

APPENDIX

INLAND
RAIL 

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Groundwater Technical Report

CALVERT TO KAGARU ENVIRONMENTAL IMPACT STATEMENT

Inland Rail Calvert to Kagaru EIS

Appendix O – Groundwater
Technical Report

**Australian Rail Track
Corporation**

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Calvert to Kagaru Preliminary Hydrogeological Interpretative Report

Appendix B

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Abbreviation

| Abbreviation | Explanation |
|--------------|---|
| ANZECC | Australian and New Zealand Environment and Conservation Council |
| ARD | Acid rock drainage |
| ASS | Acid sulphate soils |
| ATMS | Advanced Train Management System |
| BoM | Bureau of Meteorology |
| C2K | Calvert to Kagaru |
| Ch | Chainage (in kilometres) |
| CIA | Cumulative impact assessment |
| cm | Centimetre |
| CRD | Cumulative rainfall departure |
| EC | Electrical conductivity |
| EIS | Environmental impact statement |
| EVs | Environmental values |
| GDE | Groundwater dependent ecosystem |
| H2C | Helidon to Calvert |
| K2ARB | Kagaru to Acacia Ridge and Bromelton |
| km | kilometres |
| L/sec | Litres per second |
| m | metres |
| m/day | Metres per day |
| mAHD | Australian height datum in metres |
| mBGS | Metres below ground surface |
| mBNS | Metres below natural surface |
| mg/L | Milligrams per litre |
| mm | Millimetre |
| mm/yr | Millimetres per year |
| MNEs | Matters of national environmental significance |
| PASS | Potential acid sulfate soils |
| QA/QC | Quality assurance/quality control |
| TDS | Total dissolved solids |
| ToR | Terms of reference |
| WQO | Water quality objective |
| µS/cm | Micro siemens per centimetre |

Executive summary

The Project

The Calvert to Kagaru Project (the Project) consists of approximately 53 kilometres (km) of greenfield railway track between Calvert and Kagaru. It will involve the construction of embankments, bridges, cuttings and a 1,015 metre (m) tunnel through the Teviot Range to facilitate the required gradient across the undulating topography.

Purpose

This groundwater technical report has been prepared to address the relevant groundwater Terms of Reference (ToR) of the Project by assessing potential impacts on groundwater levels, flow and quality. The groundwater study area is defined as the area within 1 km of the centreline of the rail alignment.

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

Existing environment

The Project is located within the Logan River and Bremer River catchments and will intersect a number of defined watercourses and drainage features, and broadly consists of three distinct topographical areas: the western lowlands, the central ranges (Teviot Range), and the Beaudesert Basin.

The climate is typically hot and dry with seasonally distributed rainfall; where rainfall is predominant during summer months. Mean monthly evaporation is greater than mean monthly rainfall for all months, typically leading to a deficit in annual rainfall compared to evaporation.

The geology west of the Teviot Range is underlain by interbedded sandstone, mudstone and siltstone of the Walloon Coal Measures. The central portion of the groundwater study area is dominated by medium to coarse grained sandstone of the Gatton Sandstone that forms the topographic high of the Teviot Range. To the east the alignment is underlain by the interbedded siltstone, claystone and sandstone of the Koukandowie Formation and Walloon Coal Measures.

Relatively thin deposits of alluvial sediments overlay the sedimentary rocks in places and are associated with the primary surface water features within the groundwater study area. The alluvial sediments are limited in extent, both laterally and vertically, away from the watercourses.

A summary of the existing groundwater environment is provided below:

- The key groundwater units are the unconfined alluvial sediment aquifers associated with the key watercourses, and the low permeability aquifers of the Walloon Coal Measures, Koukandowie Formation and Gatton Sandstone
- The water table is typically a subdued version of topography, with the depth to groundwater increasing beneath topographic highs (for example the Teviot Range), and shallower groundwater in lower lying reaches (such as close to surface water drainage lines)
- Depths to groundwater in the alluvial sediments are anticipated to be between 5 m and 15 m but have been measured at less than 5 m in several locations across the groundwater study area
- In the main outcrop areas of Walloon Coal Measures, the water table is expected to be at least 5 m, and greater than 10 m beneath higher relief. Within the Gatton Sandstone of the Teviot Range the water table will be in the order of 60 m or more below ground surface at its deepest.
- Groundwater quality is variable across the key groundwater units, with groundwater in the alluvial sediments generally fresher than the underlying sediments

- 43 registered bores were identified within the groundwater study area, designated as being for monitoring or water supply purposes. No licensed allocations were identified, and groundwater use is anticipated to be for stock and domestic use only.
- Potential aquatic and terrestrial groundwater dependent ecosystems were identified as being present within the groundwater study area
- Stock watering and aquatic ecosystems were the only groundwater EVs considered relevant in the groundwater study area.

Potential impacts

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

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

Significant residual impact assessment

The sensitivity and magnitude of the potential impacts were used to identify the significance of the Project on groundwater and groundwater users.

Proposed mitigation measures (after design considerations) were identified in order to reduce the initial magnitude and significance of the potential impacts. Following the application of the mitigation hierarchy (i.e. avoid, minimise, mitigate) which included a range of mitigation measures and management plans, the residual impacts were reduced.

After the application of mitigation, it is anticipated that there will be a low significance of residual impacts on groundwater levels, groundwater flow, and water quality across most of the groundwater study area. Potential residual risks were identified as being moderate for groundwater users (that is groundwater bore users and potential GDEs) from reduced groundwater levels due to seepage into the free draining Teviot Range tunnel and deep cuttings. Ongoing and further investigations are anticipated to confirm that risks posed to groundwater users are acceptable. Should this not be the case, works will be completed during subsequent phases (i.e. detailed design and early works) to develop mitigation and management strategies that achieve acceptable residual risks.

Cumulative impacts

A cumulative impact assessment (CIA) was undertaken where potential groundwater impacts of the Project were assessed together with existing or planned surrounding activities. The CIA identified low significance of residual impacts for changes in groundwater levels and groundwater quality; primarily due to the physical distance of each project from the Project and the proposed adoption and implementation of recommended mitigation measures.

1 Introduction

1.1 Project background and purpose

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

The Inland Rail Program provides a more direct route between Melbourne and metropolitan Brisbane in comparison with the existing inland and coastal road and rail networks and meets the Australian Government's objective of providing a long-term rail solution for competitive freight movement. At commencement of operations, the Project will complete Inland Rail, and fulfil the Australian Government's plan to accommodate the use of double-stacked, 1,800 m long trains allowing for the transit of freight volumes equivalent to 110 B-double trucks.

This groundwater technical report includes:

- A description of relevant Project details
- An overview of existing environmental, geological and hydrogeological conditions
- An assessment of potential impacts to EVs relevant to groundwater
- A description of proposed measures to mitigate these impacts
- An assessment of potential residual impacts of the Project by application of a significance assessment approach.

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

This technical report has been prepared to address groundwater related requirements listed in the ToR for an Environmental Impact Statement: Inland Rail – Calvert to Kagaru (C2K) Project, December 2017 (refer Section 1.3).

1.2 Project overview

The Project is located within the Ipswich City Council, Logan City Council, and Scenic Rim Regional Council local government area (LGAs) in south-east Qld. It is the second most-northern package of the Inland Rail Program, running from Calvert to Kagaru (refer Figure 1).

The Project is a new greenfield railway, approximately 53 km in length, generally following the Southern Freight Rail Corridor (SFRC) and is one of the "missing links" within the Inland Rail Program.

The design has responded to key environmental features and has been developed in line with engineering constraints for a feasible rail design. The rail design is based on minimising environmental impact, minimising disturbance to existing infrastructure and meeting engineering design criteria.

Key components of the Project are:

- Approximately 53 km of single track dual gauge rail line with four crossing loops to ultimately accommodate trains up 3,600 m long based on business needs, but initially constructed for 1,800 m long trains
- An approximately 1,015 m long Teviot Range Tunnel, and bridges to accommodate topography and Project crossings of waterways and other infrastructure
- Tie-ins to the existing West Moreton Railway Line at the Project boundary near Calvert

- Allowance for a future connection to the Ebenezer Industrial Area at Willowbank
- The construction of associated rail infrastructure including maintenance sidings and signalling infrastructure to support the Advanced Train Management System
- Rail crossings including level crossings, grade separations/road overbridges, occupational/private crossings, fauna crossing structures, signage and fencing
- Tie-ins to the existing operational Sydney to Brisbane Interstate railway line
- Significant embankments and cuttings will be required along the length of the alignment
- Ancillary works including road and public utility crossings and realignments, signage and fencing and provision of services within the corridor (excluding those undertaken as enabling works)
- Construction workspace and access roads.

Although ARTC are applying for approval to build infrastructure to accommodate trains up to 1,800 m in length, infrastructure will be designed such that the future extension of some crossing loops to accommodate 3,600 m trains is not precluded. ARTC intend to acquire the land for the future 3,600 m crossing loop extension with the initial land acquisition, however, the approval for the construction of future 3,600 m crossing loops will be subject to separate approval applications in the future. Future proofing for future 3,600 train lengths have not been considered in the assessment.

It is anticipated that construction of the Project will commence in 2021, with operation expected to commence in 2026.

1.3 Objectives and scope of report

This technical report addresses the relevant groundwater ToR for the Project, as summarised in Table 1.1. Compliance of the EIS against the full ToR is documented in the EIS Appendix B: Terms of Reference Compliance Table.

Table 1.1 Groundwater project objectives

| ToR ID | Objective | Relevant section |
|--------------------|--|--|
| Groundwater | | |
| 11.36 | Identify the water-related EVs and describe the existing surface water and groundwater regime within the study area and the adjoining waterways in terms of water levels, discharges and freshwater flows. | Sections 6.2, 6.6 and 7 |
| 11.38 | At an appropriate scale, detail the chemical, physical and biological characteristics of groundwater within the area that may be affected by the project. Include a description of the natural water quality variability within the study area associated with climatic and seasonal factors, and flows. | Sections 4.3, 4.4 and 6 |
| 11.39 | Describe any existing and/or constructed waterbodies adjacent to the preferred alignment. | Section 4.3 |
| 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 presents registered groundwater bores and Table 6.8 includes the reported source aquifer per registered bore (as available). |
| 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. | Section 2.3.4 |
| 11.44 | Where significant cuttings or tunnelling is proposed, identify the presence of any sulphide minerals in rocks with potential to create acidic, metalliferous and saline drainage. Should they be found present, describe the practicality of avoiding their disturbance. If avoidance is not practicable, characterise the potential of the minerals to generate contaminated drainage and describe abatement measures that will be applied to avoid adverse impacts to surface and groundwater quality. | Sections 5, 11 and 12 |

| ToR ID | Objective | Relevant section |
|--------|---|--|
| 11.47 | Describe how the water quality objectives would be achieved, monitored and audited, and how environmental impacts would be avoided or minimised and corrective actions would be managed. | Sections 12 and 13 |
| 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. | Section 2.1 provides an overview of relevant legislation. Sections 11.1, 11.2.1.7 and 11.2.2 |
| 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: (c) direct and indirect impacts arising from the project (d) impacts to aquatic ecosystems, including groundwater-dependent ecosystems and environmental flows. | Sections 8, 9 and 10 |
| 11.55 | Provide information on the proposed water usage by the project, including: (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 | Section 11.1.6 |
| | (d) sufficient hydrogeological information to support the assessment of any temporary water permit applications | Sections 6, 7 and 10 |
| 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, 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. | Section 6.4.2 |
| 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 |
| 11.60 | Identify and quantify likely activities involving the excavation or placement of fill that will be undertaken in any watercourse, lake or spring. | Section 11.1 |
| 11.62 | Describe measures to minimise impacts on ground water resources. | Section 12 |
| 11.63 | Provide a policy outline of compensation, mitigation and management measures where impacts are identified. | Section 12 |

2 Legislation, policy, standards, and guidelines

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

2.1 Legislation

2.1.1 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act) is the Australian Government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important environmental assets, defined in the EPBC Act as Matters of National Environmental Significance (MNES).

The Project was referred to the Commonwealth Minister for the Environment in May 2017 and was subsequently deemed to be a 'controlled action' due to potentially significant impacts on listed threatened species and communities (Sections 18 and 18A of the EPBC Act). Controlled actions require assessment and approval under the EPBC Act. As such the EIS includes an assessment of the Projects impacts on MNES as per the EPBC Act.

As the project is not a coal seam gas development or large coal mine, groundwater is not required to be assessed under this Act.

2.1.2 Environmental Protection Act 1994

The *Environmental Protection Act 1994* (Qld) (EP Act) aims 'to protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends' (EP Act, Part 2). Under the EP Act, environmental protection policies are developed to cover specific aspects of the environment.

The EP Act is administered by the Queensland government's Department of Environment and Science (DES) and provides a wide range of tools for the protection of the environment including environmental protection policies and environmental authorities.

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

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

Further information regarding EVs is presented in Section 2.2.

2.1.3 Water Act 2000

The *Water Act 2000* (Qld) (Water Act) provides a framework to deliver sustainable water planning, allocation management and supply processes to provide for the improved security of water resources in Queensland.

The Water Act provides a framework for the following:

- Sustainable management of Queensland'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 south-east Qld 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, and 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.

2.1.4 Water Regulation 2016

The Water Regulation 2016 (Qld) is subordinate legislation made under the Water Act and prescribes administrative and operational matters for the Act. Such matters governed by the Water Regulation 2016 with relevance to the 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) 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 that isn't managed through a water plan.

2.2 Policies and plans

2.2.1 Environmental Protection (Water and Wetland Biodiversity) Policy 2019

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

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

EVs relevant to the Project are presented in detail in Section 7.

2.2.2 Water Plans

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

The purposes of the Water Plans are to:

- Define the availability of water in the plan area
- 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.

If groundwater is to be used as a construction water source, a permit to secure an entitlement would be required. This can be either as a new entitlement (where allocation is available) or buying/sharing from existing entitlements. Temporary water permits may provide a suitable water supply option for the construction phase of the Project. Water permits can be issued for temporary projects that have a foreseeable conclusion date and are anticipated to have short term impacts on the resource – typically granted up to a maximum timeframe of two years and cannot be renewed, transferred or amended.

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

The groundwater study area is wholly within the Water Plan (GABORA) 2017 area. The Water Plan (GABORA) 2017 is divided into a number of groundwater units (based hydrogeological formations and geography); groundwater units of relevance to the project are the Hutton, Precipice, and Springbok Walloon groundwater units.

The groundwater units are further divided into geological formations. The relevant groundwater units and geological formations of relevance to the Project are:

- Hutton groundwater unit
 - Southern Clarence Moreton Marburg groundwater sub-area:
 - Gatton Sandstone
 - Koukandowie Formation
- Springbok Walloon groundwater unit
 - Southern Clarence Moreton Walloon groundwater sub-area:
 - Walloon Coal Measures.

The plan suggests the groundwater study area is part of the Precipice groundwater unit (Woogaroo Subgroup) however the groundwater study area is not expected to encounter the Woogaroo Subgroup based on the Project design therefore this unit has been excluded from the assessment. However, in the instance construction water supply options are investigated from the Woogaroo Subgroup, this plan governs the management of this aquifer.

2.2.2.2 Water Plan (Moreton) 2007

This Water Plan (Moreton) 2007 is applicable to groundwater other than those included in the Water Plan (GABORA) 2017 listed above. The plan is divided into four groundwater management areas (GMAs) based on geography, with the Project located within only the Warrill - Bremer Alluvial GMA. This GMA is applicable to alluvial sediments within the Bremer River sub-catchment to ensure management of groundwater from the alluvial sediments.

The plan provides a framework for water entitlements/allocations to be managed. It includes a process for granting or amending interim resource operation licenses, and interim water allocations for the construction of infrastructure to which the interim resource operation licences are related.

The alluvial aquifers of the groundwater study area and consideration if construction water supply options require investigation from these units are governed under this plan.

2.2.2.3 Water Plan (Logan Basin) 2007

The eastern portion of the Project is located within the plan area, specifically, within the Teviot Brook sub-catchment of the plan. Groundwater managed under this plan includes “water in springs not connected to water which the Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017 applies”.

There are no mapped springs within the groundwater study area (refer Section 14.5.7), therefore this plan is not considered relevant to the Project.

2.3 Guidelines

2.3.1 Australia and New Zealand Guidelines for Fresh and Marine Water Quality

The objective of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) is to provide authoritative guidance on the management of water quality in Australia and New Zealand. The guidelines include setting water quality and sediment quality objectives designed to sustain current, or likely future, community values for natural and semi-natural water resources.

The Water Quality Guidelines provide:

- A platform for consistent water quality management and planning
- Technical support for Australia’s National Water Quality Management Strategy and New Zealand’s National Policy Statement for Freshwater Management
- Sound tools for governments and the community to assess and manage ambient water and sediment quality.

The ANZG (2018) has been used to assess groundwater quality in the groundwater study area.

2.3.2 Australian Drinking Water Guidelines

The National Health and Medical Research Council (NHMRC) and National Resource Management Ministerial Council (NRMMC) Australian Drinking Water Guidelines (ADWG) (2018) provide guidance to water regulators and suppliers on monitoring and managing drinking water quality. The ADWG provides details on the framework for Management of Drinking Water Quality, which is a preventive management approach that encompasses all steps in water production from catchment to consumer, and aims to assure safe, good quality drinking water. The ADWG is used by State and territory health departments, local health authorities and water utilities.

The ADWG (NHMRC and NRMMC 2018) were used to assess groundwater quality in the groundwater study area.

2.3.3 Application requirements for activities with impacts to water guideline

This guideline is applicable to the following Environmentally Relevant Activities (ERAs):

- Controlled/planned releases to water
- Uncontrolled/unplanned releases to water
- Changes to the quantity and quality of stormwater runoff from the site of the ERA
- Indirect impacts
 - Disturbance to the bed or banks of waters
 - Turbidity due to disturbance or clearing of riparian vegetation during construction
 - Changes to groundwater formation characteristics
 - Changes to groundwater ecology (and surface water ecology).

Based on the proposed works associated with the Project, this guideline is not considered relevant to groundwater in the groundwater study area.

2.3.4 Terms of Reference EIS Information Guideline - Water 2016

The DES have developed an informational guideline to assist in the development and assessment of water resources for EISs. This guideline was incorporated into the methodology, approach, and data sources for the groundwater impact assessment. The guideline is complimentary to the Project-defined ToR, established in December 2017 by the Coordinator-General.

2.3.5 Queensland Water Quality Guidelines 2009

The Queensland Water Quality Guidelines by DES provide the approach to determine guideline values for physical and chemical stressors. The guidelines indicate the ANZG (2018) includes default guidelines values however local water quality information is the first reference point and the water quality guideline values for physical and chemical stressors follows the hierarchy defined below:

1. EPP (Water and Wetland Biodiversity) scheduled EVs and WQOs
2. End of catchment anthropogenic pollutant reduction targets in Great Barrier Reef catchments
3. Queensland water quality guidelines (in the absence of EPP (Water and Wetland Biodiversity) scheduled EVs and WQOs
4. Water monitoring protocols contained in the Queensland Monitoring and Sampling Manual (2018).

This assessment includes EVs and WQOs provided in the EPP (Water and Wetland Biodiversity), which is the priority source for water quality guideline values as they are developed based on local water quality.

3 Methodology

3.1 Groundwater study area

In this groundwater report, the groundwater study area is defined as the area within 1 km of the centre line of the alignment. The groundwater study areas are illustrated on Figure 1.

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

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 steps were undertaken to prepare these assessments:

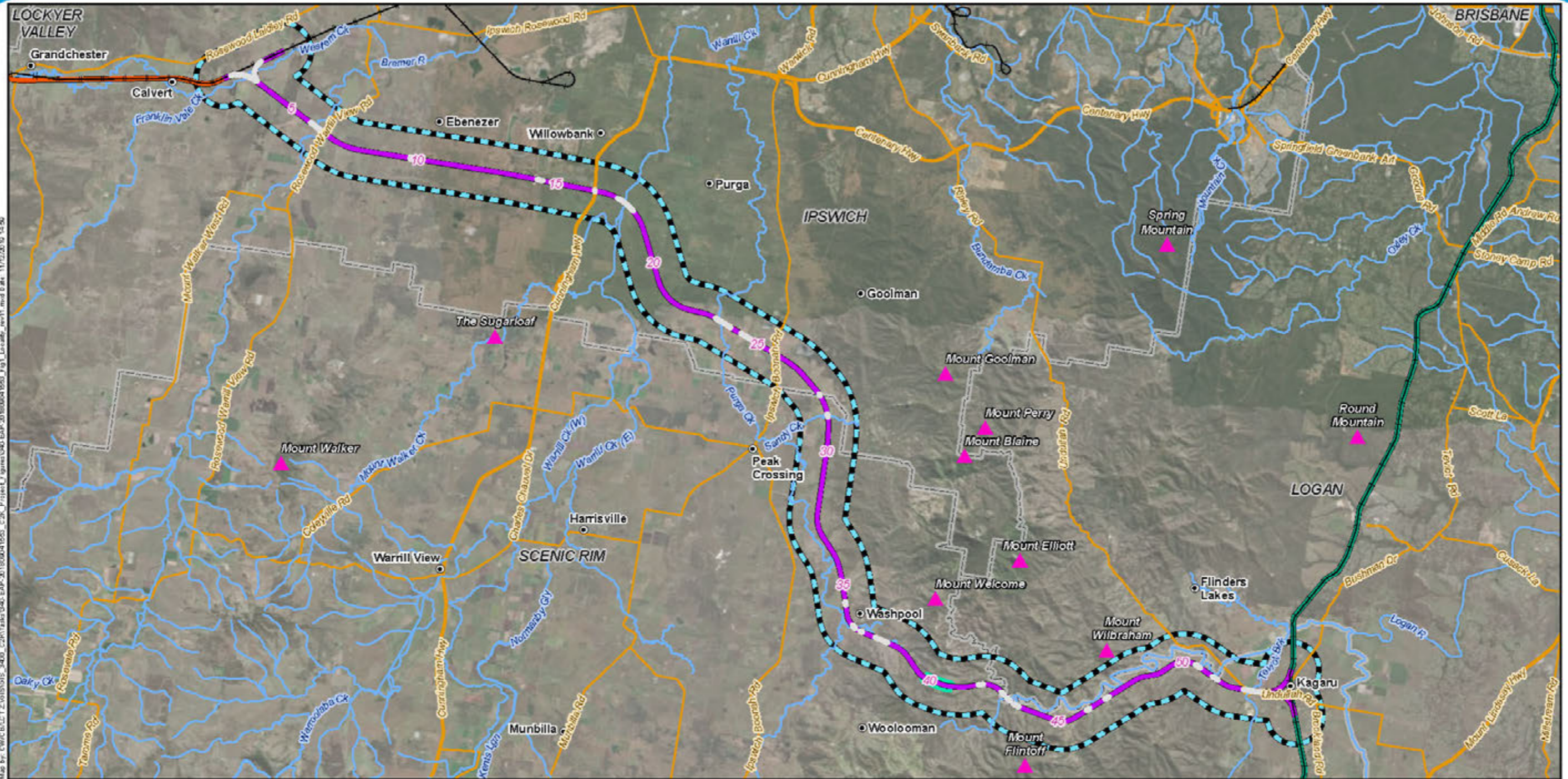
- Stage 1 – Desktop study
- Stage 2 – Geotechnical and hydrogeological investigations
- Stage 3 – Groundwater impact assessment
- Stage 4 – Significance assessment
- Stage 5 – Reporting.

Each of these 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 EVs. Interrogation of publicly available databases, inclusive of registered groundwater bores and use, was undertaken and a review of relevant studies and reports was performed.

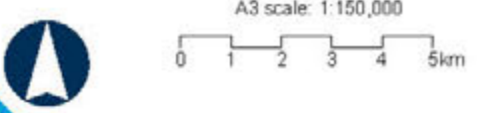
The primary data sources utilised in the preparation of this report are presented in Table 3.1.



Map by: C:\WC\BCT\Z\VISIONS\3400_C2K\Tasks\040_EAP_30\1500041553_C2K_P\Project\Ipswich\040_EAP_30\1500041553_Fig_1_Locality_v011.mxd Date: 11/12/2019 14:26

Legend

- Localities
- 5 Chainage (km)
- ▲ Mountain
- Bridges
- Existing rail
- H2C project alignment
- C2K project alignment
- K2ARB project alignment
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- Local Government Areas
- Tunnel



Calvert to Kagaru
Figure 1: Project location

Table 3.1 Data sources

| Data | Source |
|---|---|
| Hydrology/climate | Historical Climate Database - Bureau of Meteorology (BoM) (www.bom.gov.au/climate/data/) Inland Rail Section 340 – Calvert to Kagaru Preliminary Hydrogeological Interpretive Report Feasibility Design Stage (Golder 2019) (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) Geotechnical Factual Report. Inland Rail Project – Calvert to Kagaru Section – Phase 2 Section 340 (Golder 2018) Queensland Globe datasets (https://QLDglobe.information.QLD.gov.au/) |
| Soil types | Inland Rail Section 340 – Calvert to Kagaru Preliminary Hydrogeological Interpretive Report Feasibility Design Stage (Golder 2019) (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) |
| Geology/hydrostratigraphy | Inland Rail Section 340 – Calvert to Kagaru Preliminary Hydrogeological Interpretive Report Feasibility Design Stage (Golder 2019) (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) Department of Natural Resources, Mines and Energy (DNRME) groundwater database (accessed 14 January 2019) Geotechnical Factual Report. Inland Rail Project – Calvert to Kagaru Section – Phase 2 Section 340 (Golder 2018) Queensland Globe datasets (https://QLDglobe.information.QLD.gov.au/) |
| Groundwater levels and quality | DNRME groundwater database (accessed 14 January 2019) Inland Rail Section 340 – Calvert to Kagaru Preliminary Hydrogeological Interpretive Report Feasibility Design Stage (Golder 2019) (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) Clarence-Moreton Bioregional Assessment (May 2014) Geotechnical Factual Report. Inland Rail Project – Calvert to Kagaru Section – Phase 2 Section 340 (Golder 2018) Queensland Globe datasets (https://QLDglobe.information.QLD.gov.au/) |
| Groundwater Dependent Ecosystems (GDEs) | BoM: Groundwater Dependent Ecosystem Atlas: www.bom.gov.au/water/groundwater/gde/map.shtml Clarence-Moreton Bioregional Assessment (May 2014) Queensland Globe datasets (https://QLDglobe.information.QLD.gov.au/) |
| Groundwater use and management | DNRME groundwater database (accessed 14 January 2019) QLD water entitlements database (DNRME) (accessed 12 August 2019) Clarence – Moreton Bioregional Assessment (May 2014) Water Plan (GABORA) 2017 Water Plan (Logan Basin) 2007 Water Plan (Moreton) 2007 Geotechnical Factual Report. Inland Rail Project – Calvert to Kagaru Section – Phase 2 Section 340 (Golder 2018) |

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 April and December 2018. Investigation findings to date are provided in the Geotechnical Factual Report. Inland Rail Project – Calvert to Kagaru Section – Phase 2 Section 340 (Golder 2018), and Inland Rail Section 340 – Calvert to Kagaru Preliminary Hydrogeological Interpretive Report – Feasibility Design Stage (Golder 2019) (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive 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.

These investigations are described further below. Findings from these investigations were used to complement the desktop geological and hydrogeological reviews presented in Section 4 and Section 5.

3.2.2.1 Groundwater monitoring bore installation

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

Groundwater monitoring bores are equipped with 50 mm diameter class 18 PVC screw jointed pipes with 0.4 mm slotted screens and blank casing. A borehole diameter of 96 mm was drilled for the installation of the standpipe piezometers, except 340-01-BH2101 which was drilled at 120 mm diameter. 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 cover was installed.

Eight of the completed groundwater monitoring bores were flushed after installation to remove drilling fluids, and subsequently developed using manual bailing and/or pumping techniques, as appropriate. Bore 340-1-BH2226 was not developed due to access issues.

3.2.2.2 Groundwater level monitoring

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

3.2.2.3 Aquifer testing

In situ hydraulic testing using the slug test method was conducted in eight of the standpipe piezometers completed as monitoring bores. Bore 340-1-BH2226 was not tested due to access issues. 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.

3.2.2.4 Groundwater sampling and laboratory analysis

One round of groundwater sampling was conducted at eight of the completed monitoring bores for collection of baseline water quality, durability, and salinity parameters. A total of nine samples were collected, with two samples collected at two depths from 340-1-BH2333. Bore 340-1-BH2226 was not sampled due to access issues.

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 potential, 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 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 NATA¹-accredited laboratory for analysis.

The analysed chemical parameters for each sample were as follows:

- Major anions and cations (calcium, magnesium, sodium, potassium, chloride, fluoride, sulphate, carbonate and bicarbonate alkalinity, hardness)
- pH, EC and total dissolved solids (TDS)
- Total and dissolved metals (arsenic, boron, barium, beryllium, cadmium, chromium, cobalt, copper, manganese, iron, nickel, lead, selenium, vanadium, zinc, mercury)
- 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- and long-term impacts on the existing groundwater regime, at local and regional scales, were assessed based on review of construction and rail operations with respect to the current geological and hydrogeological setting.

Geotechnical predictive modelling has been used to inform the assessment of potential impacts on groundwater resources as a result of the construction and operation of the Teviot Range Tunnel. Preliminary analysis of potential groundwater inflows to cuts along the alignment has been carried out and reported as part of the preliminary hydrogeological interpretative assessment. These assessments are reported in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report.

3.2.4 Stage 4 – Significance assessment

A qualitative significance assessment was undertaken of the identified potential short- and long-term groundwater impacts (as described Section 3.3). The sensitivity of the EV and the magnitude of the impacts are the key elements considered to determine significance. The sensitivity of the EV and the magnitude of the impacts were assessed via a significance matrix which defines appropriate significance classifications. These classifications are detailed in Section 3.3.

The predictive modelling undertaken as a component of the geotechnical works has allowed for the assessment of potential impacts on groundwater resources based upon sensitivity and magnitude criteria. The hierarchy of avoid, minimise and mitigate then monitor has been applied in the significance assessment. Evaluation of significance classifications, with initial and proposed mitigation, was then performed, the results of which provide input into a Groundwater Monitoring and Management Program (GMMP).

3.2.5 Stage 5 – Reporting

This 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. The report, including the consideration of cumulative impacts, was utilised to compile the groundwater chapter within the main body of the EIS report.

¹ NATA – National Association of Testing Authorities

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 the purpose of 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. Determination of the sensitivity/vulnerability of the groundwater EVs and the magnitude of the potential impact facilitate the assessment of the significance of potential groundwater impacts. 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. For the purposes of the groundwater assessment, impact magnitude is defined as 'being comprised of the nature and extent of the potential impacts, including direct and indirect impacts.

The impact magnitude is divided into four categories, as included in Table 3.2. The magnitude of a potential impact is determined with techniques and tools that facilitate an estimation of the extent, duration, and frequency of the potential impacts. Table 3.3 presents the timeframes for impact duration terms utilised to inform the assessment of 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; 6 to 12 months) |
| Short term | Up to 2 years (i.e. 12 to 24 months) |
| Medium term | From 2 to 11 years ¹ |
| Long term/long lasting | From 11 to 21 years ² |
| Permanent or irreversible | More than 21 years ³ |

Table notes:

- 1 Derived from the term 'moderate' EAM Risk Management Framework 2009 (GBRMPA 2009)
- 2 Derived from the term 'major' EAM Risk Management Framework 2009 (GBRMPA 2009)
- 3 Derived from the term 'catastrophic' EAM Risk Management Framework 2009 (GBRMPA 2009)

3.3.2 Sensitivity

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

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

Table 3.4 Sensitivity criteria

| Sensitivity | Description |
|-------------|---|
| Major | <ul style="list-style-type: none"> ■ The EV is listed on a recognised or statutory State, national or international register as being of conservation significance ■ The EV is entirely intact and wholly retains its intrinsic value ■ 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 ■ 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 | <ul style="list-style-type: none"> ■ The EV is listed on a recognised or statutory State, national or international register as being of conservation significance ■ The EV is intact and retains its intrinsic value ■ 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 ■ 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 | <ul style="list-style-type: none"> ■ The EV is recorded as being important at a regional level, and may have been nominated for listing on recognised or statutory registers ■ 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 ■ It is relatively well represented in the systems/areas in which it occurs but its abundance and distribution are exposed to threatening processes ■ Threatening processes have reduced its resilience to change. Consequently, changes resulting from Project activities may lead to degradation of the prescribed value ■ Replacement of unavoidable losses is possible due to its abundance and distribution. |
| Low | <ul style="list-style-type: none"> ■ 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 ■ The EV is in a poor to moderate condition as a result of threatening processes, which have degraded its intrinsic value ■ It is not unique or rare and numerous representative examples exist throughout the system/area ■ It is abundant and widely distributed throughout the host systems/areas ■ There is no detectable response to change or change does not result in further degradation of the EV ■ The abundance and wide distribution of the EV ensures replacement of unavoidable losses is achievable. |
| Negligible | <ul style="list-style-type: none"> ■ The EV is not listed on any recognised or statutory register and is not recognised locally by relevant suitably qualified experts or organisations ■ It is not unique or rare and numerous representative examples exist throughout the system/area ■ 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, its sensitivity of the EVs, and the magnitude of the potential impact. Although the sensitivity of the EVs 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 quantitatively to facilitate the prediction of the significance of the potential impact.

Once the EVs 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. The resultant significance classifications are summarised in Table 3.6.

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 impact to identify the residual 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).

3.3.4 Cumulative impact assessment

A 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.

Section 13.3 details the CIA undertaken for groundwater; a summary of the methodology is presented below. For a full assessment of cumulative impacts refer to EIS Chapter 22: Cumulative Impacts.

