived using an analytical method (Perrochet method) and a numerical modelling approach (SEEP/W model). The analytical method can simulate transient discharge into the tunnel and the development of groundwater table drawdown. Steady-state numerical models using the modelling code SEEP/W have been developed to compare with the results obtained with the analytical solution.

Seepage flow and drawdown were analysed using a modified Perrochet analysis (Maréchal et. al., 2014) implemented in MATLAB code of MathWorks® to derive inflows and drawdown during construction and in the long-term. The analysis method was modified to account for topographic effects on seepage and drawdown. The Perrochet analysis method as documented by Maréchal et. al. (2014) is based on the assumption of an

[1] Although groundwater levels will generally reflect topographic variations and will be generally consistent with the best-fit correlation that has been developed between groundwater level and ground surface elevation, groundwater levels will vary more gradually than would be implied by a direct application of the best-fit correlation.

infinite horizontal ground surface in the dimension perpendicular to the tunnel. In this case, the topography is such that the ground surface drops away in the third dimension, eventually to a level below the level of the tunnel. This will limit the area from which tunnel inflows are derived from recharge.

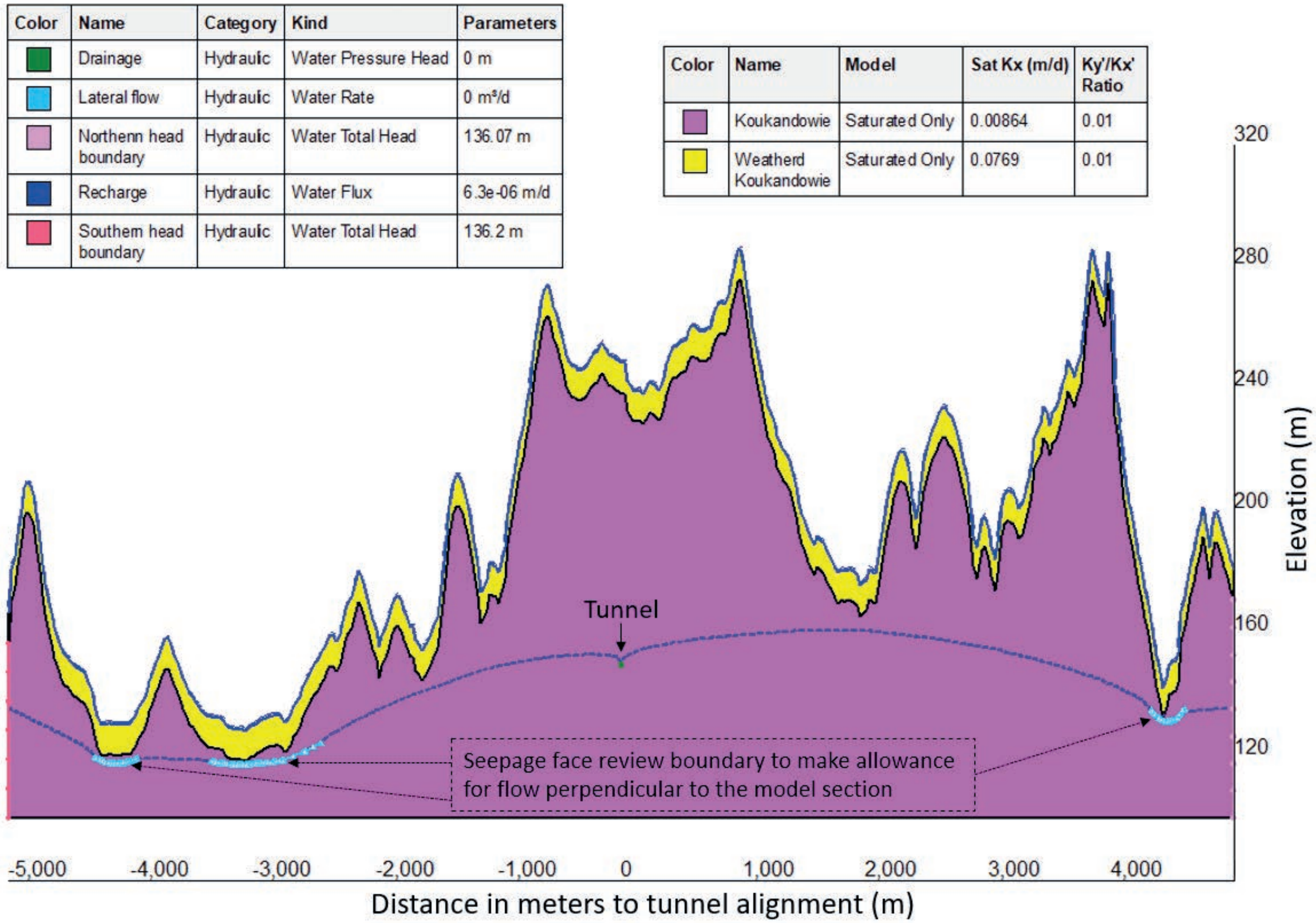
The inflow and drawdown analysis is based on the following assumptions:

- Groundwater flows only horizontally within a plane perpendicular to the tunnel axis towards the tunnel.
- Tunnel excavation will start from west to east with the approximate tunnel construction rate of 4 m per day. Duration of tunnel construction is approximately 205 days.
- Water inflows to drained tunnel sections are along the entire length of the tunnel, and the tunnel has been divided into 20 m intervals for the calculation.
- The geological material (Koukandowie Formation) is assumed to be homogenous and isotropic with respect to hydraulic characteristics of the material above and below the tunnel invert.
- Groundwater recharge occurs at a constant rate and does not change along the length of the tunnel.
- As discussed in Section 6.1, a value of 1 x 10^{-7} m/s has been adopted for the horizontal hydraulic conductivity of the Koukandowie Formation.

A cross-sectional groundwater model has been developed using the finite element SEEP/W model code (part of the GeoStudio software suite). The modelling domain is shown in Figure 15

The inflow and drawdown analysis is based on the following assumptions:

- The modelled cross section is located at Kilometrage 62.160 km where the rock thickness above the tunnel crown is at its maximum.
- Two geological units within the Koukandowie Formation have been included in the model according to the H2C Feasibility Phase Geophysics Report (Golder 2018d): highly weathered rock with an average thickness of 10 m and underlying fresh rock.
- The boundaries to the North and South are located 5 km away from the tunnel. Constant heads of 136.2 m and 136.1 m AHD were applied at the southern boundary and northern boundary, respectively. The water levels have been inferred from correlation between groundwater level depth and ground surface elevation.
- Recharge has been applied on the surface (top boundary) of the model. The distribution of recharge has been adjusted in order to get a better match with the observed and inferred typical groundwater levels illustrated in Figure 13. Average recharge rates adopted for the Koukandowie Formation after model calibration is 1.6 mm/year and is close to the lower recharge rate reported in Table 5.
- Regional groundwater flow directions have been interpreted from groundwater level contours which have been estimated using the correlation between groundwater level and ground surface elevation. Figure 16 shows the interpreted groundwater level contours, interpreted flow directions and groundwater divides. This figure indicates lateral flows along the tunnel alignment (i.e. perpendicular to the orientation of the cross-sectional model). Potential seepage face review boundary conditions have been applied within the model domain to represent lateral flows perpendicular to the model domain (refer to Figure 15).
- The adopted hydraulic conductivity values for fresh rock and weathered rock are the typical value and upper value of hydraulic conductivity for the Koukandowie Formation listed in Table 5. An anisotropy ratio of 100 (horizontal to vertical) has been applied.



Color	Name	Category	Kind	Parameters
	Drainage	Hydraulic	Water Pressure Head	0 m
	Lateral flow	Hydraulic	Water Rate	0 m³/d
	Northenn head boundary	Hydraulic	Water Total Head	136.07 m
	Recharge	Hydraulic	Water Flux	6.3e-06 m/d
	Southem head boundary	Hydraulic	Water Total Head	136.2 m

Color	Name	Model	Sat Kx (m/d)	Ky'/Kx' Ratio
	Koukandowie	Saturated Only	0.00864	0.01
	Weatherd Koukandowie	Saturated Only	0.0769	0.01

Figure 15: Little Liverpool Tunnel cross-sectional model at Kilometrage 62.160 km

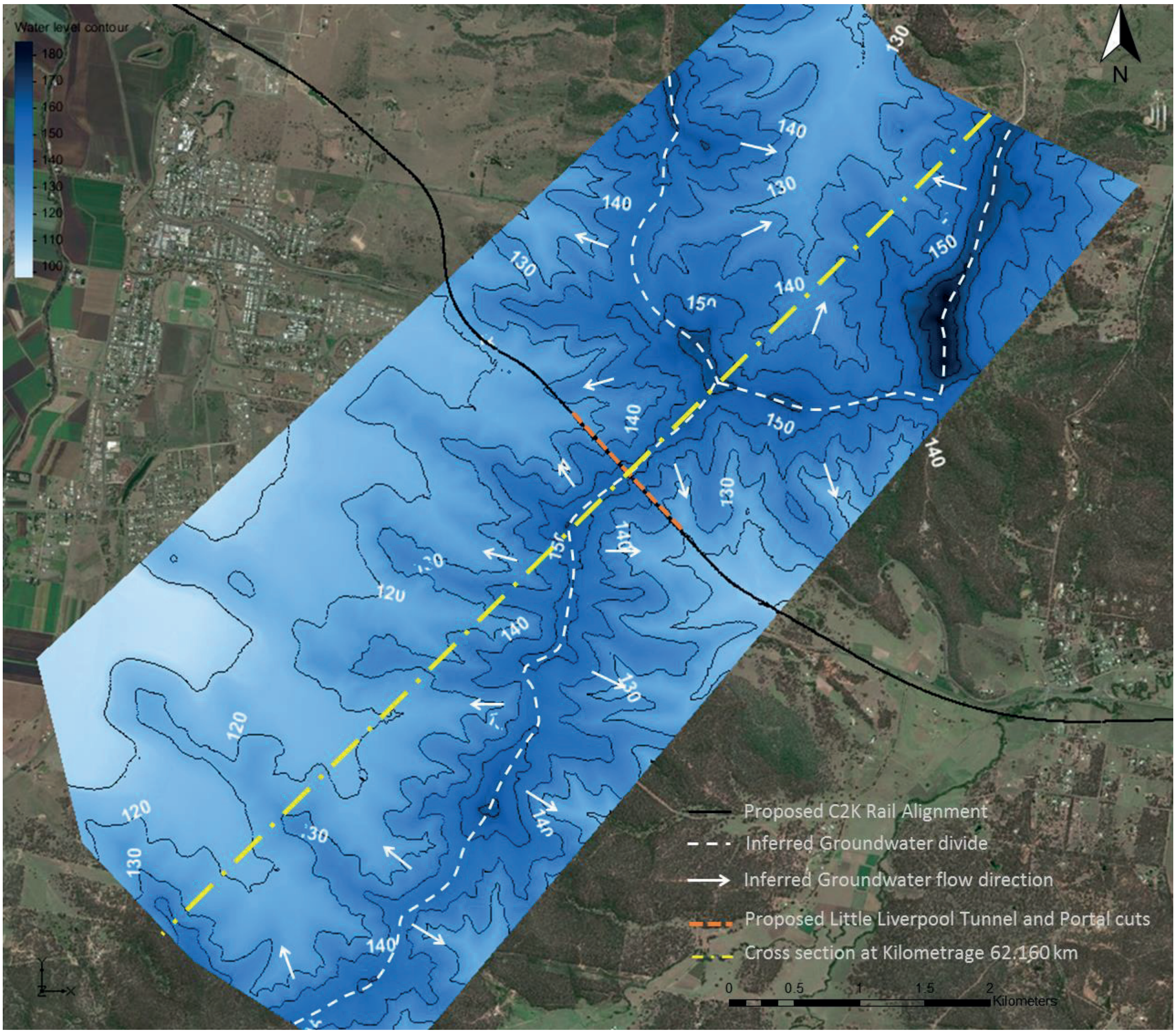


Figure 16: Groundwater level contours and groundwater flow divides. White dashed lines show groundwater flow divides. Arrows indicate the groundwater flow direction.

7.1.3 Groundwater Inflow Estimates

A long-term inflow of about 0.54 L/s has been estimated under drained conditions for the 820 m long tunnel using the analytical model. Estimated long-term inflow rates for 100 m intervals are reported in Table 9. The long-term inflow into Kilometrage 62.160 km computed by the SEEP/W model is less than 0.01 L/s per 100 m of tunnel. The predictive estimate of inflow using the analytical method for the 100 m section between Kilometrage 62.140 and 62.240 km is 0.19 L/s (refer to Table 5).

For the cuts at the portals of the tunnel, groundwater levels along the cuts are inferred to be below the design level and therefore, no permanent seepage flows are anticipated. During prolonged rainfall, some seepage from perched groundwater may occur.

Long-term inflow estimates are average rates and actual inflows to the tunnel will vary with seasons; with lower inflows during dry months and higher inflows during and after prolonged periods of rain.

Higher water inflow is expected during tunnel construction when compared with long-term inflows. Short-term inflow rates have been calculated using the analytical model. The results of this model indicate a maximum total short-term inflow rate of 2.56 L/s will need to be managed during the construction of the tunnel. Elevated inflows are expected to be of short duration and will decline after weeks or month to rates similar to long-term inflow rates. Note also that the inflow rate may peak above the calculated value of 2.56 L/s (which is based on an assumed average value for hydraulic conductivity) for short periods of time (days to weeks) if higher permeability features are encountered during tunnelling.

Table 9: Preliminary estimates of inflow to the Little Liverpool tunnel (Kilometrage 61.600 to 62.800 km).

Kilometrage (km)	Estimated Long-term Operational Groundwater Inflows (L/s) [A]
	Long-term Operational
61.600 to 61.840	0
61.840 to 61.940	0
61.940 to 62.040	0.03
62.040 to 62.140	0.12
62.140 to 62.240	0.19
62.240 to 62.340	0.13
62.340 to 62.440	0.05
62.440 to 62.540	0.02
62.540 to 62.660	0.01
62.660 to 62.800	0
Summary	**0.54**

Note: blue shade – western portal cut, red shade – tunnel, green shade – eastern portal cut

[A] Using the analytical model and, and based on "typical" estimate groundwater level as shown in Figure 13

7.1.4 Groundwater Drawdown Estimates

Queensland's Water Act 2000 specifies a trigger thresholds for drawdown of 5 m at locations of bores in rock aquifers (such as the Heifer Creek Sandstone of the Koukandowie Formation). The approximate extent of the estimated long-term drawdown associated with the drained tunnel and portal cuts is illustrated on Figure 17, indicating the estimated drawdown contour based on the Perrochet analysis. The maximum long-term drawdown along the proposed tunnel alignment computed with the Perrochet method is up to 15m, with drawdown of up to 5 m extending to 406 m along the tunnel alignment, and to 50 m from the tunnel. It is noted that the drawdown mainly extents along the tunnel alignment. This is due to the tunnel construction effects with the inferred water table in the area.

Figure 17: Estimated drawdown of groundwater table between Kilometrage 61.600 and 62.800 km due to drainage of Little Liverpool tunnel (computed with the Perrochet method)

7.1.5 Uncertainty Analysis

An uncertainty analysis has been carried out to account for the effects of higher than "typical" pre-existing groundwater levels and structural features on groundwater inflow and drawdown. The estimates of groundwater inflows for the uncertainty analysis for the entire length of the tunnel were derived using the Perrochet method.

In Section 4.1 the presence of one or two structurally affected zones of up to 2 m width is suggested along the tunnel section. However, the location of such structurally affected zones is not confirmed by site observations. The following assumptions have been made for the uncertainty analysis:

- Two structurally affected zones have been included in the model. It is assumed that the tunnel will encounter the structurally affected zones at Kilometrage 62.160 km (where the groundwater level is highest) and 62.390 km (midpoint between eastern portal and Kilometrage 62.160 km). The width of the structurally affected zone is conservatively assumed to be 10 m.
- The structural features are oriented perpendicular to the tunnel and extend beyond the drawdown zone (i.e. the entire cross section at the feature location will be affected by the structural feature) and contains moderately weathered rock mass.
- The value of hydraulic conductivity (8.9 x 10^{-7} m/s from Table 5) has been applied to the structurally affected zones.

- The elevated groundwater level is 10 m higher than the "typical" water level at all points along the tunnel alignment.

Three scenarios have been simulated:

- An elevated groundwater level with no structurally affected zones;
- Typical groundwater levels with two structurally affected zones; and
- An elevated groundwater level with two structurally affected zones.

Results from these scenarios are summarised in Table 10.

Table 10: Scenarios for sensitivity analysis

Scenario	Number of structurally affected zones	Water level	Long-term inflow (L/s)
1	0	Elevated water level	1.30
2	2	Typical water level	0.69
3	2	Elevated water level	1.58

If the water level is elevated by 10 m relative to the "typical" water level, the total long-term inflow for 820 m length of tunnel increases from 0.54 L/s to 1.30 L/s. Structural features cause a slight increase in the long-term inflow rate, from 0.69 L/s to 1.58 L/s.

The approximate extents of the predicted long-term drawdown under the three scenarios are illustrated in Figure 18, Figure 19 and Figure 20 as follows:

- Scenario 1 (elevated groundwater level with no structurally affected zones): the drawdown of up to 20 m is developed along the tunnel, with drawdown of up to 5 m extending to 746 m along the tunnel, and 64 m from the tunnel (refer to Figure 18).
- Scenario 2 (typical groundwater levels with two structurally affected zones): the drawdown of up to 15 m is developed along the tunnel, with drawdown of up to 5 m extending to 405 m along the tunnel, and 117 m from the tunnel (refer to Figure 19).
- Scenario 3 (elevated groundwater level with two structurally affected zones): the drawdown of up to 25 m is developed along the tunnel, with drawdown of up to 5 m extending to 764 m along the tunnel, and 169 m from the tunnel (refer to Figure 20).

Figure 18: Estimated drawdown of groundwater table between Kilometrage 61.600 and 62.800 km due drainage of the Little Liverpool Tunnel (Scenario 1).

Figure 19: Estimated drawdown of groundwater table between Kilometrage 61.600 and 62.800 km due to drainage of the Little Liverpool Tunnel (Scenario 2).

Figure 20: Estimated drawdown of groundwater table between Kilometrage 61.600 and 62.800 km due to drainage of the Little Liverpool Tunnel (Scenario 3).

7.1.6 Limitations

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

- The Perrochet method does not allow for anisotropy of the aquifer materials. As reported in Table 5, vertical hydraulic conductivity values are expected to be significantly lower than the horizontal hydraulic conductivity values that have been used in the inflow estimates.
- The analysis doesn't account for groundwater recharge from the direction parallel to the tunnel alignment. This will limit the spatial extents of recharge zones and consequently the model may overestimate the width of the groundwater drawdown zone;
- 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;
- The uncertainty analysis indicates the extent and location of structurally affected zones could significantly affect the inflow and drawdown due to drainage. However, information regarding potential structural features (e.g. width, length, frequency) is very limited.
- The groundwater level data used for the analysis to represent the pre-tunnel conditions is based on limited available data as discussed in Section 6.2.

7.2 Cuts along the Alignment

7.2.1 Design Assumptions

At total of 19 cuts (including two tunnel portal cuts), 17 embankments and 24 bridges are proposed in Section 330 H2C. Cuts range from 80 m up to 1180 m in length while embankments range from 230 m up to 13460 m in length. The bridges and viaducts range from 18 m up to 437 m in length.

Location of deep cuts anticipated to experience groundwater seepage are summarised in Appendix C and Table 8.

An analytical solution has been applied to estimate the groundwater inflow into slope cuts based on the following assumption:

- 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 5.
- An average of groundwater levels over the length of each cut is applied
- The toe elevation of each cut is assumed to be the level of discharge.

7.2.2 Methodology

Groundwater seepage from the proposed H2C 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 21.

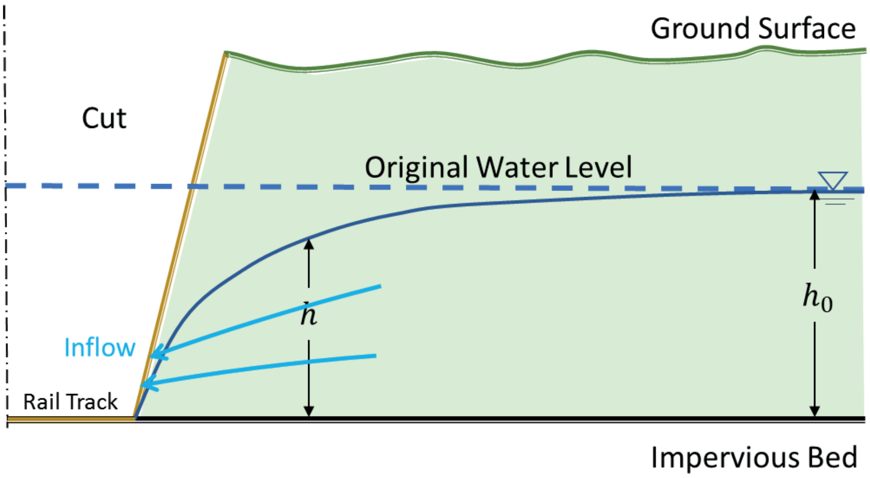


Figure 21: Seepage flow analytical model for cuts along the H2C rail track alignment where h0 is the undisturbed (ambient) piezometric water level and h is the piezometric head

7.2.3 Seepage Rate Estimates

Estimated seepage rates at 1 year after the completion of the slope cuts range from less than 0.1 L/s to 0.2 L/s. Estimated steady state seepage rates are less than 0.1 L/s. Seepage rate estimates for each cut are reported in Table 11.

It is noted that temporary increases in seepage may be observed in cuts with sandy soil or weathered sandstone after rainfall events.

Table 11: Estimated seepage rate into slope cuts along proposed H2C alignment

Cut Name	Length (m)	Geology	Total Seepage Rate (L/s)	
			1 year after construction	Long-term
330-C04	1180	Gatton Sandstone	0.1	Less than 0.1 L/s
330-C07	200	Woogaroo Subgroup	0.2	Less than 0.1 L/s
330-C08	540	Woogaroo Subgroup	0.1	Less than 0.1 L/s
330-C15	830	Koukandowie Formation and Gatton Sandstone	0.1	Less than 0.1 L/s
330-C16	470	Koukandowie Formation	Less than 0.1 L/s	Less than 0.1 L/s

7.2.4 Limitations

The following limitations of this method are noted:

- The assumption of an impervious bed below the rail track may have resulted in flow rate estimates lower than it may be encountered during construction and in the long-term.
- 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.
- The groundwater level data used for the analysis to represent the pre-cut conditions is based on limited available data as discussed in Section 6.2.

8.0 HYDROGEOLOGICAL DESIGN CONSIDERATION

8.1 Water Quality and Durability Considerations for Little Liverpool Tunnel

Data records on groundwater characteristics retrieved from the Queensland registered bore database for an approximately 5 km wide corridor along the tunnel alignment between kilometrage 61.840 km and 62.660 km include water quality data from 19 samples taken from 6 boreholes screened in the Marburg Subgroup (undifferentiated). Water quality records obtained from these 6 boreholes over a 34-year monitoring period are presented in Table 12. Site specific data was obtained from 330-01-BH2102 and 330-01-BH2104, for which results were recorded in the Koukandowie Formation for samples collected on 22 October and 24 October, 2018 respectively. Results from these locations are presented in Table 12.

Groundwater samples from the H2C FS site investigation boreholes were brackish, with TDS values of 2 340 mg/L and 2 390 mg/L and an electrical and conductivity value of 4 260 µS/cm, recorded for both samples. Additionally, low concentrations of ammonia were reported for the samples obtained from the H2C FS site investigation boreholes (<0.1 to 0.1 mg/L).

Water quality characteristics of groundwater tunnel and cut drainage are expected to generally meet EPP Water 2009 Basin No. 143 WWQ (DNRM, 2010) discharge criteria. Water quality parameter values may vary slightly due to seasonal rainfall infiltration and groundwater seepage could become slightly acidic or slightly alkaline.

Groundwater characteristics relevant to durability assessment (i.e. groundwater salinity; electrical conductivity; pH; chloride, magnesium, calcium, carbonate, bicarbonate and sulphate concentrations; and magnesium/calcium ratio, Langelier Saturation Index and Ryznar Stability Index) are summarised in Table 12 for registered bores within a search radius of 5 km and for 330-01-BH2102 and 330-01-BH2104. A total of 6 registered bores screened in the Marburg Subgroup (undifferentiated) with water quality results relevant to the durability assessment were identified within this radius, ranging in distance from the tunnel from 150 m to 2.4 km. The results are interpreted to indicate a wide range of water quality parameters for the Marburg Subgroup (undifferentiated).

Table 12: Estimated characteristics of groundwater in the Marburg Subgroup (undifferentiated) to inform durability assessment

Characteristic	Unit	Range [A,B]	330-01 BH2102	330-01-BH2104
Number of Samples	-	21	1	1
Sulphate	mg/L	43 – 366	97	98
Chloride	mg/L	980 – 11 200	1 000	980
Carbonate	mg/L	0.5 – 150	<1	7
Bicarbonate	mg/L	235 – 1 947.9	457	549
Calcium	mg/L	6.7 – 750	40	48
Magnesium	mg/L	8.2 – 729.6	24	36
Magnesium/Calcium Ratio	-	0.4 – 21	0.6	0.8
pH	-	7.1 – 8.7	8.0	8.3
Electric Conductivity	µS/cm	4 260 – 30 900	4 260	4 260
Langelier Saturation Index (LSI)	-	0.09 – 1.07	0.09	0.63
Ryznar Stability Index (RSI)	-	5.76 – 8.09	7.77	7.06

Note: [A] Records retrieved from the Queensland registered bore database for an approximately 5 km wide corridor of the track alignment between Kilometrage 61.840 km and 62.660 km.

[B] Includes registered bores and H2C FS SI bores 330-01-BH2102 and 330-01-BH2104 in this range.

8.2 Water Quality for Seepage to Cuts

Typical water quality estimates for seepage into the deep cuts ranges from fresh to saline groundwater (about 9 to 30 900 µS/cm). Water quality estimates are based on records from the Queensland Registered Bores Database (DNRM, 2018) and from four boreholes drilled at deep cuts 330-C06, 330-C08, 330-C16 and western tunnel portal cut 330-C17 (between Kilometrage 31.750 km and 32.050 km, 34.530 km and 35.070 km, 61.170 km and 61.640 km and 61.640 km and 61.820 km, respectively). For cuts 330-C16 and 330-C17, boreholes 330-01-BH2102 and 330-01-BH2104 suggest water quality is brackish, with a TDS measurement of 2340 mg/L and 2390 mg/L, respectively. At cuts 330-C06 and 330-C08, boreholes 330-01-BH2303 and 330-01-BH2207 suggest water quality is fresh, with TDS measurements of 999 mg/L and 955 mg/L, respectively. The pH values for these four cut locations range between 7.22 and 8.53 pH units.

The estimated inflow rate for cuts in rock is generally low (less than or equal to 0.01 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 where saline groundwater is present at the location of the cut. Insufficient information is currently available to identify the locations of cuts with elevated groundwater salinity.

8.3 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 C.

Based on the available records, it is assessed that at embankments overlying rock formations, low effective porosity may result in a potential groundwater rise of up 5 m immediately following large rainfall or flood events. 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 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 (Section 5.2). Table 13 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 13: Estimated groundwater level mounding at selected embankment locations

Structure Name	Median Surface Elevation (m AHD)[1]	Maximum Estimated GW Level (m AHD)[2]	Maximum Estimated GW Level (mbgl)	Potential Mounded GW Level (m bgl)
330-E1	145.5	135.1	11.2	1.2
330-E2	145.4	140.3	11.3	1.2
330-E7	138.6	150.6	11.3	1.1
330-E11	104.3	111.6	11.0	0.8
330-E12	101.8	91.9	10.8	0.8
330-E13	92.0	102.3	10.9	0.7

Structure Name	Median Surface Elevation (m AHD)[1]	Maximum Estimated GW Level (m AHD)[2]	Maximum Estimated GW Level (mbgl)	Potential Mounded GW Level (m bgl)
330-E15	143.0	141.0	11.3	1.2
330-E16	83.3	125.0	11.1	0.7
330-E17	57.9	55.5	10.5	0.5

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.

8.4 Groundwater Aggressivity for Bridge Sub-structures

Observed and inferred groundwater characteristics for bridge locations along the proposed C2K 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 14. Water quality parameters were calculated based on the typical value for each formation (Quaternary alluvium, Gatton Sandstone, Marburg Subgroup (undifferentiated) and Woogaroo Subgroup) within 5 km of the proposed alignment. Results of current data analysis across four formations indicate a broad range of water quality parameters for the Quaternary alluvium, Gatton Sandstone, the Marburg Subgroup (undifferentiated) and the Woogaroo Subgroup. In general, lower values of Mg and Ca were reported for the Gatton Sandstone and Marburg Subgroup (undifferentiated), while lower values for TDS and EC were reported for the Quaternary alluvium. Table 14 provides results for bridge locations which are located near a Golder SI bore for which water quality data was available, while a complete set of results is provided in Appendix D.

Table 14: Estimated characteristics of groundwater at proposed bridge locations along the H2C rail alignment to inform durability assessment

Bridge Location	SO_4 [mg/L]	Cl [mg/L]	CO_3 [mg/L]	HCO_3 [mg/L]	Ca [mg/L]	Mg [mg/L]	Mg/Ca [-]	pH [-]	EC [µS/cm]	T[1] (C˚)	LSI [-]	RSI [-]
330-BR04	50	438	12	116	33	33	1	8.5	1730	22.1	7.51	0.51
330-BR13	77	1340	<1	601	38	42	1.1	8.2	5500	23.4	6.46	0.85
330-BR16	41	646	194	<1	25	15	0.6	10.5	2530	24.2	5.25	2.62

Note: [1]Recorded field groundwater quality parameters from nearby SI Borehole.

9.0 RISK AND MITIGATION

Groundwater related risks and proposed mitigation measures are summarised in Table 15.

Table 15: Risks Identified and Mitigation

Risk/Issue	Proposed Mitigation
Groundwater levels in the Koukandowie Formation higher than anticipated and consequently groundwater inflows to the tunnel and portal cuts higher than estimated	Installation of monitoring bores every 200 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
Fault structures, dykes or coal seams allowing preferential groundwater flow and consequently tunnel drainage is higher than anticipated	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 characteristic of geological structures along the tunnel alignment
Hydraulic conductivity of the Woogaroo Subgroup, Gatton Sandstone, Koukandowie Formation, Walloon Coal Measures or alluvial sediment deposits lower or higher than anticipated and consequently overestimating or underestimating tunnel and cut drainage	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 200 m spacing along the tunnel alignment. Testing to be conducted below water 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 water table at cut locations anticipated to intersect the water table.
Groundwater recharge higher than anticipated and consequently groundwater inflows to the tunnel and portal cuts higher than expected	Continuous recording of groundwater levels in monitoring bores along the tunnel alignment at each cut location anticipated to intersect the water table prior to final design and construction. Assessment of recharge from water level records of several larger rainfall events and chloride concentrations in groundwater
Groundwater 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 boreholes drilled along the tunnel alignment at 200 m spacing and each cut location anticipated to intersect the groundwater table.

Risk/Issue	Proposed Mitigation
Magnesium concentrations higher than expected and consequently impact of groundwater on concrete durability larger than expected	Repeated groundwater sampling of the Marburg Subgroup (undifferentiated) along the tunnel alignment and testing for magnesium and calcium concentration
Groundwater aggressivity and scaling potential of tunnel drainage higher than expected	Repeated groundwater sampling of the Marburg Subgroup (undifferentiated) along the tunnel alignment and testing for aggressivity and scaling potential parameters prior to final design and construction

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11.0 IMPORTANT INFORMATION

Your attention is drawn to the document - “Important Information Relating to this Report”, which is included as an Attachment 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.