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

- Are currently being assessed under Part 1 of the Chapter 3 of the EP Act and, as a minimum, have an initial advice statement available on the DES website
- Have been declared a 'coordinated project' by the Coordinator-General under the *State Development and Public Works Organisation Act 1971* (Qld) and an EIS is currently being prepared or is complete, or an initial advice statement is available on the Queensland Department of State Development, Manufacturing, Infrastructure and Planning website
- May use resources located within the region (including materials, groundwater, road networks or workforces) that are the same as those to be used by the Project
- Could potentially compound residual impacts that the Project may have on environmental or social values.

Projects excluded from the CIA include:

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

The CIA process applied for groundwater included:

- A review of the potential impacts identified within the impact assessment (the existing environment at the time of the ToR is the baseline, prior impacts from past land use have not be considered)
- A register of assessable projects has been collated with timelines to demonstrate the temporal relationship between projects, inclusive of:
 - Identification of projects outside of the Inland Rail Program
 - Only 'State significant' or 'strategic' projects that are in the public domain as being planned, constructed or operated at the time of the ToR have been considered
 - Where additional projects worthy of consideration have arisen after the finalisation of the ToR, the Coordinator-General has been consulted to determine if assessment is required
 - The Inland Rail projects immediately adjacent to the Project within the assessment:
 - Helidon to Calvert Project (H2C)
 - Kagaru to Acacia Ridge and Bromelton Project (K2ARB)
- 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 Existing environment

4.1 Location

The Project is located within the Ipswich City Council, Logan City Council, and Scenic Rim Regional Council local government areas in south-east Qld. The Project is the second most-northern package of the Inland Rail Program. The location of the Project and its regional context are presented on Figure 1.

The Project will generally be located within the existing SFRC, protected in November 2010 as future railway land under Section 242(1) of the *Transport Infrastructure Act 1994* (Qld). The Project connects the adjacent Inland Rail projects of H2C in the northwest and K2ARB to the south-east.

For the purposes of this groundwater study, the groundwater study area is considered to occur across, and be defined by, three broad areas: west of the Teviot Range (approximately Chainage (Ch) 00 km to Ch 38 km), the Teviot Range (Ch 38 km to Ch 51 km), and east of the Teviot Range (Ch 51 km to Ch 53 km), as depicted on Figure 1.

4.2 Land use

Land use in the Calvert area (western portion of the groundwater study area) is typically of a rural nature and most properties within the groundwater study area consists of large-lot grazing areas. Ebenezer (east of Calvert) is characterised by predominantly rural and rural-residential land uses, with a considerable amount of remnant vegetation. The former Ebenezer coal mine is in proximity to this section of the Project. An existing high voltage transmission line and the decommissioned Moonie-Brisbane high pressure oil pipeline also cross the Project. The Project traverses the Ebenezer and Park Ridge Industrial Development Areas.

The area south of Purga, towards Peak Crossing, contains a mixture of land uses inclusive of rural-residential properties and agricultural estates, poultry farms, Purga Quarry, Yackatoon Grazing Co feedlot, Ivory's Rock Conventions and Events, and the township of Peak Crossing. Washpool is characterised predominantly by vegetated mountainous areas in the east and rural land uses in the west. The Purga Nature Reserve is also located in this region.

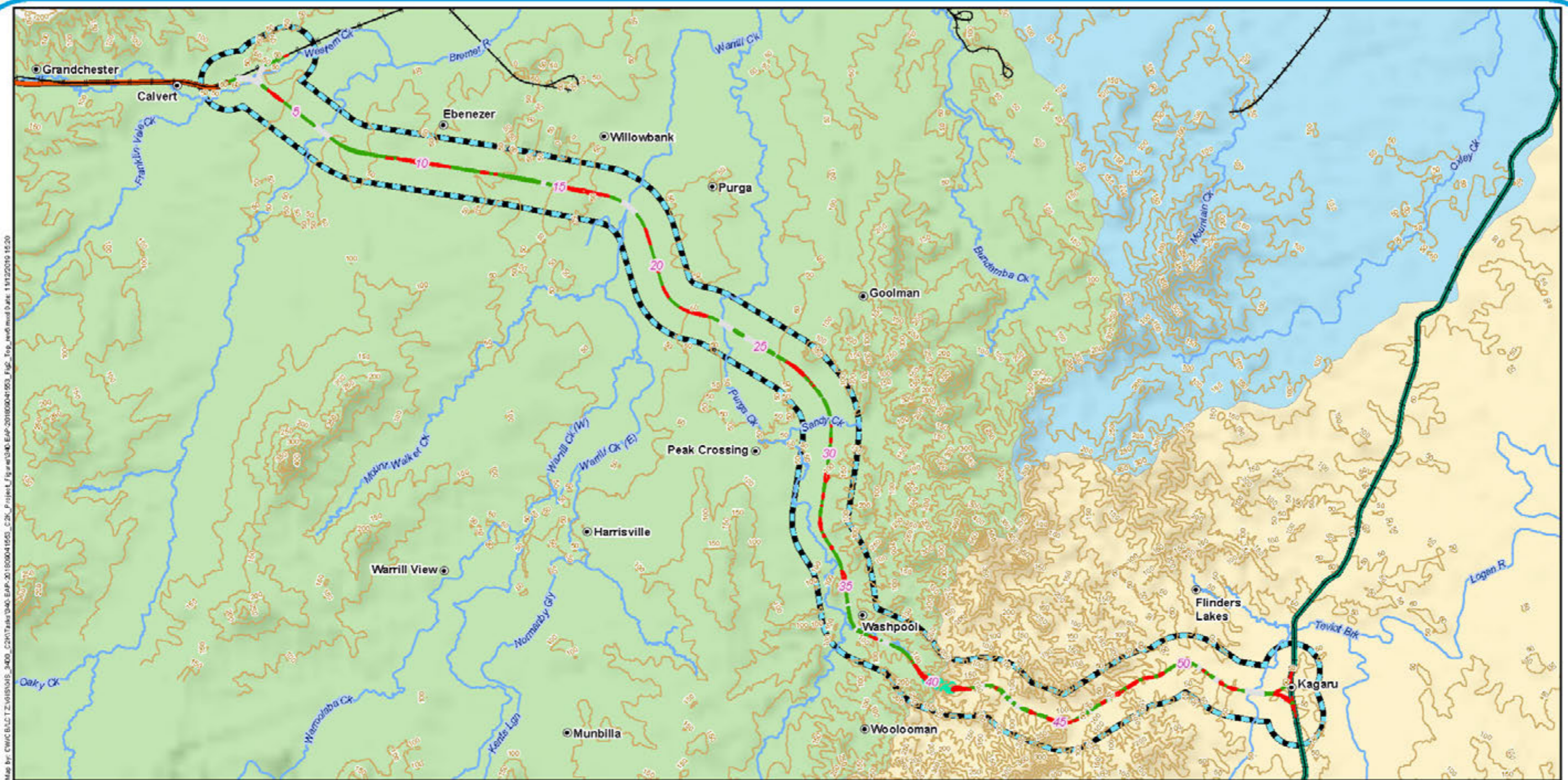
Throughout the Woolooman area (eastern portion of the groundwater study area) and the Teviot Range (Flinders Peak Conversation Park), terrain is of a rugged nature and there is minimal development. Wyaralong Dam is located to the south. Kagaru, the eastern boundary of the groundwater study area, is predominantly rural; the groundwater study area adjoins the southern boundary and intersects a small portion of the Greater Flagstone Priority Development Area. The groundwater study area also intersects the Bromelton State Development Area when joining the existing Interstate rail line at Kagaru.

The intended land use for the Project is rail and associated infrastructure, to include road realignments, grade separations, and ancillary infrastructure, including a new Energex powerline to power the tunnel.

4.3 Topography and drainage

Topography in the groundwater study area ranges from approximately 30 m Australian Height Datum (mAHD) at several drainage lines/surface water features to greater than 200 mAHD in the Teviot Range (refer Figure 2), where most slopes have a grade of less than 30 per cent along the proposed rail alignment.

The groundwater study area broadly consists of three distinct topographical areas: the western lowlands, the central ranges (Teviot Range), and the Beaudesert Basin.



Map by: CIVIC B/LT Z/VISS/015 3400_C2K1/Texas/D40 EAP_30/15004/1543_C2K1/Project/L/figure/3400 EAP_2018/04/15/30_Fig_top_wellhead/0.dwg: 1:1/2019 15:20

Legend

- | | | |
|-----------------|---------------------------|---------------------|
| ● Localities | — H2C project alignment | Subcatchment |
| 5 Chainage (km) | — K2ARB project alignment | ■ Bremer River |
| — Bridges | ■ Tunnel | ■ Brisbane River |
| — Cut | — Watercourses | ■ Logan River |
| — Fill | — Contour 50m | |
| — Existing rail | ■ Groundwater study area | |



A3 scale: 1:150,000
 0 1 2 3 4 5 km

The landscape reflects the underlying geology with a central anticline, forming rugged sandstone hills, and flanking synclines containing coal, sedimentary, and igneous rocks that form gently undulating lowlands. The lowlands are traversed by numerous ephemeral and perennial watercourses that have given rise to several wide floodplains. The geology of the groundwater study area is discussed in Section 5.

The alignment traverses two catchment areas: the Bremer River catchment, between Calvert and east of Woolooman as the alignment reaches the peak of the Scenic Rim mountain range, and the Logan River catchment area, as the alignment descends the mountain range towards Kagaru (DES 2018), as can be observed in Figure 2.

The Bremer River catchment is situated west of Brisbane within the local government boundaries of Ipswich City Council and the Scenic Rim Regional Council and expands to an area of approximately 2,030 km² with the main Bremer River channel surrounded by smaller sub-catchments. The Project alignment predominantly traverses through the Mid Bremer River, Lower Bremer River, Lower Warrill Creek, Western Creek and Purga Creek. Rainfall in the catchment is high along its steeper sections which are situated to the south and east. The remainder of the catchment experiences average rainfall of under 1,000 mm/yr (SEQC 2006).

Warrill Creek is supplemented by Moogerah Dam, which is a large reservoir on Reynolds Creek in the upper Warrill Creek catchment. It has a catchment area of 226 km² (25 per cent of the catchment area to Amberley). The dam has an uncontrolled spillway into Warrill Creek, which can result in recharge of the Warrill Creek Alluvium during significant rainfall events.

The Logan River catchment is situated to the south of Brisbane with its headwater in the McPherson and Main Ranges. The catchment area expands over 3,000 km² with an approximate 5,500 km of stream network. The Project alignment intercepts the sub-catchment area of the Lower Teviot Brook. Rainfall in the catchment is very high especially in the eastern headwaters which combined with good recharge of groundwater associated with basalt geology lead to permanent flow (SEQC 2017).

A review of the watercourse identification map was undertaken to identify watercourses that intercept the Project alignment. The following defined watercourses intercept the Project alignment at the chainage listed:

- Western Creek – at chainage locations Ch 3.1 km and Ch 1.2 km
- Bremer River – at chainage location Ch 6.3 km
- Warrill Creek – at chainage location Ch 17.6 km
- Purga Creek – at chainage locations Ch 23.4 km and Ch 32.1 km (access road intercept)
- Sandy Creek – at chainage location Ch 28.7 km
- Upper tributary (unnamed) of Purga Creek – at chainage locations Ch 36.6 km, Ch 37.5 km, and Ch 37.9 km
- Teviot Brook – at chainage location Ch 52.8 km.

Watercourse locations are depicted on Figure 2.

There are a number of artificial/constructed waterbodies located within the water quality study area with some of these waterbodies intersected by the proposed alignment. These artificial/constructed waterbodies are predominantly rural farm dams used by stock. The artificial/constructed waterbodies that are intersected by the Project alignment are provided in Table 4.1.

Table 4.1 Constructed (artificial) waterbodies which intersect the Project alignment

| Artificial waterbody (approximate chainage (km)) | Associated waterway |
|---|---|
| Ch 2.90, 4.60, 6.10, 6.60, 8.60, 9.00, 9.70, 10.20, 10.30, 10.80 | Unmapped waterway of Bremer River |
| Ch 11.70, 12.20, 13.40, 14.40, 16.10, 16.40, 17.50 | Unmapped waterway of Warrill Creek |
| Ch 20.70, 21.00, 21.50, 21.80, 22.40, 24.90 | Unmapped waterway of Purga Creek |
| Ch 26.60 | Unmapped waterway of tributary of Purga Creek |
| Ch 28.20, 28.80, 29.20, 30.40, | Unmapped waterway of tributary of Purga Creek |
| Ch 31.80, 32.20, 33.80, 34.00, 35.10, 35.20, 36.40, 37.00, 37.80, 39.00 | Unmapped waterway of Purga Creek |
| Ch 45.20, 45.60, 45.70 | Unmapped waterway of Teviot Brook |
| Ch 49.60, 50.20, 50.90 | Unmapped waterway of Teviot Brook |
| Ch 51.30, 53.90 ^a , 53.90 ^b , 54.00 | Unmapped waterway of Teviot Brook |

Table note:

a, b Denotes discrete waterbodies located at the same relative chainage

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 Amberley Aeronautical Meteorological Office (AMO) BoM weather station (040004) is the nearest monitoring station with long-term statistical climate data (1941 to 2018), located approximately 38 km north-west of Kagaru. A summary of climate data is provided in Table 4.2.

Table 4.2 Climate summary for Amberley AMO for the period 1941 to 2018 (Station 040004)

| Month | Mean maximum temperature (°C) | Mean minimum temperature (°C) | Mean monthly rainfall (mm) |
|---------------------|-------------------------------|-------------------------------|----------------------------|
| January | 31.2 | 19.6 | 116.9 |
| February | 30.4 | 19.5 | 121.2 |
| March | 29.4 | 17.8 | 85.5 |
| April | 27.2 | 14.0 | 54.5 |
| May | 24.1 | 10.0 | 52.8 |
| June | 21.6 | 7.1 | 46.9 |
| July | 21.3 | 5.4 | 37.6 |
| August | 22.8 | 6.2 | 28.6 |
| September | 25.6 | 9.5 | 33.3 |
| October | 27.8 | 13.3 | 73.3 |
| November | 29.6 | 16.3 | 81.5 |
| December | 30.8 | 18.4 | 119.4 |
| Annual total | 26.8 | 13.1 | 864.0 |

The University of Queensland Gatton BoM weather station (040082) is approximately 78 km north-west of Kagaru, and has daily evaporation data from 1968 to 2002, and daily rainfall data from 1897 to present. Mean daily evaporation data ranges from 3 mm/day in June to 7.8 mm/day in January (1968 to 2002). Average monthly evaporation (estimated from mean daily values) is compared to mean monthly rainfall data in Figure 3 and shows that evaporation exceeds rainfall for each month of the year.

An overall negative climate budget generally prevails in the region, which means annual evaporation is greater than rainfall. A mean annual rainfall of 772 mm per year compares to a mean annual evaporation of 1,753 mm at University of Queensland Gatton BoM weather station (040082).

4.4.2 Cumulative Rainfall Departure

The cumulative rainfall departure (CRD) method (Weber and Stewart 2014) 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 are expected to reflect trends (including muted trends) in the CRD. This is particularly helpful to understand the impacts of seasonal rainfall on shallow and subcrop aquifers.

The CRD graph for the groundwater study area is presented in Figure 4 for the period 1941 to 2018, from the Amberley AMO (Station 040004). The CRD graph indicates:

- Drought condition from 1995 to 2006 is apparent in the consecutive years of below average rainfall
- At the break of drought, a period of generally above average rainfall was experienced between 2008 and 2011
- Since 2011, rainfall has been relatively stable compared to long term averages, with the exception a brief period of lower rainfall between 2013 to 2015.

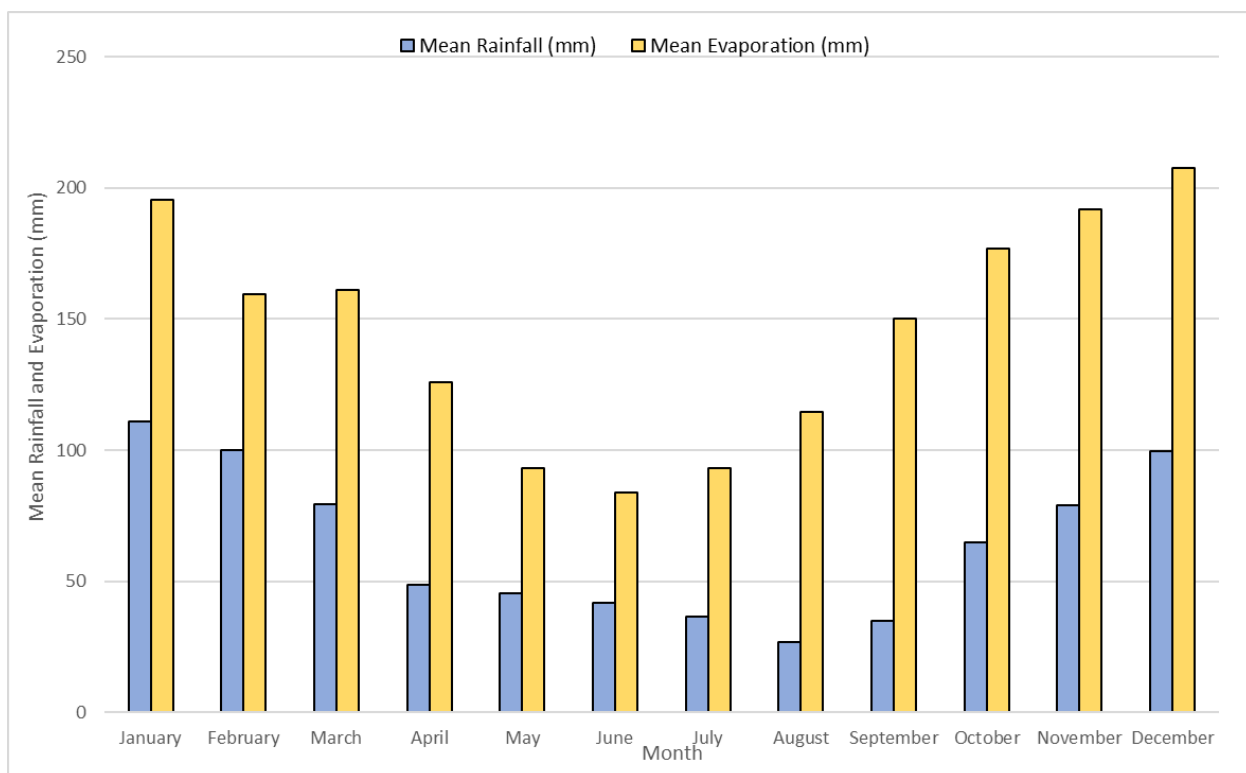


Figure 3 Mean monthly evaporation and rainfall at University of Queensland Gatton Bureau of Meteorology station (040082)

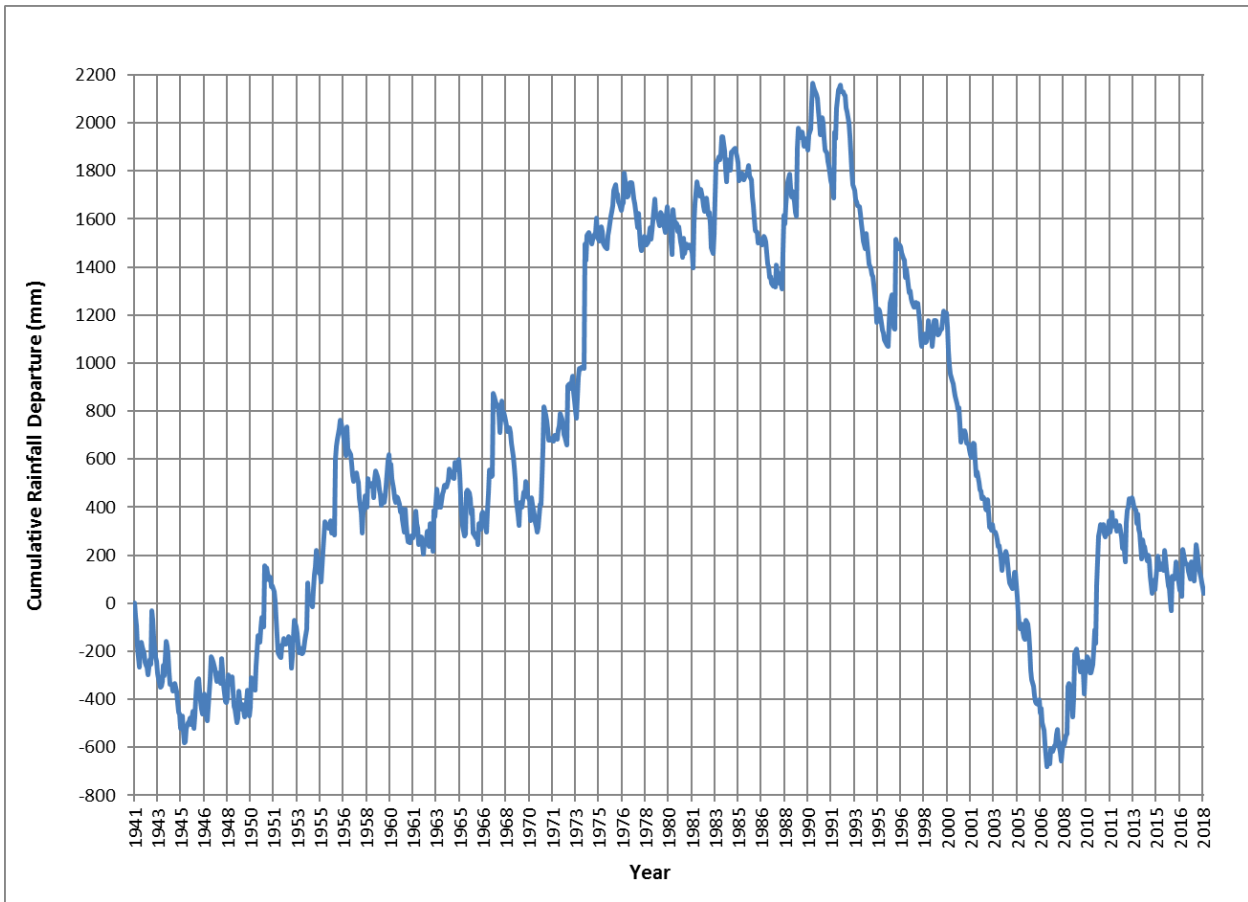


Figure 4 Cumulative Rainfall Departure plot for Amberley AMO Bureau of Meteorology station (040004)

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 overlies the mid-to-late Palaeozoic rocks of the New England Orogen. The Clarence – Moreton Basin is located within northern New South Wales and south-east Qld and is an eastern extension of the Late Triassic to Cretaceous Surat-Euromanga super-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 period, some 300 million years ago. Strike-slip movement occurred along several major faults which are inferred to controlling the magnitude of extension during evolution of the basin. As a result, the basin comprises three sub-basins: Cecil Plains sub-basin, Laidley sub-basin, and Logan sub-basin.

Structural features with a major influence on the development of depositional centres include:

- West Ipswich Fault: forms part of the Great Moreton Fault System and forms the eastern limit of the Laidley sub-basin
- Gatton Arch: a broad basement ridge, over which sedimentary rocks of the Clarence-Moreton Basin are folded over and become relatively thin; the Gatton arch separates 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 the West Ipswich Fault and to the east by the East Richmond Fault.

Figure 5 depicts the location of the Clarence - Moreton Basin and key structural features.

The Clarence - Moreton Basin covers approximately 43,000 km² and comprises Middle and Late Triassic to Early Cretaceous-aged sedimentary sequences with a combined thickness of 3,500 to 4,000 m (Rassam et al. 2014). Paleogene and Neogene age cover are present across some parts of the 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 in Table 5.1, with units relevant to the groundwater study area highlighted.

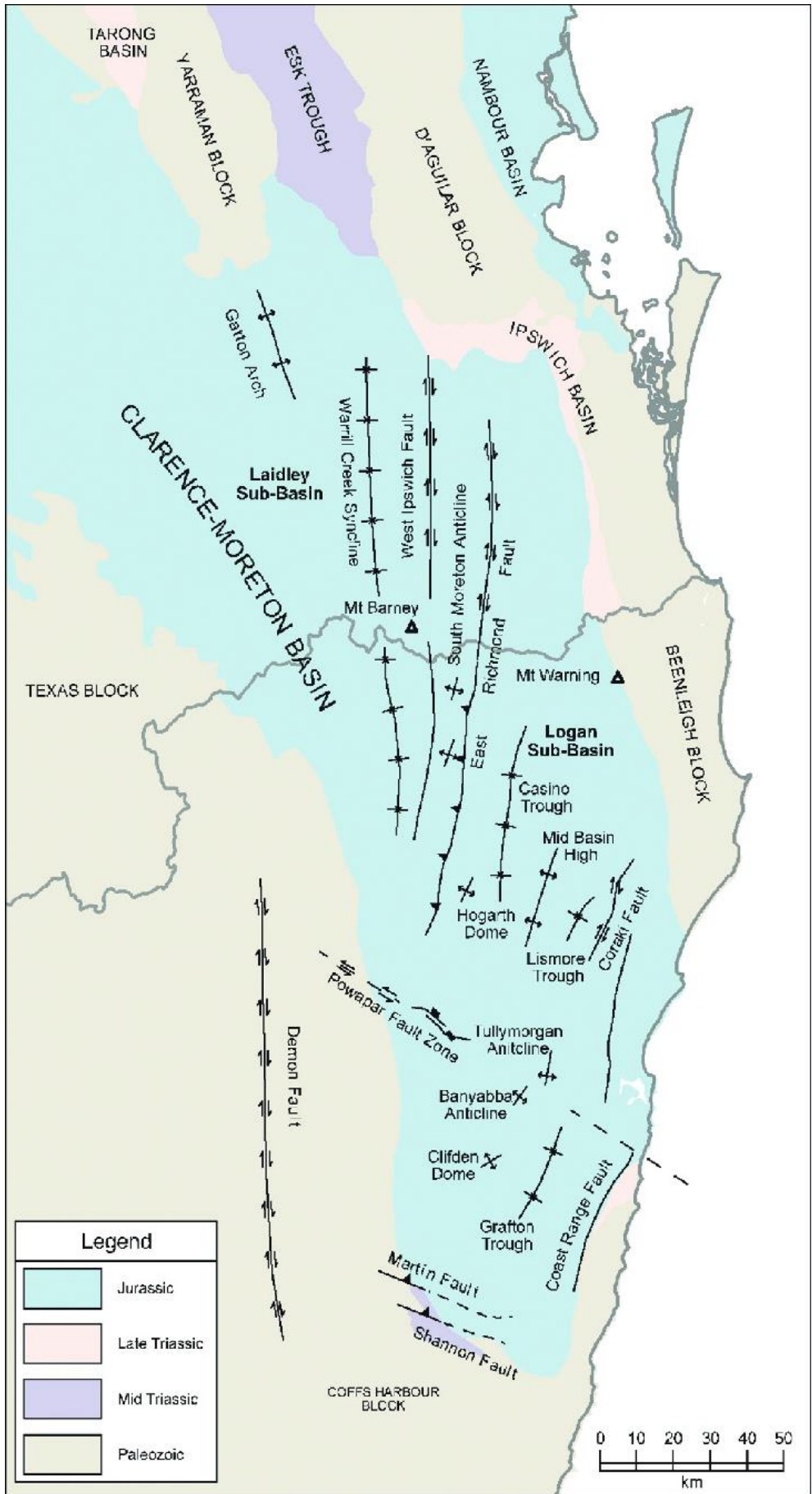


Figure 5 Clarence-Moreton Basin and key structural features

Source: Doig, A & Stanmore, Peter 2012

Table 5.1 Clarence-Moreton Basin stratigraphy

| Age | | Major stratigraphic unit | Stratigraphic subdivision | Depositional environment | Generalised hydraulic characteristics ² |
|------------------------------|------------------------|---|--|--|--|
| 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 ¹ | | Aquicludes? |
| | | | Piora Member ¹ | | Aquifer/Aquitard ¹ |
| | Late Jurassic | Orara Formaton ¹ (Kangaroo Creek Sandstone) | Bungawalbin Member ¹ | Fluvial to low-energy overbank | Aquicludes? |
| | | | Kangaroo Creek Sst Member ¹ Maclean Sandstone Member | Fluvial channel | Aquifer/Aquitard ¹ |
| | Middle Jurassic | Walloon Coal Measures | | Sinuuous meandering streams and backswamps | Aquifer/Aquitard ¹ |
| | | | Koukandowie Formation | Heifer Creek Sandstone Member | Sandy bedload channels |
| | | | Ma Ma Creek Sandstone Member | Lacustrine environment | |
| | | | Towallum Basalt | | |
| | Early Jurassic | Gatton Sandstone | | Stacked channel sands in low-sinuosity streams | Low permeability aquifer/aquitard |
| | | | Calamia Member | Low-energy fluvial system | |
| Koreelah Conglomerate Member | | | Valley-fill sediments | | |
| Triassic | Late Triassic | Woogaroo Subgroup | Ripley Road Sandstone | Point bars and channel fills | Good aquifer |
| | | | Raceview Formation | Mixed fluvial environment | |
| | | | Aberdare/Laytons Range conglomerates | Braided river and alluvial fan | |
| | Early-Middle Triassic | Ipswich Coal Measures | Redcliffe Coal Measures | | Aquifer/Aquitard ¹ |
| | | | Evans Head Coal Measures | | Aquifer/Aquitard ¹ |
| | Nymboida Coal Measures | | | Aquifer/Aquitard ¹ | |

¹proposed stratigraphic revision by Doig and Stanmore (2012)
²further discussed in Chapter 1.1.4 Hydrogeology and groundwater quality

Source: Rassam et al. 2014

5.2 Local geology

Much of the groundwater study area is located to the west of the Teviot Range (approximately Ch 0 km to Ch 35 km) and is underlain by the Jurassic-aged Walloon Coal Measures. Relatively thin deposits of Quaternary alluvial sediments are associated with the primary surface water features in the groundwater study area, inclusive of Western Creek, Bremer River, Warrill Creek, and Purga Creek which flow through the west side of the groundwater study area (refer Figure 6). The alluvial sediments are considered limited in extent, both laterally and vertically, from the watercourses.

The central portion of the groundwater study area (approximately Ch 35 km to Ch 50 km) is underlain by Gatton Sandstone which forms the topographic high known as the Teviot Range; which appear to be associated with the northern extension of the Moreton Bay Anticline basement high.

The eastern extent of the groundwater study area (approximately Ch 50 km to end) is underlain by the Koukandowie Formation and Walloon Coal Measures, which are overlain in some parts by alluvial sediments associated with Teviot Brook.

The geological units within the groundwater study area, inclusive of those which outcrop and sub-crop, are described below, from youngest to oldest (based on Rassam et al. 2014 and Golder 2018).

Figure 6 presents a generalised cross section of the groundwater study area and surface geology is depicted on Figure 7.