Signature Page

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Appendix A
Hydrographs from 2018 FFJV Investigations

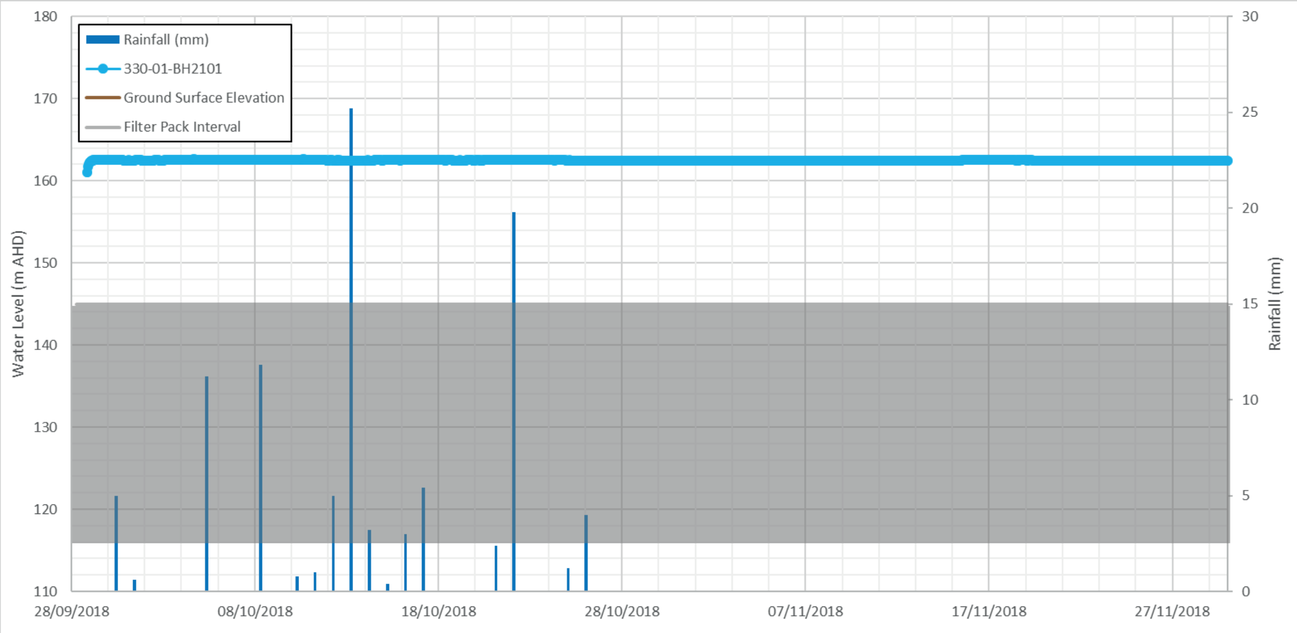

Figure A1: Hydrograph of 330-01-BH2101, rainfall from the University of Queensland Gatton (Station 040082)

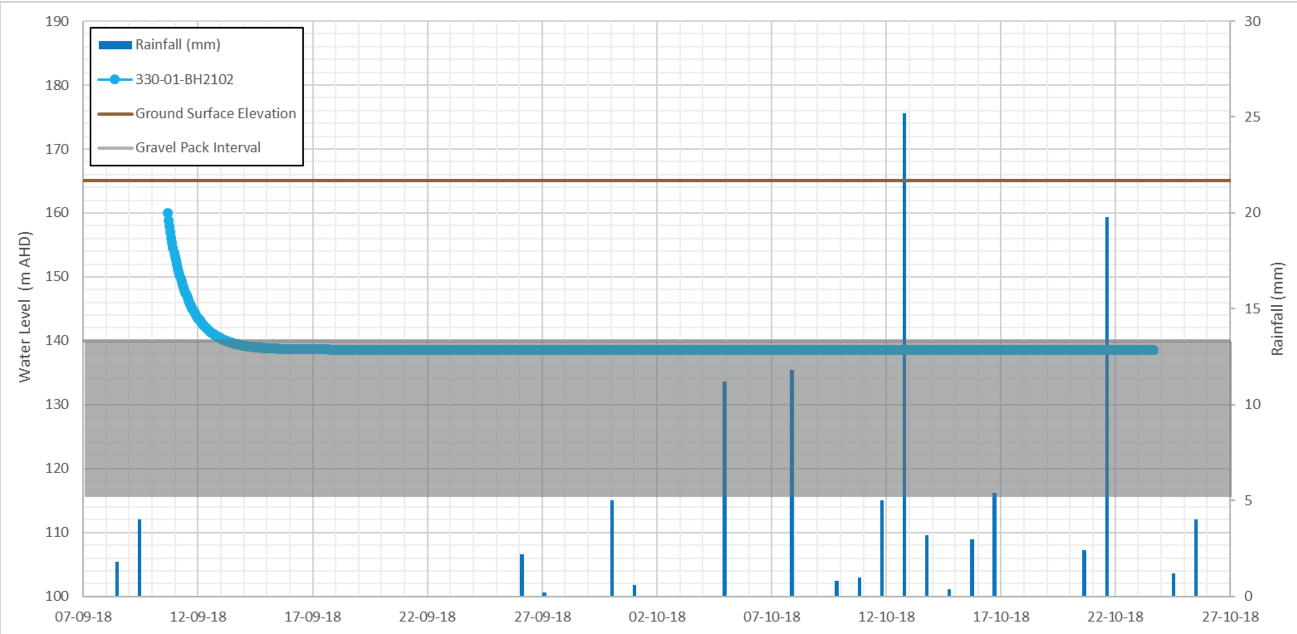

Figure A2: Hydrograph of 330-01-BH2102, rainfall from the University of Queensland Gatton (Station 040082)

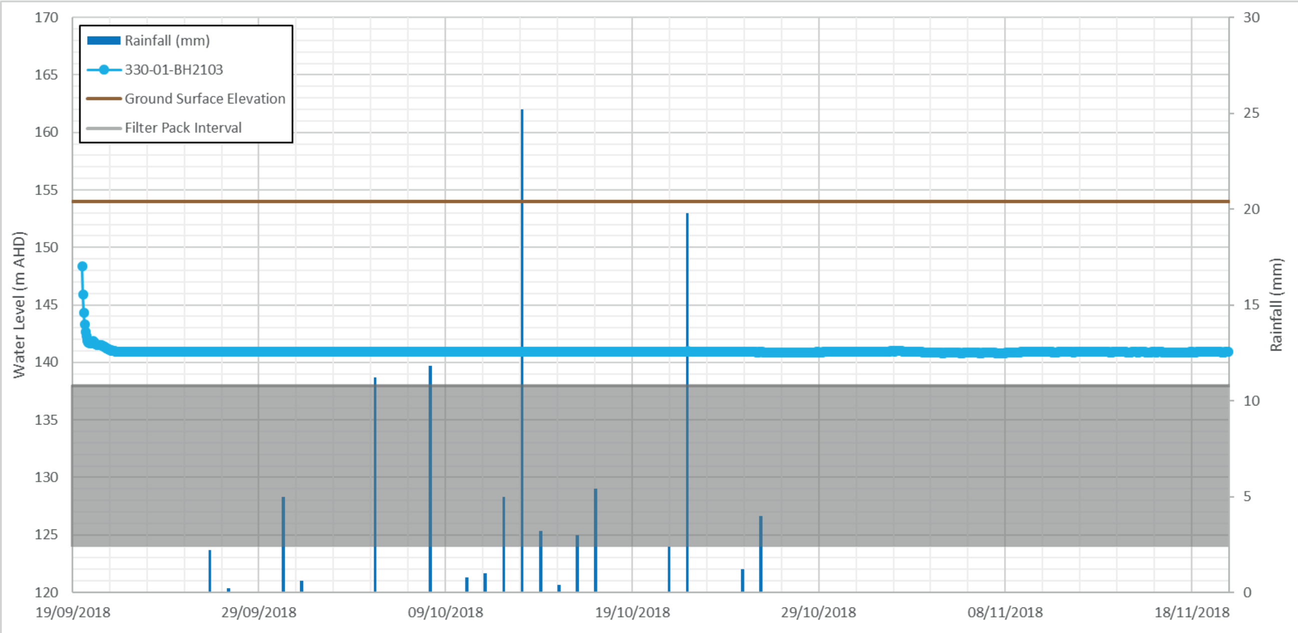

Figure A3: Hydrograph of 330-01-BH2103, rainfall from the University of Queensland Gatton (Station 040082)

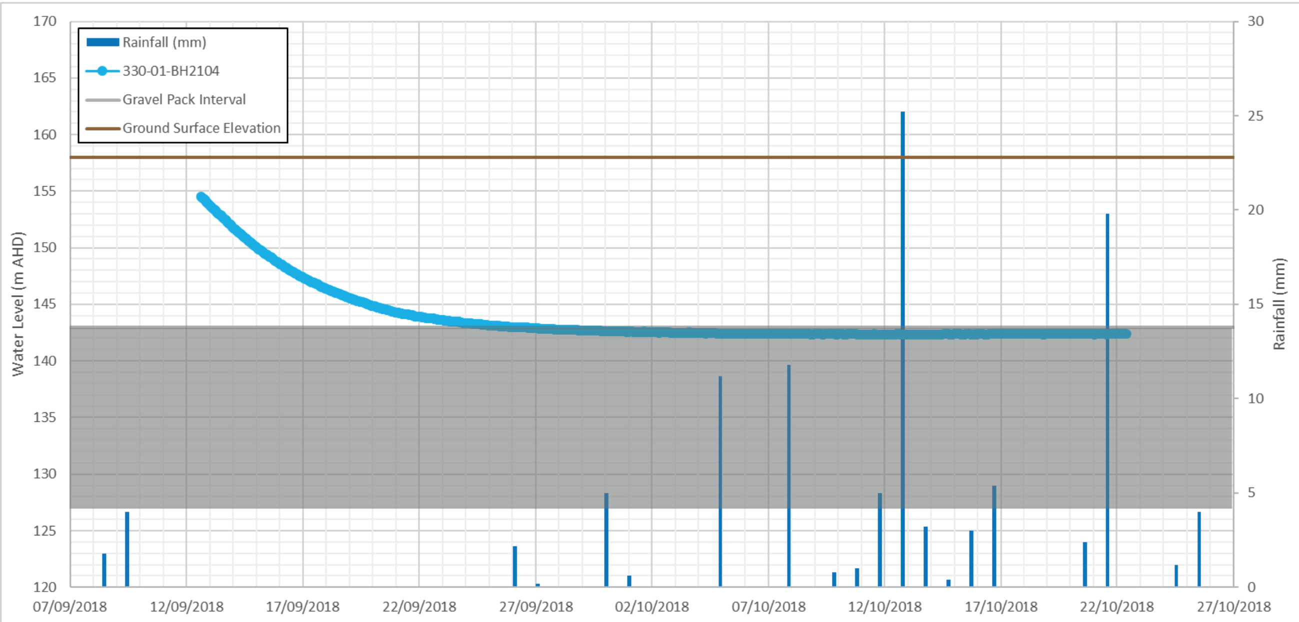

Figure A4: Hydrograph of 330-01-BH2104, rainfall from the University of Queensland Gatton (Station 040082)

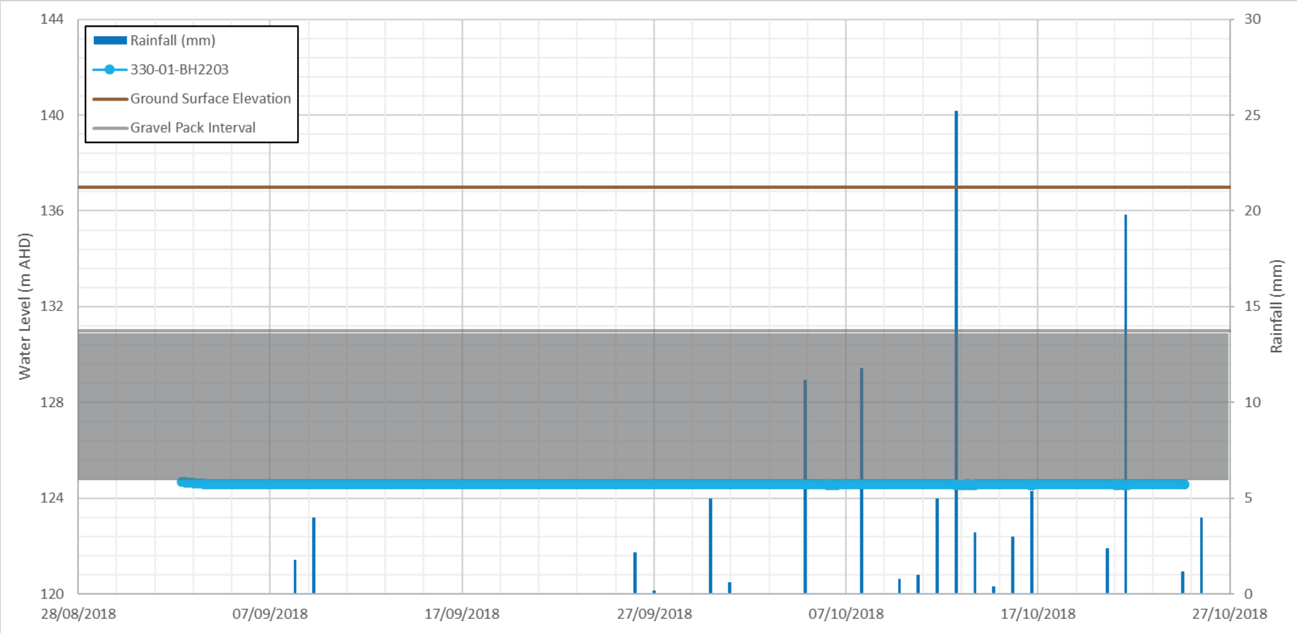

Figure A5: Hydrograph of 330-01-BH2203, rainfall from the University of Queensland Gatton (Station 040082)

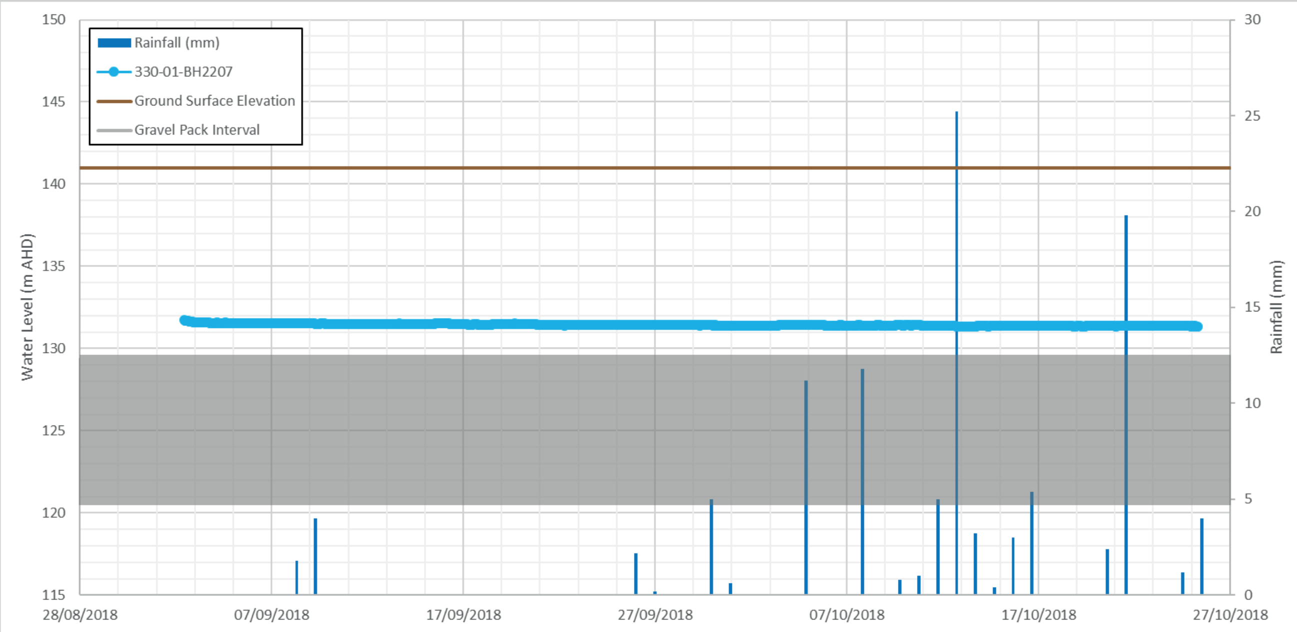

Figure A6: Hydrograph of 330-01-BH2207, rainfall from the University of Queensland Gatton (Station 040082)

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Figure A7: Hydrograph of 330-01-BH2212, rainfall from the University of Queensland Gatton (Station 040082)

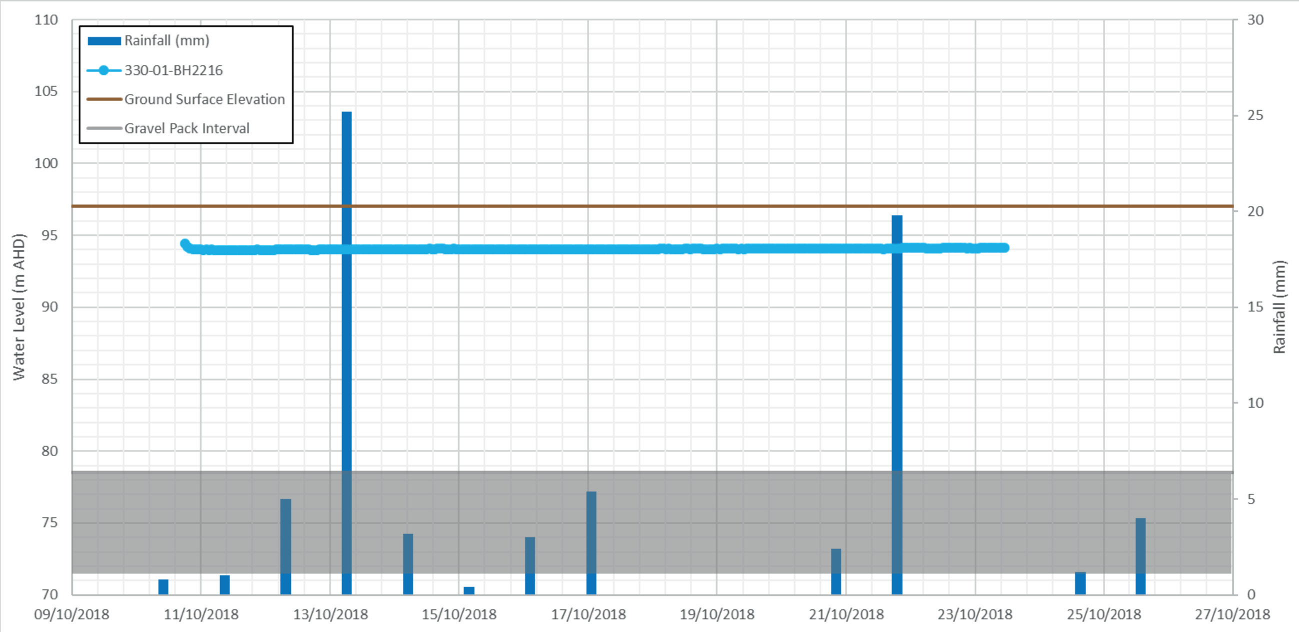

Figure A8: Hydrograph of 330-01-BH2216, rainfall from the University of Queensland Gatton (Station 040082)

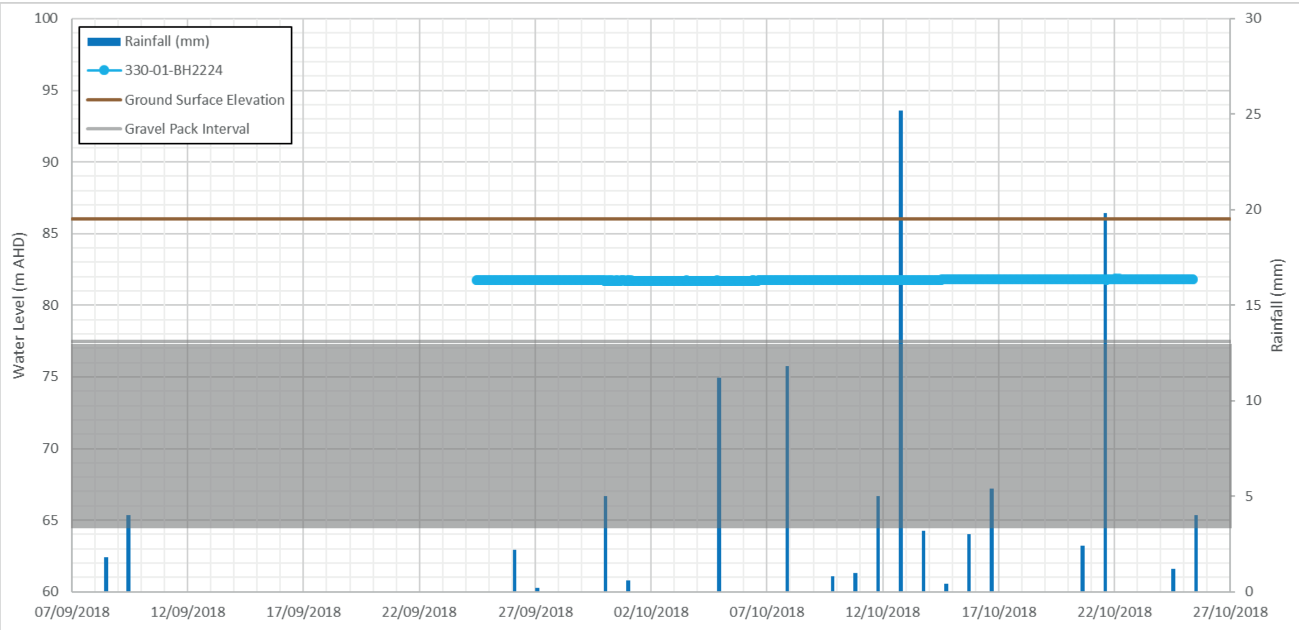

Figure A9: Hydrograph of 330-01-BH2224, rainfall from the University of Queensland Gatton (Station 040082)

Not available at the time of reporting

Figure A10: Hydrograph of 330-01-DH2227, rainfall from the University of Queensland Gatton (Station 040082)

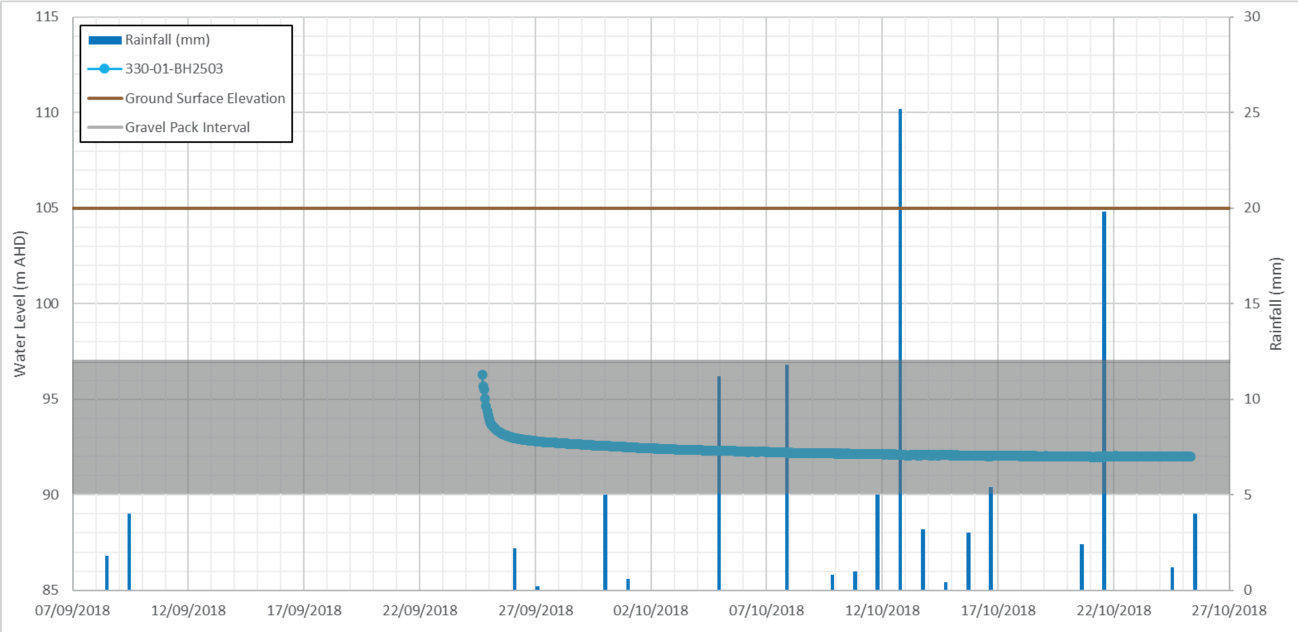

Figure A10: Hydrograph of 330-01-DH2503, rainfall from the University of Queensland Gatton (Station 040082)

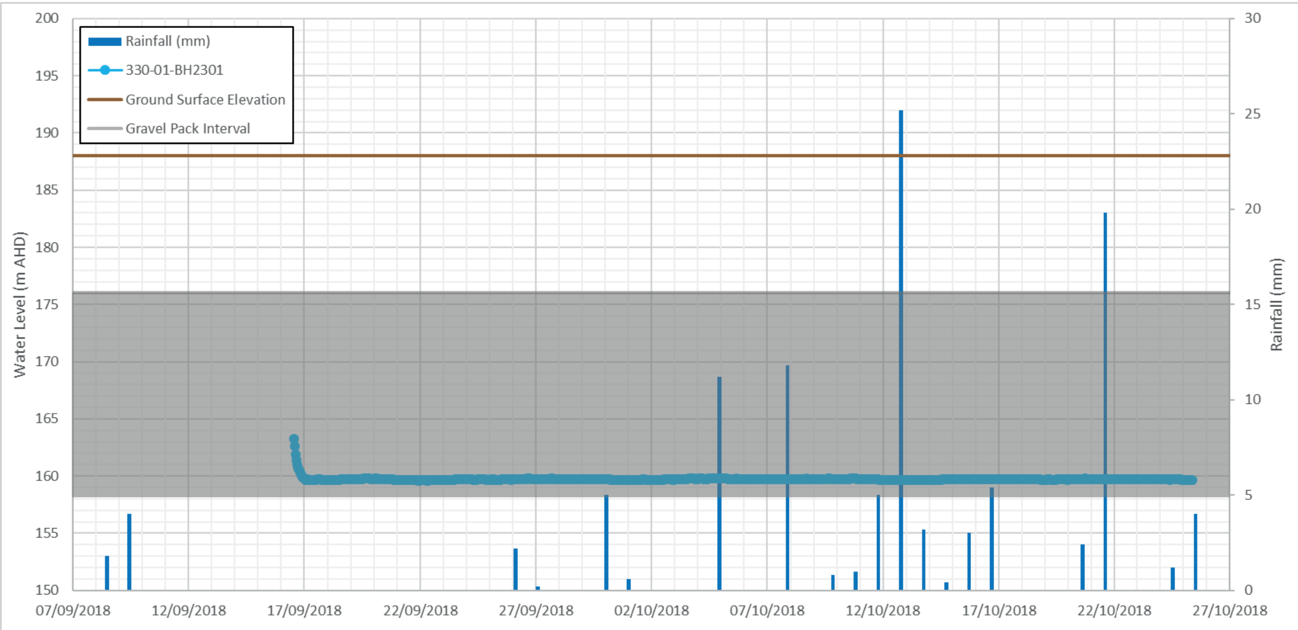

Figure A11: Hydrograph of 330-01- BH2301, rainfall from the University of Queensland Gatton (Station 040082)

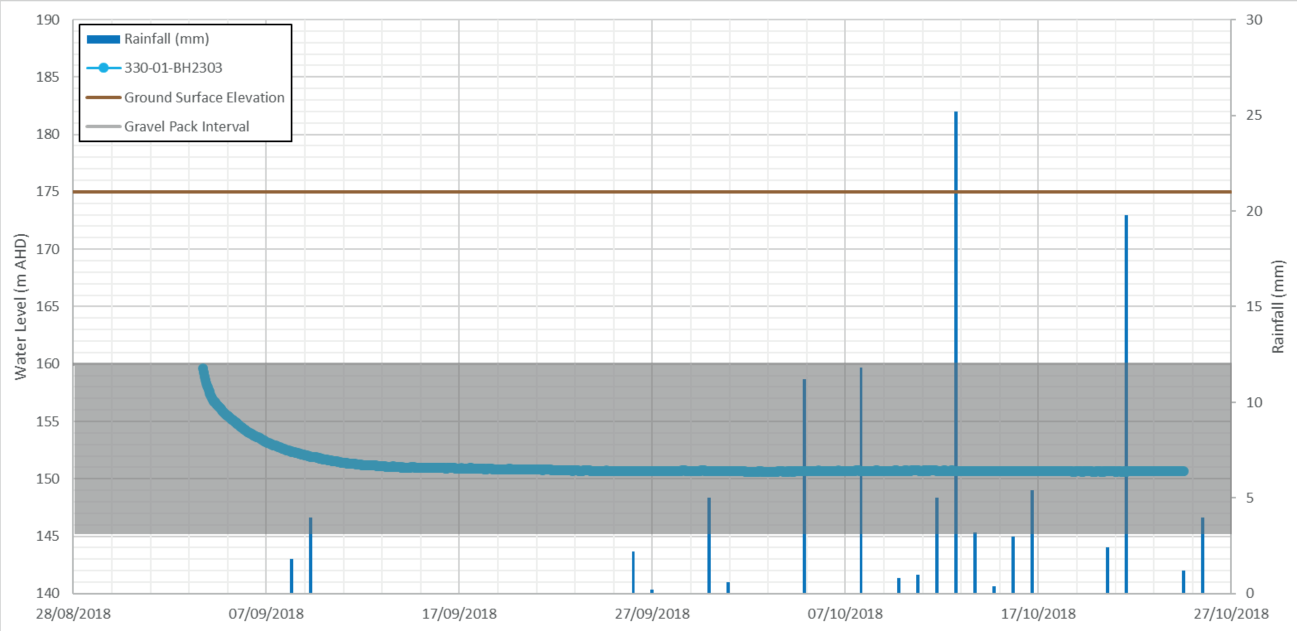

Figure A12: Hydrograph of 330-01-BH2303, rainfall from the University of Queensland Gatton (Station 040082)

Appendix B
Basic Groundwater Level Statistics from Available Groundwater Bores

IR_1381

Table B1: Groundwater levels statistics for 2018 FFJV investigation bores and registered groundwater bores (DNRME, 2018) within 500 m of the Section 330 alignment

Bore ID	Formation	Kilometrage (Km)	Water Level (m AHD)						
			Date From	Date To	Min	Max	Median	Mean	Count
RN75749	Lockyer Creek Alluvium	45.250	5/30/2007	-	-	-	82.1	-	1
RN75961	Lockyer Creek Alluvium	45.250	6/9/2001	-	-	-	76.9	-	1
RN75962	Lockyer Creek Alluvium	45.400	1/25/2001	-	-	-	77.2	-	1
RN98328	Laidley Creek Alluvium	56.200	4/14/2000	-	-	-	79.3	-	1
RN106267	Lockyer Creek Alluvium	43.000	12/4/2000	-	-	-	78.1	-	1
RN106472	Laidley Creek Alluvium	57.200	3/2/2000	-	-	-	70.1	-	1
RN106625	Lockyer Creek Alluvium	43.200	11/24/2016	-	-	-	84.9	-	1
RN106648	Lockyer Creek Alluvium	41.000	10/28/2016	-	-	-	85.8	-	1
RN120196	Western Creek Alluvium	71.600	6/9/2016	-	-	-	132.4	-	1
RN124569	Western Creek Alluvium	71.600	1/3/2015	-	-	-	147.8	-	1
RN129229	Lockyer Creek Alluvium	26.200	10/23/2014	-	-	-	91.3	-	1
RN143150	Lockyer Creek Alluvium	42.600	8/12/2013	-	-	-	51.6	-	1
RN143347	Western Creek Alluvium	67.600	3/26/2010	-	-	-	124.9	-	1
RN143435	Lockyer Creek Alluvium	49.200	3/20/2007	-	-	-	82.8	-	1
RN154063	Lockyer Creek Alluvium	43.000	4/8/2007	-	-	-	80.2	-	1

Bore ID	Formation	Kilometrage (Km)	Water Level (m AHD)						
			Date From	Date To	Min	Max	Median	Mean	Count
RN154064	Lockyer Creek Alluvium	43.200	3/30/2007	-	-	-	82.1	-	1
RN154065	Lockyer Creek Alluvium	42.800	5/5/2009	-	-	-	88.1	-	1
RN154066	Lockyer Creek Alluvium	41.800	8/28/2008	-	-	-	67.7	-	1
RN154552	Western Creek Alluvium	72.000	1/23/2008	-	-	-	65.9	-	1
RN154728	Lockyer Creek Alluvium	41.000	1/12/2000	-	-	-	85.7	-	1
RN173204	Lockyer Creek Alluvium	41.200	3/2/2000	-	-	-	97.6	-	1
RN173231	Laidley Creek Alluvium	54.400	1/12/2000	-	-	-	84.3	-	1
RN106471	Laidley Creek Alluvium	57.100	04/12/2003	10/12/2003	85.8	86.2	86.0	86.0	2
RN14320522	Laidley Creek Alluvium	50.200	28/02/2000	15/12/2009	79.6	84.3	81.9	82.1	28
RN14310261	Western Creek Alluvium	72.000	05/05/2010	21/12/2017	48.4	52.3	51.2	51.0	30
RN14320165	Lockyer Creek Alluvium	42.800	12/01/2000	03/03/2003	83.3	85.7	84.5	84.6	31
RN73644	Sandy Creek Alluvium	52.000	02/03/2000	01/06/2015	67.3	81.0	69.8	72.0	50
RN75312	Lockyer Creek Alluvium	45.000	04/12/2000	23/09/2016	76.4	84.1	77.0	78.8	63
RN14320595	Lockyer Creek Alluvium	46.000	28/02/2000	21/11/2017	67.0	75.6	69.8	70.7	67
RN14320725	Lockyer Creek Alluvium	47.000	28/02/2000	21/11/2017	70.2	75.0	70.3	71.1	70

Bore ID	Formation	Kilometrage (Km)	Water Level (m AHD)						
			Date From	Date To	Min	Max	Median	Mean	Count
RN14320659	Laidley Creek Alluvium	52.600	02/03/2000	21/11/2017	70.6	87.4	73.4	77.6	72
RN14320517	Lockyer Creek Alluvium	47.000	28/02/2000	21/11/2017	67.0	74.4	68.8	69.6	73
RN14320596	Lockyer Creek Alluvium	48.000	12/01/2000	21/11/2017	66.9	73.6	68.8	69.4	74
RN14320463	Lockyer Creek Alluvium	41.800	28/02/2000	20/11/2017	80.6	89.	82.9	83.9	76
RN14320527	Laidley Creek Alluvium	56.00	14/01/2000	23/11/2017	76.8	93.2	85.1	84.7	95
RN14320816	Laidley Creek Alluvium	54.000	12/01/2000	12/12/2017	72.9	88.2	76.4	79.3	152
RN14320277	Laidley Creek Alluvium	54.200	12/01/2000	14/11/2017	74.5	89.1	79.2	80.6	215
RN14320822	Lockyer Creek Alluvium	42.800	12/01/2000	04/12/2017	80.2	87.9	84.1	84.2	225
RN14320820	Marburg Subgroup (undifferentiated)	57.600	02/03/2000	23/11/2017	96.6	98.6	97.4	97.3	72
RN14310203	Marburg Subgroup (undifferentiated)	65.900	16/08/2004	12/12/2017	81.8	83.8	82.9	82.9	33
RN124075	Marburg Subgroup (undifferentiated)	66.200	7/21/2004	-	-	-	87.2	-	1
RN124574	Marburg Subgroup (undifferentiated)	72.400	3/28/2004	-	-	-	51.0	-	1
RN138252	Koukandowie Formation	66.600	2/17/2001	-	-	-	87.0	-	1
RN154139	Marburg Subgroup (undifferentiated)	60.600	7/9/2004	-	-	-	81.3	-	1
RN154775	Woogaroo Subgroup	28.000	12/16/2003	-	-	-	88.7	-	1

Bore ID	Formation	Kilometrage (Km)	Water Level (m AHD)						
			Date From	Date To	Min	Max	Median	Mean	Count
RN173167	Gatton Sandstone	26.000	12/4/2003	-	-	-	85.8	-	1
RN138345	Walloon Coal Measures	29.200	5/8/2003	-	-	-	82.5	-	1
330-01-BH2101	Koukandowie Formation	62.200	-	-	-	-	-	-	-
330-01-BH2102	Koukandowie Formation	61.800	9/10/2018	10/23/2018	138.5	159.9	138.6	139.0	1033
330-01-BH2103	Koukandowie Formation	62.800	-	-	-	-	-	-	-
330-01-BH2104	Koukandowie Formation	61.700	9/12/2018	10/22/2018	142.3	154.5	142.5	143.8	956
330-01-BH2203	Alluvium	33.500	9/2/2018	10/24/2018	124.5	124.7	124.6	124.6	1254
330-01-BH2207	Woogaroo Subgroup	34.200	9/2/2018	10/25/2018	131.3	131.7	131.4	131.4	1270
330-01-BH2212#	Gatton Sandstone	51.600	9/20/2018	10/23/2018	84.0	89.5	84.1	84.3	765
330-01-BH2216	Gatton Sandstone	57.300	10/10/2018	10/23/2018	94.0	94.4	94.1	94.1	306
330-01-BH2303	Woogaroo Subgroup	33.600	9/3/2018	10/25/2018	150.6	159.6	150.7	151.2	1221
330-01-DH2503	Gatton Sandstone	42.200	9/24/2018	10/25/2018	92.0	96.3	92.2	92.3	736
330-01-BH2224	Gatton Sandstone	66.000	9/24/2018	10/25/2018	81.7	81.8	81.7	81.8	742
330-01-BH2227	Alluvium	67.700	-	-	-	-	-	-	-
330-01-BH2301	Gatton Sandstone	29.000	9/16/2018	10/25/2018	159.6	163.3	159.7	159.7	932

Note:

* Surface elevations were used from LiDAR because survey data was not available at the time of reporting. These bores are fitted with a data logger.