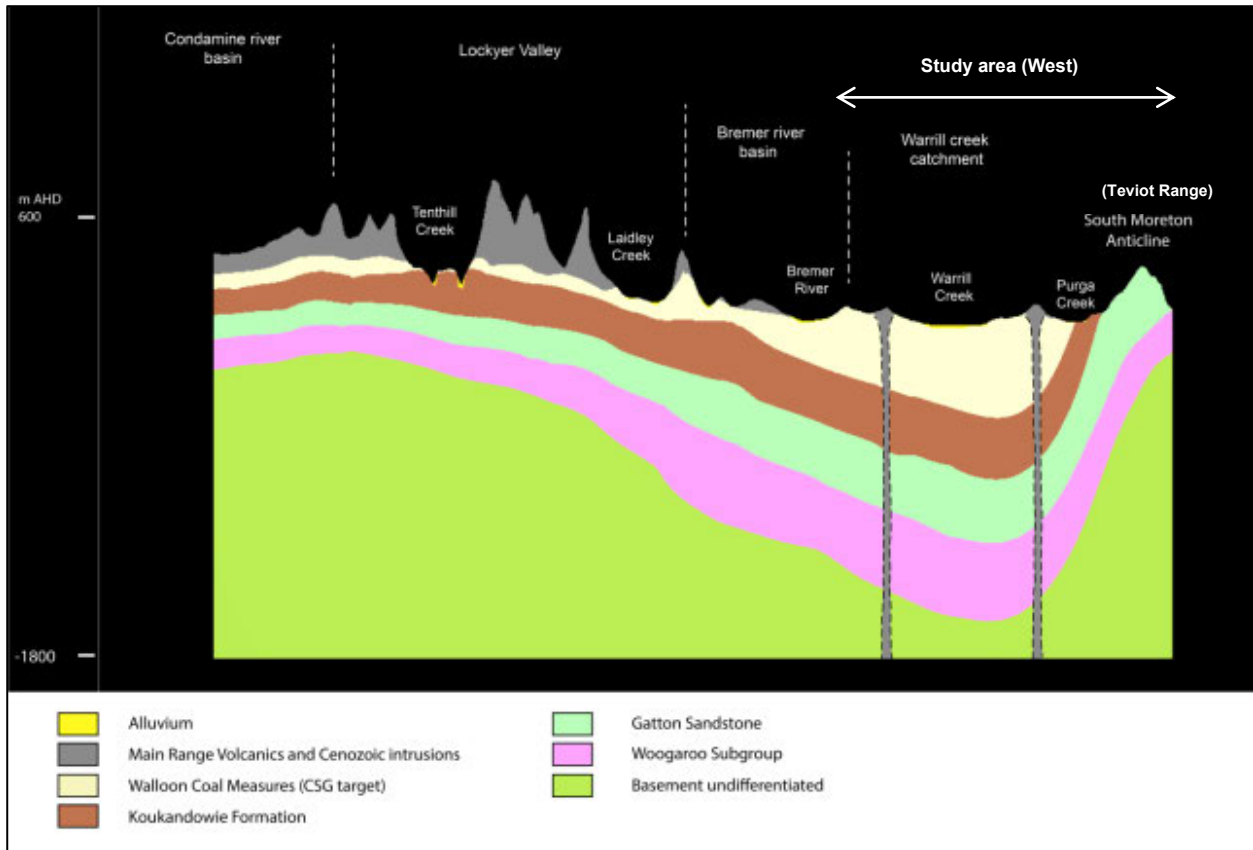


Figure 6 Generalised cross section of the groundwater study area with major surface water features

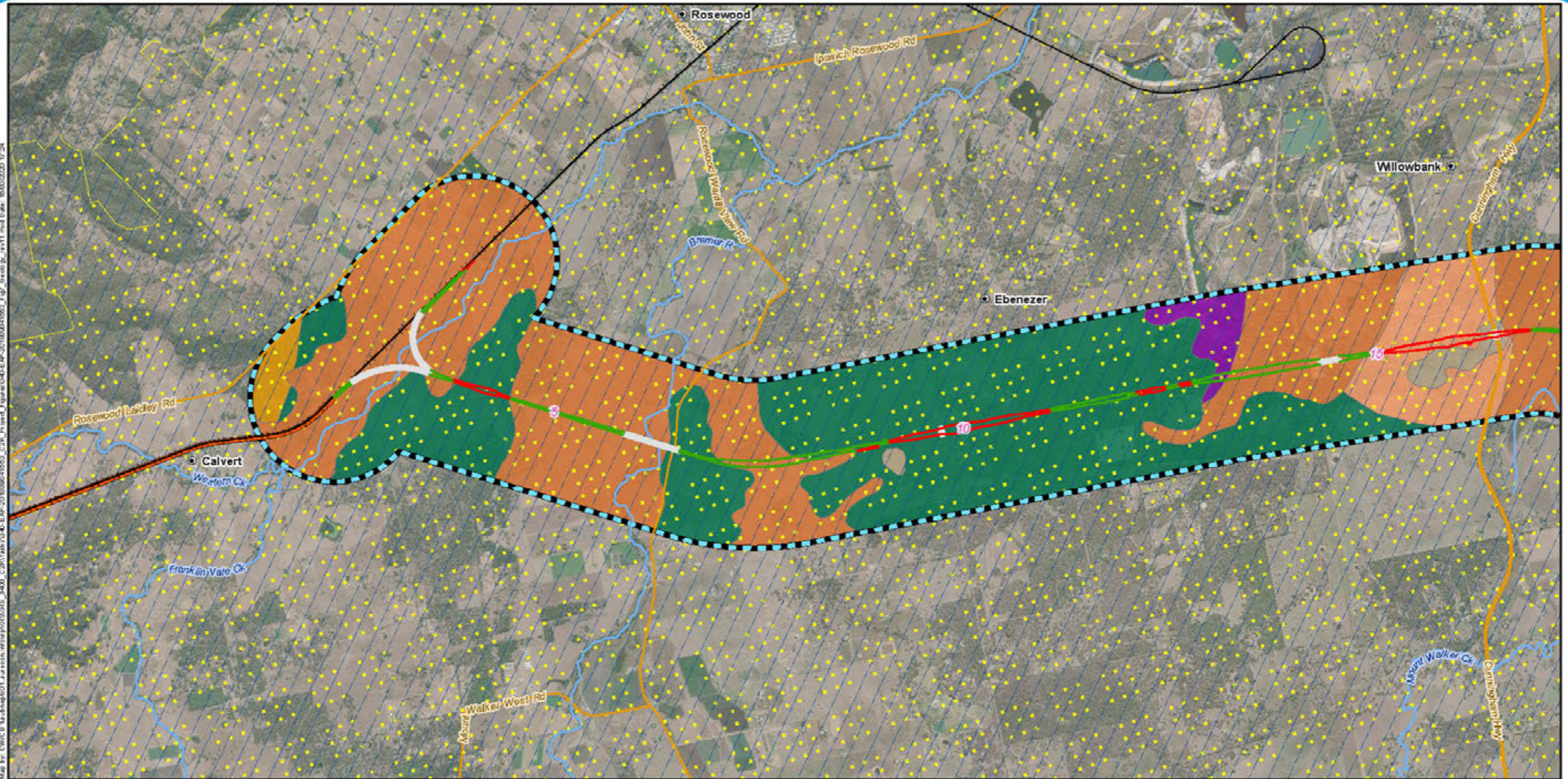
Source: Raiber et al. (2016)

5.2.1 Quaternary alluvium

Extensive alluvial sequences have infilled river basins in the Clarence - Moreton Basin in south-east Qld. The headwaters of the Queensland alluvial systems are deeply incised into the Cainozoic volcanics (e.g. Main Range Volcanics located southwest of the groundwater study area), which gives rise to the characteristic black soils in this region.

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

Alluvial sediments associated with various drainage lines in the groundwater study area (such as the Bremer River, Warrill Creek, and Teviot Brook) form a relatively thin veneer which overlies the Walloon Coal Measures to the west and east of the Teviot Range. Thicknesses of around 20 to 25 m have been reported for alluvial sediments within the Bremer River and Warrill Creek basins (Rassam et al. 2014).



Legend

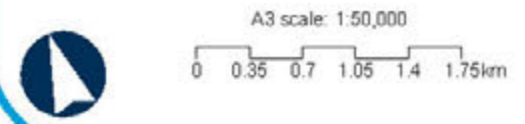
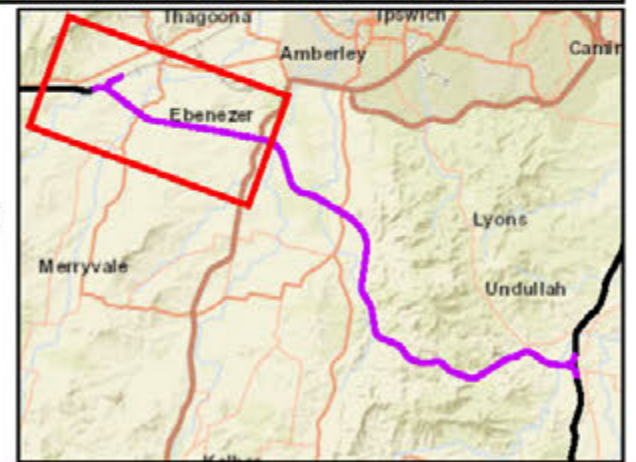
- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Existing rail
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Groundwater study area

Groundwater management areas

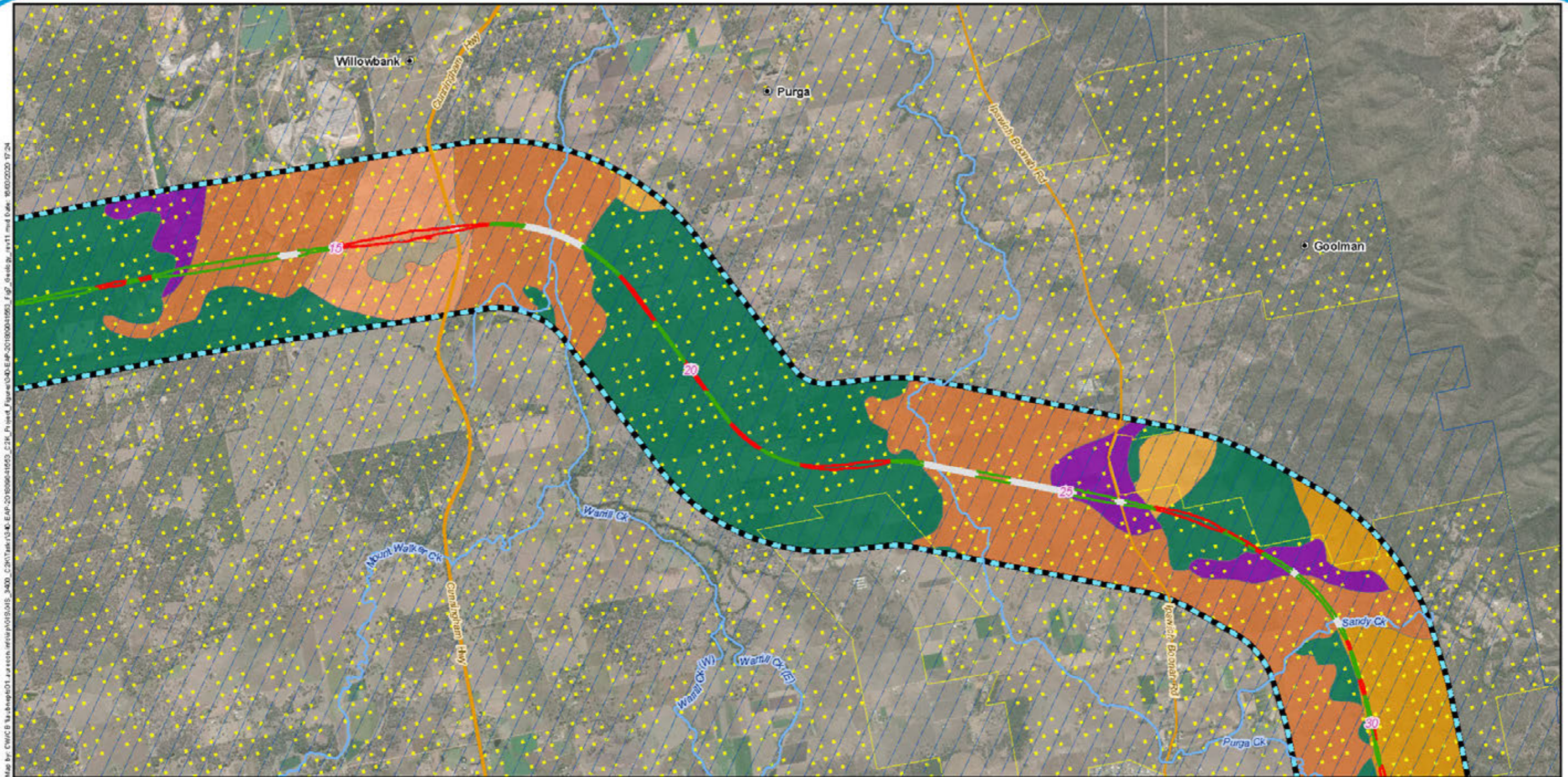
- Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017
- Water Plan (Moreton Basin) 2007

Detailed surface Geology

- Oa-OLD (Oa)
- TQw-QLD (TQw)
- Tid-SEQ (Tid)
- Tv/1-SEQ (Tv/1)
- Ts/1-SEQ (Ts/1)
- Walloon Coal Measures (Jw)
- Koukandowie Formation (Jbrnk)



Calvert to Kagaru
Figure 7a: Surface geology



Legend

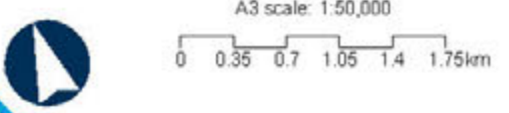
- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Watercourses
- Major roads
- Minor roads
- ▭ Groundwater study area

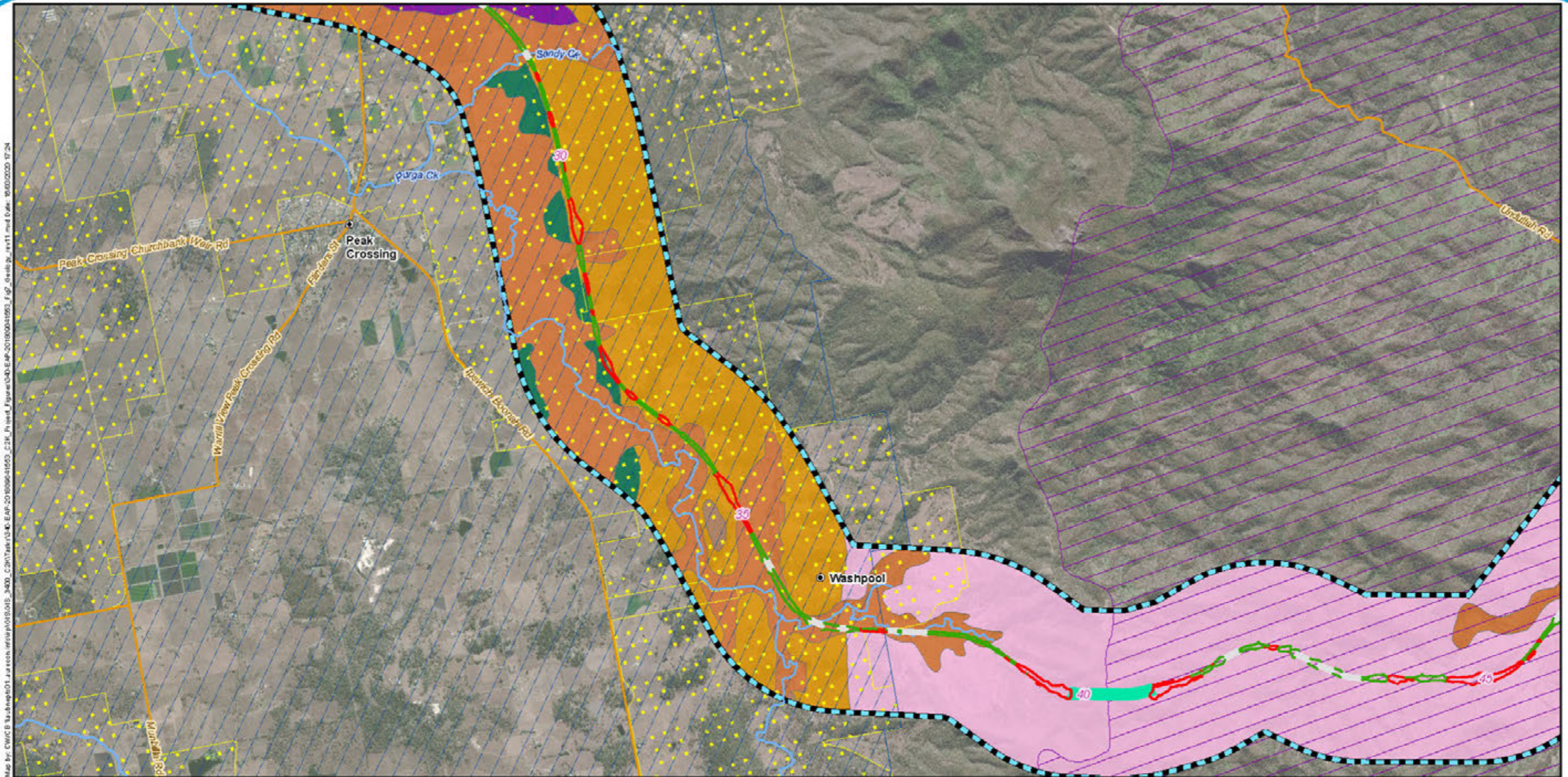
Groundwater management areas

- ▭ Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017
- ▭ Water Plan (Moreton Basin) 2007

Detailed surface Geology

- Tv/1-SEQ (Tv/1)
- Oa-OLD (Oa)
- TQw-QLD (TQw)
- Tid-SEQ (Tid)
- Ts/1-SEQ (Ts/1)
- Walloon Coal Measures (Jw)
- Koukandowie Formation (Jbmk)





Legend

- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Tunnel
- Watercourses
- Major roads
- Minor roads
- ▣ Groundwater study area

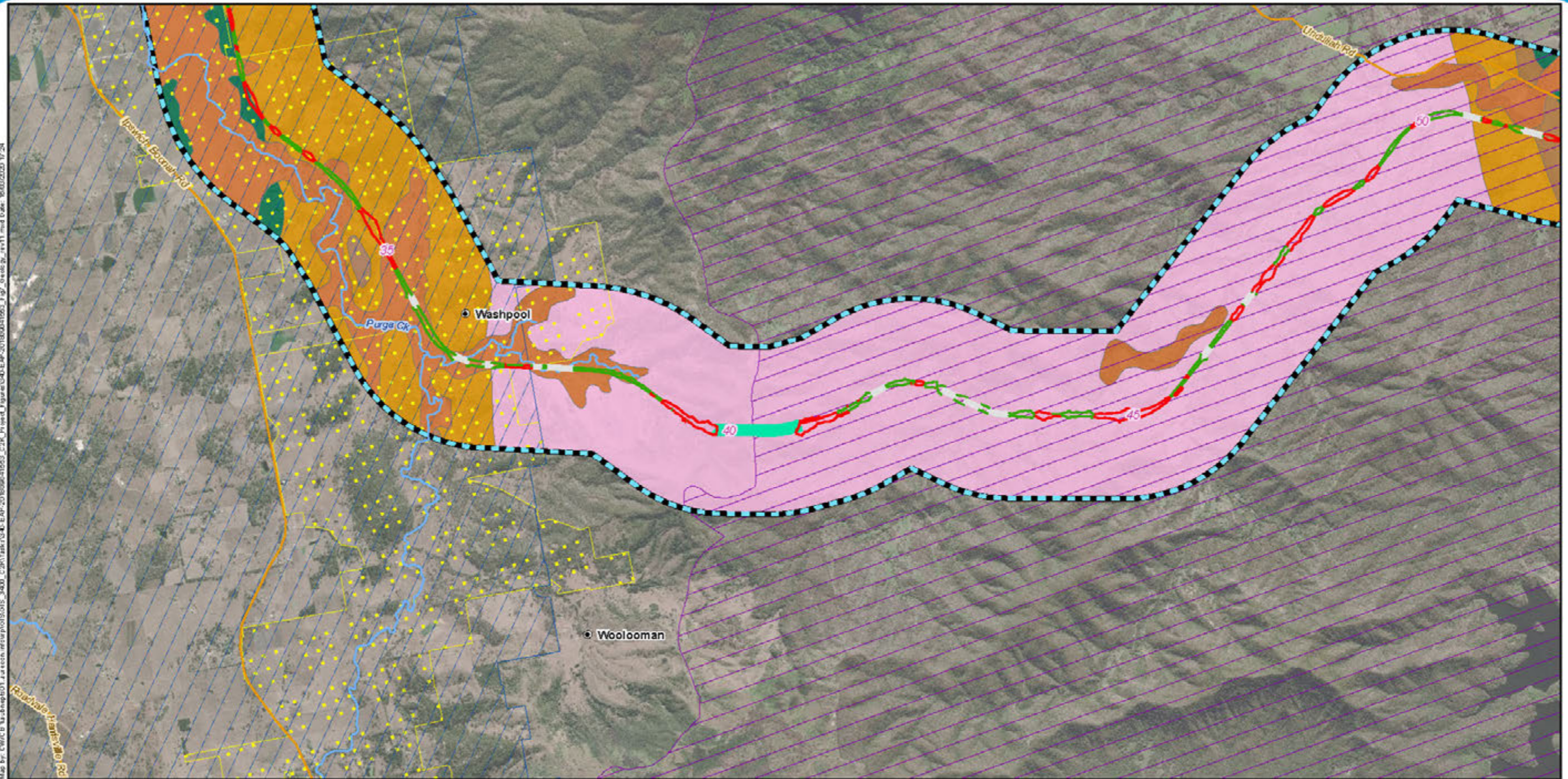
Groundwater management areas

- ▣ Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017
- ▣ Water Plan (Moreton Basin) 2007
- ▣ Water Plan (Logan Basin) 2007

Detailed surface Geology

- ▣ Tid-SEQ (Tid)
- ▣ Oa-QLD (Oa)
- ▣ TQw-QLD (TQw)
- ▣ Tit-SEQ (Tit)
- ▣ Walloon Coal Measures (Jw)
- ▣ Koukandowie Formation (Jbmk)
- ▣ Gatton Sandstone (Jbmg)





Legend

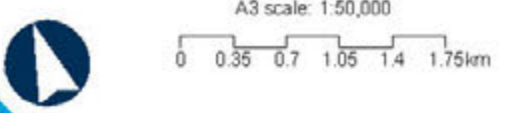
- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Tunnel
- Watercourses
- Major roads
- Minor roads
- ▣ Groundwater study area

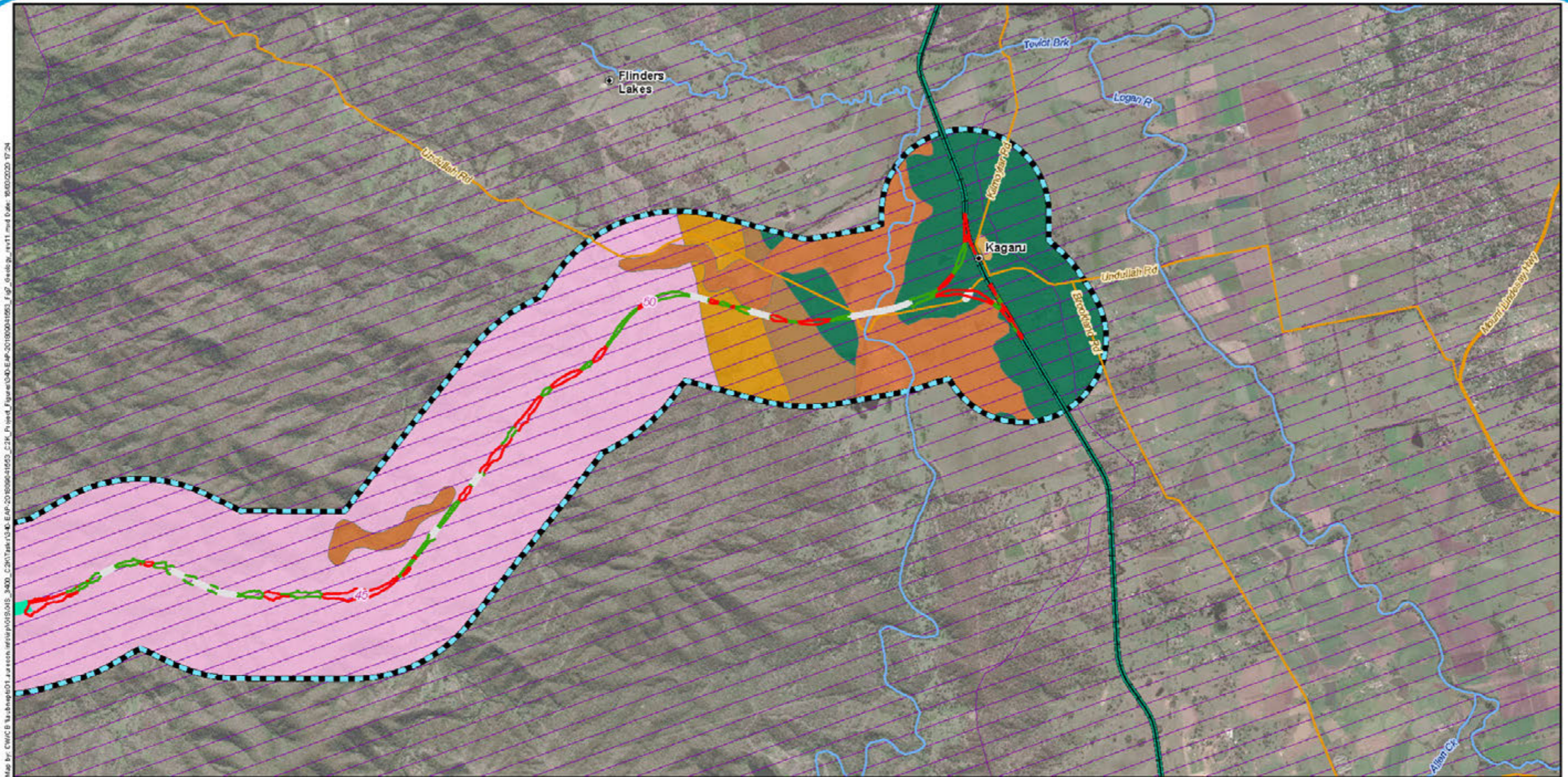
Groundwater management areas

- ▣ Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017
- ▣ Water Plan (Moreton Basin) 2007
- ▣ Water Plan (Logan Basin) 2007

Detailed surface Geology

- Oa-OLD (Oa)
- Tit-SEQ (Tit)
- Heifer Creek Sandstone Member (Jbmkh)
- Walloon Coal Measures (Jw)
- Koukandowie Formation (Jbmk)
- Gatton Sandstone (Jbmg)

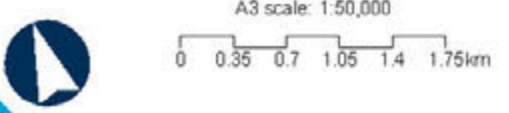




Legend

- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Existing rail
- K2ARB project alignment
- Tunnel
- Watercourses
- Major roads
- Minor roads
- Groundwater study area

- Groundwater management areas**
- Water Plan (Logan Basin) 2007
- Detailed surface Geology**
- Oa-OLD (Oa)
 - Tv/2-SEQ (Tv/2)
 - Heifer Creek Sandstone Member (Jbmkh)
 - Walloon Coal Measures (Jw)
 - Koukandowie Formation (Jbmk)
 - Gatton Sandstone (Jbmg)



Calvert to Kagaru
Figure 7e: Surface geology

5.2.2 Tertiary Volcanics

Paleogene and Neogene volcanoes were widespread throughout the Clarence - Moreton Basin, associated with rifting of the Australian east coast in the Early Cretaceous period. Prominent central volcanoes within the basin include the Main Range Volcanics southwest of the groundwater study area and the Lamington Volcanics located in northern New South Wales. There are only minor occurrences of Tertiary age volcanics and Cainozoic intrusives within the groundwater study area and comprise basalts, rhyolite, dolerite and gabbro.

5.2.3 Walloon Coal Measures

The Middle Jurassic Walloon Coal Measures are composed of volcanoclastic, lithic and silty sandstone with interbedded mudstone and siltstone, and numerous coal seams and carbonaceous coal shales. 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.

5.2.4 Marburg Subgroup

The Marburg Subgroup formed in meandering stream environments and has been subdivided into the lower Gatton Sandstone and the upper Koukandowie Formation. Continuous across the Kumberilla Ridge, a structural high which separates the basin from the adjacent Surat Basin, the Marburg Subgroup's equivalents include the Evergreen Formation and the Hutton Sandstone. The Marburg Subgroup is inferred to be transitional with the overlying Walloon Coal Measures (Jell 2013). Each of the Marburg Subgroup members are discussed below.

5.2.4.1 Koukandowie Formation

The Lower Jurassic Koukandowie Formation is a mixed facies sequence with a thickness of 250 to 500 m and 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: the 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.

5.2.4.2 Gatton Sandstone

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.

5.3 Acid sulphate soils

Acid sulphate 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 Sulphate Soils (Fitzpatrick et al. 2011), except for a dam located immediately south of where the Cunningham Highway intersects the alignment (at approximately Ch 16.4 km). The dam is mapped as having a high probability (very low confidence) 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 study area and based on a review of existing ASS mapping, it is considered that there is a low risk of inland ASS or potential inland ASS being present within the groundwater study area.

6 Hydrogeology

This section provides a description of the existing hydrogeological regime and is based on a review of available hydrogeological reports, site investigations between July to October 2018 (refer Section 7), and State government data sets described in Table 3.1.

There are two main aquifer systems present which are considered relevant to the groundwater study area:

- Cainozoic to recent alluvium and volcanic formations: shallow alluvial systems along river valleys within the basin, and volcanic formations including Cainozoic basalt aquifers
- Jurassic to Cretaceous sandstones: includes the Walloon Coal Measures, Koukandowie Formation, and Gatton Sandstone.

Both aquifer systems are considered to have potential to be sensitive to activities associated with the groundwater study area.

The subsections below describe the physical and chemical aspects of these aquifers in the context of their respective hydrogeological regime.

6.1 Hydrostratigraphy

To the west of Teviot Range the alignment is located within the alluvial plains of the Bremer River and Warrill Creek and their tributaries; to the east of the range, the groundwater study area is located within the alluvial plains of the Logan River. The alluvial plains have infilled valleys with gravels, sands, loams and clays carrying large supplies of fresh to slightly brackish groundwater. The aquifers are recharged primarily 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 where the sediments are more conductive to groundwater flow in these areas. The areas surrounding the watercourses, 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 may constrain groundwater flow within the subsurface.

Colluvium deposits may be located at the base of the Teviot Range 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. 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 located in colluvium may occur intermittently following rainfall.

Within the Project alignment, Walloon Coal Measures overlie the Koukandowie Formation and the Gatton Sandstone formations of the Marburg Subgroup. The Walloon Coal Measures are not considered a major aquifer on a regional scale because they dominantly consist of low permeability sandstone, siltstone, shales, carbonaceous mudstones with minor sandstones and coal seams. However, coal seams and geological structures such as faulting may locally increase the potential for groundwater movement and storage. The Walloon Coal Measures are considered a Great Artesian Basin aquifer in the Water Resource Great Artesian Basin 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, and/or coal seams. Storage of this unit is anticipated to be low and will likely result in low long-term seepage rates.

The Koukandowie Formation is comprised of two members occupying the lower part of the formation and an undifferentiated succession of interbedded argillaceous lithic sandstones, carbonaceous siltstones and shales (Ingram and Robinson 1996). The two lower members of the Koukandowie Formation are the basal Ma Ma Creek Member and the Heifer Creek Sandstone Member (Ingram and Robinson 1996). The Ma Ma Creek Member conformably overlies the Gatton Sandstone. It consists of thinly interbedded siltstones, claystones, and fine-grained sandstones generally 10 to 20 m thick (Ingram and Robinson 1996). The Heifer Creek Sandstone Member comprises interbedded sandstone, siltstone and shale with minor coal. The sandstones coarsen upwards with less frequent siltstone and shale layers. This member commonly forms prominent topographic features with steep slopes and is often exposed in cliffs, benches and cuttings (Wells and O'Brien 1994). The sandstones are quartzose, fine- to coarse-grained, thin- to massive-bedded with a variable amount of lithic grains, clay and calcareous cement. The shales and siltstones are typically carbonaceous (Ingram and Robinson 1996). The Koukandowie Formation is broadly correlated with the upper Evergreen Formation and the lower Hutton Sandstone of the Surat Basin (Jell 2013).

Rocks of the Koukandowie Formation are generally described as low permeable 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 and referred to as the Koukandowie Formation.

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. The Gatton Sandstone is described by Wells and O'Brien (1994) as primarily thick bedded, relatively uniform, medium and coarse grained, quartz-lithic and feldspathic sandstone commonly with argillaceous matrix and cements rich in sodium, calcium and magnesium carbonates (McTaggart 1963). Pebble beds, carbonised wood fragments and large-scale planar and cross-bedding are characteristic of this formation. 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). The formation contains water, but overall, is of low to moderate permeability and the water is of poor quality with saline water at depth in places. Due to the lack of spatially continuous beds of low permeability rock or a thick low permeability soil layer, groundwater in the Gatton Sandstone is believed to be unconfined below ridges and mostly unconfined elsewhere.

The Project is anticipated to encounter the Walloon Coal Measures and Quaternary alluvial sediments in low lying areas (between Ch 0.0 km and Ch 22.9 km and between Ch 53.2 km and Ch 56.2 km) and the Marburg Subgroup (Koukandowie Formation/Gatton Sandstone) in the Teviot Range between Ch 22.9 km and Ch 53.2 km. At the Teviot Range tunnel section (between Ch 39.5 km and Ch 41.3 km) the Gatton Sandstone is locally exposed at the surface or blanketed by a thin layer of red and yellow podzolics, lithosols and solodic soils, typical for soils of steep hills on sandstone (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

The primary aquifers considered relevant to the Project are summarised in Table 6.1. Characteristics of each hydrostratigraphic unit are discussed below.

Table 6.1 Groundwater occurrence within the groundwater study area

| Hydrostratigraphic unit | Main occurrences | Approximate proportion of alignment | Thickness ¹ | Lithology | Comments |
|-----------------------------------|--|-------------------------------------|--------------------------|---|----------------------|
| Quaternary alluvium | Mainly west of Teviot Range. Associated watercourses include Bremer River, Warrill Creek and Purga Creek. Small deposit east of Teviot Range associated with Teviot Brook. | 32% | Up to approximately 30 m | Clay, silt, sand and gravel; in a generally fining upward sequence. | Aquifer (unconfined) |
| Tertiary Volcanics and intrusives | Minor occurrences west of Teviot Range (e.g. Ch 14.9 to Ch 16.6, and Ch 24.8 to Ch 26.2) | 7% | various | Basalts, rhyolite, dolerite and gabbro. | Aquifer (unconfined) |

| Hydrostratigraphic unit | Main occurrences | Approximate proportion of alignment | Thickness ¹ | Lithology | Comments |
|-------------------------|---|-------------------------------------|------------------------|--|---------------------------------------|
| Walloon Coal Measures | Mostly west of Teviot Range. Outcrops between watercourses, and sub-crops beneath alluvial sediments. Small outcrop and subcrop east of Teviot Range. | 28% | 400 to 600 m | Lithic and silty sandstone with interbedded mudstone and siltstone | Aquifer/ Aquitard |
| Koukandowie Formation | Parallel to, and abutting, the Teviot Range (i.e. immediately east and west). | 12% | >1,000 m | Interbedded sandstone, siltstone, claystone and minor coal | Low permeability aquifer/ aquitard |
| Gatton Sandstone | The Teviot Range. Includes proposed tunnel section. | 21% | | Medium- to coarse-grained sandstone | Low permeability aquifer/ aquitard |

Table note:

¹ Raiber et al. (2016)

6.2 Groundwater occurrence

6.2.1 Groundwater levels

The water table (shallow, unconfined aquifer) is typically a subdued version of topography, with the depth to groundwater increasing beneath topographic highs (for example the Teviot Range), and shallower in lower lying reaches (such as close to surface water drainage lines). The presence of shallow aquitards, surface water features and groundwater extraction would locally affect depths to groundwater.

The water table occurs in the alluvial sediments or outcropping Walloon Coal Measures across much of the groundwater study area west and east of the Teviot Range. The Gatton Sandstone of the Teviot Range comprises the upper (water table) aquifer in the central portion of the study area.

A summary of groundwater level data from the groundwater study area is provided in Table 6.2 and includes:

- Data from DNRME groundwater database bores with recent (i.e. 2017/2018) results
- 2016 data for three monitoring bores installed during a preliminary geotechnical investigation (Jacobs-GHD 2016)
- 2018 data available for eight of nine monitoring bores installed along the alignment as part of the ongoing geotechnical investigation (and reported in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

Registered bores identified in Table 6.2, and project bores, are depicted on Figure 8a-e.