^ Groundwater levels obtained after bore development. Data logger information was not available at the time of reporting.
# Data logger was installed lower after initial download.

Appendix C
Groundwater Chemistry

Data_Source	Project_Number	Package	Database_Name	N		N	DATE	RDATE_FORMATTED	DEPTH	CONDUCT	PH	TURB	SIO2	HARD	LK	FIG_MERIT	NA_ADS_RATIO	RES_ALK	OTAL_IONS	OTAL_SOLIDS	NA		A	MG		MN	HCO3	CO3	CL		NO	SO4	ZN	AL		U	O4	BR	FORM_DESC
Water_Analysis	1893803	Pkg13	Alluv_Pkg13_98265_36217	98265	439243	6943755	26/02/1999	36217		2150	8.3	1	41	794	424	2.3	2.5		1418.67	1205.52	160	1.1	120	120	0.02	0.02	500	7.8	465	0.1	34.5	10	0.02	0.05	0.01	0.05			ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99694_29403	99694	436782	6947866	1/07/1980 0:00	29403		2080				661	471	1.5	3.4		1105.2	1105.2	200		40	136.2				282	447										LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99694_30742	99694	436782	6947866	1/03/1984 0:00	30742		2360				786	632	1.6	3.6		1230.8	1230.8	229.9		88.1	137.4				378.1	397.3										LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99659_29403	99659	436566	6947249	1/07/1980 0:00	29403		2560				721	592	1.3	4.2		1291.9	1291.9	262.1		28	158.1				354.1	489.6										ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99659_30742	99659	436566	6947249	1/03/1984 0:00	30742		2910				1031	481	1.6	3.9		1561.2	1561.2	289.7		96.1	192.1				288	695.3										ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99663_29403	99663	436101	6947124	1/07/1980 0:00	29403		3600				1421	401	2.7	2.8		1968.1	1968.1	241.4		106.1	280.9				240	1099.7										SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99663_30742	99663	436101	6947124	1/03/1984 0:00	30742		4460				1637	451	2.7	3		2301.5	2301.5	280.5		194.2	279.7				270	1277.1										SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99675_29403	99675	435455	6946720	1/07/1980 0:00	29403		5770				2162	176	2.6	3.6		3065.1	3065.1	379.4		220.2	391.6				105	1968.9										SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99675_30742	99675	435455	6946720	1/03/1984 0:00	30742		7460				2552	456	2.1	4.7		3899.5	3899.5	549.5		330.3	419.5				273	2327.2										SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99696_29403	99696	436518	6946069	1/07/1980 0:00	29403		3940				1442	592	1.8	4.2		2248.5	2248.5	363.3		80.1	301.6				354.1	1149.4										SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_55778_34669	55778	421779	6949640	1/12/1994 0:00	34669		1960	7.6			711	376	2.8	1.9		981.6	981.6	115		140.1	87.6				225	411.5		2.4								LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_55773_34669	55773	422172	6949396	1/12/1994 0:00	34669		2930	7.5			961	441	2.1	3		1505.6	1505.6	213.8		186.2	120.4				264	720.1		1.1								LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_55783_34669	55783	422447	6949100	1/12/1994 0:00	34669		1755	7.9			476	326	1.4	3.2		873.4	873.4	160.9		74.1	70.5				195	372.5		0.4								LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320819_36249	14320819	440103	6947191	30/03/1999	36249		23900	8	9999	13	2229	860	0.2	50.2	0	16375.15	15870.49	5448.4	5.7	130.7	462.7	0	0	1018.2	15.2	8770	0.71	5.5	518	0	0	0.2	0.26			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320820_36264	14320820	440884	6945188	14/04/1999	36264		28100	7.9	1342	19	3392	900	0.3	47	0	19494.05	18968.89	6289.2	10.2	157.1	729.6	0	0	1069.6	14	10890	0.42	0	334	0	0	0.6	0.16			MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320821_36281	14320821	440907	6947331	1/05/1999 0:00	36281		3850	8.5	1061	15	119	1560	0.1	37.6	28.8	3349.63	2446.71	944	4.8	11.6	22	0.01	0.61	1806.7	47.4	408.3	1.14	2.4	101.4	0.01	0	0.6	0			MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320673_36404	14320673	438177	6951632	1/09/1999 0:00	36404		563	8.2	1522	23	104	218	0.6	3.7	2.27	442.25	333.2	86.5	3	15.8	15.7	0	0	260.2	2.6	49.1	0.21	3.9	5.3	0	0	0	0.01			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320674_36404	14320674	437903	6951892	1/09/1999 0:00	36404		1051	8.3	1675	21	278	352	1	3.4	1.47	793.12	602.34	129.8	4.8	40.5	43	0	0	416.5	6.2	141.8	0.15	4.3	6	0.06	0	0	0.01			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_75654_36368	75654	439481	6944824	27/07/1999	36368		1850	8.3	0.6	38	698	318	2.9	1.9	0	1144.55	991.41	112.5	0.7	108	104.1	0	0	376.6	5.3	413.5	0.1	7.4	16.3	0	0	0	0			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_75654_36433	75654	439481	6944824	30/09/1999	36433		5410	7.8	4.7	40	2217	395	3.6	2.6	0	3143.03	2941.62	281.5	1.8	350	326.7	0	0	475.1	3.1	1640	0.02	16.1	48.7	0.04	0	0	0			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320547_37049	14320547	438954	6940198	7/06/2001 0:00	37049	15	1617	7.8	1810	30	502	295	1.6	2.8	0	1026.05	874.37	144.2	3.4	75.8	76	0.02	0.09	356.8	1.5	340.9	0.16	13.2	14.1	0.01	0	0.04	0.01			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320553_37049	14320553	438764	6940236	7/06/2001 0:00	37049	20	2597	8.1	6	33	860	595	1.7	3.4	0	1746.22	1417.79	229.2	1.7	142.3	122.7	0.03	0.75	711.3	7.4	525.2	0.11	0.4	5.9	0	0	0.05	0			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320332_37053	14320332	438508	6940103	11/06/2001	37053	18	1426	8.2	159	34	450	508	1.4	3	1.16	1072.07	799.01	145.5	1.7	59.2	73.4	0.02	0.03	604.5	7.3	175	0.19	0.6	4.7	0	0	0.04	0			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320450_37053	14320450	438949	6941472	11/06/2001	37053	20	571	8	2	41	230	238	3	1	0.15	444.45	339.33	34.9	0.6	34.3	35.2	0.01	0.01	286.7	1.7	43.5	0.15	0.2	7.2	0	0	0.01	0			LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320314_37054	14320314	433962	6945917	12/06/2001	37054	8	2906	7.4	9895	28	585	491	0.6	7.6	0	1934.8	1659.6	421.4	4.5	102.6	80.1	0.04	1.93	595.9	1.3	634	0.26	1.3	93.5	0.02	0	0.1	0.01			SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_37054	14320313	435502	6946259	12/06/2001	37054	20	7470	7.4	380	37	3240	396	4.5	2.5	0	4267.31	4060.3	332.6	2.9	422.7	531.4	0.05	0.02	480.5	1.3	2367	0.15	35.9	92.9	0.03	0.01	0.03	0			SANDY CREEK ALLUVIUM

Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320963_41458	14320963	418238	6949577	3/07/2013 0:00	41458		7410	7.8	80	30	1110	830	0.4	16	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_40751	14320496	416745	6950149	27/07/2011 0:00	40751		2150	7.7	8	39	319	417	0.5	7.6	1.9
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_40735	14320277	438510	6947061	11/07/2011 0:00	40735		2280	7.8	27	40	648	431	1.3	3.8	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320432_40750	14320432	415912	6949392	26/07/2011 0:00	40750		1370	7.7	1	25	489	542	1.8	2.4	1.1
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320527_40765	14320527	439254	6945667	10/08/2011 0:00	40765		691	8.1	1	38	276	293	3.1	1.1	0.4
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320897_40728	14320897	415404	6948183	4/07/2011 0:00	40728		7090	7.4	14	34	2700	442	3	3.5	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14310144_41120	14310144	456297	6941490	30/07/2012 0:00	41120		11100	7.7	7	43	1920	1300	0.5	17	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320542_41738	14320542	436320	6947186	9/04/2014 0:00	41738		4130	7.4	119	29	1540	318	3.2	2.4	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320819_41753	14320819	440103	6947191	24/04/2014 0:00	41753		11600	7.5	220	15	1070	457	0.2	29	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320528_41738	14320528	437140	6947756	9/04/2014 0:00	41738		2140	8	1	28	571	820	1	4.9	5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_55874_34345	55874	433632	6952557	11/01/1994 0:00	34345			7.8			1192	581	4.1	1.7	
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_55874_34596	55874	433632	6952557	19/09/1994 0:00	34596		3000	7.5			1172	526	3.5	1.9	
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_64310_34596	64310	433878	6952620	19/09/1994 0:00	34596		3000	7.4			1155	516	3.5	1.9	
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320493_40751	14320493	416582	6949241	27/07/2011 0:00	40751		10200	7.5	2	40	4120	556	3	4.3	0
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320963_40756	14320963	418238	6949577	1/08/2011 0:00	40756		5410	7.6	188	29	877	893	0.5	13	0.3
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320525_40499	14320525	437124	6948947	17/11/2010 0:00	40499		998	8.4	1	35	172	441	0.4	5.9	5.4
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_41765	14320313	435502	6946259	6/05/2014 0:00	41765		7620	7.7	11	38	3060	356	4.3	2.6	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320527_40499	14320527	439254	6945667	17/11/2010 0:00	40499		649	8.3	1	39	271	289	3	1.1	0.4
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320527_41738	14320527	439254	6945667	9/04/2014 0:00	41738		656	8	1	38	267	292	3.1	1.1	0.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320525_41738	14320525	437124	6948947	9/04/2014 0:00	41738		992	8	1	30	163	431	0.4	5.8	5.4
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320970_41465	14320970	426207	6949230	10/07/2013 0:00	41465		13600	7.6	93	36	4450	417	1.7	7.9	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320432_41458	14320432	415912	6949392	3/07/2013 0:00	41458		2480	7.7	1	26	896	419	2.6	2.3	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_41458	14320496	416745	6950149	3/07/2013 0:00	41458		2110	7.8	7	41	330	447	0.5	7.7	2.3
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320447_41463	14320447	427468	6951646	8/07/2013 0:00	41463		2830	7.6	7	45	874	653	1.6	3.8	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_41858	14320277	438510	6947061	7/08/2014 0:00	41858		4960	8	29	36	2130	355	5.6	1.7	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320515_41459	14320515	425329	6949836	4/07/2013 0:00	41459		1360	8.1	2	47	554	486	3	1.6	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14310144_42045	14310144	456297	6941490	10/02/2015 0:00	42045		11600	7	61	50	2530	1590	0.6	18	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14310066_42045	14310066	457843	6938387	10/02/2015 0:00	42045		1080	7.7	4	34	423	467	2.6	1.6	0.9
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320447_42551	14320447	427468	6951646	30/06/2016 0:00	42551		3170	7.3	32	50	926	756	1.2	4.9	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320970_42555	14320970	426207	6949230	4/07/2016 0:00	42555		14100	7.6	93	40	4510	502	1.6	8.4	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320515_42550	14320515	425329	6949836	29/06/2016 0:00	42550		1450	8	4	48	589	546	2.9	1.7	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320489_42550	14320489	423871	6948881	29/06/2016 0:00	42550		3160	7.6	14	34	1090	439	2.2	3	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320491_42551	14320491	426623	6950607	30/06/2016 0:00	42551		6950	7.3	1	39	2490	556	2.3	4.3	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_42555	14320496	416745	6950149	4/07/2016 0:00	42555		2280	8.3	81	43	373	498	0.5	8.1	2.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320787_42509	14320787	434048	6953015	19/05/2016 0:00	42509		2240	7.7	1	44	806	464	2.3	2.5	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320432_42509	14320432	415912	6949392	19/05/2016 0:00	42509		4780	7.3	2	28	1670	540	2.3	3.6	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320493_42509	14320493	416582	6949241	19/05/2016 0:00	42509		12100	7.3	2	42	4710	555	3	4.6	0
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98234_27541	98234	438891	6947528	27/05/1975 0:00	27541	20	4950	7.5			2073	285	6	1.5	
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98252_27549	98252	439150	6945816	4/06/1975 0:00	27549	14	1310	8			374	370	1.5	2.7	
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98265_27551	98265	439243	6943755	6/06/1975 0:00	27551	28	1170	7.9			368	420	1.8	2.2	1.03
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98265_29578	98265	439243	6943755	23/12/1980 0:00	29578		850	7.8		42	265	357	1.4	2.3	1.85
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98269_28745	98269	439658	6943019	12/09/1978 0:00	28745		3900	7.5		35	1407	405	2.7	2.8	0
Water_Analysis	1893802	Pkg13	Woogaroo_Pkg13_55821_28711	55821	415369	6948382	9/08/1978 0:00	28711		5350	7.6		1	209	2353		38.5	42.86

Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320352_30264	14320352	431435	6953057	9/11/1982 0:00	30264		1000	7.6	34	257
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320352_30652	14320352	431435	6953057	2/12/1983 0:00	30652	31	1150	7.8	32	309
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320352_31161	14320352	431435	6953057	24/04/1985 0:00	31161	31	1200	7.3	32	321
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320354_29837	14320354	431994	6954501	8/09/1981 0:00	29837	17	330	7.6	22	56
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320354_30277	14320354	431994	6954501	22/11/1982 0:00	30277		680	7.6	24	171
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320354_30690	14320354	431994	6954501	9/01/1984 0:00	30690	17	465	7.8	20	83
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320355_30265	14320355	432156	6954976	10/11/1982 0:00	30265		235	7.4	31	39
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320355_30650	14320355	432156	6954976	30/11/1983 0:00	30650	3	350	7.5	22	67
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320355_31232	14320355	432156	6954976	4/07/1985 0:00	31232	9	550	8.2	27	58
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320356_30265	14320356	432133	6954931	10/11/1982 0:00	30265		270	8	48	52
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320356_30650	14320356	432133	6954931	30/11/1983 0:00	30650	8	300	7.4	43	65
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320356_30888	14320356	432133	6954931	25/07/1984 0:00	30888	8	270	7.8	45	86
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320356_31233	14320356	432133	6954931	5/07/1985 0:00	31233	8	290	6.9	46	65
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320357_30265	14320357	432100	6954873	10/11/1982 0:00	30265		440	7.7	57	103
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320357_30650	14320357	432100	6954873	30/11/1983 0:00	30650	9	760	8	50	211
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320358_30265	14320358	432080	6954824	10/11/1982 0:00	30265		710	7.6	40	153
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320358_30650	14320358	432080	6954824	30/11/1983 0:00	30650	10	670	8	47	160
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320358_30888	14320358	432080	6954824	25/07/1984 0:00	30888	10	590	8	44	126
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320360_30650	14320360	431974	6954640	30/11/1983 0:00	30650	11	1450	7.9	32	400
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320360_30887	14320360	431974	6954640	24/07/1984 0:00	30887	10	1400	6.9	32	370
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320363_30650	14320363	431454	6954422	30/11/1983 0:00	30650	5	300	7.4	19	67
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320364_29405	14320364	431326	6954445	3/07/1980 0:00	29405		1430	7.6	60	338
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320364_30264	14320364	431326	6954445	9/11/1982 0:00	30264		640	8.5	40	163
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320364_30867	14320364	431326	6954445	4/07/1984 0:00	30867	13	465	7.9	31	108
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320364_30650	14320364	431326	6954445	30/11/1983 0:00	30650	13	990	7.9	50	266
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_43229_26918	43229	431375	6952442	11/09/1973 0:00	26918		2000	7.6		596
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320544_33382	14320544	439926	6943503	24/05/1991 0:00	33382		2600	8.1	27	740

Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320487_31140	14320487	420353	6949191	3/04/1985 0:00	31140	19	1700	8.4	40	439	280	1.1	3.7	0	1087.63	959.9	180	1.5	82	57	0.02	0.01	330	5.9	390	0.2	30	11		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320488_31461	14320488	422009	6949237	18/02/1986 0:00	31461	0	1900	8.2	33	543	323	1.5	3.2		1185.53	1022.83	170	1.7	89	78	0.02	0.01	385	4.6	445	0.2	0	12	0	LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320489_31460	14320489	423871	6948881	17/02/1986 0:00	31460	0	3550	8.1	30	1268	335	2.8	2.5		2039.37	1866.05	205	3.8	145	220	0.07	0	400	4.4	1000	0.1	34	27	0	LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320490_31154	14320490	423300	6948816	17/04/1985 0:00	31154	25	3150	7.7	32	1251	409	4	1.8		1859.82	1640.21	145	4.6	130	225	0.1	0.02	495	2.1	830	0.1	8.9	19		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320491_31455	14320491	426623	6950607	12/02/1986 0:00	31455	0	5900	7.8	31	2050	400	1.4	6.7	0	4180	3970	450	4	305	330	0.12	0	320	2	2000	0.1	0	130	0	LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320492_31126	14320492	416681	6949731	20/03/1985 0:00	31126	14	4200	7.7	34	1329	480	1.8	4		2438.26	2177.45	335	6	120	250	0.04	0.02	580	2.6	1300	0.3	5.3	39		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320493_31128	14320493	416582	6949241	22/03/1985 0:00	31128	23	7100	7.5	38	2680	512	2.7	3.8		4124.69	3847.54	455	4.5	200	530	0.14	0.05	620	2.1	2200	0.2	7.7	105		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320493_31183	14320493	416582	6949241	16/05/1985 0:00	31183		7900	7.6	35	2902	405	2.5	4.3	0	4490.87	4276.81	530	4	190	590	0.42	0.05	490	2.2	2550	0.2	9	125		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99695_34052	99695	436682	6946111	24/03/1993 0:00	34052		1810	7		526	380	1.1	4.1		1287.2	1051.35	218		46	100			464		425	0.2		34		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99696_34052	99696	436518	6946069	24/03/1993 0:00	34052		4190	7.3		1680	590	1.9	4.3		2936.2	2570.22	409		134	327			720		1322	0.2		24		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320672_33294	14320672	438321	6951530	25/02/1991 0:00	33294	18	1000	8.3	39	347	479	1.1	3.3	2.65	926.53	675.8	140	2.7	40	60	0.02	0.01	570	7.1	91	0.3	2.4	13		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320669_33295	14320669	437316	6951316	26/02/1991 0:00	33295	16	750	8.2	32	228	326	1.8	1.6	1.96	616.22	449.98	57	1.5	4	53	0.01	0.01	390	3.7	94	0.2	1.8	11		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320596_33147	14320596	433090	6950757	1/10/1990 0:00	33147		1150	8	32	411	482	1.6	2.5	1.41	948.62	685.81	115	2.1	46	72	0.01	0.01	580	3.8	120	0.3	0.5	8.9		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320528_33147	14320528	437140	6947756	1/10/1990 0:00	33147		2550	8.2	26	690	730	1	5.5	0.79	1907.22	1491	330	1.9	54	135	0.01	0.01	870	10	490	0.3	1	15		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320659_33147	14320659	436465	6947762	1/10/1990 0:00	33147		3350	8	33	966	575	1.2	5.2		2259.42	1941.69	375	3.1	82	185	0.01	0.01	690	5.6	840	0.2	47	31.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320658_33147	14320658	437524	6947448	1/10/1990 0:00	33147		3850	8.1	27	751	485	0.6	9		2457.62	2189.81	570	2.7	70	140	0.01	0.01	580	5.4	1050	0.5	19.5	19.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99671_28080	99671	435250	6947273	16/11/1976 0:00	28080		4150	8	32	688	505	0.5	10.2		2535.4	2259.37	616	4	114	98			606	5	965	0.4	67	60		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99678_28083	99678	435658	6948014	19/11/1976 0:00	28083		4200	8	43	1168	265	1.3	5.4		2399.4	2278.22	422	1	240	138			323		1110	0.4		165		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99696_28083	99696	436518	6946069	19/11/1976 0:00	28083		3400	8.2	40	999	555	1.4	4.6		2097.3	1801.31	332	1	110	176			661	7.6	790	0.3	4.4	15		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320494_31128	14320494	416291	6949248	22/03/1985 0:00	31128	18	4400	7.9	35	1497	499	2.4	3.3		2515.79	2245.81	290	3.5	130	285	0.07	0.02	600	4.4	1200	0.3	0.5	2		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320495_31105	14320495	416104	6950087	27/02/1985 0:00	31105		2300	8.3	33	269	499	0.3	10.3	4.6	1539.78	1272.88	390	2.7	22	52	0.07	0.01	590	9.1	440	0.4	0.5	33		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320495_31139	14320495	416104	6950087	2/04/1985 0:00	31139	21	2350	8	31	279	499	0.3	10.2	4.4	1544.34	1270.37	390	2	31	49	0.03	0.01	600	4.4	445	0.4	0.5	22		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_31105	14320496	416745	6950149	27/02/1985 0:00	31105		2300	7.8	35	374	530	0.5	7.8	3.11	1560.38	1270.07	345	2.5	51	60	0.07	0.01	640	3.1	425	0.2	0.5	33		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_31139	14320496	416745	6950149	2/04/1985 0:00	31139	20	2150	8	33	303	533	0.4	8.9	4.59	1517.43	1225.12	355	2	34	53	0.02	0.01	640	4.7	395	0.2	0.5	33		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320497_31140	14320497	416206	6950558	3/04/1985 0:00	31140	23	2450	8.6	33	291	609	0.3	11	6.36	1698.99	1376.18	430	1.8	39	47	0.08	0.01	700	21	445	0.6	0.5	14		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320502_31160	14320502	425449	6950382	23/04/1985 0:00	31160	29	2750	8	42	1126	459	4	1.7		1698.66	1461.1	130	2	105	210	0.04	0.02	550	4.5	630	0.1	51	16		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320503_31160	14320503	432310	6952095	23/04/1985 0:00	31160	29	2750	8	34	710	550	1.1	5.1		1799.06	1497.58	310	3.6	70	130	0.14	0.02	660	5.2	560	0.1	49	11		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320514_31784	14320514	424911	6949839	7/01/1987 0:00	31784	28	2300	8.1	37	836	570	2.5	2.3		1543.44	1234.8	155	2.7	63	165	0.04	0	680	7.4	455	0.2	1.1	14	0	LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320515_31784	14320515	425329	6949836	7/01/1987 0:00	31784	28	2150	8.2	37	855	489	3.6	1.6		1392.65	1134.84	110	2.6	54	175	0.05	0	580	7.8	450	0.2	1.5	11.5	0	LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320171_22136	14320171	425404	6949984	8/08/1960 0:00	22136	25		7.6		962	544	3.7	1.7	0	1203	0	120.1		107.3	168.7			0	326	480.5	0.4		0		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320173_22147	14320173	425697	6949373	19/08/1960 0:00	22147	25		7.6		734	654	1.4	3.9	0	1259	0	241.7		44.3	151.6			0	391.8	429	0.6		0		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320182_22082	14320182	419964	6949212	15/06/1960 0:00	22082	27		7.7		235	361	0.7	4.5	2.51	622	622	157.3		91.5	1.4			0	215.9	150.2	0		5.7		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320195_22094	14320195	413516	6951224	27/06/1960 0:00	22094	13		7		414	334	0.8	5.2	0	1011.1	0	244.5		78.7	52.9			0	200.2	429	0.1		5.7		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_29699	14320286	440256	6942923	23/04/1981 0:00	29699	10	8000	7.4	52	2322	465	1.4	6.9		4613.6	4377.39	765	2.5	460	285			567	0	2440	0.1	0	94		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_28996	14320451	439101	6942009	21/05/1979 0:00	28996	9	750	7.6	43	282	255	2.8	1.2		531.6	417.03	46	0.8	52	37			310	0.7	80	0.1	0	5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_28998	14320451	439101	6942009	23/05/1979 0:00	28998	27	740	7.3	20	276	355	2.2	1.5	1.57	621.3	421.71	59	0.8	53	35			432	0.5	40	0	0	1		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320660_33147	14320660	436240	6946131	1/10/1990 0:00	33147		4500	8	30	1539	525	2	4		2795.97	2505.74	360	2.4	155	280	0.01	0.16	630	5.3	1350	0.3	2.8	10		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320555_33147	14320555	435634	6947306	1/10/1990 0:00	33147		4650	8	29	680	576	0.4	13.3		3048.72	2726.99	800	4.4	58	130	0.01	0.01	690	5.9	1250	0.4	59	51		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_33147	14320313	435502	6946259	1/10/1990 0:00	33147		6800	7.5	35	2903	273	4.2	2.6		3959.14	3826.4	320	2.6	355	490	0.02	0.02	330	1.3	2350	0.2	31	79		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320525_33147	14320525	437124	6948947	1/10/1990 0:00	33147		1100	8.3	26	194	437	0.5	6.1	4.85	910.12	671.8	195	1.2	21	34.5	0.01	0.01	520	6.5	120	0.4	0.5	11		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320661_33147	14320661	437305	6947626	1/10/1990 0:00	33147		1450	8.5	26	263	490	0.5	6.6	4.53	1112.82	849.09	245	1.2	25.5	48.5	0.01	0.01	570	13.5	200	0.4	0.5	8.2		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320222_33297	14320222	424575	6947701	28/02/1991 0:00	33297	12	1100	8.5	40	442	369	2	2.1		877.92	699.35	100	0.3	32	88	0.01	0.01	430	9.7	160	0.4	0.5	57		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320532_33318	14320532	437507	6948953	21/03/1991 0:00	33318	5	650	8.1	45	296	292	4.1	0.8		542.72	409.82	33	1.2	59	36	0.01	0.01	350	2.7	54	0.2	0.5	6.1		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320486_33311	14320486	420315	6949537	14/03/1991 0:00	33311	10	960	8.2	38	347	268	2	1.8		695.02	570.36	78	1.1	60	48	0.01	0.01	320	3.1	180	0.2	0.5	4.1		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320673_33294	14320673	438177	6951632	25/02/1991 0:00	33294	15	930	8.3	34	176	430	0.4	6.1	5.07	844.72	619.49	185	2.3	26	27	0.01	0.01	510	6.9	78	0.3	0.5	8.7		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320667_33295	14320667	438781	6947625	26/02/1991 0:00	33295	4	880	8.3	33	315	404	1.6	2.2	1.79	765.63	554.65	91	0.7	47	48	0.02	0.01	480	6.5	87	0.2	1.2	4		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320322_33312	14320322	439290	6944286	15/03/1991 0:00	33312	9	990	8.4	32	425	467	2	2	0.85	888.52	640.95	96	1.9	53	71	0.01	0.01	550	9.7	94	0.1	1.8	11		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320221_33297	14320221	424270	6947895	28/02/1991 0:00	33297	12	1200	8.3	32	523	296	3.4	1.4		861.43	715.53	71	1.6	79	79	0.02	0.01	350	5.1	230	0.2	0.5	45		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320674_33294	14320674	437903	6951892	25/02/1991 0:00	33294	17	1150	8.5	34	233	531	0.5	6.1	5.95	1044.92	763.77	215	1.5	34	36	0.01	0.01	620	13.5	115	0.3	0.8	8.8		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320327_33312	14320327	439506	6943376	15/03/1991 0:00	33312	10	1800	8.2	36	723	391	2.9	1.9		1215.02	1014.66	115	1	100	115	0.01	0.01	465	5.8	385	0.2	12	16		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320597_33316	14320597	433220	6951556	19/03/1991 0:00	33316	16	1900	8	25	636	416	2.2	2.3		1237.43	1008.28	135	1.7	90	100	0.02	0.01	500	3.5	375	0.2	13	19		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320666_33295	14320666	438593	6947189	26/02/1991 0:00	33295	7	1800	8.1	35	728	321	3.4	1.6		1126.72	966.02	99	1.7	110	110	0.01	0.01	385	3.4	410	0.1	0.5	7		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320220_33297	14320220	423772	6947956	28/02/1991 0:00	33297		2050	8.2	33	722	400	1.8	3		1380.52	1172.08	185	3.2	75	130	0.01	0.01	475	6	420	0.3	37	49		MA MA CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320517_33316	14320517	432190	6951243	19/03/1991 0:00	33316	18	2550	8	36	785	625	1.3	4.2		1747.32	1402.1	270	2.9	59	155	0.01	0.01	750	6.2	480	0.2	11	13		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_33295	14320277	438510	6947061	26/02/1991 0:00	33295	6	2300	8.1	40	714	569	1.2	4.4		1691.12	1385.48	270	0.8	80	125	0.01	0.01	680	7.1	500	0.2	11	17		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320668_33295	14320668	438835	6947890	26/02/1991 0:00	33295	3	2800	7.8	36	723	286	2.3	2.3		1597.12	1457.76	145	2	215	45	0.01	0.01	345	1.9	820	0.2	1	22		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320445_33311	14320445	427440	6950532	14/03/1991 0:00	33311	15	3550	7.8	30	1107	332	1.5	4.5		2156.82	1983.5	345	5	155	175	0.01	0.01	400	2.3	960	0.1	9.4	105		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320665_33295	14320665	438750	6947386	26/02/1991 0:00	33295	5	4300	7.8	28	1952	299	6	1.5		2432.72	2277.73	150	2.4	320	280	0.01	0.01	360	2.2	1300	0.1	3	15		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320276_16943	14320276	438316	6947223	21/05/1946 0:00	16943	28				627	329	1.4	3.6		1148.2	1148.2	204.5		154.4	58.6			0	197.3	516.2			17.2		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_29108	14320277	438510	6947061	10/09/1979 0:00	29108	28	940	8.3	40	354	355	2.2	1.7	0.01	725.7	551.71	74	0.8	33	66			421	5.7	120	0.1	0.1	5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_29717	14320277	438510	6947061	11/05/1981 0:00	29717	28	1100	8.3	40	421	421	2.8	1.5	0	821.6	607.45	70	1	58	67			500	6.5	113	0.1	1	5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_30245	14320277	438510	6947061	21/10/1982 0:00	30245		1750	8.1	45	504	519	1.2	3.9	0.3	1278.8	1008.65	200	1	75	77			620	6.6	285	0.2	4	10		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_30627	14320277	438510	6947061	7/11/1983 0:00	30627	28	1300	8.3	38	324	454	1	3.7	2.6	974.07	737.59	155	0.7	49	49	0.07	0	540	6.8	155	0.2	13	5.3		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_31188	14320277	438510	6947061	21/05/1985 0:00	31188	28	2100	8	39	568	441	1.2	4		1356.55	1126.15	220	0.5	71	95	0.04	0.01	530	3.8	410	0.2	16	10		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320278_16938	14320278	438697	6947497	16/05/1946 0:00	16938	25				344	470	1.6	2.3	2.52	542	542	98.7		38.6	60.1			0	281.7	62.9			0		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320278_29510	14320278	438697	6947497	16/10/1980 0:00	29510	9	1390	7.4	31	510	400	2.9	1.5		954.2	738.17	80	2	89	70			486	0.9	220	0.1	0.2	6		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320278_29767	14320278	438697	6947497	30/06/1981 0:00	29767	9	1250	7.8	30	485	411	2.7	1.6		928.7	706.07	83	0.5	87	65			497	2.1	171	0.1	15	8		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320278_30741	14320278	438697	6947497	29/02/1984 0:00	30741		1550	8.1	28	587	402	2.8	1.7		1069.43	853.45	95	1.2	100	82	0.02	0.01	480	4.9	295	0.1	2.9	8.3		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320279_16943	14320279	439061	6947697	21/05/1946 0:00	16943	13	750			325	416	1.9	1.9	1.81	482	482	78.7		47.2	50.1			0	248.8	57.2			0		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320279_29255	14320279	439061	6947697	4/02/1980 0:00	29255		2220	7.8	48	763	191	2.8	2		1226.7	1157.28	124	11	126	109			231	1	610	0.1	2.6	12		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320279_29732	14320279	439061	6947697	26/05/1981 0:00	29732	12	2380	7.8	46	905	403	3.2	1.9		1486.4	1284.86	130	1	176	113			487	2.3	567	0.1	1	9		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320279_30245	14320279	439061	6947697	21/10/1982 0:00	30245		2250	7.5	47	790	334	2.7	2.1		1342.8	1183.94	135	1.5	135	110			405	1.1	540	0.2	0	15		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320279_30245	14320279	439061	6947697	21/10/1982 0:00	30245		2150	7.6	48	753	289	2.6	2.1		1273.4	1143.5	135	1	120	110			350	1.2	540	0.2	0	16		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320279_30627	14320279	439061	6947697	7/11/1983 0:00	30627	12	2050	7.7	45	719	306	2.5	2.1		1233.56	1090.49	130	1.2	115	105	0.06	0	370	1.3	495	0.1	2.9	13		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320283_16952	14320283	440097	6947182	30/05/1946 0:00	16952	10				3873	195	0.4	29.5		10394	10273.33	4221.4		163	842.3			237.4		4741.9	0.7		187.3		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320284_29133	14320284	439651	6943025	5/10/1979 0:00	29133		2250	8.3	14	355	420	0.5	7.9	1.3	1467.3	1229.18	344	1	25	71			496	7.8	490	0.5	20	12		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320284_29699	14320284	439651	6943025	23/04/1981 0:00	29699		6200	8.7	18	404	729	0.2	26.6	6.5	3756.6	3391.85	1230	0	20	86			753	67	1580	0.6	0	20		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99959_28160	99959	435655	6953737	4/02/1977 0:00	28160		1700	8	46	731	420	3.9	1.4		1165.6	954.91	86	1	128	100			505	3.4	304	0.2	28	10		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99963_28160	99963	435762	6954261	4/02/1977 0:00	28160		2200	8	50	952	545	3.5	1.7		1537.1	1254.16	124	1	170	128			655	4.6	448	0.1	6.4			ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_56293_34104	56293	425785	6949550	15/05/1993 0:00	34104		6060	7.1		2150	645	2.2	4.2		3718.8	3318.77	451	3.5	307	336			787		1797	0.1	37.2			TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_73677_33863	73677	434095	6953144	16/09/1992 0:00	33863		2017	8.9	49	795	465	3	1.9	0	1334	1130.93	122	2.1	110.9	126.1	0.17	0	494.9	35.1	392.4	0.09	30	20.2		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_29102	14320451	439101	6942009	4/09/1979 0:00	29102		640	8.6	33	262	260	2.7	1.2		518.4	397.39	45	1	49	34			303	6.9	70	0.1	0.4	9		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_29703	14320451	439101	6942009	27/04/1981 0:00	29703	28	700	8	40	266	253	3.1	1.1	0	506.7	391.67	40	0.8	47	36			305	1.8	67	0.1	0	9		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_30245	14320451	439101	6942009	21/10/1982 0:00	30245		620	8	42	237	245	2.8	1.1	0.18	464	356.05	39	0.8	42	32			295	2.1	45	0.1	0	8		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_30623	14320451	439101	6942009	3/11/1983 0:00	30623	28	590	8.2	38	230	247	2.7	1.1	0.33	455.2	343.26	39	0.6	41	31	0.09	0.01	295	2.9	36	0.1	0.5	9		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320451_31189	14320451	439101	6942009	22/05/1985 0:00	31189	28	580	8.4	36	223	245	2.7	1.1	0.43	446.76	335.35	38	0.5	40	30	0.05	0.01	290	4.2	37	0.1	0.7	6.2		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320452_29003	14320452	439356	6942903	28/05/1979 0:00	29003	20	690	8.1	25	248	230	2.3	1.4		499.2	383.4	50	1.5	50	30			277	1.9	80	0.1	0.7	8		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320452_29104	14320452	439356	6942903	6/09/1979 0:00	29104		600	7.9	25	195	196	1.8	1.5	0.03	432.4	336.93	49	1	40	23			237	1.1	76	0.3	0	5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320452_29700	14320452	439356	6942903	24/04/1981 0:00	29700	19	540	8.1	29	181	206	2	1.3	0.5	397	300.45	41	1	36	22			247	1.8	38	0.2	0	10		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320452_30245	14320452	439356	6942903	21/10/1982 0:00	30245		640	8.1	30	235	230	2.7	1.1		458.4	348.62	40	0.8	48	28			275	2.4	57	0.2	0	7		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320452_30624	14320452	439356	6942903	4/11/1983 0:00	30624	2	530	8.5	30	198	192	2.6	1.1		381.67	297.3	35	0.6	38	25	0.06	0.01	225	4.3	46	0.2	0.5	7		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320452_31189	14320452	439356	6942903	22/05/1985 0:00	31189	20	820	8	31	336	345	3.6	1	0.18	638.14	458.2	43	0.5	57	47	0.03	0.01	415	2.6	55	0.1	4.9	13		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320505_31385	14320505	439053	6943566	4/12/1985 0:00	31385	14	6200	7.9	32	1135	425	0.6	11.5	0	3656.63	3429.4	890	6	100	215	0.08	0.05	510	4.3	1700	0.2	160	71	0	MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320506_31385	14320506	438960	6944019	4/12/1985 0:00	31385	27	2850	7.4	38	906	400	1.9	3.1	0	1712.28	1503.76	215	2.2	165	120	0.06	0.02	485	1.1	700	0.2	7.7	16	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320507_31386	14320507	438950	6944027	5/12/1985 0:00	31386	12	4800	7.6	40	1651	331	2.3	3.5	0	2760.69	2597.38	330	1.8	290	225	0.07	0.02	400	1.6	1450	0.1	9.1	53	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320508_31387	14320508	438898	6944071	6/12/1985 0:00	31387	27	10500	7.7	34	4077	170	2.7	4.8		6241.75	6171.55	700	5	660	590	0.2	0.05	205	1.4	3850	0.1	15	215	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320508_31387	14320508	438898	6944071	6/12/1985 0:00	31387	12	8500	9.1	2	2304	9	1.1	8.9	0	5262.45	5260.19	980	8	800	74	0.1	0.05	8.4	1.3	2850	0.1	0.5	540	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320509_31387	14320509	438840	6944111	6/12/1985 0:00	31387	27	8300	7.5	43	2977	215	2.4	4.5		4756.35	4667.19	570	4.5	475	435	0.2	0.05	260	1	2900	0.1	0.5	110	0	MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320510_31390	14320510	438990	6944116	9/12/1985 0:00	31390	31	8600	7.6	41	3686	315	4.5	2.7		5060.79	4908.64	380	3	660	495	0.2	0.09	380	1.9	3000	0.1	0.5	140	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320511_31390	14320511	438885	6944103	9/12/1985 0:00	31390	27	9100	7.6	40	3886	336	4.2	3		5397.9	5232.04	425	2.5	740	495	0.2	3	405	2.1	3200	0.1	5	120	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320512_31757	14320512	438939	6944038	11/12/1986 0:00	31757	30	2350	8.1	42	815	444	2.4	2.4		1493.94	1266.54	155	1.1	145	110	0.02	0.01	530	5.8	540	0.01	2.2	4.8	0	LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320485_33311	14320485	420432	6949736	14/03/1991 0:00	33311	11	880	8.3	48	282	139	2.1	1.6		539.01	503.14	63	1.6	60	32	0.01	0.7	165	2.2	210	0.2	0.5	3.8		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320525_33315	14320525	437124	6948947	18/03/1991 0:00	33315	11	1050	8.4	27	185	420	0.5	5.9	4.71	863.32	638.71	185	1	19.5	33	0.01	0.01	495	8.5	110	0.3	0.5	10.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320379_33318	14320379	435040	6954340	21/03/1991 0:00	33318	14	1200	8.4	29	516	396	2.9	1.6		935.92	728.56	83	2.4	78	78	0.01	0.01	465	8.6	185	0.3	0.6	35		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_33310	14320496	416745	6950149	13/03/1991 0:00	33310	11	1800	8.4	37	226	579	0.3	10	7.05	1389.02	1080.38	345	1.6	28	38	0.01	0.01	680	13	260	0.4	0.5	22.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320326_33312	14320326	439708	6944026	15/03/1991 0:00	33312	6	1900	8.2	39	563	361	1.6	3		1220.64	1041.07	165	1.1	97	78	0.03	0.01	430	5.3	390	0.2	42	12		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320520_33316	14320520	433333	6952322	19/03/1991 0:00	33316	15	1900	8.3	27	666	482	2.3	2.3		1284.02	1021.29	135	2.4	69	120	0.01	0.01	570	8.9	360	0.2	0.5	18		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320526_33315	14320526	436731	6949585	18/03/1991 0:00	33315	17	2050	8.4	28	510	640	0.8	5.4	2.59	1550.42	1197.2	280	2	49.5	94	0.01	0.01	750	15	340	0.2	1.2	18.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320519_33317	14320519	432444	6953040	20/03/1991 0:00	33317	12	1700	8.5	37	498	353	1.4	3.1		1126.82	955.42	160	1.7	79	73	0.01	0.01	410	9.8	355	0.2	4.1	34		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320531_33315	14320531	436833	6950755	18/03/1991 0:00	33315	14	2100	8.3	26	439	601	0.7	6.2	3.24	1535.62	1200.73	300	2.4	40.5	82	0.01	0.01	710	11	375	0.2	1	13.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320518_33317	14320518	432393	6952733	20/03/1991 0:00	33317	13	1900	8.2	38	512	370	1.3	3.5		1244.72	1059.07	180	1.6	70	82	0.01	0.01	440	5.4	370	0.2	44.5	51		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320515_33298	14320515	425329	6949836	1/03/1991 0:00	33298	14	2200	8.2	37	864	572	3.5	1.7		1468.92	1160.28	115	2.3	66	170	0.01	0.01	680	8.9	410	0.2	1	15.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320497_33310	14320497	416206	6950558	13/03/1991 0:00	33310	11	2150	8.6	38	262	628	0.3	11	7.32	1613.92	1285.94	410	1.8	31.5	44.5	0.01	0.01	720	22.5	355	0.6	1	27		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320523_33315	14320523	435489	6950289	18/03/1991 0:00	33315	13	2600	8.5	44	807	458	1.6	3.4		1641.42	1416.02	225	1.2	84	145	0.01	0.01	530	14	630	0.2	1	11		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320557_33298	14320557	426175	6950452	1/03/1991 0:00	33298	14	2050	8.3	30	711	402	2.4	2.2		1305.52	1094.08	135	3.2	95	115	0.01	0.01	475	7.6	400	0.2	52	22.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320514_33298	14320514	424911	6949839	1/03/1991 0:00	33298		2250	8.3	35	895	560	2.5	2.4		1581.02	1280.54	165	2.8	70	175	0.01	0.01	660	11	475	0.2	1	21		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320384_33316	14320384	437057	6952662	19/03/1991 0:00	33316	20	2850	8.2	35	888	464	1.6	3.8		1833.42	1588.86	260	2.2	92	160	0.01	0.01	550	7.5	740	0.2	1	20.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320445_33298	14320445	427440	6950532	1/03/1991 0:00	33298	15	3600	8.2	29	1095	329	1.5	4.4		2235.23	2065.99	335	4.4	150	175	0.02	0.01	390	5.6	1050	0.2	10	115		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320494_33309	14320494	416291	6949248	12/03/1991 0:00	33309	12	4550	8.3	35	1691	460	2.4	3.5		2660.62	2421.14	330	3.8	125	335	0.01	0.01	540	10.5	1250	0.3	3	63		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320529_33315	14320529	436064	6950033	18/03/1991 0:00	33315	21	5600	8.5	36	1068	664	0.5	12.1		3689.24	3338.93	910	2.2	65	220	0.02	0.02	760	24.5	1650	0.3	8.2	49		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320284_30245	14320284	439651	6943025	21/10/1982 0:00	30245		6100	8.2	10	606	790	0.2	22.1	3.67	4134.6	3671.88	1250	7.5	45	120			930	16.5	1750	0.6	0	15		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320284_30624	14320284	439651	6943025	4/11/1983 0:00	30624	28	4550	8.3	42	447	681	0.2	17.5	4.68	2977.54	2612.9	850	1.7	34	88	7.3	0.04	800	15	1150	0.5	12	19		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320284_31190	14320284	439651	6943025	23/05/1985 0:00	31190	28	6200	8.7	11	465	771	0.2	24.2	6.12	3896.71	3470.57	1200	2	23	99	0.06	0.05	860	39.5	1650	0.6	0.5	22		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320285_29509	14320285	439708	6943009	15/10/1980 0:00	29509		1630	7.4	34	604	425	2.5	1.9		1148.7	920.42	109	1.5	100	86			516	1.1	310	0.1	5	20		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320285_30741	14320285	439708	6943009	29/02/1984 0:00	30741	13	1650	8	4	486	108	1.7	2.7	0	947.95	885.88	135	15	66	78	0.04	0.01	130	1.1	460	0.1	56	6.7		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_29118	14320286	440256	6942923	20/09/1979 0:00	29118	10	7300	7.3	48	1862	190	1.1	8.2		4075.2	4005.27	810	2.5	325	255			232	0	2350	0	0.7	100		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_29598	14320286	440256	6942923	12/01/1981 0:00	29598	10	6800	7	38	2153	420	1.4	6.8		4400.1	4177.85	725	5	425	265			512	0	2390	0.1	0	78		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_29699	14320286	440256	6942923	23/04/1981 0:00	29699	7	8200	7.1	54	2219	436	1.3	7.3		4632.1	4415.68	795	5	435	275			532	0	2500	0.1	0	90		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_30245	14320286	440256	6942923	21/10/1982 0:00	30245		7600	7.3	48	2161	383	1.2	7.7		4518.3	4329.94	820	3	420	270			465	1.2	2450	0.1	1	88		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_30624	14320286	440256	6942923	4/11/1983 0:00	30624	10	8200	7.6	48	2405	352	1.3	7.8		4844.45	4676.42	880	3.5	460	305	3.3	0.15	425	1.9	2650	0.1	0.5	115		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_30825	14320286	440256	6942923	23/05/1984 0:00	30825	10	7800	7.6	37	2289	351	1.4	6.9		4530.4	4351.37	760	3.5	455	280	0.2	0.8	425	1.7	2500	0.1	4.1	100		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_30245	14320286	440256	6942923	21/10/1982 0:00	30245		6800	7.1	48	1892	341	1.2	7.1		3957.8	3794.86	710	3	370	235			415	0.6	2150	0.2	0	74		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_30624	14320286	440256	6942923	4/11/1983 0:00	30624	7	8000	7.4	50	2119	309	1.1	8.6		4699.43	4558.82	910	2.4	395	275	0.83	0	375	1.1	2600	0.1	10	130		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320286_31190	14320286	440256	6942923	23/05/1985 0:00	31190	7	8000	7.4	47	2078	313	1.1	8.6		4614.85	4468.7	900	3	395	265	0.2	0.05	380	1	2550	0.1	0.5	120		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_27221	14320287	440728	6942858	11/07/1974 0:00	27221	21	13000	8.6		1210	929	0.2	36.3		8936.78	8409.67	2900	12.5	15	285			1037	47.1	4440	0.18	0	200		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_29115	14320287	440728	6942858	17/09/1979 0:00	29115	21	13500	8.5	25	889	1382	0.1	41.9	9.85	8875.5	8199.05	2870	5	10	210			1380	150	4000	0.2	0.3	250		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_29699	14320287	440728	6942858	23/04/1981 0:00	29699	21	15000	7.6	30	1261	1246	0.2	38.2		9995.3	9252.68	3120	5	60	270			1520	0	4800	0.3	0	220		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_30245	14320287	440728	6942858	21/10/1982 0:00	30245		14500	7.8	30	1013	1294	0.2	41	5.6	9253.8	8495.94	3000	10	35	225			1550	13.5	4200	0.3	0	220		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_30623	14320287	440728	6942858	3/11/1983 0:00	30623	21	15000	8	30	1097	1137	0.2	40.7	0.8	9671.7	9015.49	3100	6.9	19	255	0.49	0.01	1350	18	4700	0.3	17	205		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_31190	14320287	440728	6942858	23/05/1985 0:00	31190	21	14000	7.8	30	1016	1332	0.2	38.9	6.3	9116.03	8332.75	2850	7	61	210	0.13	0.1	1600	12	4150	0.3	0.5	225		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320186_33865	14320186	415495	6950809	18/09/1992 0:00	33865	10	582	8.8	61	130	160	0.9	2.5	0.59	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		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320189_33865	14320189	415034	6950054	18/09/1992 0:00	33865	20	1973	8.2	35	307	538	0.4	8	4.61	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		ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320220_33844	14320220	423772	6947956	28/08/1992 0:00	33844	25	2251	7.9	40	735	446	1.8	3.1	0	1475.68	1242.64	190	2.2	86.8	126	0	0	536.8	3.6	437	0.21	37.4	55.7		MA MA CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320221_33844	14320221	424270	6947895	28/08/1992 0:00	33844	25	1275	8	39	475	291	2.9	1.5	0	833.97	694.61	75	1	73.8	70.7	0	0	350.1	2.4	217	0.16	0	43.8		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320222_33848	14320222	424575	6947701	1/09/1992 0:00	33848	18	1574	8.2	47	541	315	2	2.4		1023.07	879.91	127	0.1	30.6	113	0	0	374.1	5	305	0.27	0.3	67.7		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99554_32524	99554	433817	6945261	16/01/1989 0:00	32524	8	3400	8.3	25	662	392	0.6	8.2		2204.26	1995.44	485	4.6	105	97	0.04	0.02	460	8.7	880	0.2	3.7	160		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320525_32149	14320525	437124	6948947	7/01/1988 0:00	32149	27	1500	8.3	29	319	584	0.7	5.2	5.3	1180.02	858.29	215	1.6	35.5	56	0.01	0.01	690	11	160	0.2	0.7	10		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320528_32151	14320528	437140	6947756	9/01/1988 0:00	32151	29	2300	8.2	28	621	717	1	5.1	1.91	1727.75	1323.7	290	1.6	51	120	0.03	0.02	850	12	395	0.2	1	6.9		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320531_32148	14320531	436833	6950755	6/01/1988 0:00	32148	28	2500	8.6	29	551	580	0.7	6.3	0.59	1707.54	1401.06	340	2.4	31	115	0.02	0.02	660	23.5	530	0.1	1	4.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320532_32149	14320532	437507	6948953	7/01/1988 0:00	32149	20	900	7.9	29	328	374	2.2	1.7	0.91	716.83	517.1	69	1.2	49	50	0.02	0.01	450	2.7	84	0.3	1	9.6		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320537_32148	14320537	439576	6945988	6/01/1988 0:00	32148		1350	8.2	33	272	521	0.6	5.3	4.98	1043.83	761.68	200	1.1	29	48.5	0.02	0.01	620	7.7	130	0.3	4.1	3.1		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320538_32151	14320538	439392	6946237	9/01/1988 0:00	32151		2000	8.2	35	672	392	2.1	2.5		1277.54	1076.18	150	1	55	130	0.02	0.02	465	6.4	465	0.1	1	4		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320547_32555	14320547	438954	6940198	16/02/1989 0:00	32555		2000	8.2	33	649	454	1.8	2.9		1353.19	1111.71	170	1.2	87	105	0.07	0.02	540	6.6	435	0.2	1	7.1		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320553_32555	14320553	438764	6940236	16/02/1989 0:00	32555		1950	8.3	29	621	558	1.7	2.9		1366.56	1060.08	165	1.1	97	92	0.05	0.01	660	10	335	0.2	0.5	5.7		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320555_32555	14320555	435634	6947306	16/02/1989 0:00	32555		6600	8	34	1625	603	0.9	8.5		3979.94	3647.96	790	4.5	140	310	0.19	0.05	720	7.4	1950	0.3	26.5	31		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_61054_28403	61054	431488	6953325	5/10/1977 0:00	28403	21	385	6.6		48									19											REDBANK CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98057_32998	98057	437296	6950004	5/05/1990 0:00	32998		980	7.6		363	321	2.2	1.7		712.8	514.05	76	0.8	40	64			391		131			10		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320493_33309	14320493	416582	6949241	12/03/1991 0:00	33309	12	8400	7.9	37	3381	460	2.7	4.3		4962.44	4719.88	580	6.5	250	670	0.02	0.02	550	5.2	2750	0.2	10.5	140		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Gatton_Pkg13_83408_34037	83408	408295	6951747	9/03/1993 0:00	34037		3250	7.4		1157	566	1.1	6		2662.3	2311.57	467	6.6	188	167			690		1092	0.2	3.5	48		GATTON SANDSTONE
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320321_33312	14320321	439165	6944092	15/03/1991 0:00	33312	8	1100	8.4	39	390	432	1.7	2.3	0.84	899.72	679.49	105	0.4	67	54	0.01	0.01	510	8.1	120	0.2	22	13		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320495_33310	14320495	416104	6950087	13/03/1991 0:00	33310	11	2350	8.2	33	324	588	0.4	10.1	5.27	1713.32	1390.51	420	2.9	31	60	0.01	0.01	700	8.4	455	0.5	1	34.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320503_33316	14320503	432310	6952095	19/03/1991 0:00	33316	20	3300	8	32	944	525	1.2	5		2180.52	1892.29	355	3.7	73	185	0.01	0.01	630	5.2	780	0.1	125	23.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320492_33309	14320492	416681	6949731	12/03/1991 0:00	33309	6	4100	7.9	31	1398	450	2	3.7		2436.42	2192.94	320	3	115	270	0.01	0.01	540	4.1	1100	0.3	31	53		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320325_33322	14320325	439560	6944051	25/03/1991 0:00	33322	7	1250	8.4	26	516	451	3	1.5		978.52	735.12	79	1.3	83	75	0.01	0.01	530	9.6	170	0.1	23	7.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320457_33319	14320457	429208	6952770	22/03/1991 0:00	33319	16	1750	8.1	38	538	435	1.5	3.1		1207.62	981.3	165	3.3	77	84	0.01	0.01	520	5	335	0.2	3.1	15		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320510_33322	14320510	438990	6944116	25/03/1991 0:00	33322	8	8100	7.2	40	3322	420	3.1	3.7		4836.84	4617.61	490	2.8	580	455	0.02	0.02	510	0.9	2600	0.1	3	195		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320277_33840	14320277	438510	6947061	24/08/1992 0:00	33840	25	2723	7.8	49	861	797	1.4	4.3	0	2016.94	1576.96	287	0.3	126	133	0	0.01	961.6	5.3	475	0.17	9.2	19.4		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320285_33849	14320285	439708	6943009	2/09/1992 0:00	33849		2029	8.2	31	717	471	2.2	2.4	0	1344.9	1091.77	147	2.4	111	107	0.08	0.06	559	7.6	396	0.05	10.6	4.2		ALLUVIUM
Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_33840	14320287	440728	6942858	24/08/1992 0:00	33840	15	12085	7.8	32	827	1622	0.2	39.1	15.88	8346.57	7387.93	2583	5.2	77.8	154	0.08	0.07	1947.9	15.2	3360	0.44	0	203		MARBURG SUBGROUP
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320321_33841	14320321	439165	6944092	25/08/1992 0:00	33841	20	1121	8.1	44	364	420	1.5	2.5	1.11	861.52	649.46	109	0.7	65.2	49	0	0.01	503.2	4.5	116	0.13	4.2	9.6		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320326_33841	14320326	439708	6944026	25/08/1992 0:00	33841	11	2168	8	47	699	405	1.8	3	0	1400.54	1200.29	181	1.4	135	88	0.01	0	486	3.9	447	0.15	51.5	6.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320327_33841	14320327	439506	6943376	25/08/1992 0:00	33841	25	2601	7.9	42	976	409	2.8	2.3	0	1594.85	1386.4	162	0.8	134	156	0	0	492.1	3.3	620	0.06	16	10.5		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320352_33863	14320352	431435	6953057	16/09/1992 0:00	33863	25	1624	8.3	40	461	84	2.1	2	0	797.08	786.33	99.4	6.2	99.5	51.7	0.05	9.87	99.8	1.3	435.5	0.01	0	3.6		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320357_33863	14320357	432100	6954873	16/09/1992 0:00	33863	7	276	8.5	59	69	85	1.1	1.6	0.31	207.65	215.44	29.9	5.3	14.1	8.3	0.04	0.2	100.2	1.7	36.6	0.13	5	6.4		REDBANK CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320368_33863	14320368	432140	6954487	16/09/1992 0:00	33863	15	593	8.6	33	81	119	0.5	3.9	0.74	388.64	351.07	81.8	3.5	16.8	9.6	0.13	0.03	138.1	3.2	93.7	0.01	33.7	8.2		REDBANK CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320405_33864	14320405	429616	6952688	17/09/1992 0:00	33864	25	1622	9	48	671	347	4.6	1.1	0	1012.72	873.18	66.9	1.5	101	101.8	0.04	0.52	369.8	26	313.3	0.15	13.5	18.6		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320431_33868	14320431	415212	6949823	21/09/1992 0:00	33868	7	4586	7.6	26	1036	580	0.9	7.6	0	2835.61	2505.01	563	16.9	196	133	0	0.42	702.1	2.7	1190	0.19	2.1	29.6		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320432_33851	14320432	415912	6949392	4/09/1992 0:00	33851	18	3065	8.1	28	1092	440	2.3	2.9	0	1866	1627.32	219	3.4	136	183	0	0.81	525.1	5.7	758	0.19	0	35.6		FLAGSTONE CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320465_33864	14320465	428422	6952220	17/09/1992 0:00	33864	20	2323	8.9	51	593	428	1.1	4.6	0	1449.06	1264.92	259.3	2	94.4	87	0.09	0	462	29.1	499	0.16	4	11.9		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320485_33864	14320485	420432	6949736	17/09/1992 0:00	33864	20	772	8.8	56	222	145	1.8	1.7	0	450.35	423.42	57.4	1.5	47.6	25.2	0.03	0.67	163	6.7	146.8	0.12	0	2		SANDY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320487_33864	14320487	420353	6949191	17/09/1992 0:00	33864	18	1585	9	51	432	316	1.3	3.2	0	976.57	856.14	152	1.5	77.7	57.9	0.19	0.01	336.3	24	315.5	0.25	5.9	5.4		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320490_33864	14320490	423300	6948816	17/09/1992 0:00	33864	25	4375	8.5	38	1896	428	4.8	1.8		2551.07	2339.65	181.1	4.8	267	298.5	0	0.26	490.7	15.4	1183.1	0.11	61	49.1		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320491_33864	14320491	426623	6950607	17/09/1992 0:00	33864	25	7409	8.4	41	2900	428	3.1	3.5	0	4199.04	3987.61	432.6	2.9	435.9	440.8	0.02	0	496.4	12.6	2281.2	0.14	49.1	47.3		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320493_33851	14320493	416582	6949241	4/09/1992 0:00	33851	20	9651	8	45	3997	592	3	4.2	0	5799.18	5486.02	617	5.8	343	764	0.02	1.07	704.2	8.8	3218	0.21	8.1	130		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320496_33864	14320496	416745	6950149	17/09/1992 0:00	33864		1887	9.1	47	261	584	0.4	8.9	6.44	1341.54	1088.69	328.6	1.5	41.8	38.1	0.07	0.25	589.9	59.8	261.8	0.3	0	19.5		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320503_33863	14320503	432310	6952095	16/09/1992 0:00	33863	25	3661	8.8	43	1133	568	1.5	4.5	0	2300.74	2029.57	350.6	3.4	119	203.3	0.03	0	618.1	36.8	833	0.1	119	17.3		LOCKYER CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320511_33841	14320511	438885	6944103	25/08/1992 0:00	33841	25	10127	7.7	52	4063	640	2.4	5.2	0	6489.25	6149.38	768	2.5	796	505	0.08	4.8	770.8	4.9	3412	0.07	0	230		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320516_33864	14320516	425764	6949642	17/09/1992 0:00	33864	25	1587	8.9	32	613	343	3	1.6	0	1017.94	860.86	93.4	1.9	90.3	94.2	0.02	1.14	371.4	22.7	288.4	0.1	0	55.4		TENTHILL CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320473_33340	14320473	439752	6942534	12/04/1991 0:00	33340	5	3150	8.2	32	930	447	1.2	5		2069.64	1832.24	350	3.7	150	135	0.02	0.02	530	7.3	860	0.1	14.5	19		LAIDLEY CREEK ALLUVIUM
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320473_33340	14320473	439752	6942534	12/04/1991 0:00	33340	5	3500	8.1	27	935	419	1	6		2229.34	2002.19	420	4.9	160	130	0.02	0.02	500	5.6	990	0.3	1	17.5		LAIDLEY CREEK ALLUVIUM