Table 6.2 Groundwater level data

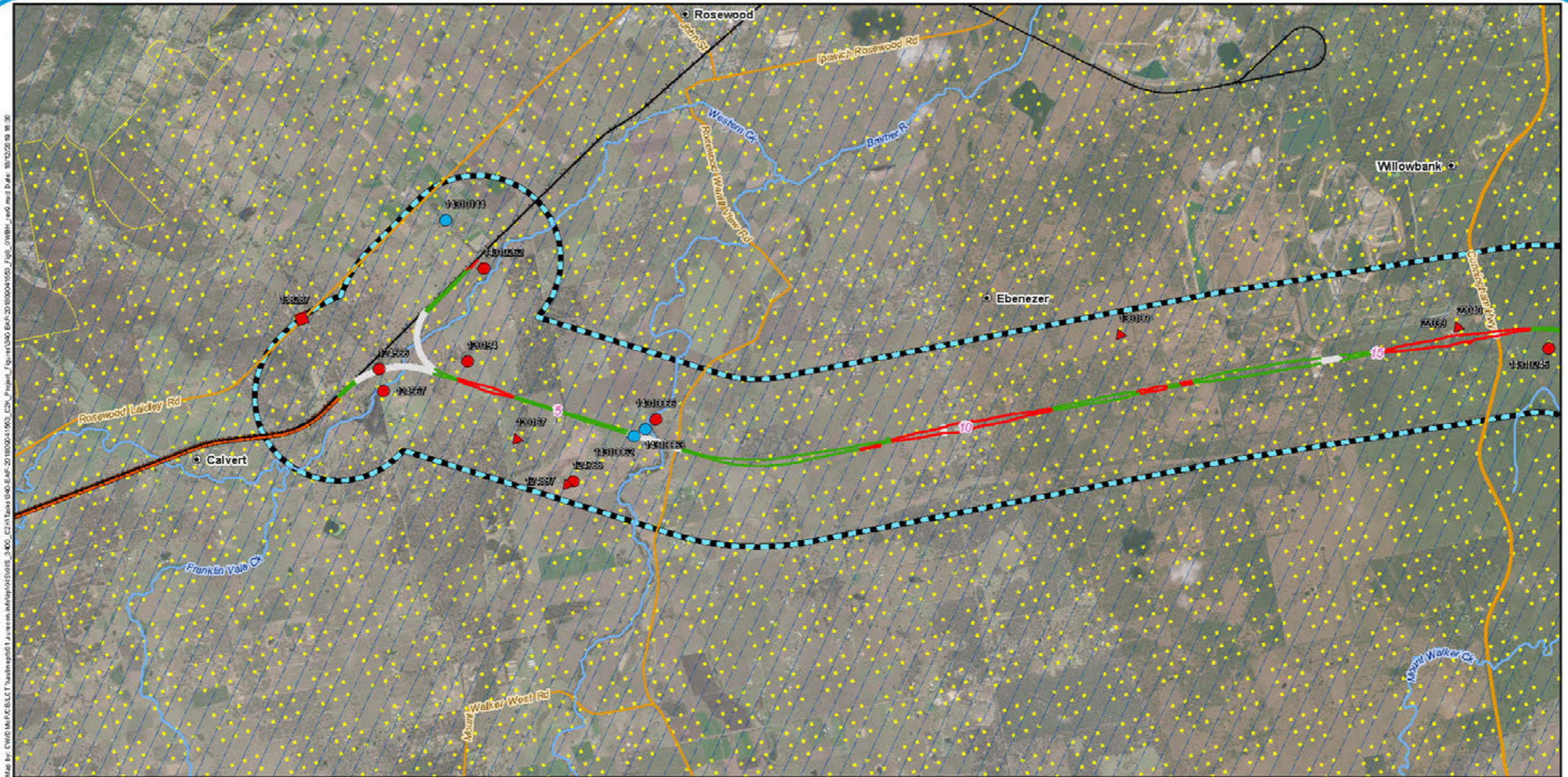
| RN Bore ID | Aquifer | Groundwater elevation* (mAHD) | Depth to groundwater (mbNS) | Screen interval (mbNS) | Location |
|--------------|-------------------------------|-------------------------------|-----------------------------|------------------------|--|
| 14310262 | Western Creek Alluvium | 42 | 6 | 10.7 to 18.3 | 100 m northwest of Western Creek. 1.2 km ENE of Western Creek rail loop crossing. Refer to Figure 8a |
| 14310144 | Western Creek Alluvium | 43 | 5 | 8.5 to 13.7 | 850 m northwest of Western Creek. 1.5 km NE of Western Creek rail loop crossing Refer to Figure 8a |
| 14310066 | Bremer River Alluvium | 34 | 8.5 | 14.5 to 17.4 | 280 m north of Bremer River Crossing (Ch 6.3). Refer to Figure 8a |
| 14310245 | Warrill Creek Alluvium | 23 | 10 | 12 to 18.6 | 530 m west of Warrill Creek crossing at Ch 17.6. Refer to Figure 8b |
| 14310223 | Walloon Coal Measures | 34 | 20 | 84 to 96 | 500 m west of Purga Creek crossing at Ch 23.4. Screened below alluvial sediments. Refer to Figure 8b |
| 14310224 | Walloon Coal Measures | 45.2 | 10.8 | 16 to 23 | 250 m SW of Ch 27.8. Screened below alluvial sediments. Refer to Figure 8b |
| 14310277 | Purga Creek Alluvium | 52.4 | 2.7 | 11.3 to 18 | 390 m east of Purga Creek, and 590 m west of Ch 31.2. Refer to Figure 8c |
| BH-04 | Koukandowie Formation | 73.4 | 12.1 | 10.9 to 16.9 | Approximately Ch 31.1. Refer to Figure 8c |
| BH-05 | Gatton Sandstone | 82.6 | 16.9 | 18.97 to 24.97 | Approximately Ch 44.8. Refer to Figure 8e |
| BH-07 | Gatton Sandstone | 117.8 | 20.2 | 29.5 to 35.5 | Approximately Ch 39.8. Refer to Figure 8d |
| 340-1-BH2101 | Gatton Sandstone | 146 | 72 | 112 to 124 | Approximately Ch 40.0. Refer to Figure 8d |
| 340-1-BH2215 | Alluvium | 23 | 9 | 19 to 25 | Approximately Ch 17.4. Refer to Figure 8b |
| 340-1-BH2220 | Koukandowie Formation | 39 | 9 | 16 to 25 | Approximately Ch 25.4. Refer to Figure 8b |
| 340-1-BH2224 | Walloon Coal Measures | 65 | 9 | 16 to 25 | Approximately Ch 35.2. Refer to Figure 8d |
| 340-1-BH2225 | Alluvium | 69 | 1 | 19 to 25 | Approximately Ch 36.6. Refer to Figure 8d |
| 340-1-BH2226 | Koukandowie Formation | Not available | Not available | 17 to 26 | Approximately Ch 37.2. Refer to Figure 8d |
| 340-1-BH2229 | Koukandowie Formation | 47 | 7 | 11 to 20 | Approximately Ch 46.4. Refer to Figure 8e |
| 340-1-BH2233 | Alluvium and Gatton Sandstone | 23 | 9 | 16 to 25 | Approximately Ch 52.8. Refer to Figure 8e |
| 340-1-BH2303 | Gatton Sandstone | 73 | 18 | 22 to 31 | Approximately Ch 35.0. Refer to Figure 8d |

Table notes:

* Indicative recent groundwater elevation based on review of hydrographs mbNS = metres below natural surface

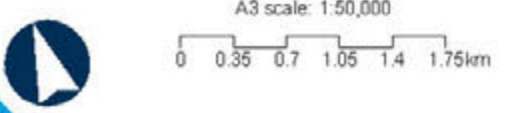
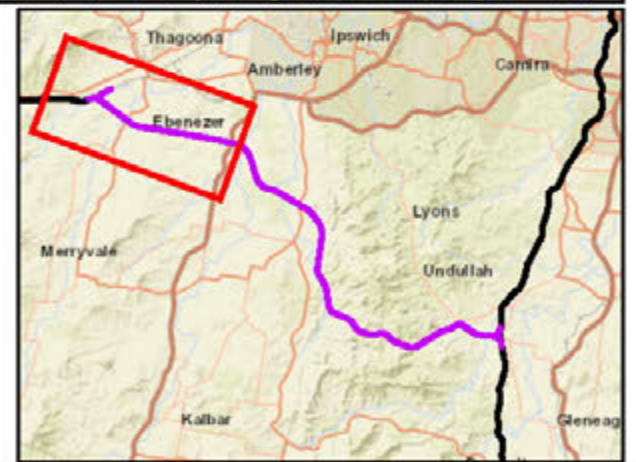
BH-0x series from 2016 preliminary geotechnical investigation (Jacobs-GHD 2016)

340-1-BH222x series from 2018 geotechnical investigation (Golder 2019)

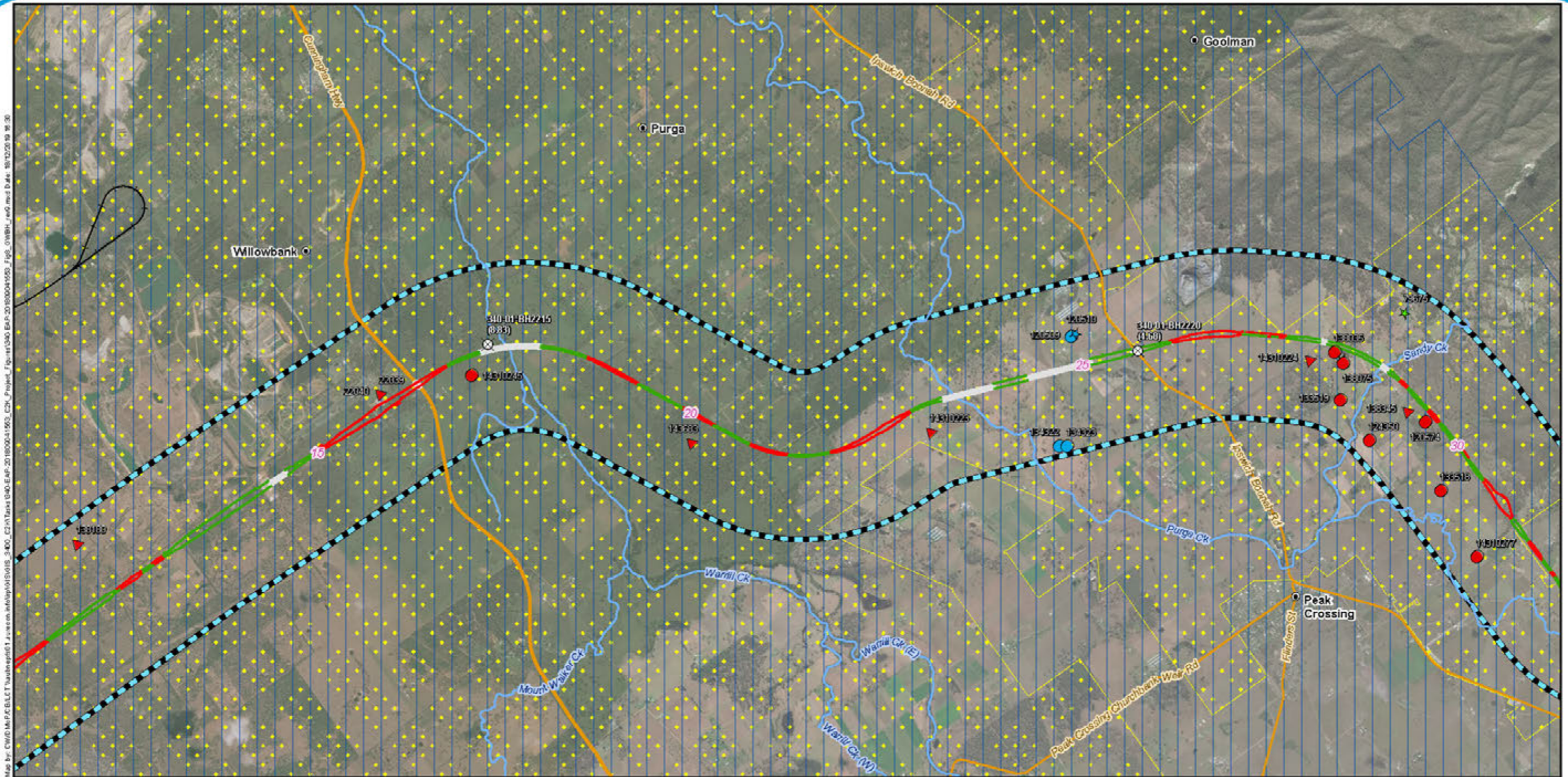


Legend

- Localities
- 5 Chainage (km)
- Cut
- Fill
- Bridges
- Existing rail
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Groundwater study area
- Alluvium
- ▲ Walloon Coal Measures
- Marburg Subgroup
- ★ Unknown
- Shallow (<15m)
- Deep (>15 m)
- (911) Groundwater level in metres below ground surface
- Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017
- Water Plan (Moreton Basin) 2007

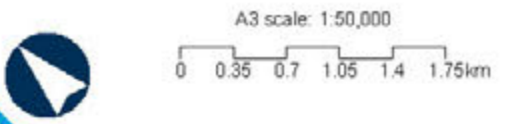
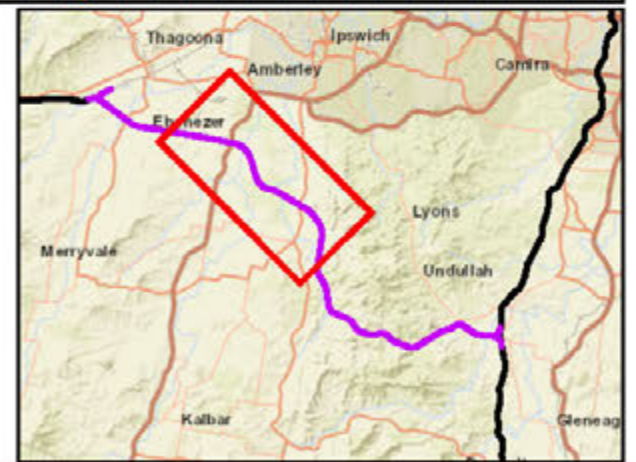


Calvert to Kagaru
Figure 8a: Registered groundwater bores and project bores

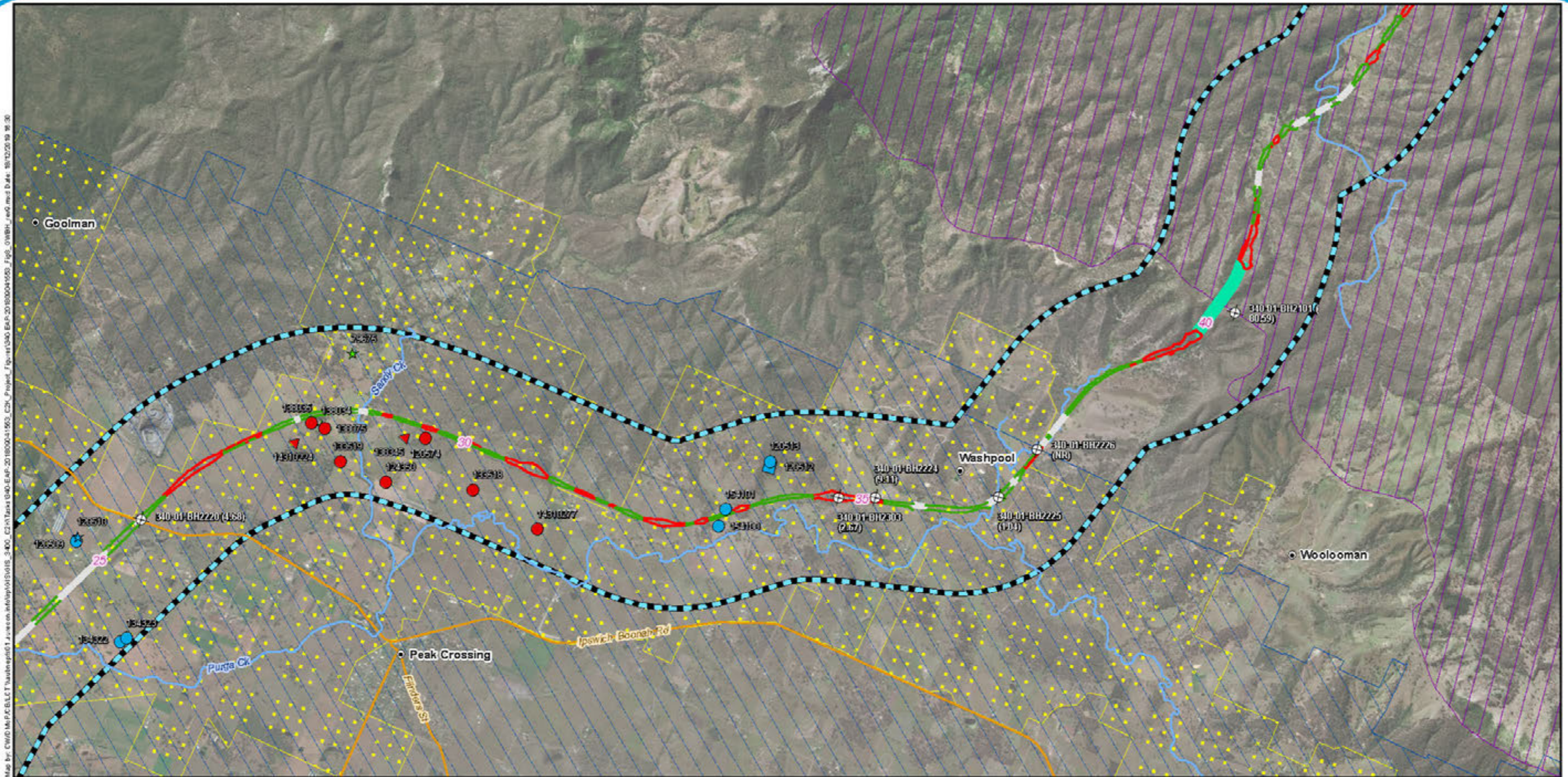


Legend

- | | | | | |
|----------------------------|--------------------------|-------------------------|---|--|
| ● Localities | — Watercourses | Aquifer | Groundwater bore depths | Groundwater management areas |
| 5 Chainage (km) | — Major roads | ● Alluvium | ■ Shallow (<15m) | □ Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017 |
| ⊕ Project monitoring bores | — Minor roads | ▲ Walloon Coal Measures | ■ Deep (>15 m) | □ Water Plan (Moreton Basin) 2007 |
| — Cut | ▨ Groundwater study area | ■ Marburg Subgroup | (g1) Groundwater level in metres below ground surface | |
| — Fill | | ★ Unknown | | |
| — Bridges | | | | |
| — Existing rail | | | | |

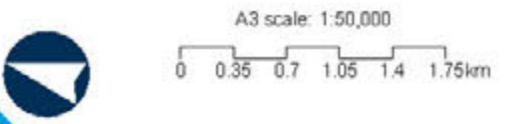
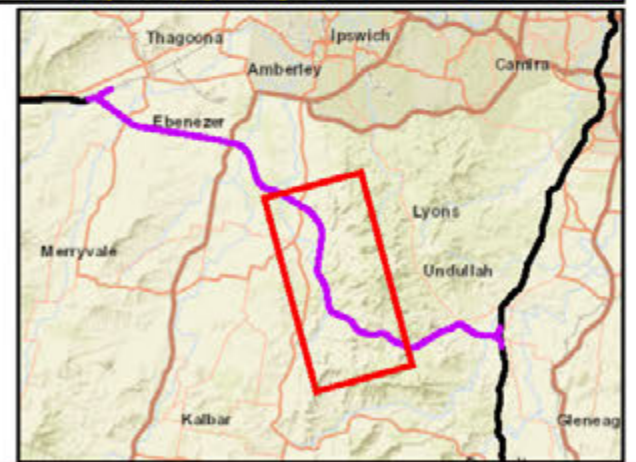


Calvert to Kagaru
Figure 8b: Registered groundwater bores and project bores

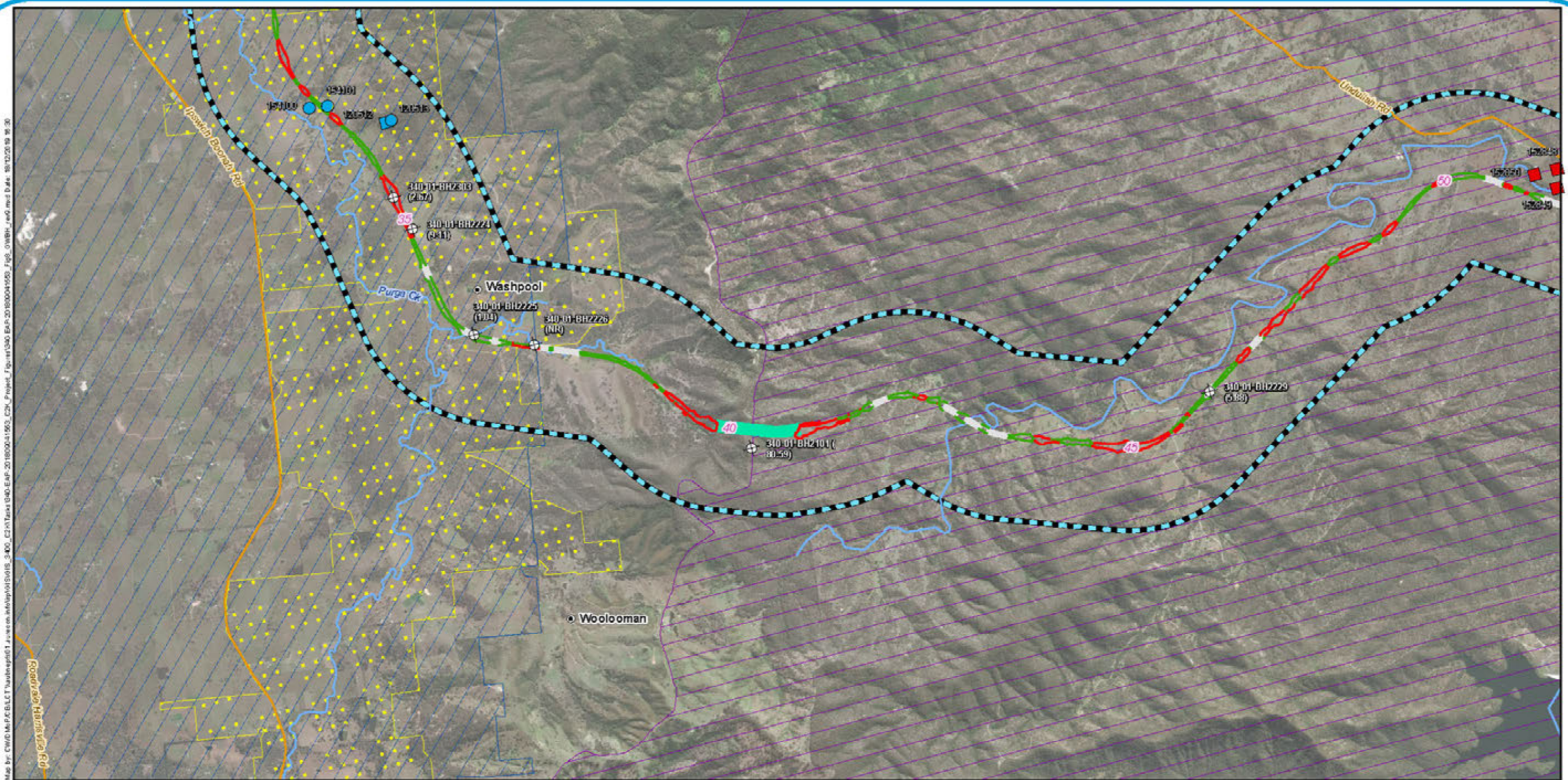


Legend

- | | | | | |
|----------------------------|--------------------------|-------------------------|--|--|
| ● Localities | — Watercourses | Aquifer | Groundwater bore depths | Groundwater management areas |
| 5 Chainage (km) | — Minor roads | ● Alluvium | ■ Shallow (<15m) | Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017 |
| ⊕ Project monitoring bores | ▭ Groundwater study area | ▲ Walloon Coal Measures | ■ Deep (>15 m) | Water Plan (Moreton Basin) 2007 |
| — Cut | | ■ Marburg Subgroup | (g11) Groundwater level in metres below ground surface | Water Plan (Logan Basin) 2007 |
| — Fill | | ★ Unknown | | |
| — Bridges | | | | |
| — Tunnel | | | | |

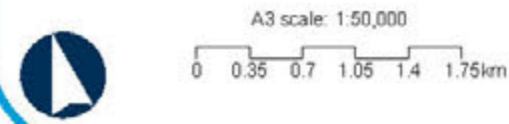
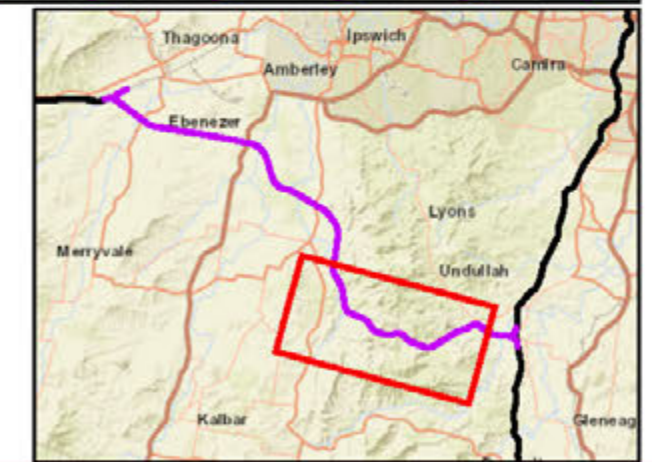


Calvert to Kagaru
Figure 8c: Registered groundwater bores and project bores

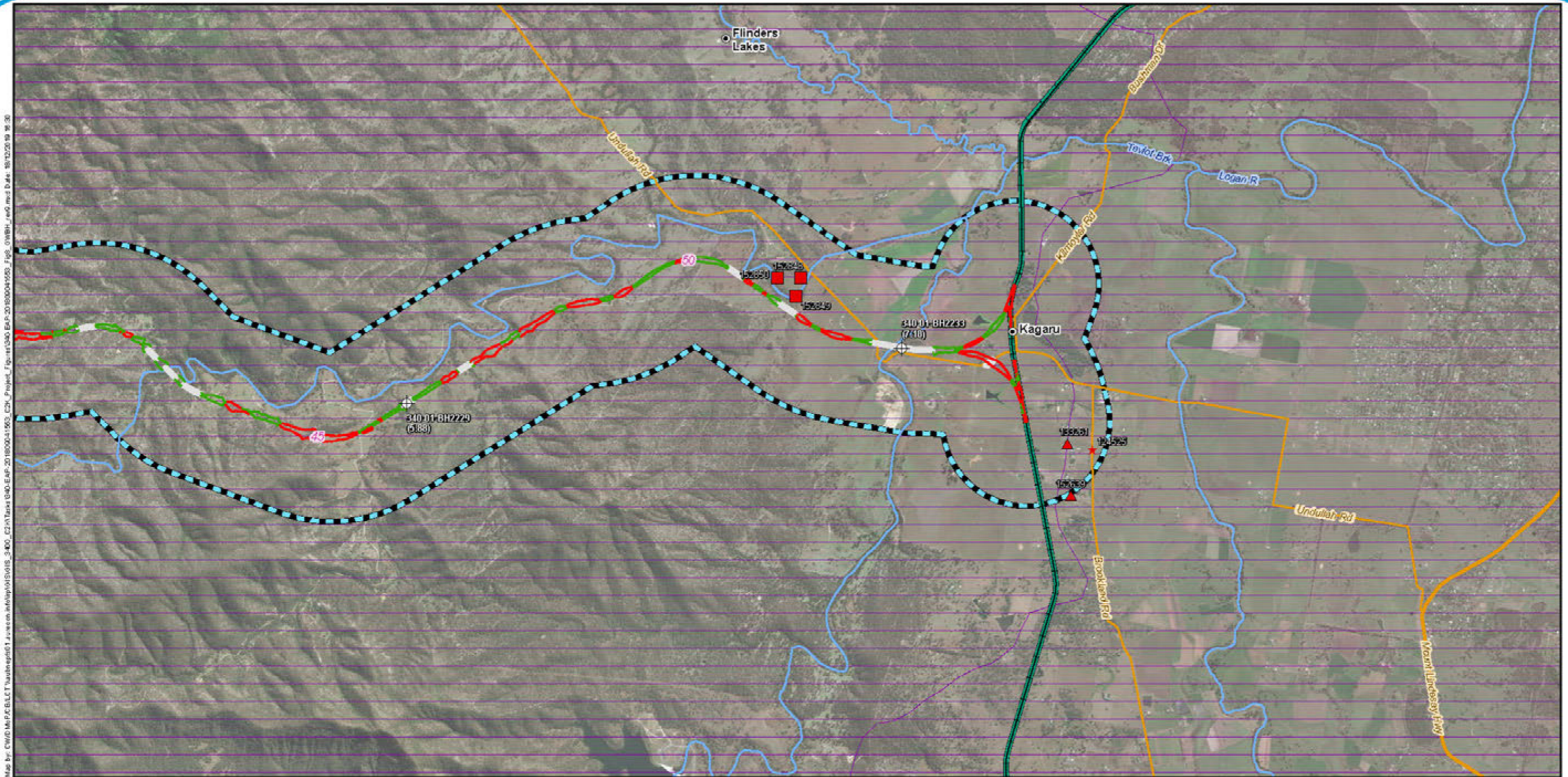


Legend

- | | | | | |
|----------------------------|--------------------------|-------------------------|--|--|
| ● Localities | — Watercourses | Aquifer | Groundwater bore depths | Groundwater management areas |
| 5 Chainage (km) | — Minor roads | ● Alluvium | ■ Shallow (<15m) | Water Plan (Great Artesian Basin and Other Regional Aquifers) 2017 |
| ⊕ Project monitoring bores | ▭ Groundwater study area | ▲ Walloon Coal Measures | ■ Deep (>15 m) | Water Plan (Moreton Basin) 2007 |
| — Cut | | ■ Marburg Subgroup | (g11) Groundwater level in metres below ground surface | Water Plan (Logan Basin) 2007 |
| — Fill | | ★ Unknown | | |
| — Bridges | | | | |
| — Tunnel | | | | |

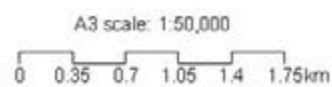
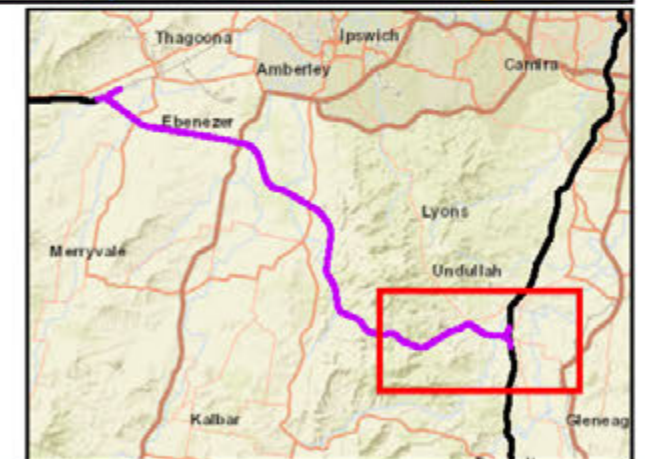


Calvert to Kagaru
Figure 8d: Registered groundwater bores and project bores



Legend

- | | | | | |
|----------------------------|--------------------------|-------------------------|--|-------------------------------------|
| ● Localities | — Watercourses | Aquifer | Groundwater bore depths | Groundwater management areas |
| 5 Chainage (km) | — Major roads | ● Alluvium | ■ Shallow (<15m) | □ Water Plan (Logan Basin) 2007 |
| ⊕ Project monitoring bores | — Minor roads | ▲ Walloon Coal Measures | ■ Deep (>15 m) | |
| — Cut | ▨ Groundwater study area | ■ Marburg Subgroup | (9.1) Groundwater level in metres below ground surface | |
| — Fill | | ★ Unknown | | |
| — Bridges | | | | |
| — Existing rail | | | | |
| — K2ARB project alignment | | | | |



Calvert to Kagaru
Figure 8e: Registered groundwater bores and project bores

Regional mapping indicates a mean groundwater depth of 5 to 15 m in Bremer River basin alluvium for a wet period in 2008 to 2012 (Raiber et al. 2016). This is generally consistent with the limited 2018 data for alluvial aquifers which indicate depths to groundwater of less than 10 m. Three locations indicate depths to groundwater of around 5 m or less (14310144, 14310277 and 340-1-BH2225), assuming these are indicative of depths to the water table. It is expected that shallow groundwater in the alluvial sediments will typically occur in low lying areas near to watercourses where fill/embankments and/or bridges are proposed, with no cuttings proposed through the alluvial sediments.

There are no recent water table data available for the unconfined Walloon Coal Measures. Bores RN14310223, RN14310224 and 340-1-BH2224 are screened below overlying sediments and could potentially represent confined pressure head (rather than the water table elevation). Regional scale mapping indicates a potentiometric surface of around 40 mAHD might be expected in the groundwater study area which is generally consistent with RN14310223 and RN14310224 data. In the main areas of outcrop from Ch 8 km to Ch 13 km and Ch 18 km to Ch 23 km (refer Figure 7) the water table might be expected to be at least 5 m, and greater than 10 m beneath higher relief; based on the limited data available and topographical profile of the alignment.

There are no DNRME groundwater level data available for the Koukandowie Formation and Gatton Sandstone (i.e. Teviot Range section) in the groundwater study area. However, three geotechnical bores (BH-04, BH05 and BH07) were converted to monitoring wells during a preliminary geotechnical investigation in 2016 (Jacobs-GHD 2016); refer Table 6.2. A groundwater depth of 12.1 metres below natural surface (mbNS) was recorded in June 2016 at monitoring bore BH-04 (Koukandowie Formation), corresponding to an approximate groundwater elevation above the proposed base of cut in this location. It is possible therefore that cuts in the alignment from around Ch 29 km to Ch 36 km could intersect groundwater, although this is based on one data point only (BH-04).

Monitoring bores BH-05 at Ch 44.8 km (refer Figure 8e) and BH-07 at Ch 39.8 km; western portal (refer Figure 8d) were screened in the Gatton Sandstone. At BH-05 the groundwater elevation indicates the potential for groundwater to be intersected by the proposed cut along this section of the alignment. The groundwater elevation at BH-07 was also higher than the floor elevation of the proposed western portal indicating groundwater inflows will occur in this area, and throughout the tunnel section. An estimate of pre-construction groundwater levels along the tunnel alignment (Ch 39.5 km to Ch 41.3 km) was provided in a preliminary technical memorandum; assessing potential groundwater inflows and drawdowns for the tunnel and portals (Golder 2018). It was assumed that groundwater in the Gatton Sandstone is unconfined due to the absence of continuous beds of low permeability rock or thick low permeability soil layer. The groundwater level (water table) was depicted as a subdued version of the Teviot Range topography. A maximum water table depth of approximately 60 m (40 m above tunnel elevation) was estimated beneath the topographic high, with groundwater discharge on the lower slopes assumed, due to the features considered likely to be surface expressions of groundwater.

Where groundwater levels are above the base of cut elevations, consideration will be required with respect to potential geotechnical implications (such as wall failure and floor heave), reduced groundwater levels and flow at receptors, and the quality of groundwater discharge (for example to surface water courses). It is noted that the 2018 geotechnical monitoring bores 340-1-BH2224 and 340-1-BH2303 (refer Figure 8d) were constructed near a proposed cutting, with all others targeting bridges (six bores) and the tunnel (one bore). Further discussion of potential inflows to cuttings is included in Section 10.

6.2.2 Groundwater flow

Intermediate and regional groundwater flow systems in alluvial sediments are northeast and north through the western groundwater study area following that of the associated rivers and creeks as they drain towards the Brisbane River. East of the Teviot Range, groundwater flow within the alluvial sediments is inferred to be northward through the groundwater study area as the Teviot Brook drains to the Logan River. Local groundwater flow systems will be influenced by surface water-groundwater interaction where there is a hydraulic connection.

The regional potentiometric surface of the Walloon Coal Measures shows that groundwater flow is generally east and northeast towards the eastern margin of the Clarence-Moreton Basin (Raiber et al. 2016). As basin sediments are thin and terminate against basement rocks, groundwater likely discharges to surface at the eastern margins and is expressed as discharge into the Bremer River, or as wetlands and/or springs beyond the groundwater study area.

Mapping of Gatton Sandstone groundwater elevations indicate that regional groundwater flowpaths are northeast beneath the Bremer River basin (Raiber et al. 2016). The potentiometric surface indicates that lower groundwater elevations correspond to alluvial sediments suggesting these acts as regional discharge areas for the underlying Clarence-Moreton Basin sedimentary sequence. In the groundwater study area, the Gatton sandstone outcrops as the Teviot Range. Groundwater flow direction will be controlled by a groundwater divide coinciding with the main ridge line. Deeper groundwater will follow regional flowpaths, with shallow local groundwater flow paths influenced by discrete groundwater discharge areas expressing as surface features (i.e. aquatic and terrestrial GDEs).

6.2.3 Groundwater quality and yield

6.2.3.1 Groundwater quality

Groundwater quality is discussed here in terms of salinity (i.e. TDS as mg/L or EC as $\mu\text{S}/\text{cm}$).

Groundwater in the alluvial sediments is generally fresher than the underlying sediments (primarily the Walloon Coal Measures in the groundwater study area). Groundwater in the Bremer River and Warrill River alluvium gradually becomes more saline (i.e. the quality decreases) down gradient, likely due to increasing influence of Walloon Coal Measures connectivity in the lower reaches (including the groundwater study area). Groundwater quality is expected to vary seasonally, where rainfall events can flush the aquifer and result in lowered salinity.

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).

An assessment of groundwater salinity and EC in the Clarence-Moreton Basin was provided by Rassam et al. (2014) in the bioregional assessments published by the Australian Government. The purpose of the bioregional assessments is to provide transparent scientific information to better understand the potential impacts of unconventional gas and coal mining developments on water and the environment. The assessment provides a comprehensive understanding of the Clarence-Moreton Basin including a detailed hydrogeological model and groundwater quality assessment. The groundwater quality assessment provides a comprehensive summary of groundwater quality data. Data was primarily sourced from two hydrogeological investigations conducted for the National Action Plan for Salinity and Water Quality by Pearce et al. (2007) and the DNRME groundwater database (2013).

A summary is provided in Table 6.3, together with data from bores within the groundwater study area where available.

Table 6.3 Summary of groundwater salinity – regional

| Aquifer unit | Salinity (mg/L) | | | EC (µS/cm) | | | Groundwater study area |
|---|-----------------|------------------|---------|------------|--------------------|---------|--|
| | Minimum | Mean | Maximum | Minimum | Mean | Maximum | |
| Alluvium (Bremer River and Warrill Creek) | ~500 | - | ~6,350 | 500 | 2,508 [#] | 1,000 | 2,100; 2,200 and 2,300 µS/cm Purga Creek Alluvium 1,370 µS/cm (median) Bremer River Alluvium 9,650 µS/cm (median) Warrill Creek Alluvium 3,000 µS/cm (median) Western Creek Alluvium |
| Walloon Coal Measures | 1,500 | 750 [#] | 19,475 | 3,000 | 8,554 [#] | 6,000 | 3,990 and 23,200 µS/cm |
| Koukandowie Formation | 359 | 4,248 | 14,496 | - | 6,607 | - | 13,500 µS/cm (Koukandowie Formation) |
| Gatton Sandstone | 333 | 6,452 | 24,294 | - | 9,971 | - | 300; 2,812 and 4,000 µS/cm (Marburg Subgroup – undifferentiated) |

Table note:

The table has been sourced from Rassam et al. (2014) however the source cites various sources including Mckibbin (1995), Metagasco (2007) and Pearce et al. (2007). As a result, the mean appears to be higher than the minimum however this is a reflection of two difference data sources being used.

One round of groundwater sampling was completed across September and October 2018, as a component of the overall geotechnical investigations (July through October 2018), at eight of the geotechnical investigation monitoring bores, providing a snapshot of baseline water quality along sections of the alignment that could help to inform a future groundwater monitoring and management plan. A summary of the laboratory results for EC and TDS for one round of samples taken in September/October 2018 is provided in Table 6.4.

Table 6.4 Summary of groundwater salinity – site investigations

| Bore ID | Formation sampled | TDS (mg/L) | EC (µS/cm) |
|---------------------------|-----------------------|------------|------------|
| 340-1-BH2101 | Gatton Sandstone | 5,990 | 10,200 |
| 340-1-BH2215 | Alluvium | 487 | 782 |
| 340-1-BH2220 | Koukandowie Formation | 8,950 | 13,000 |
| 340-1-BH2224 | Walloon Coal Measures | 1,230 | 2,230 |
| 340-1-BH2225 | Alluvium | 1,720 | 2,250 |
| 340-1-BH2229 | Koukandowie Formation | 357 | 760 |
| 340-1-BH2233 ¹ | Alluvium | 528 | 916 |
| | Gatton Sandstone | 2,780 | 4,290 |
| 340-1-BH2303 | Gatton Sandstone | 1,150 | 2,020 |

Table note:

1 BH2233 was sampled at 10 mbNS and 23 mbNS

Source: Golder 2018

The TDS and EC ranges are generally consistent with the findings of Rassam et al. (2014) for the wider Clarence - Moreton basin, and show the same variability for the various formations. It is noted that samples were collected from two depth at bore 340-1-BH2233 which is identified in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report as being screened across alluvium and underlying Gatton Sandstone. The samples collected using a manual bailer seem to suggest distinct TDS/EC values in the bore profile, possibly coinciding with the two groundwater systems/aquifers.

6.2.3.2 Groundwater yield

It is likely that yields from bores in the alluvium will vary considerably across the groundwater study area due to the variable extent and nature of alluvial sediments that can vary from coarse gravels to silty clays.

Regional studies have reported yields from the Walloon Coal Measures to be on average 0.5 litres per second (L/sec), with a maximum recorded of 5 L/sec (Rassam et al. 2014). In general, yields from bedrock sediments in the groundwater study area are likely to be relatively low, but dependent on the lithology intersected (sandstone, siltstone, mudstone etc) and frequency, size and interconnectivity of fractures. Individual bore yield estimates will also be affected by the available drawdown, bore construction and capacity of the pump used during testing.

Yields are generally low for bores in the groundwater study area, with all but two outliers below 1.6 L/sec (i.e. 80 per cent). The outliers were for a bore in the Purga Creek Alluvium (4.38 L/sec) and Western Creek Alluvium (12.6 L/sec). A summary of yields by aquifer is provided in Table 6.5.

Table 6.5 Study area bore yields

| Aquifer unit | No. of bores | Yield (L/sec) | | |
|-------------------------------------|----------------|---------------|------|---------|
| | | Minimum | Mean | Maximum |
| Alluvium | 8 | 0.25 | 2.85 | 12.60 |
| | 6 ¹ | 0.25 | 0.97 | 1.60 |
| Walloon Coal Measures | 9 ² | 0.13 | 0.43 | 1.23 |
| Marburg Subgroup (Undifferentiated) | 4 | 0.13 | 0.53 | 1.00 |

Table notes:

1 Two 'outliers' removed

2 One unknown aquifer considered likely to be Walloon Coal Measures

6.2.3.3 Summary

Available groundwater quality data in the groundwater study area was tabulated into Table 6.6 to compare the quality of the aquifers within the groundwater study area. As a general overview of water quality in each aquifer zone, the analytical results were compared with the NHMRC and NRMCC ADWG (2018) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG 2018) for livestock drinking water quality. Analytes identified as exceeding guideline values include:

- TDS exceeds the ADWG and ANZG livestock drinking water guidelines across all aquifers
- Hardness exceeds the ADWG within the Walloon Coal Measures
- Chloride exceeds the ADWG in all aquifers
- Sulphate exceeds the ADWG in the Western Creek alluvium and Walloon Coal Measures
- Sodium exceeds the ADWG in all aquifers
- Calcium exceeds the ANZG livestock drinking water guidelines in the Walloon Coal Measures
- Zinc exceeds the ADWG in the Warrill Creek alluvium.

Table 6.6 Comparison of groundwater quality data to guideline values in the groundwater study area

| Parameter | Guidelines | | Bremer River Alluvium (n = 7) | | | Warrill Creek Alluvium (n = 3) | | | Western Creek Alluvium (n = 5) | | | Walloon Coal Measures (n = 2) | | |
|---------------------------------|--------------------------------------|-----------------------------|----------------------------------|-------|-------------------|-----------------------------------|--------|--------|-----------------------------------|--------|-------------------|----------------------------------|--------|-------------------|
| | ANZG livestock drinking water (2018) | NHMRC and NRMCC ADWG (2018) | Min | Max | Median | Min | Max | Median | Min | Max | Median | Min | Max | Median |
| Physiochemical | | | | | | | | | | | | | | |
| Electrical conductivity (µS/cm) | - | - | 990 | 4,858 | 1,370 | 983 | 11,000 | 9,650 | 646 | 11,400 | 3,000 | 3,990 | 23,200 | 13,595 |
| pH value (pH units) | - | 6.5-8.5 | 7.2 | 8.3 | 7.9 | 7.3 | 7.4 | 7.4 | 6.7 | 8.0 | 7.4 | 7.6 | 7.6 | 7.6 |
| Turbidity (NTU) | - | - | 1 | 347 | 169 | 22 | 1427 | 94 | 149 | 1,239 | 694 | 20 | 84 | 52 |
| Hardness as CaCO3 (mg/L) | 4,000 | 6,000 | 305 | 1,800 | 529 | 311 | 3,540 | 3,237 | 187 | 2,140 | 965 | 279 | 6,540 | 3,410 |
| Alkalinity (mg/L) | - | - | 340 | 554 | 438 | 292 | 598 | 395 | 117 | 1150 | 504 | 172 | 651 | 412 |
| Sodium adsorption ratio | - | - | 1.3 | 10 | 1.8 | 2 | 7.1 | 7.1 | 1.2 | 18 | 2.7 | 19 | 20 | 19.5 |
| Total Dissolved Solids (mg/L) | 2,000 ^b | 600 | 527 | 2,630 | 792 | 539 | 6,040 | 5,690 | 293 | 7,120 | 1,638 | 2,250 | 16,000 | 9,125 |
| Dissolved anions | | | | | | | | | | | | | | |
| Bicarbonate (mg/L) | - | - | 415 | 676 | 518 | 355 | 727 | 479 | 143 | 1,380 | 615 | 207 | 788 | 498 |
| Carbonate (mg/L) | - | - | 0.9 | 8.1 | 3.1 | 0.6 | 1.7 | 1.2 | 3.7 | 6.9 | 5.3 | 1.4 | 3 | 2.2 |
| Chloride (mg/L) | - | 250 | 100 | 1,362 | 213 | 143 | 3,460 | 3,393 | 117 | 3,180 | 720 | 956 | 9,500 | 5,228 |
| Fluoride (mg/L) | 2 | 1.5 | 0.07 | 0.25 | 0.1 | 0.04 | 0.11 | 0.08 | 0.1 | 0.25 | 0.13 | 0.1 | 0.2 | 0.15 |
| Sulfate as SO4 (mg/L) | 1,000 | 250 | 1 | 30 | 6.5 | 3.7 | 46 | 44.6 | 1 | 741 | 5.95 | 10 | 822 | 416 |
| Dissolved cations | | | | | | | | | | | | | | |
| Sodium (mg/L) | - | 180 | 70 | 402 | 88 | 79.5 | 965 | 923.8 | 37.4 | 1,890 | 175.4 | 783 | 3,490 | 2,137 |
| Potassium (mg/L) | - | - | 1 | 5.8 | 1.9 | 0.9 | 8.2 | 7.7 | 0.6 | 4.8 | 2.1 | 3.9 | 33 | 18.45 |
| Iron (mg/L) | - | 0.3 | - | - | 0.01 ^a | - | - | - | - | - | 0.01 ^a | - | - | 0.01 ^a |
| Calcium (mg/L) | 1,000 | - | 20 | 366 | 99 | 66.8 | 725 | 632.2 | 32.6 | 262.6 | 104 | 49 | 1,010 | 530 |
| Magnesium (mg/L) | - | - | 47 | 216 | 68 | 35 | 421 | 403.6 | 25.8 | 462 | 113 | 38 | 976 | 507 |

| Parameter | Guidelines | | Bremer River Alluvium (n = 7) | | | Warrill Creek Alluvium (n = 3) | | | Western Creek Alluvium (n = 5) | | | Walloon Coal Measures (n = 2) | | |
|-------------------------|--------------------------------------|-----------------------------|----------------------------------|------|--------|-----------------------------------|------|-------------------|-----------------------------------|------|-------------------|----------------------------------|------|-------------------|
| | ANZG livestock drinking water (2018) | NHMRC and NRMCC ADWG (2018) | Min | Max | Median | Min | Max | Median | Min | Max | Median | Min | Max | Median |
| Nutrients | | | | | | | | | | | | | | |
| Phosphate (mg/L) | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Nitrogen (mg/L) | - | - | 1 | 30 | 3.2 | 1.3 | 24.8 | 10 | 1.3 | 6 | 1.5 | 2.5 | 25 | 13.75 |
| Dissolved metals | | | | | | | | | | | | | | |
| Zinc (mg/L) | 20 | 3 | 0.01 | 0.03 | 0.025 | 0.05 | 4.8 | 0.54 | 0.32 | 0.53 | 0.425 | - | - | 0.01 ^a |
| Aluminum (mg/L) | 5 | 0.2 | 0.05 | 0.05 | 0.05 | 0.05 | 0.08 | 0.065 | 0.02 | 0.07 | 0.045 | 0.05 | 0.05 | 0.05 |
| Boron (mg/L) | 5 | 4 | 0.02 | 0.02 | 0.02 | - | - | 0.04 ^a | - | - | 0.34 ^a | 0.43 | 0.54 | 0.485 |
| Copper (mg/L) | 0.5 | 2 | 0.01 | 0.03 | 0.03 | 0.01 | 0.03 | 0.02 | - | - | 0.03 ^a | - | - | 0.03 ^a |

Table notes:

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

a Only single data value available

b Most conservative guideline value out of the range provided in Table 9.3.3

6.2.4 Groundwater recharge

In areas with alluvial or colluvial materials, recharge will be via throughflow in the aquifers from up hydraulic gradient of the groundwater study area (that is, from the south), by direct infiltration of rainfall, and by seepage from ephemeral streams during periods of flow following rainfall. 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. Throughflow from up hydraulic gradient of the groundwater study area (that is, from the south) is also a recharge mechanism in the bedrock aquifers.

There is a net monthly and annual deficit of rainfall on average, with average evaporation exceeding average rainfall (refer Figure 3). Direct infiltration of rainfall to groundwater is unlikely during dry periods, when light rainfall events will be absorbed as 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 at the site are expected to be low – with typical (median) values estimated to be around 11 mm/year for the alluvium and 4 mm/year for the bedrock sediments (Golder 2019).

Responses of groundwater levels to climate variability in alluvial sediments was reported by Cui et. al. 2018 for the Bremer River valley. The report indicated a decrease in the median of 0.3 m/year during drought conditions and an increase of 0.5 m/year during wet periods, though the results for the wet period may have been influenced by the extreme conditions from the 2011 floods. These rates are less pronounced in sedimentary rock units with the median levels of the Walloon Coal Measures 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 an increase of as much as 0.7 m/year during wet periods.

6.2.5 Groundwater discharge

In areas with alluvial or colluvial materials, discharge out of the groundwater study area is as throughflow of groundwater to the north within the alluvial aquifers. Other discharge mechanisms include evaporation and transpiration from vegetation growing in the creek beds and along the banks, seepage to the underlying units (following flood events), and groundwater extraction.

Discharge mechanisms from the bedrock aquifers are throughflow out of the groundwater study area towards the north, via leakage into the underlying and/ or adjacent aquifers, evaporation and transpiration, and as groundwater extraction.

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 and site-specific hydraulic conductivity values were estimated from slug tests conducted in October and November 2018 at eight of the nine groundwater monitoring bores constructed during geotechnical site investigation (Golder 2018).

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 2019) | | Slug tests (Golder 2018) | |
|---|--|--------------------------------|---------------------------------|--------------------------------|---------------------------|--------------------------------|
| | No. of bores | Hydraulic conductivity (m/day) | No. of tests | Hydraulic conductivity (m/day) | No. of tests ^b | Hydraulic conductivity (m/day) |
| Alluvium | 193 | 0.09 to 1,500 | 96 | 0.09 to 1,470 | 2 | 0.01 to 0.85 |
| Walloon Coal Measures | 7 | 0.5 to 17.2 | 79 | 0.0002 to 0.95 | 1 | 0.20 to 0.54 |
| Marburg Subgroup (undifferentiated) | 8 | 0.03 to 5.8 | | - | - | - |
| Marburg Subgroup: Koukandowie Formation | - | - | 26 | 0.004 to 0.82 | 2 | 0.007 to 1.7 |
| Marburg Subgroup: Gatton Sandstone | 2 | 1.1 to 4.9 | 80 | 0.00009 to 0.071 | 1 | 0.0001 to 0.0003 |

Table notes:

a Raiber et al. (2016)

b Results for seven bores included. 34001-BH2233 screened across two formations not included.

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, will be at the lower end range provided in Table 6.7; due to the fining upwards sequence of gravels and coarse sands at the base, and fine-grained flood-plain sediments at the top.

6.4 Groundwater users

6.4.1 Registered bores

A desktop survey of registered groundwater bores was conducted via a search of the DNRME groundwater database (accessed online 14 January 2019). This provides information on the location, depths and aquifer of registered bores. Where licensed groundwater extraction exists for registered bores these are identified, noting that no entitlement (permit to take water) is required for domestic and stock watering use.

A total of 65 groundwater bores were identified within 1 km of the proposed rail alignment. Of the 65 identified, 43 are designated existing and 22 abandoned. It should be noted that bores constructed prior to 2002 were not required to register with DNRME and as a result the DNRME 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.

Key attributes for the 43 existing registered bores are included in Table 6.8, and bore locations in proximity to the alignment are depicted on Figure 8a-e.

6.4.2 Groundwater entitlements

Part of the groundwater study area is managed under either the Water Plan (GABORA) 2017 or Water Plan (Moreton) 2007. The QLD water entitlements database (DNRME) (accessed 12 August 2019) was reviewed for bores with extraction licences (licences are only required for bores with extraction other than domestic and stock watering purposes) for bores within either Plan. The database search indicated there were no such bores within 1 km of the Project. Therefore, the Project is not expected to impact on existing water plans.

Table 6.8 Registered groundwater bores within 1 km of Project alignment

| Bore ID | Use | Drilled depth (mbNS) | Bore depth (mbNS) | Screen top (mbNS) | Screen base (mbNS) | Aquifer | Yield (L/s) | Quality |
|----------|--|----------------------|-------------------|-------------------|--------------------|------------------------|-----------------------------------|--------------------------------------|
| 14310144 | - | 18.59 | 12.8 | 8.5 | 13.7 | Western Creek Alluvium | - | Brackish to saline |
| 14310262 | Water resource investigation/ subartesian monitoring | 19.8 | 19.2 | 10.7 | 18.3 | | - | - |
| 124566 | Water supply | 18 | 18 | 12.5 | 17.8 | | 3 | Fresh |
| 124567 | Water supply | 21 | 21 | 12 | 20.9 | | 1 | Fresh |
| 120194 | Water supply | 22 | 22 | 16.2 | 21.7 | | 12.6 | Fresh |
| 14310062 | - | 15.24 | 14.4 | 13.4 | 14.3 | Bremer River Alluvium | - | Slightly brackish |
| 14310063 | - | 13.71 | 12.2 | 11.3 | 11.9 | | - | Fresh to slightly brackish |
| 14310066 | - | 18.89 | 16.8 | 14.5 | 17.4 | | - | Fresh to slightly brackish |
| 124768 | Water supply | 18 | 18 | 12 | 18 | | 1.25 | Brackish |
| 14310245 | Subartesian monitoring | 19.6 | 19.6 | 12 | 18.6 | Warrill Creek Alluvium | - | Brackish to saline |
| 134322 | Water supply | 14.7 | 14.7 | 7.5 | 14.7 | | - | - |
| 134323 | Water supply | 14.7 | 14.7 | 11.4 | 14.3 | | - | - |
| 14310277 | WR investigation/ subartesian monitoring | 19 | 18 | 11.3 | 18 | Purga Creek Alluvium | - | Slightly brackish |
| 133518 | Water supply | 17.1 | 17.1 | 11.4 | - | | 1.6 | Slightly brackish (2,200 μ S/cm) |
| 154100 | Water supply | 14.6 | 14.6 | 3 | - | | 0.6 | Slightly brackish (2,300 μ S/cm) |
| 154101 | Water supply | 11.5 | 11.5 | 10 | 11 | | 0.25 | Slightly brackish (2,100) |
| 120509 | Water supply | 11 | 11 | 8.5 | 11 | | 1.37 | Brackish |
| 120513 | - | 10 | 10 | 7.6 | 10 | | - | Fresh |
| 124350 | Water supply | 17.4 | 17.4 | 5 | 17.4 | | 4.38 | - |
| 120574 | Water supply | 18 | 18 | 12 | 18 | | Sandy Creek Alluvium ¹ | 0.75 |
| 133519 | Water supply | 17 | 17 | 14 | 17 | 1.9 | | - |
| 138035 | Water supply | 29 | 28.9 | 23 | 28.9 | - | | Brackish |
| 138075 | Water supply | 23 | 21.2 | 7 | 21.2 | - | | Brackish |

| Bore ID | Use | Drilled depth (mbNS) | Bore depth (mbNS) | Screen top (mbNS) | Screen base (mbNS) | Aquifer | Yield (L/s) | Quality |
|----------|------------------------|----------------------|-------------------|-------------------|--------------------|-------------------------------|---------------------------------|------------------------|
| 14310223 | Subartesian monitoring | 100 | 97.4 | 85.4 | 97.4 | Walloon Coal Measures | - | Brackish to saline |
| 14310224 | Subartesian monitoring | 24 | 23 | 16 | 23 | | 0.25 | Brackish |
| 124897 | Water supply | 32 | 32 | 24 | 32 | | 0.31 | Brackish |
| 133261 | Water supply | 30.3 | 30.3 | 18.3 | 30.3 | | 0.29 (coal) 0.41 (gravel) | Potable to brackish |
| 138180 | Water supply | 147 | 147 | 135 | 147 | | 0.65 (sandstone) 0.14 (coal) | Brackish to saline |
| 22039 | - | 87.78 | - | 66 | - | | - | Salty |
| 22040 | - | 195.07 | - | 46.77 | - | | - | - |
| 120167 | Water supply | 57 | 57 | 45 | 57 | | 0.35 | Brackish |
| 138345 | Water supply | 120 | 32 | 20 | 32 | | 1.23 | Brackish (3,700 µS/cm) |
| 143683 | Water supply | 30 | 30 | 18 | 30 | | 0.4 | Brackish |
| 152639 | Water supply | 30 | 30 | 13 | 30- | | 0.13 to 0.88 | Brackish |
| 138287 | WR Investigation | 38 | 38 | 28 | 34 | | Koukandowie Formation | - |
| 152848 | Water supply | 36.7 | 36 | 22.6 | 28.6 | Marburg Subgroup ² | 0.13 | Brackish (4,000 µS/cm) |
| 152849 | Water supply | 24.5 | 18.1 | 11.1 | 17.1 | | 0.5 | Fresh (300 µS/cm) |
| 152850 | Water supply | 30 | 28.8 | 16 | 27.8 | | 1 to 2 | Good |
| 120512 | Water supply | 10 | 10 | 8 | 10 | | 0.5 | Brackish (2,812 µS/cm) |
| 79675 | Water supply | - | - | - | - | - | - | Fresh |
| 120510 | Water supply | 12.9 | 12.9 | 9.9 | 12.9 | - | - | Slightly brackish |
| 138034 | - | - | - | - | - | - | - | - |
| 124525 | Water supply | 59 | 59 | 15 47 | 21 59 | Coal | 0.23 to 0.47 | Potable |

Table notes:

- 1 Possibly equivalent to Upper Tributary of Purga Creek
 - 2 Includes Koukandowie Formation (upper unit) and Gatton Sandstone (lower unit)
- '-' – Data not reported

Groundwater users in the groundwater study area taking groundwater for purposes other than stock or domestic from aquifers managed under either Water Plan (GABORA or Moreton) at the commencement of the groundwater management plans, are authorised to continue taking groundwater. No licences have been issued to such bores in the groundwater study area. Therefore, a groundwater survey and property inspections can determine if any authorised users are located in the study area.

6.5 Groundwater dependent ecosystems

The GDE Atlas (BoM 2020) was developed as a national dataset of Australian GDEs and potential GDEs. The GDE 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 GDE Atlas 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, this is confirmed by undertaking an ecological investigation to identify the location, extent and source of the GDE. Ground truthing of GDEs was not possible due to land access conditions therefore the modelled extent of the aquatic GDEs are accepted as true presence, and thus form a potentially sensitive receptor.

6.5.1 Aquatic groundwater dependent ecosystems

Numerous watercourses traversing the groundwater study area are designated as moderate potential GDEs from regional studies; including Western Creek, Bremer River, Warrill Creek, Purga Creek and Teviot Brook (refer Figure 9a-e). The potential GDEs are described as wetlands 'supplied by alluvial aquifers with near-permanent flow'.

No springs were observed during ecological field assessments for the Project associated with surface water or identified from the GDE Atlas (BoM 2020) within the study area. Noting this, several first order streams intersect the Project alignment and may be associated with natural springs.

6.5.2 Terrestrial groundwater dependent ecosystems

Within the groundwater study area, to the west and east of the Teviot Range, several moderate potential terrestrial GDEs (from regional studies) are either intersected or close to the proposed rail line. These are described as wetland or riparian vegetation 'supplied by alluvial aquifers with near-permanent flow'.

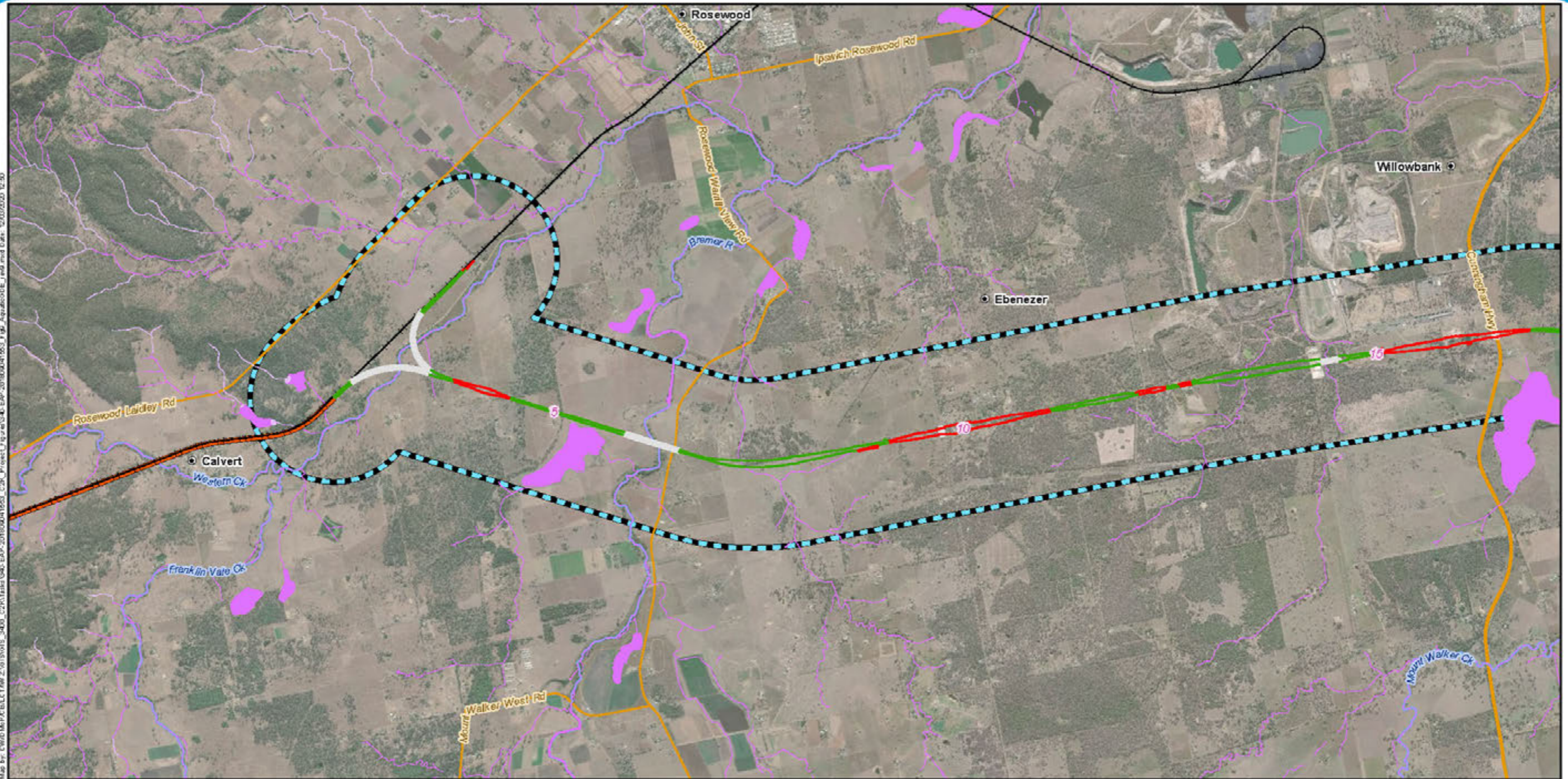
Low and moderate potential terrestrial GDEs (from regional studies) have been identified within the Teviot Range portion of the groundwater study area. These are generally described as wetland vegetation supplied by low porosity sedimentary rock with intermittent flow. Wetland supplied by alluvial aquifers with near permanent flow (eastern flank) and riparian vegetation supplied by sedimentary rocks with saline flow (western flank) are also indicated (refer Figure 10a-e).

6.6 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.

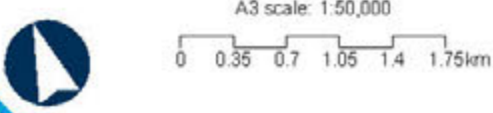
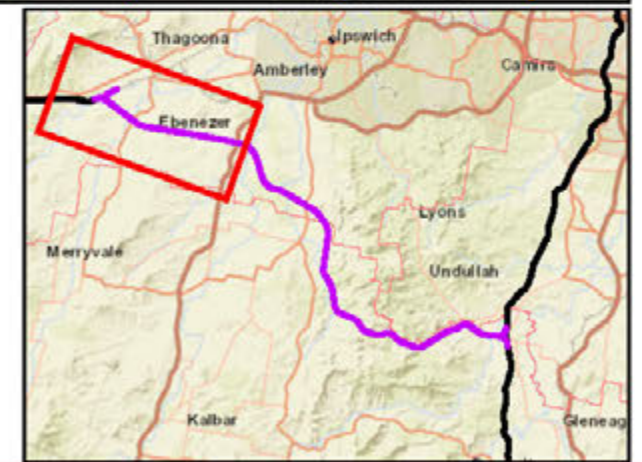
It is anticipated that there will be interaction between watercourses and shallow groundwater in the associated alluvial sediments at some locations; particularly where drainage channels are more deeply incised, and groundwater levels are shallow. The degree of interconnection will vary laterally due 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 in the Bremer River basin found that hydraulic connection between the aquifer and river was relatively poor and of limited lateral extent (Raiber et al. 2016). This was thought to be linked to the broad valley of the Bremer River and limited depth of incision into the underlying alluvial sediments, with upper sections typically fine-grained clay rich floodplain sediments.