Water_Analysis	1893802	Pkg13	Marb_Pkg13_14320287_33340	14320287	440728	6942858	12/04/1991 0:00	33340	3	11000	8.3
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_73599_32540	73599	413391	6952430	1/02/1989 0:00	32540	15	960	8
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_52878_28543	52878	431453	6953081	22/02/1978 0:00	28543	20	830	6
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99178_27095	99178	432120	6954354	7/03/1974 0:00	27095		315	7.4
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_99179_26919	99179	432178	6954329	12/09/1973 0:00	26919		610	7.6
Water_Analysis	1893802	Pkg13	Gatton_Pkg13_71064_30277	71064	417805	6952754	22/11/1982 0:00	30277	38	1750	7.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_55874_28713	55874	433632	6952557	11/08/1978 0:00	28713	31	1800	7.9
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_43206_26919	43206	431315	6954883	12/09/1973 0:00	26919		375	7.6
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_66442_30336	66442	437244	6948730	20/01/1983 0:00	30336	25	1200	7.9
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_98071_27535	98071	437504	6951531	21/05/1975 0:00	27535		890	7.6
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_29166	14320313	435502	6946259	7/11/1979 0:00	29166		5500	7.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_29720	14320313	435502	6946259	14/05/1981 0:00	29720	24	6000	7.7
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_30257	14320313	435502	6946259	2/11/1982 0:00	30257		5900	7.7
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_30615	14320313	435502	6946259	26/10/1983 0:00	30615	24	6700	7.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320313_31196	14320313	435502	6946259	29/05/1985 0:00	31196	24	7100	7.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320314_29516	14320314	433962	6945917	22/10/1980 0:00	29516	8	5160	7.1
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320314_29720	14320314	433962	6945917	14/05/1981 0:00	29720	8	4400	7.6
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320314_30257	14320314	433962	6945917	2/11/1982 0:00	30257		4000	7.7
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320314_30615	14320314	433962	6945917	26/10/1983 0:00	30615	9	3200	7.8
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320314_31196	14320314	433962	6945917	29/05/1985 0:00	31196	9	4150	7.6
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320321_27221	14320321	439165	6944092	11/07/1974 0:00	27221	26	745	8.5
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320321_29509	14320321	439165	6944092	15/10/1980 0:00	29509		4230	7
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320321_29706	14320321	439165	6944092	30/04/1981 0:00	29706	26	3400	8
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320517_33863	14320517	432190	6951243	16/09/1992 0:00	33863	25	4519	8.6
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320519_33863	14320519	432444	6953040	16/09/1992 0:00	33863	20	1680	8.8
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320527_33841	14320527	439254	6945667	25/08/1992 0:00	33841	25	900	8.1
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320531_33863	14320531	436833	6950755	16/09/1992 0:00	33863	25	2203	9.1
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320538_33840	14320538	439392	6946237	24/08/1992 0:00	33840	25	1370	7.9
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320542_33841	14320542	436320	6947186	25/08/1992 0:00	33841	20	718	7.7
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320545_33841	14320545	438891	6942546	25/08/1992 0:00	33841	25	6272	7.8
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320546_33841	14320546	438528	6941902	25/08/1992 0:00	33841	8	6544	7.9
Water_Analysis	1893802	Pkg13	Alluv_Pkg13_14320665_33840	14320665	438750	6947386	24/08/1992 0:00	33840	21	5808	7.8