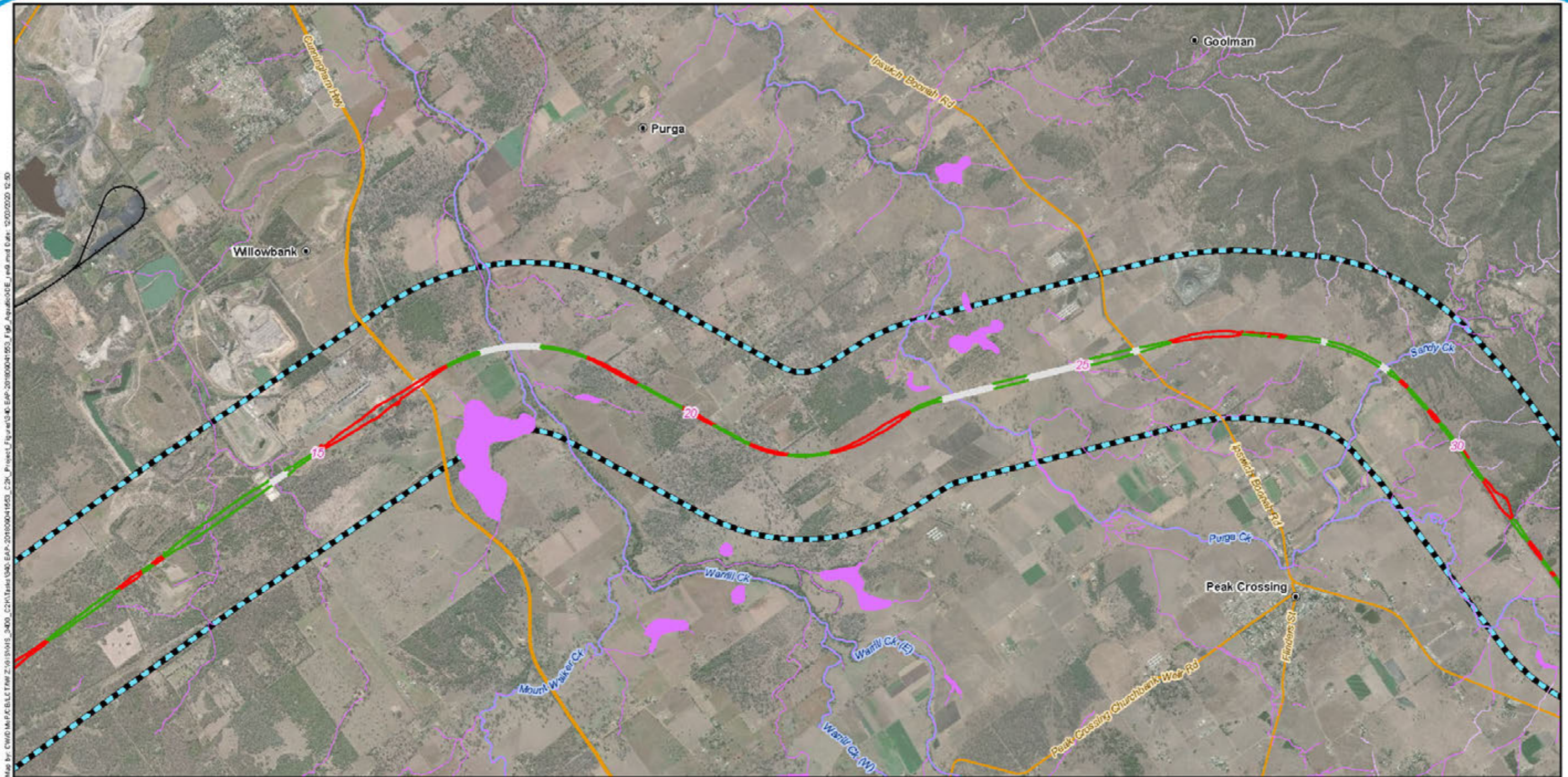


Legend

- | | | | |
|-----------------|-----------------|--------------------------|--|
| ● Localities | — Cut | — H2C project alignment | Aquatic GDEs |
| 5 Chainage (km) | — Fill | — Watercourses | ■ Moderate potential GDE - from regional studies |
| — Bridges | — Existing rail | — Major roads | ■ Low potential GDE - from regional studies |
| | | — Minor roads | |
| | | ■ Groundwater study area | |



Calvert to Kagaru
Figure 9a: Potential aquatic GDEs



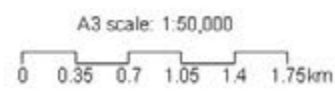
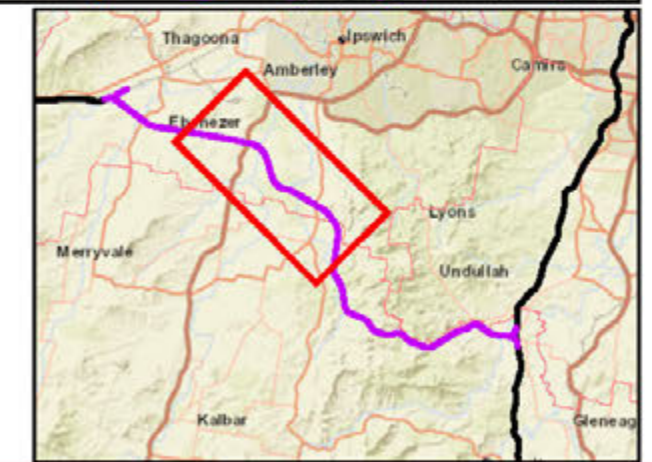
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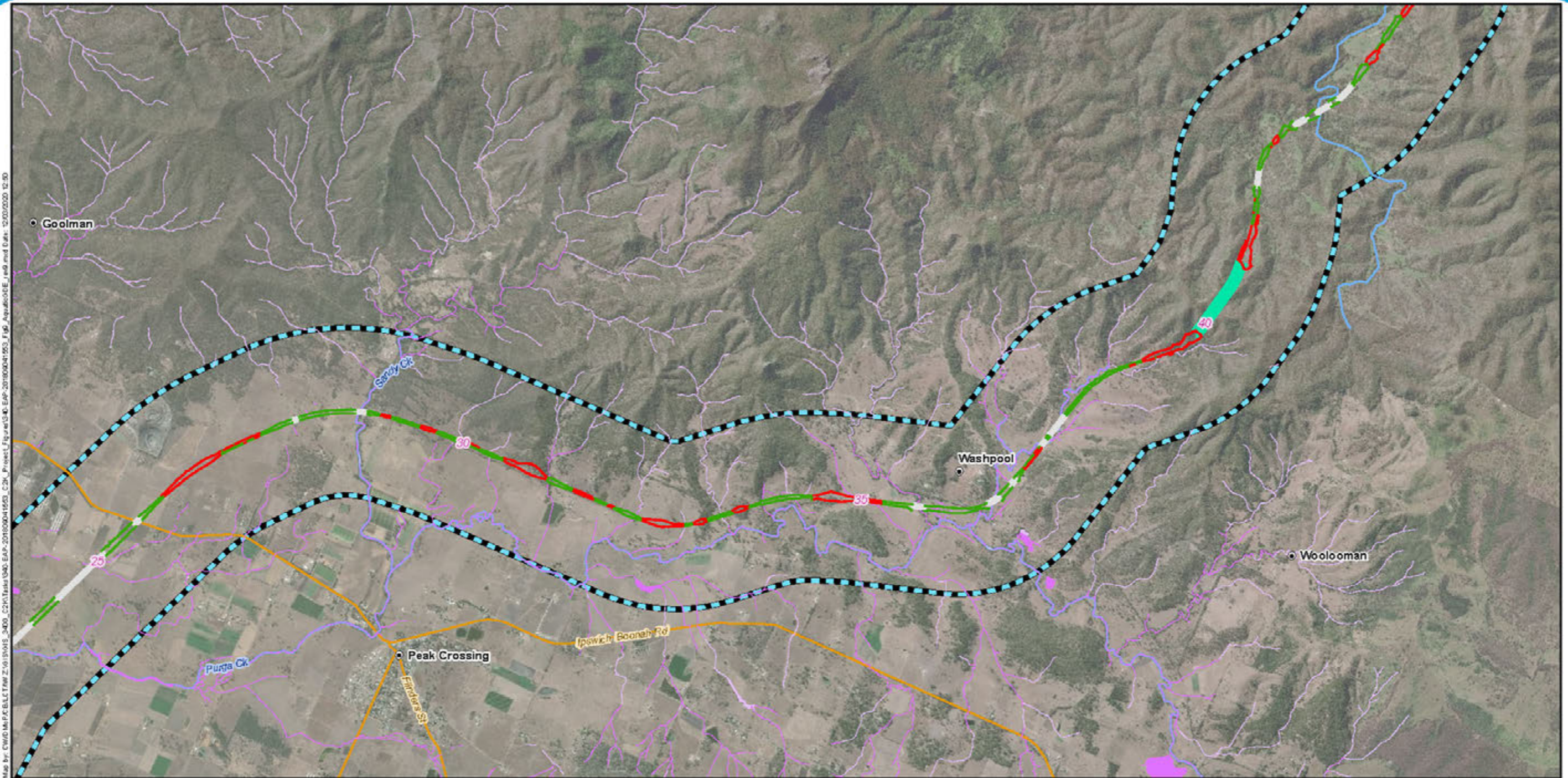
Legend

- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Existing rail
- Watercourses
- Major roads
- Minor roads
- ▭ Groundwater study area

Aquatic GDEs

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



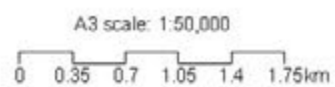
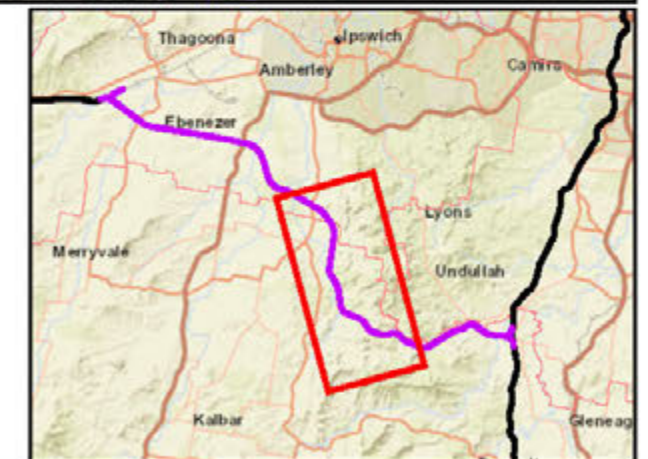


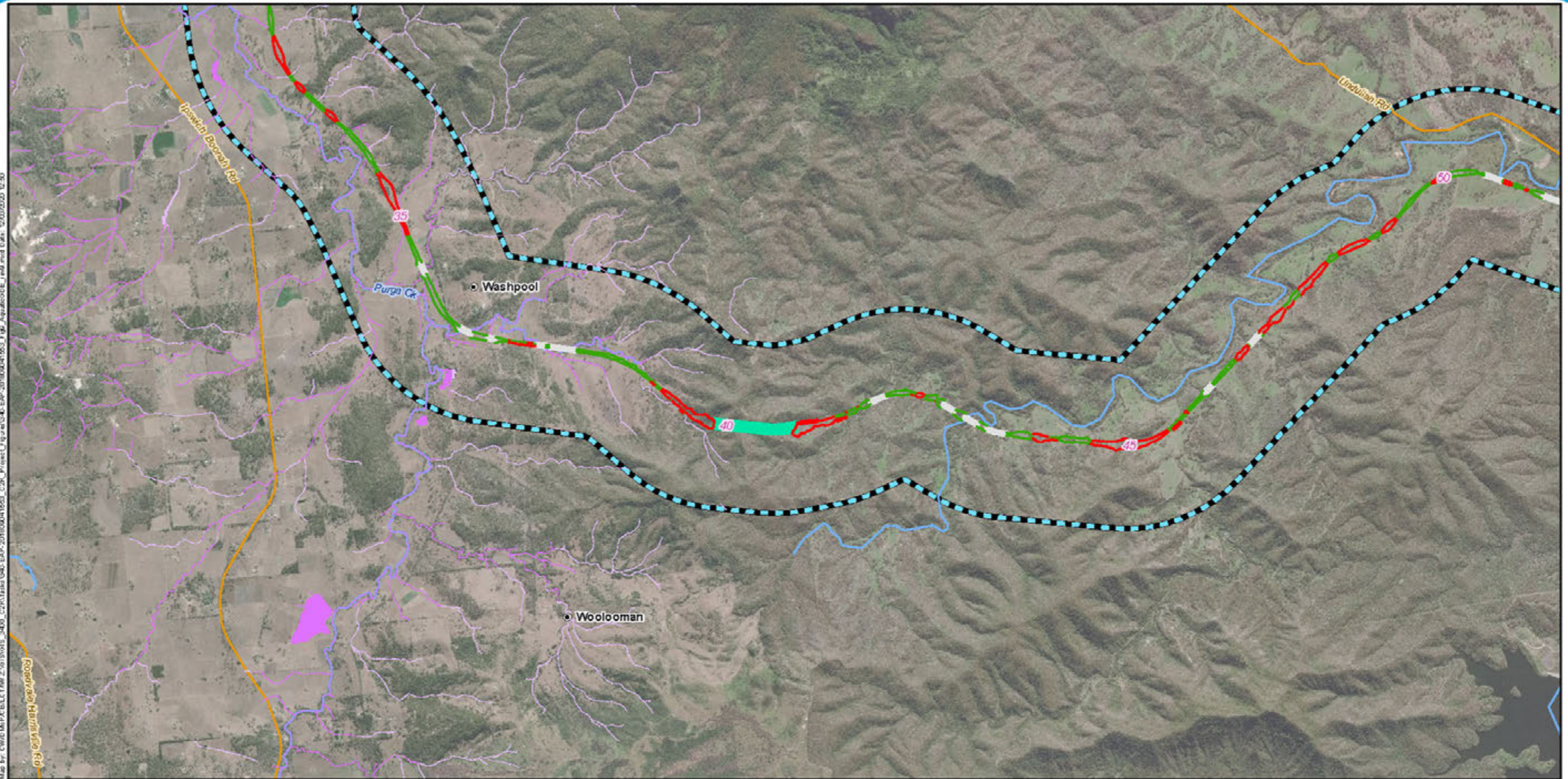
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- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Tunnel
- Watercourses
- Minor roads
- Groundwater study area

Aquatic GDEs

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



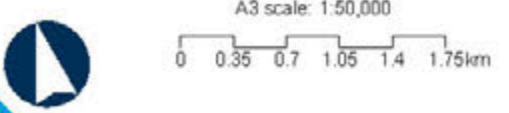
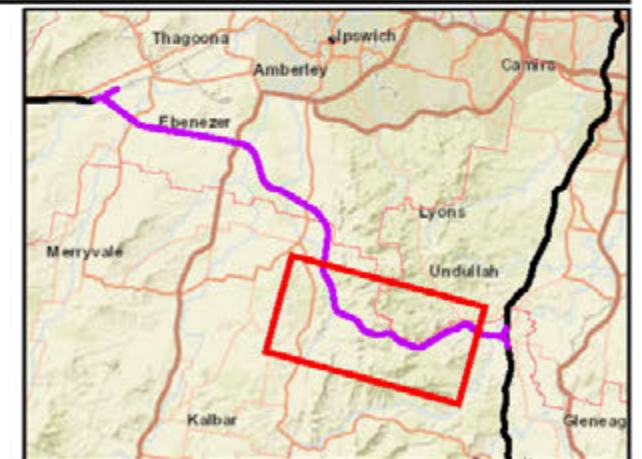


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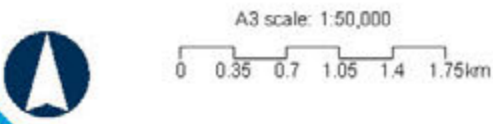
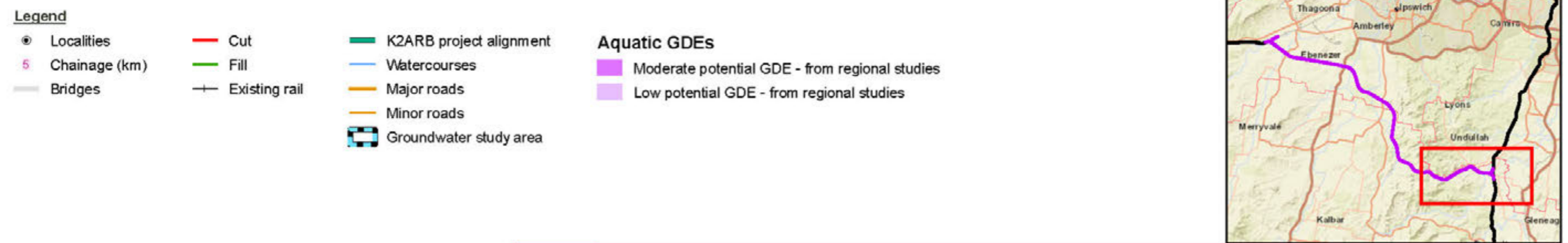
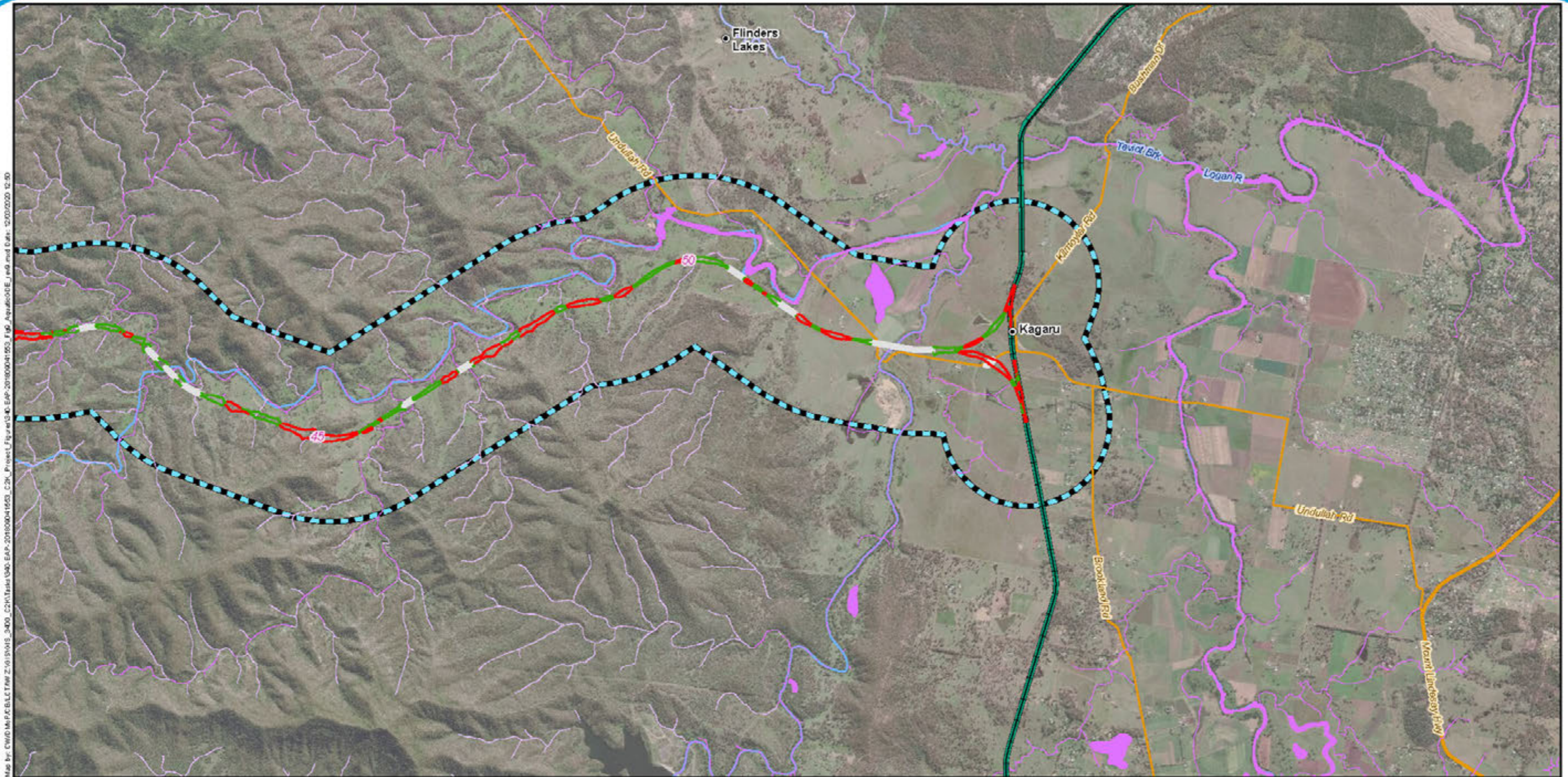
- Localities
- 5 Chainage (km)
- Bridges
- Cut
- Fill
- Tunnel
- Watercourses
- Minor roads
- Groundwater study area

Aquatic GDEs

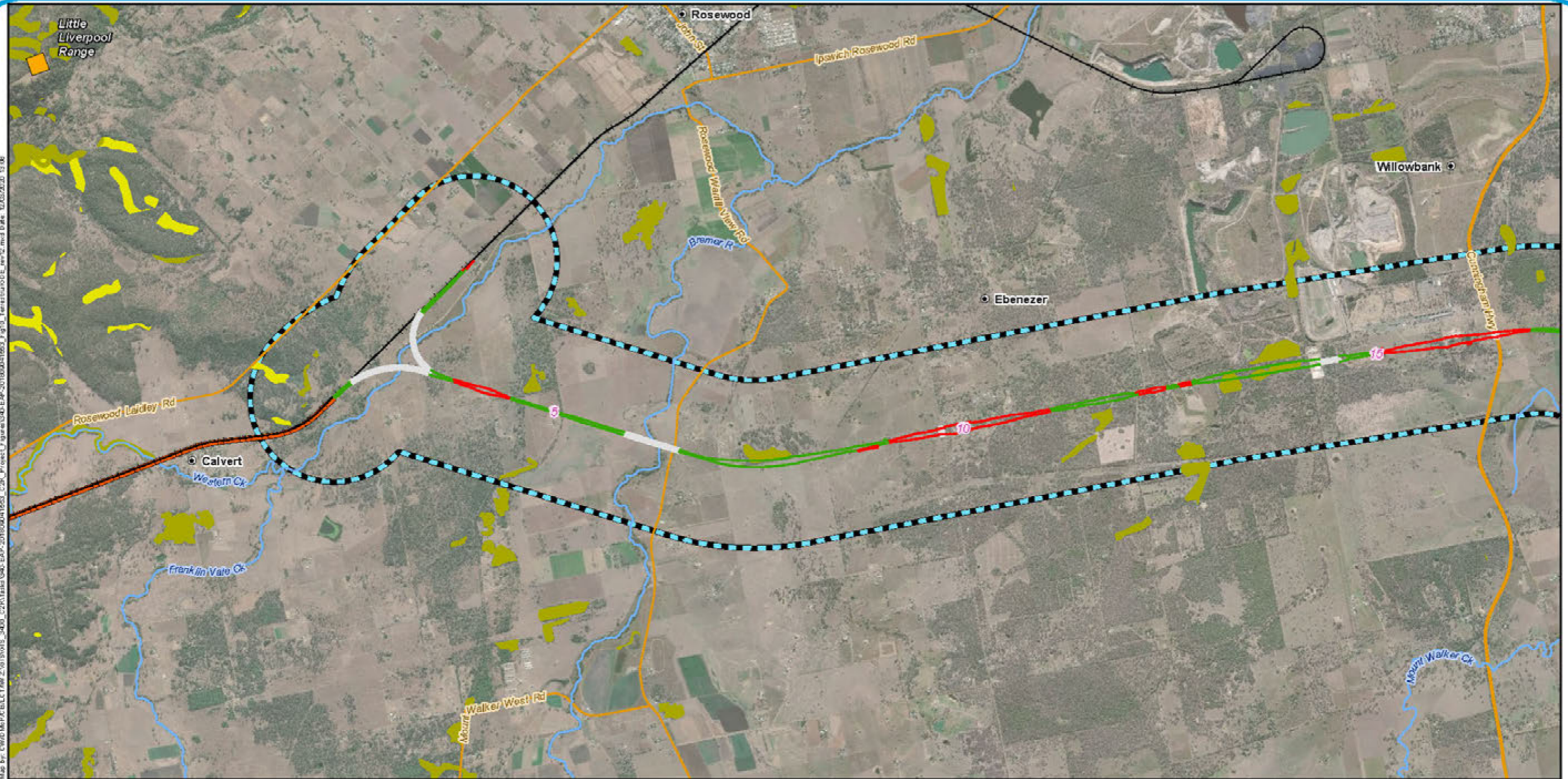
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



Calvert to Kagaru
Figure 9d: Potential aquatic GDEs



Calvert to Kagaru
Figure 9e: Potential aquatic GDEs

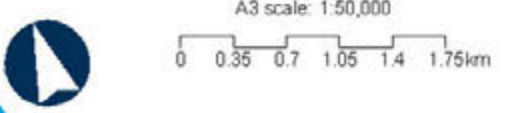
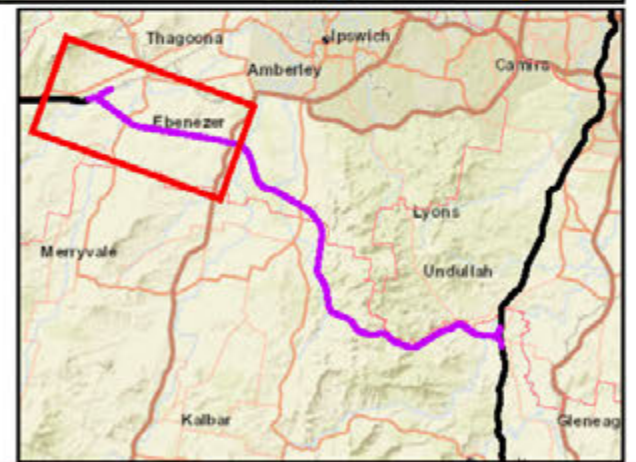


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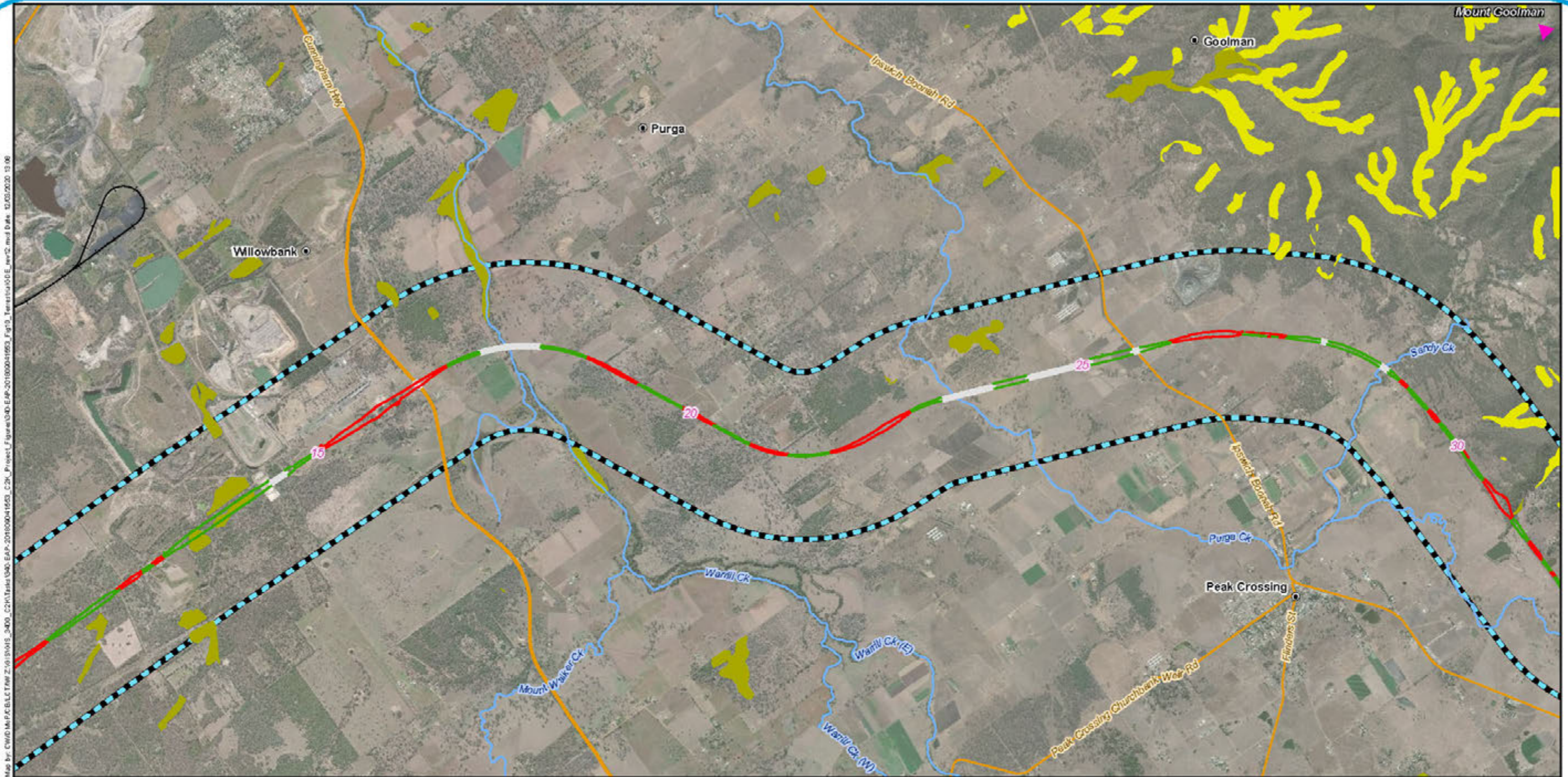
- Localities
- 5 Chainage (km)
- Range
- Bridges
- Cut
- Fill
- Existing rail
- H2C project alignment
- Watercourses
- Major roads
- Minor roads
- Groundwater study area

Terrestrial GDE

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



Calvert to Kagaru
Figure 10a: Potential terrestrial GDEs

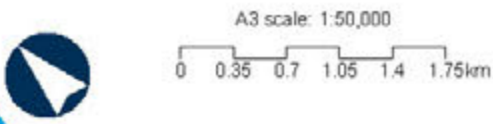
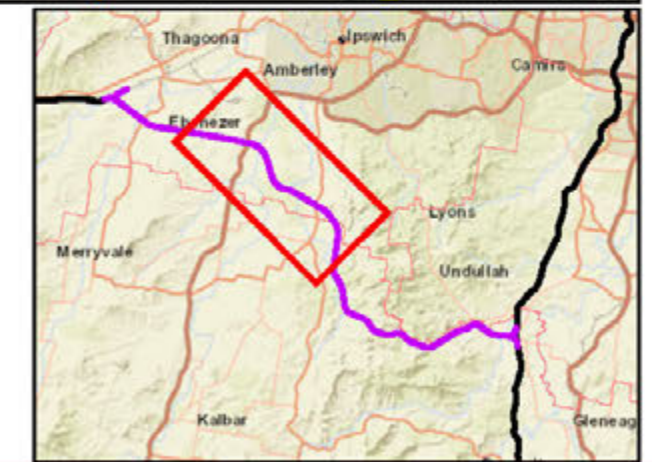


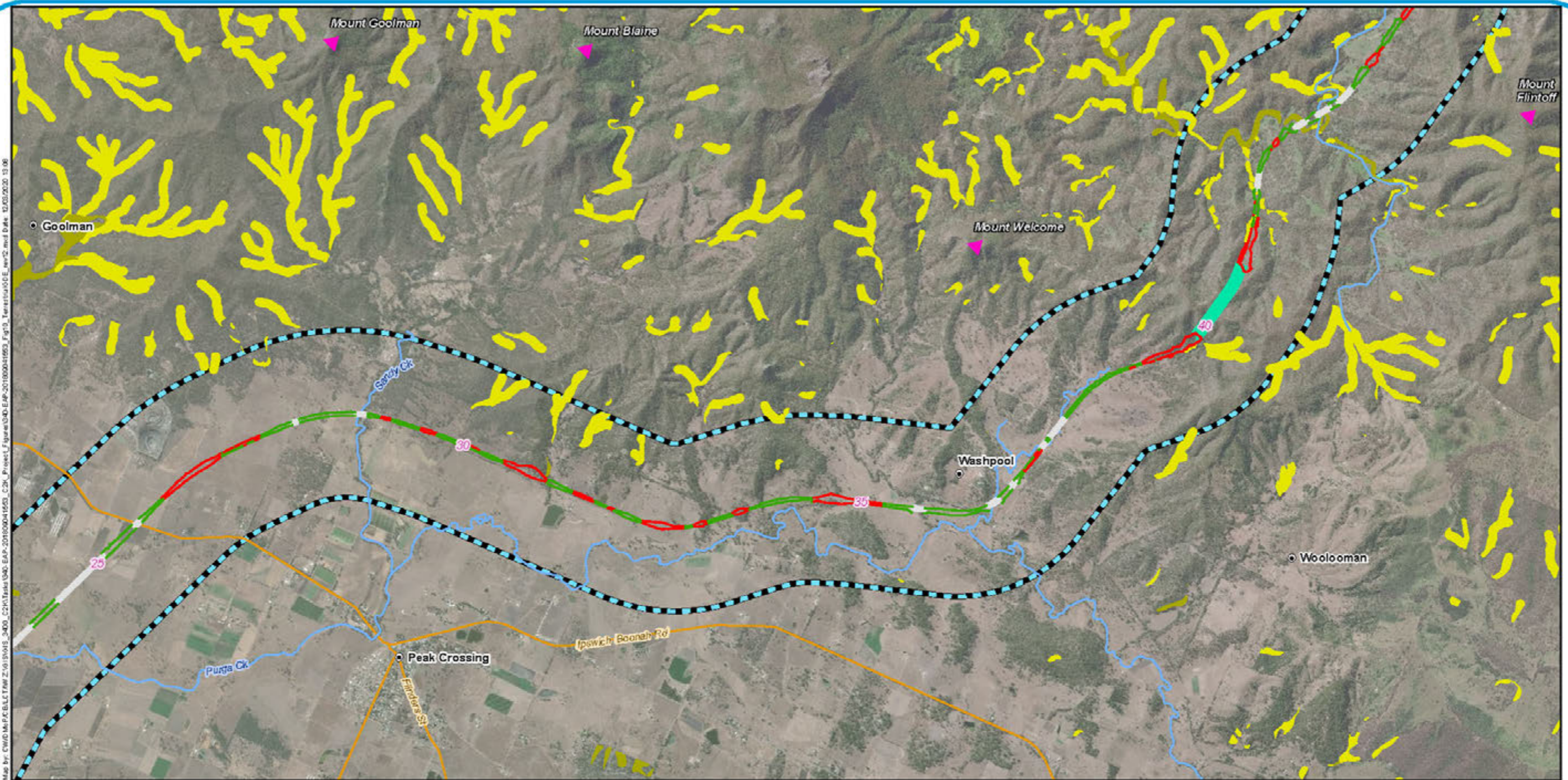
Legend

- Localities
- 5 Chainage (km)
- ▲ Mountain
- Bridges
- Cut
- Fill
- Existing rail
- Watercourses
- Major roads
- Minor roads
- Groundwater study area

Terrestrial GDE

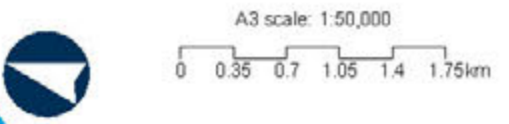
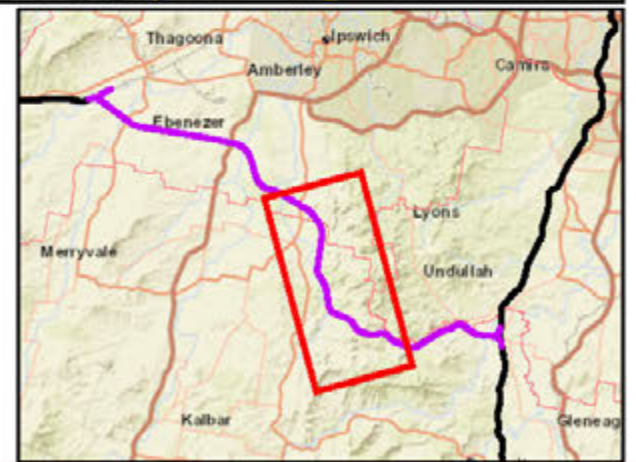
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies

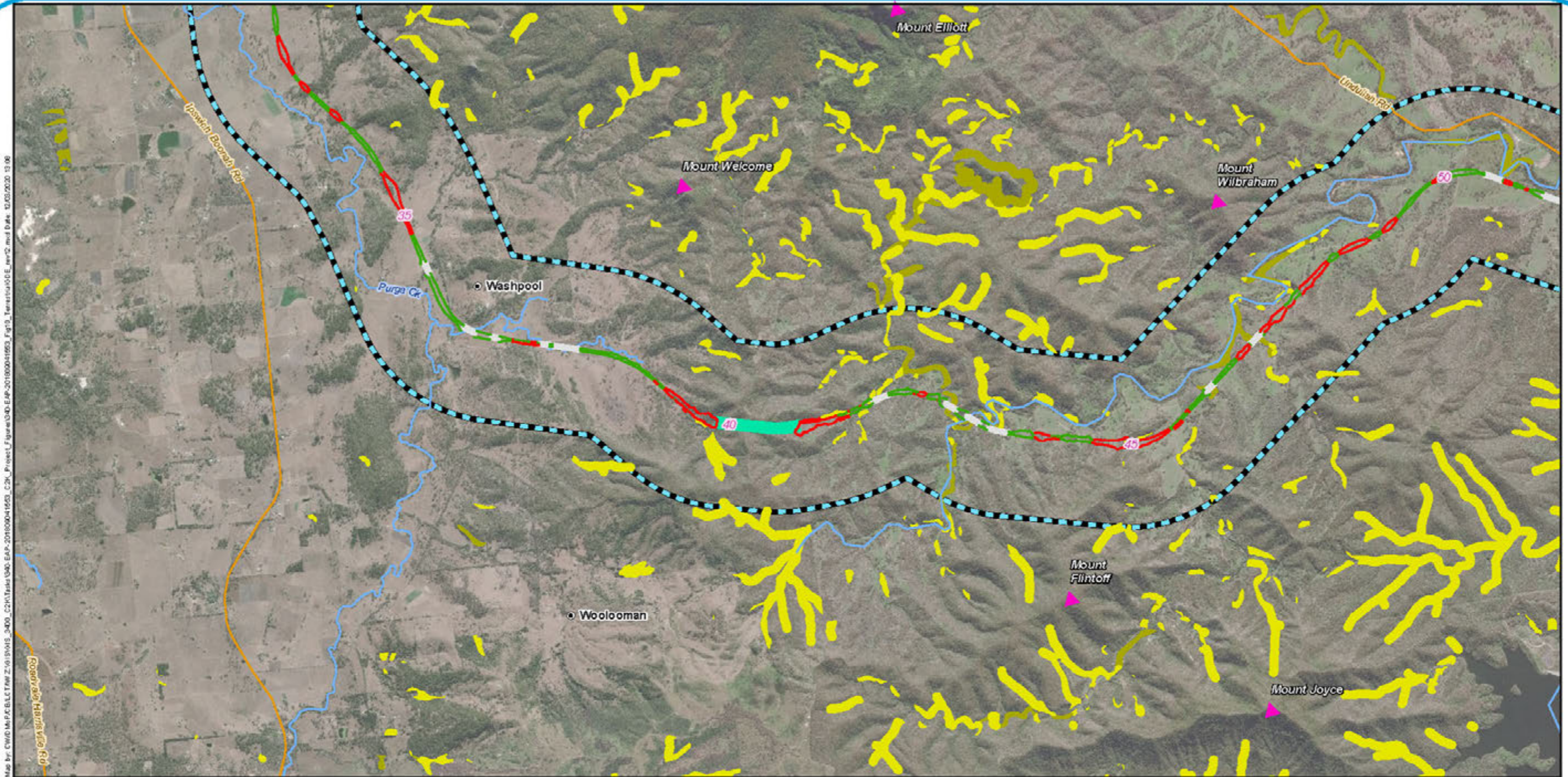




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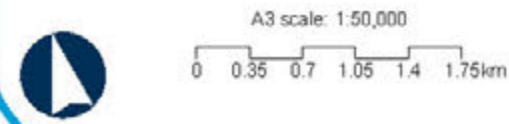
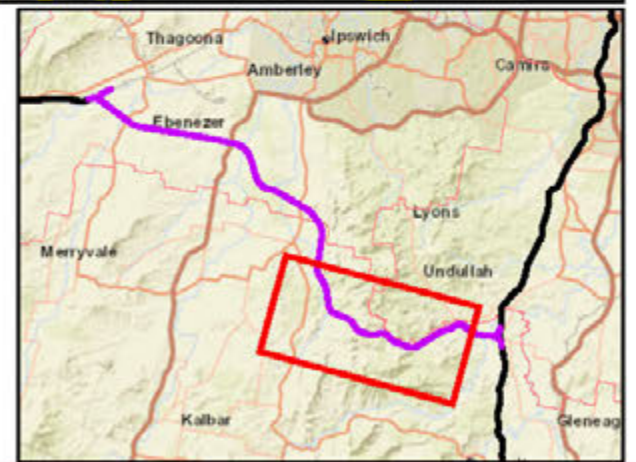
- Localities
- 5 Chainage (km)
- ▲ Mountain
- Bridges
- Cut
- Fill
- Tunnel
- Watercourses
- Minor roads
- Groundwater study area
- Moderate potential GDE - from regional studies
- Low potential GDE - from regional studies



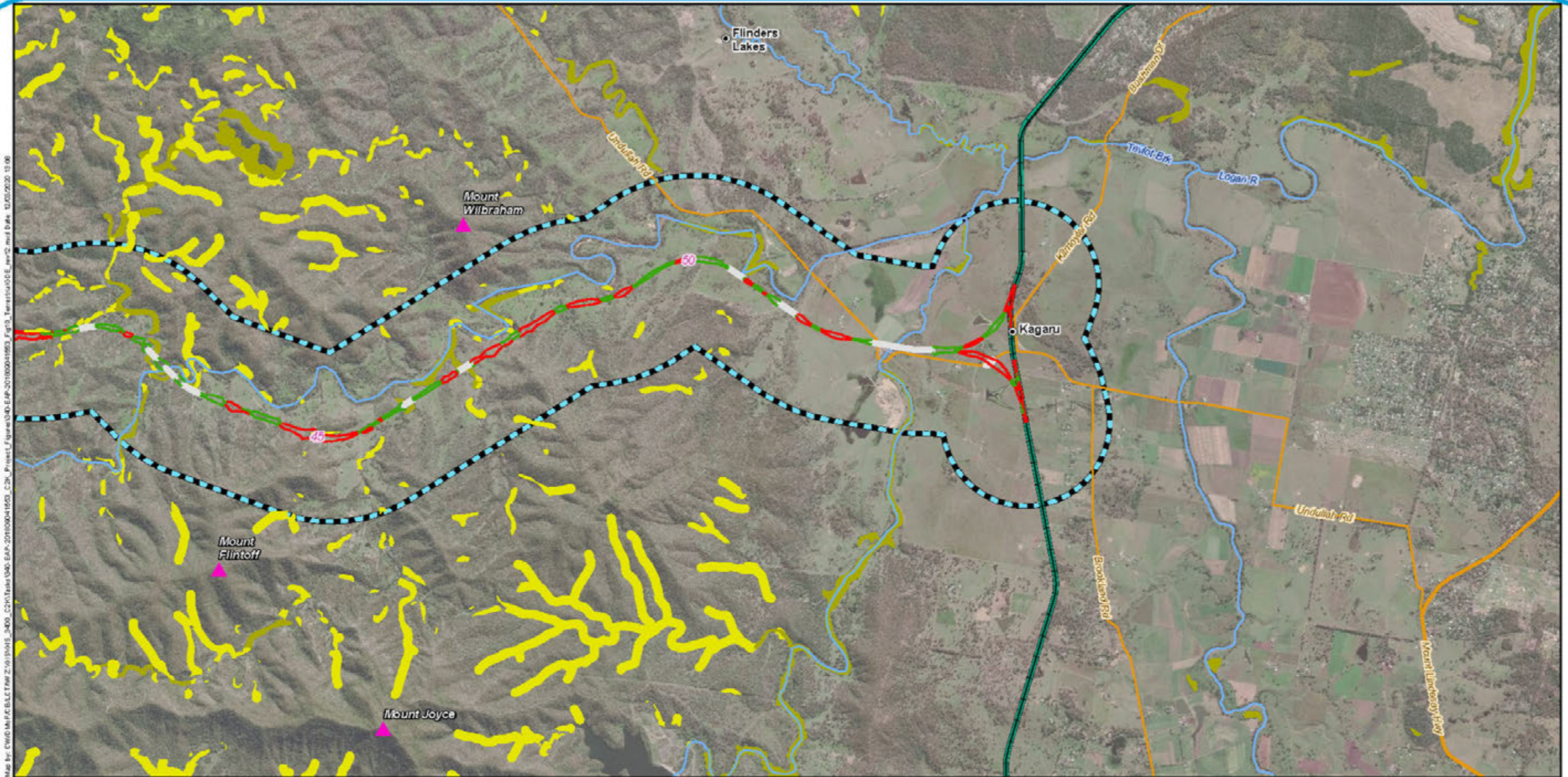


Legend

- | | | | |
|-----------------|----------|--------------------------|--|
| ● Localities | — Cut | — Watercourses | Terrestrial GDE |
| 5 Chainage (km) | — Fill | — Minor roads | ■ Moderate potential GDE - from regional studies |
| ▲ Mountain | — Tunnel | — Groundwater study area | ■ Low potential GDE - from regional studies |
| — Bridges | | | |



Calvert to Kagaru
Figure 10d: Potential terrestrial GDEs

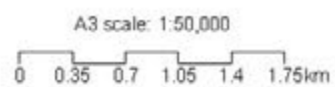
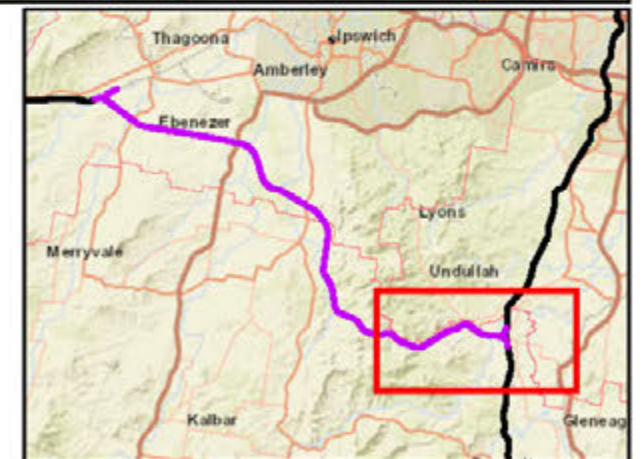


Legend

- | | | |
|-----------------|---------------------------|--------------------------|
| ● Localities | — Cut | — Watercourses |
| 5 Chainage (km) | — Fill | — Major roads |
| ▲ Mountain | — Existing rail | — Minor roads |
| — Bridges | — K2ARB project alignment | ■ Groundwater study area |

Terrestrial GDE

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



7 Groundwater environmental values

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

This section identifies and describes groundwater related EVs within the groundwater study area. For the purposes of 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 sufficiently important to be protected or enhanced.

The following relevant sub areas of EPP (Water and Wetland Biodiversity) were identified in accordance with Schedule 1:

- The western part of the groundwater study area (Ch 0 km to Ch 40 km): in the Bremer River area, part of the Brisbane basin, with relevant EVs described in *Bremer River environmental values and water quality objectives* (DERM 2010a); and
- The eastern part of the groundwater study area (Ch 40 km to Ch 56 km): in the Logan River area, part of the South Coast basin, with relevant EVs described in *Logan River environmental values and water quality objectives* (DERM 2010b).

EVs for groundwater to be protected or enhanced in the groundwater study area, as prescribed by Schedule 1 (EPP (Water and Wetland Biodiversity)), are listed in Table 7.1; the relevant EVs maps for the groundwater study area are included Appendix B: Relevant environmental value maps for groundwater study area.

Table 7.1 Environmental values for groundwater

| Environmental value | Definition |
|---|--|
| Aquatic ecosystems | <p>‘A community of organisms living within or adjacent to water, including riparian or foreshore area’ (EPP (Water and Wetland Biodiversity)).</p> <p>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.</p> <p>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.</p> |
| 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. |
| Drinking water supply | Suitability of raw drinking water supply. This assumes minimal treatment of water is required, for example, coarse screening and/or disinfection. |
| Industrial use * - For Logan River area only (i.e. eastern part of Study area) | Suitability of water supply for industrial use – for example food, beverage, paper, petroleum and power industries. Industries usually treat water supplies to meet their needs. |

7.1 Aquatic ecosystems

Section 6.5 reports there are no known aquatic, terrestrial or subterranean GDEs that have been identified within the groundwater study area, although there is a low to moderate potential for aquatic and terrestrial GDEs to be present based on regional studies (from the GDE Atlas). The potential for aquatic ecosystems to be impacted by dewatering, or changes in groundwater quality, does therefore exist. This is considered further in Section 11.

7.2 Irrigation

The Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCAMZ) (ANZG 2018) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* states that the threshold salinity tolerances for plants grown in loamy to clayey soils are 600 $\mu\text{S}/\text{cm}$ to 7,200 $\mu\text{S}/\text{cm}$.

As discussed in Section 6.2.3, the groundwater salinity can vary widely within the alluvial sediments and underlying bedrock sediments but is typically fresher within the alluvial sediments. Groundwater salinity data (refer Table 6.3 and Table 6.4) suggest that groundwater may be locally suitable for stock watering, and more likely to be from the alluvial sediments where yields may also be higher.

However, the absence of groundwater bores with licensed allocations within 1 km the alignment indicates that groundwater is not used as a source of irrigation water.

7.3 Farm water supply/use

The high salinity of the groundwater generally precludes it from being suitable for farm supply uses such as laundry or produce preparation.

7.4 Stock watering

The review of DNRME registered bores and the bore census data indicates that groundwater in the groundwater study area is possibly used for stock watering. Noting that bores are listed as being used for 'water supply' (refer Table 6.8) but no licensed groundwater allocations are listed within the groundwater study area. It is therefore possible that these bores are used for stock and domestic purposes which is allowed without a permit (unless regulated through the Water Regulation 2016, a water plan or a moratorium – which is not the case for bores within the groundwater study area).

Although the groundwater is generally within the guidelines for livestock drinking water, Section 4.3.3.5 of the ANZG 2018 guidelines states that loss of production and a decline in animal health occurs if stock are exposed to high salinity water for prolonged periods. For beef cattle, this limit is in range the range of 5,000 mg/L to 10,000 mg/L.

As discussed in Section 6.2.3, the groundwater salinity can vary widely within the alluvial sediments and underlying bedrock sediments but is typically fresher within the alluvial sediments. Overall, groundwater salinity data (refer Table 6.3 and Table 6.4) suggest that groundwater may be locally suitable for stock watering, and more likely to be from the alluvial sediments where yields may also be higher.

7.5 Primary recreation

Primary recreation EVs are not considered applicable to groundwater in-situ. There are also no registered groundwater springs in the groundwater study area that could be considered for recreational use. Groundwater seepage from the alluvium and/or Tertiary units into water courses can provide short duration baseflow into rivers and creeks immediately after 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; however, 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

There main aspects that affect the suitability of groundwater as drinking water are groundwater quality and yield.

The suitability of water for human consumption is defined in the ADWG (NHMRC and NRMCC 2018). The guidelines indicate TDS has no health limit however it has an aesthetic based guideline value of 600 mg/L. The guidelines state the following regarding TDS (based on aesthetics):

- Less than 600 mg/L is regarded as good quality drinking water
- 600-900 mg/L is regarded as fair quality
- 900-1,200 mg/L is regarded as poor quality
- Greater than 1,200 mg/L is regarded as unacceptable.

Groundwater quality in the groundwater study area is presented in Section 6.2.3. Regional groundwater salinity (as TDS) is varied between aquifers with mean salinity ranging between 750 and 6,500 mg/L across the WCM, Koukandowie Formation and Gatton Sandstone. Salinity in the alluvium ranges between 500 and 6,400 mg/L. Groundwater quality in the investigation bores within the groundwater study area indicate salinity (as TDS) is below the guideline value of 600 mg/L across three bores, which are within the alluvium and Koukandowie Formation.

Mean groundwater yield in the groundwater study area ranges from around 0.4 L/s in the WCM and Koukandowie Formation and from 0.97 to 2.85 L/s in the alluvium. The average household used 103 kL (or 103,000 L) annually according to the Australian Bureau of Statistics (ABS). Groundwater yield of 0.4 L/s can provide 12,600 kL annually and the minimum yield observed in the groundwater study area (0.13 L/s) can provide 4,000 kL annually.

The available groundwater quality and yield data suggests groundwater is potentially suitable for drinking water (with possible water treatment) and can likely be used for domestic use. Further, the groundwater study area has experienced long-term periods of low rainfall, which suggests rainwater tanks may not be able to supply household domestic needs. In periods of extended low rainfall and drought, the rainwater tanks would be supplemented by groundwater.

7.7 Industrial use

Water taken for industrial needs will have different water quality objectives for different industries and are considered on a case-by-case basis, with water typically being treated to suit end use. The majority of land use within the groundwater study area is cleared agricultural land, and therefore the industrial EVs are considered to be of limited relevance.

7.8 Summary

In summary, the evaluation of groundwater EVs in the groundwater study area indicates that groundwater associated with the Tertiary and Permian sediments are of limited value for most uses. Groundwater associated with the alluvium is sporadic and seasonal and is not considered to provide sufficient (sustainable) supply in the groundwater study area to allow for evaluation.

Stock watering, drinking water and aquatic ecosystems are the only EVs for groundwater considered relevant in the groundwater study area.

8 Conceptual hydrogeological model

Key aspects of the hydrogeological regime within the groundwater study area are summarised below, and a conceptual understanding of the hydrogeology along the proposed alignment west of the Teviot Ranges is provided as Figure 11.

8.1 Main hydrostratigraphic units

The Project is anticipated to encounter the Walloon Coal Measures and alluvial sediments in low lying areas between Ch 0.0 km and Ch 22.9 km, and between Ch 53.2 km and Ch 56.2 km (refer Figure 7). The main occurrences of alluvial sediments are up to 30 m thick and associated with the Bremer River, Warrill Creek and Purga Creek, and grade from finer to coarser grained sands and gravels with depth. It is expected that the interbedded sandstone, mudstone and siltstone of the Walloon Coal Measures will be confined where they are overlain by alluvial sediments, but will form the upper unconfined (water table) aquifer where they crop out between drainage lines (refer Figure 11).

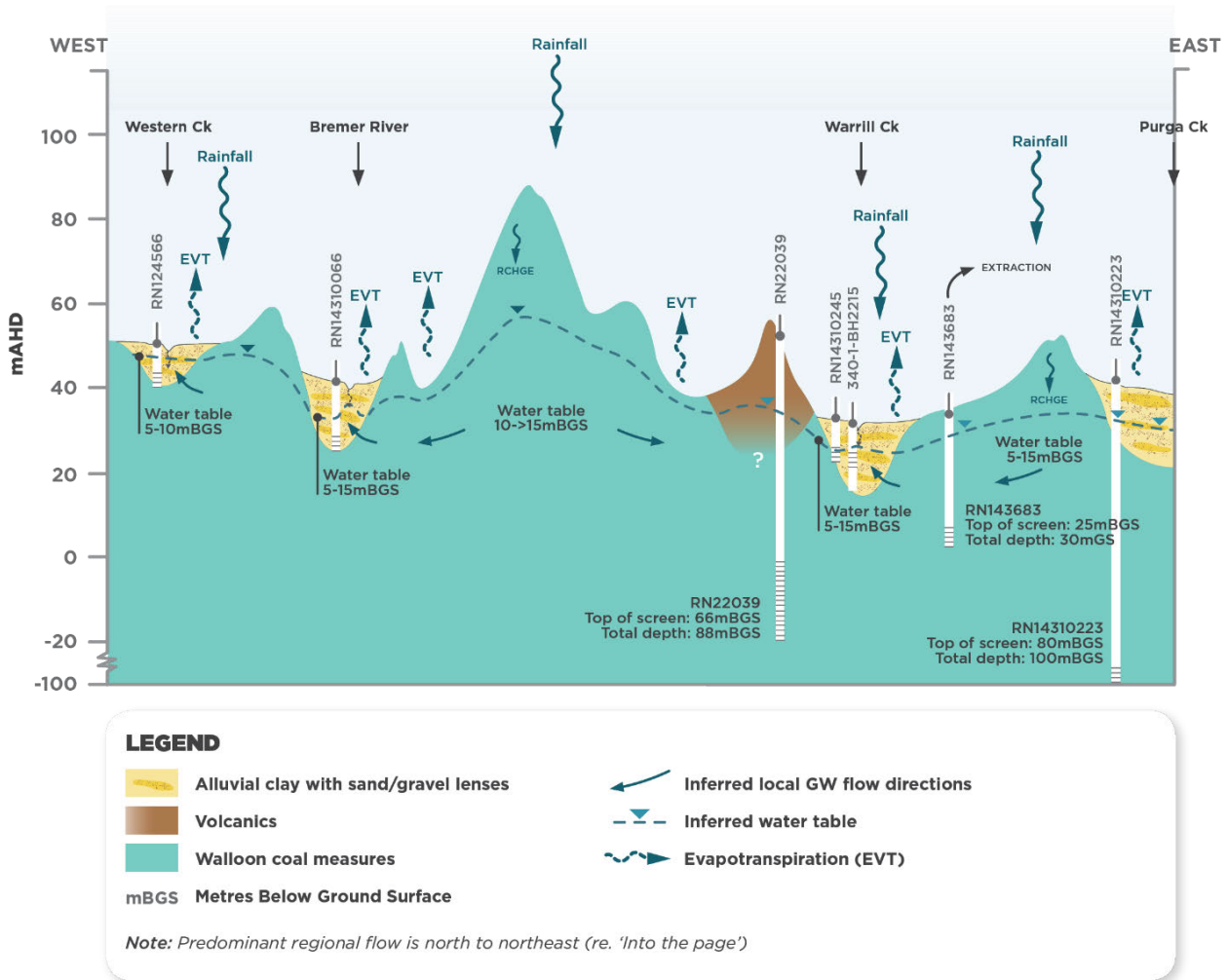


Figure 11 Conceptual hydrogeological model

The Project is anticipated to encounter the interbedded sandstones, siltstones and claystones of the Marburg Subgroup (Koukandowie Formation/Gatton Sandstone) in the Teviot Range between Ch 22.9 km and Ch 53.2 km. At the Teviot Range tunnel section (between Ch 39.5 km and Ch 41.3 km) the medium to coarse grained Gatton Sandstone is locally exposed at the surface or blanketed by a thin layer of soils (refer Figure 7).

8.2 Levels and flow

The water table is typically a subdued version of topography, with the depth to groundwater increasing beneath topographic highs (for example the Teviot Range), and shallower in lower lying reaches (such as close to surface water drainage lines). The presence of shallow aquitards, surface water features and groundwater extraction would locally affect depths to groundwater.

The water table occurs in the alluvial sediments or outcropping Walloon Coal Measures across much of the groundwater study area west and east of the Teviot Range. The Gatton Sandstone of the Teviot Range comprises the upper (water table) aquifer in the central portion of the groundwater study area.

Depths to groundwater in alluvial sediments are anticipated to be between 5 and 15 mbNS based on regional data, and typically less than 10 mbNS based on limited data for the groundwater study area. Intermediate and regional groundwater flow systems in alluvial sediments will be northeast and north through the groundwater study area (that is, across the proposed alignment), following surface drainage. Local groundwater flow systems will be influenced by surface water-groundwater interaction where there is a hydraulic connection.

From regional scale mapping, groundwater levels in the Walloon Coal Measures might be expected to be around 40 mAHD, with the water table expected to be at least 5 mbNS and greater than 10 to 15 mbNS in higher relief areas of outcrop. The regional potentiometric surface of the Walloon Coal Measures shows that groundwater flow is generally east and northeast towards the eastern margin of the Clarence-Moreton Basin (Raiber et al. 2016). Local groundwater flow will be controlled by topography and interaction with the overlying alluvial sediments.

The water table within the Teviot Range is anticipated to be a subdued version of the range's topography. A maximum water table depth of approximately 60 mbNS was estimated beneath the topographic high in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report, forming a groundwater divide. Regional groundwater flowpaths are northeast beneath the Bremer River basin (Raiber et al. 2016), with the mapped potentiometric surface indicating lower groundwater elevations corresponding to alluvial sediments, suggesting these sediments act as regional discharge areas for the underlying Clarence-Moreton Basin sedimentary sequence. Local groundwater flow direction will be controlled by a groundwater divide coinciding with the main ridge line. Deeper groundwater will follow regional flowpaths, with shallow local groundwater flow paths potentially influenced by discrete groundwater discharge areas expressing as surface features.

8.3 Recharge

Recharge mechanisms include throughflow from up hydraulic gradient of the groundwater study area, direct infiltration of rainfall in outcrop areas, seepage from creeks and rivers into alluvial aquifers, and leakage into overlying, underlying or adjacent aquifers.

Monthly average pan evaporation exceeds monthly average rainfall, and therefore direct infiltration of rainfall to groundwater is unlikely during dry periods, when light rainfall events will be absorbed by soil moisture and lost to evapotranspiration.

8.4 Discharge

Discharge mechanisms include throughflow out of the groundwater study area to the north, leakage into overlying, underlying, and adjacent aquifers, evaporation and transpiration, and groundwater extraction.

9 Groundwater modelling

9.1 Teviot Range tunnel and portal cuts

The Project includes a number of cuttings and construction of the Teviot Range tunnel that are anticipated to intersect groundwater. Dewatering during construction and long-term seepage during operation (if these features are to be free draining) will lead to a reduction in groundwater levels at and around the cuts and tunnels, and also produce discharge water volumes that will need to be managed.

Modelling has been carried out and reported in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report and has been used to inform this groundwater impact assessment. A summary of this modelling is provided in this section and Section 10.

9.1.1 Objectives

A preliminary analysis of groundwater inflows and drawdown associated with a drained tunnel and portal cuts was undertaken (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report). The objective of the analysis was to inform assessment of the potential to construct the Teviot Range tunnel and adjacent portal cuts as permanently drained structures.

9.1.2 Design assumptions

Preliminary analysis of groundwater inflows and drawdown associated with the drained tunnel and portal cuts are reported as part of the preliminary hydrogeological interpretative assessment (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

Modelling was carried out to provide design, and included the following assumptions:

- Tunnel and portal cuts permanently drained
- Modelled portal cuts and tunnel alignment between Ch 39.15 km and Ch 41.35 km, with tunnel between Ch 39.86 km and Ch 40.86 km
- No lining or grouting works for higher permeability zones associated with faults or increased fracture intensity
- Rock is considered practically impermeable beyond 50 m below the tunnel invert
- Groundwater levels used in the model derived from correlation between topography and water level shown in Figure 12.

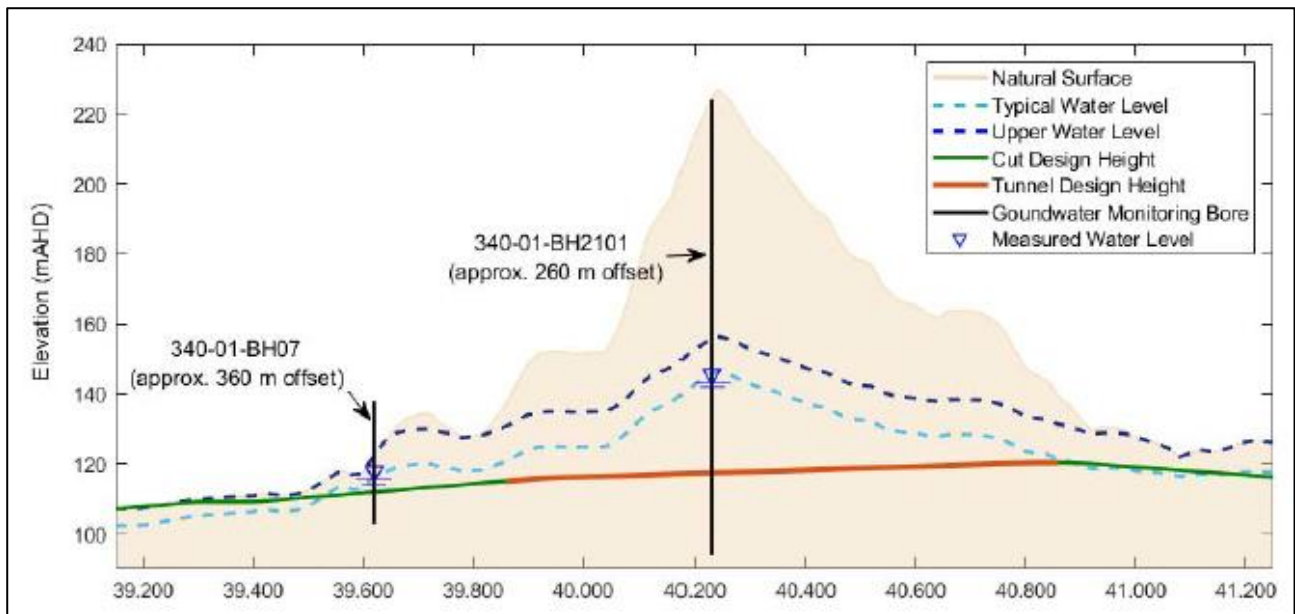


Figure 12 Estimates of groundwater levels prior to tunnel construction

Source: Golder (2019)

9.1.3 Methodology

Groundwater inflows and drawdown were estimated using the Perrochet analytical method and a numerical modelling approach using SEEP/W.

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 Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report and summarised below.

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

- Tunnel excavation will start from west to east at construction rate of 4 m per day over 250 days
- Water inflows to drained tunnel sections along entire length of the tunnel, divided into 20 m intervals
- Homogeneous and isotropic hydraulic characteristics above and below tunnel invert
- Groundwater recharge at a constant rate along the length of tunnel
- Gatton Sandstone with horizontal hydraulic conductivity of 1×10^{-8} m/s (8.6×10^{-4} m/day).

The inflow and drawdown analysis using the cross-sectional SEEP/W groundwater model was based on assumptions including:

- Modelled cross section at Ch 40.24 km where rock thickness above tunnel crown is maximum
- Three geological units: highly weathered rock, moderately weathered rock and fresh rock
- Constant head boundaries 5 km north and south of the tunnel
- Recharge applied to surface (top boundary) of the model, with rates adjusted to match inferred groundwater levels (refer Figure 12). Calibrated recharge rates between 1.46 and 3.65 mm/year
- A regional groundwater flow divide based on the correlation between groundwater level and ground surface elevation
- Horizontal hydraulic conductivity of 5.8×10^{-8} m/s (5×10^{-3} m/day) to match inferred groundwater levels
- Anisotropy ratio of 100 (horizontal to vertical).