Appendix D
Bridge GW Chemistry

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Structure Name	SO4	TDS	ALK	Cl	CO3	HCO3	Ca	Mg	Mg/Ca	pH	EC	T	LSI	RSI	Formation	Formation Depth
330-BR01	8	1495.6	1028.5	245	2	1160	37	16	0.6	7.7	2470	20.0	6.55	0.58	Gatton Sandstone	1.5 m BGL; nearby groundwater bore 330-01-BH2301
330-BR02	23.9	3233.8	377.5	457.5	1	433.5	64.6	45.6	0.7	7.8	5150	20.0	6.90	0.45	Colluvium / Woogaroo Subgroup	Woogaroo Subgroup ~21 m BGL; nearby registered bore RN 71064
330-BR03	23.9	3233.8	377.5	457.5	1	433.5	64.6	45.6	0.7	7.8	5150	20.0	6.90	0.45	Alluvium / Woogaroo Subgroup	Woogaroo Subgroup ~12 m BGL; nearby groundwater bore 330-01-BH2203
330-BR04	50	955	128	438	12	116	33	33	1	8.53	1730	22.1	7.51	0.51	Woogaroo Subgroup	Woogaroo Subgroup ~2 m BGL; nearby groundwater bore 330-01-BH2207
330-BR05	23.9	3233.8	377.5	457.5	1	433.5	64.6	45.6	0.7	7.8	5150	20.0	6.90	0.45	Woogaroo Subgroup	Unknown; no nearby groundwater bores
330-BR06	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR07	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR08	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR09	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR10	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Colluvium	Unknown; no nearby groundwater bores
330-BR11	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR12	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR13	77	2940	601	1340	<1	601	38	42	1.1	8.16	5500	23.4	6.46	0.85	Alluvium / Gatton Sandstone	Gatton sandstone ~24 m BGL; nearby groundwater bore 330-01-BH2212
330-BR14	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR15	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR16	41	1180	218	646	194	<1	25	15	0.6	10.5	2530	24.2	5.25	2.62	Alluvium / Gatton Sandstone	Gatton Sandstone ~23 m BGL; nearby groundwater bore 330-01-BH2216
330-BR17	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR18	20	2420.4	994	396	6.65	1119.2	35	23	0.9	7.8	4000	20.0	6.57	0.62	Koukandowie Formation	Koukandowie Formation ~9 m BGL; nearby groundwater bore 330-01-BH2103
330-BR19	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR20	8	1495.6	1028.5	245	2	1160	37	16	0.6	7.7	2470	20.0	6.55	0.58	Alluvium / Gatton Sandstone	Gatton Sandstone ~18 m BGL; nearby groundwater bore 330-01-BH2224
330-BR21	20	2420.4	994	396	6.65	1119.2	35	23	0.9	7.8	4000	20.0	6.57	0.62	Alluvium / Koukandowie Formation	Koukandowie Formation ~18 m BGL; nearby groundwater bore 330-01-BH2227
330-BR22	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR23	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores
330-BR24	15	1096.1	390	395	2.9	465.5	80	97	1.1	7.9	2000	20.0	6.50	0.70	Alluvium	Unknown; no nearby groundwater bores

*Based on samples from registered bores within 5 km of alignment
10 samples in Woogaroo Subgroup
36 samples in Gatton Sandstone
101 samples in Marburg Subgroup
929 samples in Alluvium
Koukandowie was counted as part of the Marburg Subgroup for the purposes of this calculation

Appendix E
Important Information

HELIDON TO CALVERT ENVIRONMENTAL IMPACT STATEMENT

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