Calibration of the model and changes to model parameters (such as hydraulic conductivity and recharge) were based on matching inferred groundwater levels that 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 three higher permeability structural features were assessed. Applying elevated groundwater levels to the model allows an assessment of the effects of climatic conditions.

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). The guidelines define a Class 1 model as a tool to provide an initial assessment of a problem which is subsequently refined and improved to higher classes as additional data is gathered (often from further monitoring).

The numerical simulations undertaken in part for this study are considered to be suitable for developing coarse relationships between groundwater extraction locations and rates and associated impacts (Barnett et al. 2012). Further these models are considered an initial assessment of the Project on groundwater resources. The numerical model will be updated with additional information gathered during the detail design phase.

9.2 Cuts along the alignment

9.2.1 Objectives

A preliminary assessment was undertaken using an analytical solution with the purpose of estimating potential groundwater inflows into slope cuts along the alignment to inform the Project's design (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

9.2.2 Design assumptions and methodology

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 (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

Assumptions are described in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report and summarised below:

- Slope cuts permanently drained
- Homogeneous and isotropic geological material
- Impermeable rock below bottom of slope cut
- Groundwater recharge not considered in analysis
- Analysis based on 'typical' hydrogeological parameters from desktop study
- An average groundwater level over length of each cut
- Toe elevation of each cut is the level of discharge.

The analytical method provides an estimation of the water table and flow rates over time, using inferred groundwater levels over 10 m intervals along each cut being considered.

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). The guidelines define a Class 1 model as a tool to provide an initial assessment of a problem which is subsequently refined and improved to higher classes as additional data is gathered (often from further monitoring).

10 Predictive simulations

10.1 Predictive drawdown

10.1.1 Teviot Range tunnel and portals

The Perrochet analytical method was used to predict long-term drawdown due to drainage of the tunnel and portal cuts. A 5 m drawdown was estimated to extend to approximately 400 m perpendicular to the tunnel, with drawdown contours offset from tunnel alignment (i.e. greater to the south) due to topographic effects and inferred initial condition groundwater levels.

Long-term drainage was anticipated to reduce groundwater levels below the ridge, to the tunnel invert elevation. This was considered to have the potential to impact deep rooted trees in areas of lower topography near portal cuts and to the north and south of the tunnel (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

Cross sectional drawdown estimates were generally comparable between the Perrochet and SEEP/W methods (refer Figure 13).

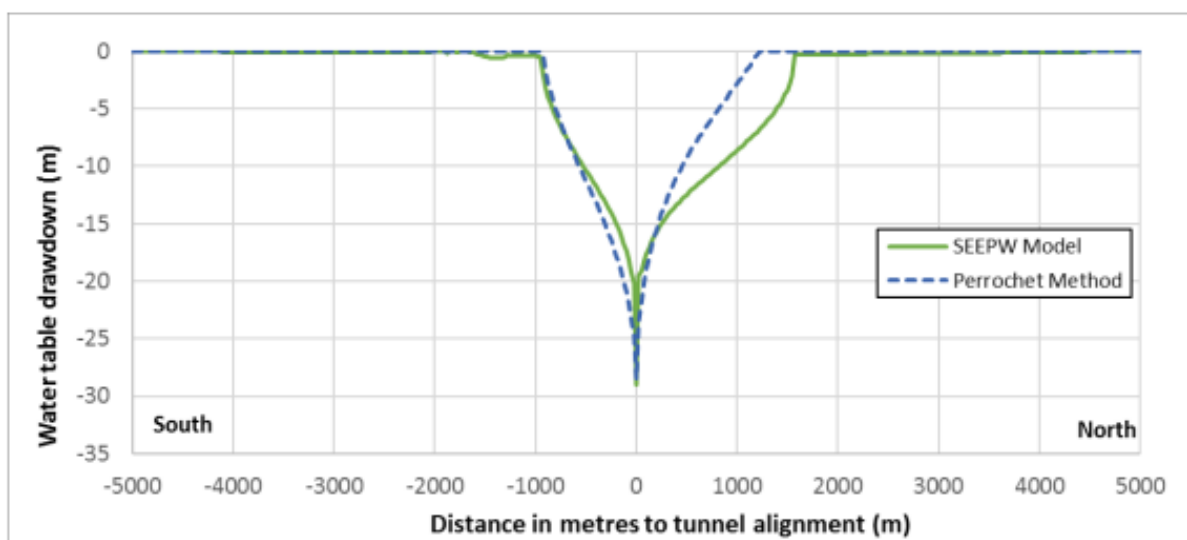


Figure 13 Modelled drawdown comparison

Source: Golder (2019)

Uncertainty analysis was also undertaken for predicted long-term drawdown based on the Perrochet analytical method. Potential effects of pre-existing groundwater levels 10 m higher than base case, and the presence of three higher permeability structural features were assessed. The three scenarios considered were:

- Scenario 1: Elevated groundwater levels (+10 m), no structural feature - 5 m drawdown contour extends out to approximately 700 m perpendicular to tunnel alignment
- Scenario 2: Base case groundwater levels, three structural features - estimated drawdown develops along the modelled structural zones
- Scenario 3: Elevated groundwater levels (+10 m), three structural features - estimated drawdown develops along the modelled structural zones.

Drawdown extents are shown in Figure 14 (Scenario 1), Figure 15 (Scenario 2), and Figure 16 (Scenario 3), respectively.

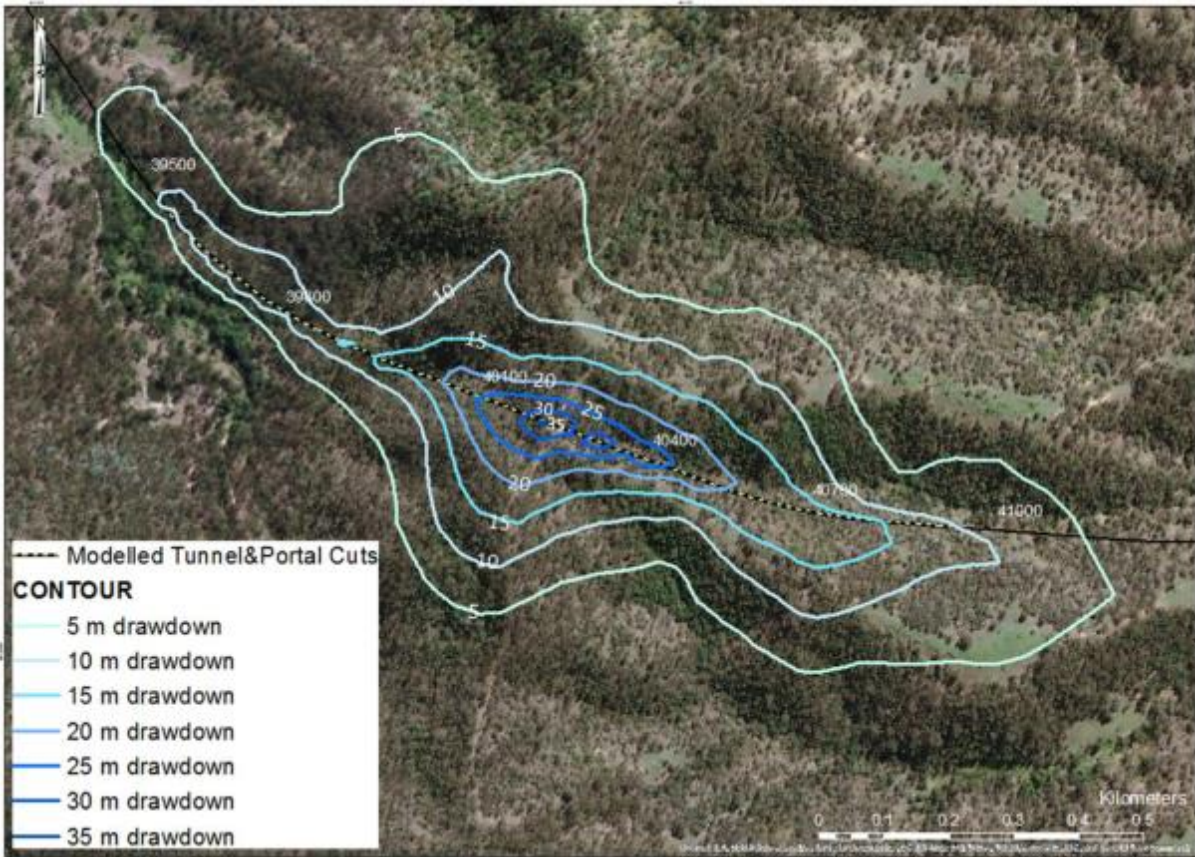


Figure 14 Scenario 1: Predicted drawdown extent

Source: Golder (2019)

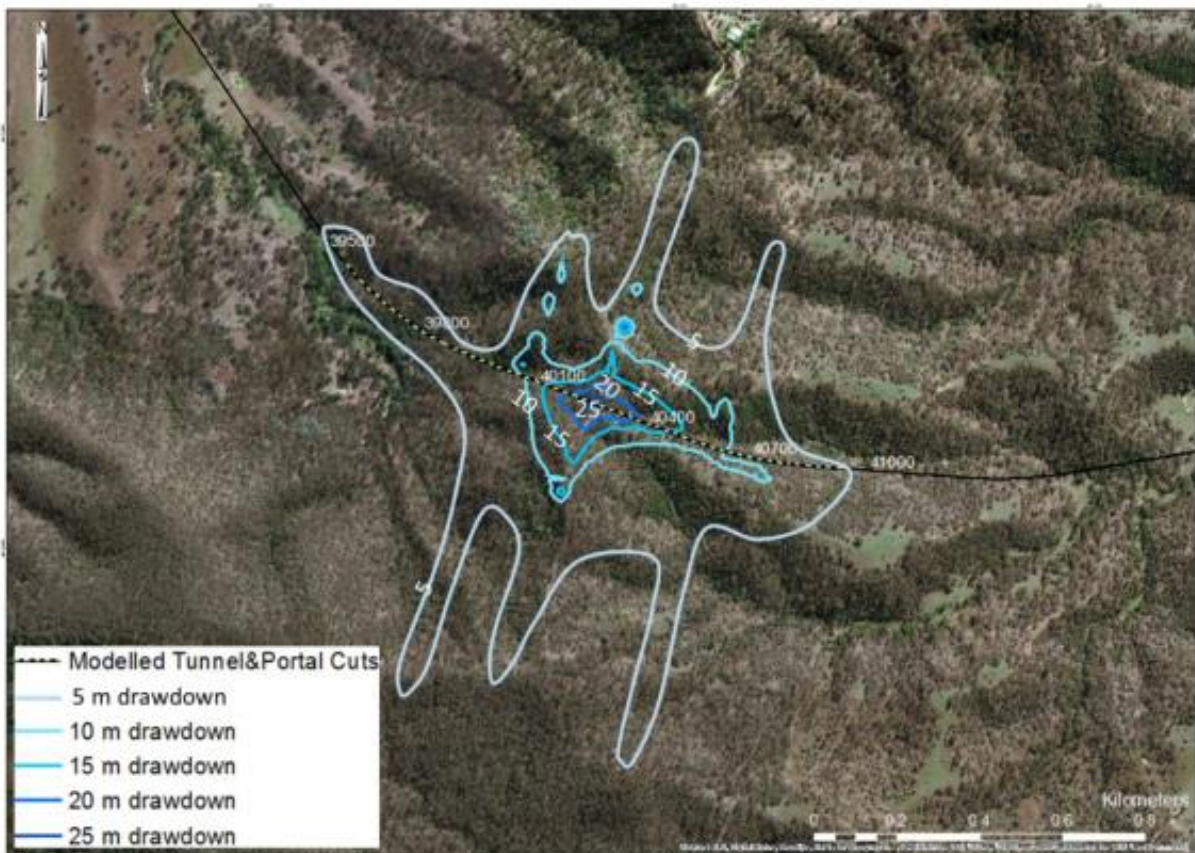


Figure 15 Scenario 2: Predicted drawdown extent

Source: Golder (2019)

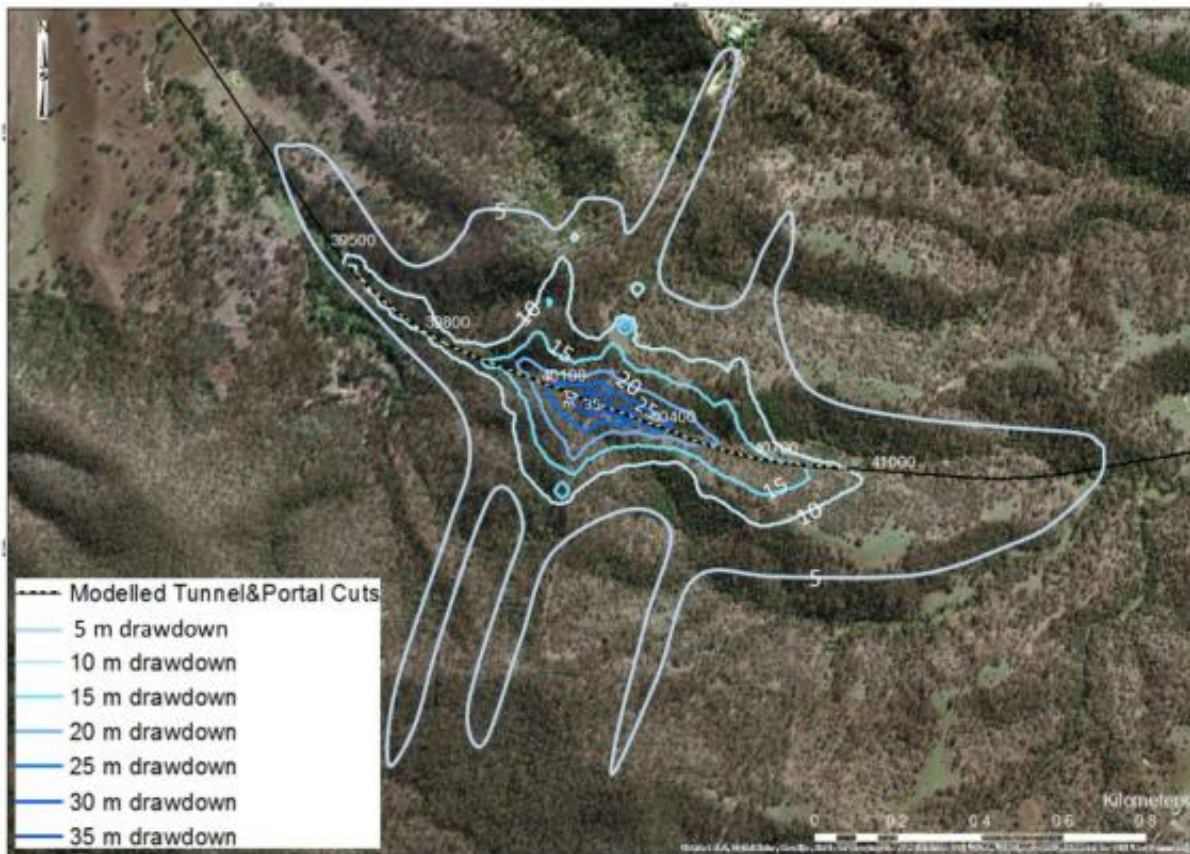


Figure 16 Scenario 3: Predicted drawdown extent

Source: Golder (2019)

10.2 Predictions of ingress

10.2.1 Teviot Range Tunnel and portals

Long-term inflow rates of up to 0.01 L/s were estimated per 100 m sections of the tunnel using the Perrochet analytical model. The long-term inflow into Ch 40.24 km was computed by the SEEP/W model to be 0.014 L/s per 100 m, comparable to the 0.01 L/s estimated over the same 100 m interval by the analytical method.

Overall, the long-term inflow rate was estimated to be 0.1 L/s for the 1,015 m long tunnel section. Short-term inflows of 0.6 L/s were estimated by the analytical method to indicate potential inflow rates to be managed during construction of the tunnel. Higher flow rates over short durations (i.e. weeks to months) might be encountered where locally higher permeability features are encountered (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

Long term seepage flows of 0.02 L/s at the western portal and 0.01 L/s at the eastern portal were estimated by the analytical method.

Overall, a base case long-term inflow rate in the order of 0.11 L/s was estimated for the combined tunnel and portal sections (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report).

Uncertainty analysis was also undertaken for tunnel inflows. Potential effects of pre-existing groundwater levels 10 m higher than base case, and the presence of three higher permeability structural features were assessed. The three additional scenarios considered were:

- Scenario 1: Elevated groundwater levels (+10 m), no structural feature - giving long-term flow rate of 0.17 L/s
- Scenario 2: Base case groundwater levels, three structural features - giving long-term flow rate of 0.13 L/s

- Scenario 3: Elevated groundwater levels (+10 m), three structural features - giving long-term flow rate of 0.23 L/s.

10.2.2 Cuts along the alignment

Predictive modelling (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) considered groundwater inflows to 20 cut sections along the alignment, where groundwater was inferred to be intersected. Inflows were estimated at one year and 50 years (i.e. long-term) after construction. The results are summarised by geological unit in Table 10.1.

Table 10.1 Estimated seepage rates for slope cuts

| Geology | Seepage rate along cut length (L/sec) | | | | | |
|-----------------------|---------------------------------------|-----------|-----------|-----------|------------------------|-----------|
| | 1 year after construction | | | | Long term seepage rate | |
| | <0.1 L/sec | 0.1 L/sec | 0.2 L/sec | 0.8 L/sec | < 0.1 L/sec | 0.1 L/sec |
| Alluvium | - | - | 1 | 1 | 1 | 1 |
| Walloon Coal Measures | 3 | - | 2 | - | 5 | - |
| Koukandowie Formation | 4 | - | 1 | - | 5 | - |
| Gatton Sandstone | 6 | 2 | - | - | 8 | - |
| Totals | 13 | 2 | 4 | 1 | 19 | 1 |

Source: Golder (2019)

All long-term seepage rates were estimated to be 0.1 L/sec or less, with most seepage rates one year after construction also estimated to be 0.1 L/sec or less. The higher seepage rate estimates were generally associated with slope cuts through alluvium (assumed higher permeability) or due to longer cut lengths.

10.3 Model limitations

10.3.1 Teviot Range tunnel and portal cuts

The preliminary hydrogeological interpretative report (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) 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
- Uncertainty analysis indicated the extent and location of structurally affected zones could significantly affect inflow and drawdown associated with the tunnel.

10.3.2 Cuts along the alignment

The following limitations were noted in Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report:

- 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.

11 Potential impacts

11.1 Design elements relevant to potential groundwater impacts

The proposed 53 km length of new dual-gauge rail line will be constructed across the landscape using a combination of cuttings, embankments, bridges and a 1,015 m tunnel through the Teviot Range (refer Figure 17).

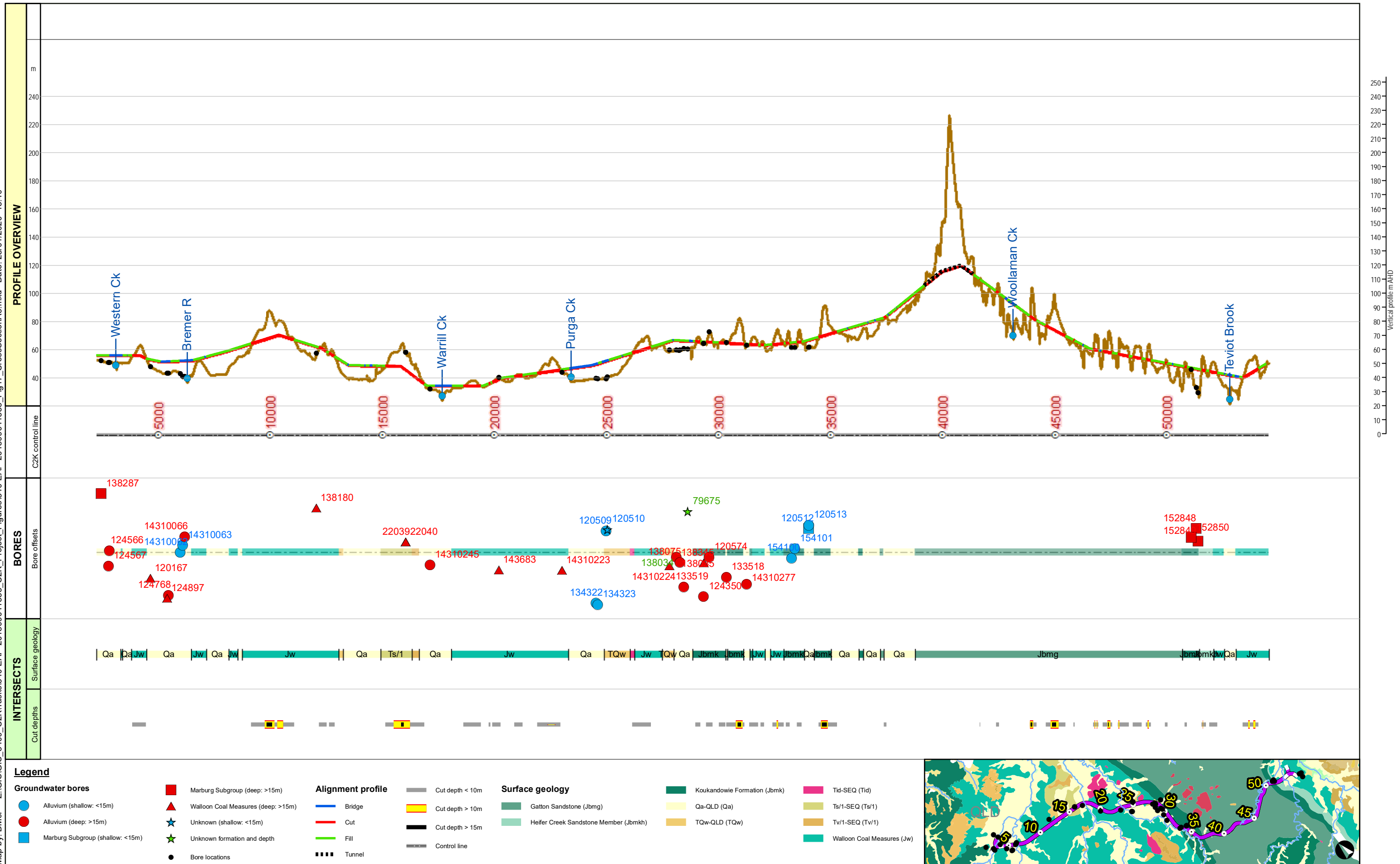
Although final design details may change, the current general construction is summarised in Table 11.1; based on the following project components and analysis of GIS project layers.

Table 11.1 Summary of construction methods and assumptions

| Method | Description | Assumptions |
|---------------------|--|--|
| Embankments | <p>Significant embankments will be required along the alignment; with estimated fill requirement of approximately 4.237 million cubic metres.</p> <p>30 fill sections, totalling approximately 33.54 km.</p> <p>Ranging from around 150 m to 4,370 m in length, maximum fill depths of up to 25 m and average fill depths typically less than 9 m.</p> | <p>Fill and bridges used to span all alluvial sediment occurrences (i.e. low-lying floodplains).</p> <p>Possibility of compaction with localised, temporary i) increases to groundwater elevations and ii) changes of groundwater flow patterns.</p> |
| Cuts | <p>Significant cuts will be required along the alignment; with estimated cut volume of approximately 5.860 million cubic metres including tunnel.</p> <p>30 cuttings, totalling approximately 17.9 km. Varying in length from less than 120 m up to 1.9 km, and maximum depths of up to 42.6 m.</p> | <p>Cuttings less than 10 m deep unlikely to intersect significant depth below water table.</p> <p>Preliminary inflow estimates (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report) indicate limited inflow rates (typically < 0.1L/sec) in cut sections.</p> <p>Shallow perched groundwater may be intersected but result in relatively small and temporary inflows.</p> <p>Preliminary drawdown estimates indicate drawdowns unlikely to exceed 0.5 m at 200 m from cuttings (Section 11.2.1.4).</p> |
| Bridges and Pilings | <p>27 new bridges to cross all major waterways and roads.</p> <p>Bridge lengths of between approximately 53 m and 1 km (from GIS analysis).</p> <p>Constructed using cast in place piles or driven piles.</p> | <p>Fill and bridges used to span all alluvial sediment occurrences (i.e. low-lying floodplains).</p> <p>Dewatering of alluvial sediments not required.</p> |
| Tunnelling | <p>Approximately 1,015 m long.</p> <p>Drill and blast or road-header using top heading and bench excavation method.</p> <p>Base of tunnel elevation between 115.4 mAHD and 119.5 mAHD.</p> <p>Maximum rock thickness above tunnel crown approximately 90 m.</p> | <p>Full tunnel length below water table (in Gatton Sandstone).</p> <p>Free draining tunnel and portals.</p> |

The locations of proposed structures along the alignment are presented in Figure 17.

Map by: DMcP_Z:\GIS\GIS_3400_C2K\Tasks\340-EAP-20180904\553_C2K_Project_Figures\340-EAP-20180904\553_Fig17_CrossSectionA3.mxd Date: 28/01/2020 15:40



Horizontal lateral scale for borehole offsets: 1:60,000
Horizontal longitudinal scale as determined by chainage markers on C/L

11.1.1 Site clearing and grading

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

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

11.1.2 Embankments

Significant embankments will be required along the alignment; with an estimated fill requirement of approximately 4.237 million cubic metres.

The anticipated subgrade for most embankments west of the Teviot Range is Quaternary alluvium or colluvium. Embankments may also be constructed on subgrade consisting of Gatton Sandstone on eastern flanks of Teviot Range.

11.1.3 Bridge and piling sections

The Project requires 27 new bridge structures; comprising 16 rail bridges over waterways, three rail bridges over roads, five bridges over waterways and roads, and three road bridges over rail.

The new bridge structures are typically founded on driven precast or bored in situ piled foundations supporting in situ reinforced concrete substructures. The piling is to comprise cast in place or driven piles. For the cast in place piling technique a concrete slurry mix is placed via a tremmie line or other pumping method. This technique allows for the removal of augered soil/rock while pumping concrete or grout through the hollow stem to stabilise the ground.

The majority of bridges span Quaternary alluvium or colluvium subgrade, with a number of spans also occurring over Gatton Sandstone in the Teviot Range.

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 10 metres below ground surface (mBGS) in areas of high relief where deep cuttings are proposed.

Sections of deep cuttings (> 10 m) are considered more likely to intersect groundwater and potentially require more significant dewatering. These cut sections are summarised in Table 11.2 and indicated on Figure 17.

Overall, cut sections greater than 10 m deep account for approximately 6 per cent (3.1 km) of the rail line, with approximately 2 per cent (1.1 km) of cuts greater than 15 m deep (not including the 1,015 m Teviot Range Tunnel)².

Table 11.2 Summary of proposed deep cuts (i.e. > 10 m) (from GIS analysis)

| Chainage start | Chainage end | Length (m) | Comment |
|----------------|--------------|------------|---|
| 9.7 | 10.2 | 437.0 | Includes 258 m section (predominantly in Walloon Coal Measures) >15 m depth |
| 10.3 | 10.5 | 261.7 | |
| 15.5 | 16.2 | 723.6 | Includes 126 m section (predominantly Ts/1) >15 m depth |
| 30.7 | 31.0 | 308.6 | Includes 161 m section (predominantly Koukandowie Formation) > 15 m depth |

² Estimates based on GIS interrogation and analysis of available GIS data/layers.

| Chainage start | Chainage end | Length (m) | Comment |
|----------------|--------------|------------|---|
| 32.5 | 32.6 | 70.6 | |
| 34.5 | 34.8 | 301.9 | Includes 223 m section (predominantly Koukandowie Formation) > 15 m depth |
| 43.9 | 44.0 | 146.7 | Includes 86 m section (predominantly Koukandowie Formation) > 15 m depth |
| 44.8 | 45.1 | 364.6 | Includes 184 m section (predominantly Koukandowie Formation) > 15 m depth |
| 46.7 | 46.9 | 57 | |
| 47.3 | 47.4 | 128.6 | Includes 31 m section (predominantly Koukandowie Formation) > 15 m depth |
| 47.8 | 47.9 | 42.0 | |
| 49.1 | 49.2 | 58.8 | |
| 51.6 | 51.6 | 19.2 | |
| 53.6 | 53.7 | 65.9 | |
| 53.8 | 53.9 | 95.3 | |
| Total Length | | 3,081.5 | |

11.1.5 Tunnelling

The Project proposes a tunnel through the Teviot Range to facilitate the required gradients for this area due to the undulating terrain. The tunnel will be approximately 1,015 m long with the maximum cover of rock above the tunnel of approximately 90 m. The tunnel excavated cross section is approximately 135 m² and the internal space requirements are driven by ventilation requirements.

Two techniques are being considered for excavation/rock-breaking:

- Roadheaders
- Drill and blast.

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

Water treatment facilities are likely to include:

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

The design of the tunnel includes a flexible sheet type membrane which is constructed 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 tunnel down to invert level, where the water would be collected by drainage systems.

11.1.6 Construction water supply

Groundwater quality indicates it can only be sourced for earthworks and track works; however, groundwater is not the only, or preferred source of construction water for the Project.

Water will be required for dust control, site compaction and reinstatement during construction. Potential water sources have been investigated, including extraction of groundwater or surface water. This will be further explored prior to construction in consultation with local councils and landowners.

Overall quantities of water have been estimated to be 950 megalitres (ML) total for earthworks and trackworks - including material conditioning and dust suppression.

Activities during the construction phase with the highest water demand are:

- Soil/material conditioning
- General dust suppression
- Dust suppression and maintenance of laydown areas and haul roads
- Construction offices and amenities.

The current estimated water demand is expected to be met using existing water sources, however further options may need to be investigated depending on engagement with water resource owners.

An appropriate quality of water will be sourced for each use. For instance, non-potable water is suitable for soil conditioning and dust suppression, while potable water must be sourced for the construction offices and amenities. Prior to sourcing any construction water, the necessary approvals and licences will be obtained.

The buying or sharing of groundwater from existing water license/entitlement/permit is an option to be considered in the instance bore water is selected as a preferred source of construction water.

Temporary water permits in accordance with the Water Act could provide a suitable water supply option for the construction phase of the proposal. Water permits are issued for temporary projects having a foreseeable conclusion date and anticipated to have short-term impacts on the resource. Normally, water permits are granted up to a maximum timeframe of three years and cannot be renewed, transferred, or amended. However, the viability of this option will need to be reviewed during the pre-construction phase to confirm the volume, if any, of available allocations to support the temporary permit.

In the instance a temporary water permit is warranted during construction, the licensed volume is expected to be within the allowable extraction limits for the relevant Water Plan. Therefore, the Project is not expected to impact on, or alter, the identified relevant Water Plans or other plans under the Water Act outside of their designated use and objectives.

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 existing landholder bores

Registered and unregistered bores within, or near, the disturbance footprint have the potential to be damaged or lost during construction, or to become inaccessible during construction (refer Figure 8a-e). 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. Once detailed design has been undertaken and ground truthing of bores has occurred (that is, the physical identification of the bore location), potential risks can be confirmed, and specific mitigation measures developed in conjunction with the affected landholder.

All bores will be decommissioned in accordance with the *Minimum Construction Requirements for Water Bores in Australia* – Edition 3 (National Uniform Drillers Licensing Committee 2012).

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 (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 Bremer Creek, Warrill Creek and Purga Creek), although bridges are typically proposed in these areas.

Overall, there is the potential for embankments to effect groundwater levels and/or the hydraulic properties of the aquifer(s) locally across some sections of the alignment (as described above). It is anticipated that ongoing and further geotechnical investigations will confirm the potential risk and inform final design.

11.2.1.3 Subsidence/settlement

Early drawdown effects due to seepage into cuttings and the tunnel has the potential to cause settlement of compressible materials, and damage to buildings or other structures within areas of settlement.

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.

Deep cuttings in high relief areas are typically in more competent bedrock sediments 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, Gatton Sandstone).

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

Reduced groundwater levels from dewatering during construction of cuts and the tunnel has the potential to impact groundwater users (e.g. registered bores and surface water flows).

Maximum drawdowns are unlikely to exceed 0.5 m at 200 m from cuttings, based on the limited data currently available and using the Theis analytical solution to approximate drawdown away from a cut³. A summary of deep cut sections and nearby registered bores is provided in Table 11.3 (refer Figure 8 and Figure 17).

Table 11.3 Deep cut and registered bore summary

| Deep cut chainage | Length | Minimum base of cut elevation ¹ (mAHD) | Registered bores | Comment ² |
|-------------------|--------|---|--|--|
| 9.7 – 10.2 | 437.0 | 55 | RN120194 – Alluvium; ~250 m from cut; ground surface 50.5 mAHD; screened 9 – 22 mBGS. | Cut and bore in different aquifers. Ground elevation at bore is below base of cut elevation. Negligible potential for groundwater levels at RN120194 to be affected by seepage into this cut. |
| 10.3 – 10.5 | 261.7 | 65 | No registered bores within 1 km. Nearest bore RN138180 – Walloon Coal Measures; ~1.6 km from cut; ground surface 72.1 mAHD; top of screen 135 mBGS; depth of bore 147mBGS. | Distance from cut and depth of screen for nearest bore (compared to base of cut) indicate no potential for impact to groundwater levels at registered groundwater bores. |
| 15.5 – 16.2 | 723.6 | 35 | RN22039 – Walloon Coal Measures; ~180 m from cut; ground surface 58.7 mAHD; top of screen 66 mBGS; depth of bore 87.8 m. | Depth of bores suggests limited potential for groundwater level impact at RN22039 and RN22040. Confirmation of final cut design, bore location, bore construction, and groundwater levels at cut and/or bore would further refine assessment. |
| | | | RN22040 – Walloon Coal Measures; ~180 m from cut; ground surface 58.7 mAHD; top of screen 47 mBGS; depth of bore 195 m. | |
| | | | RN14310245 – Alluvium; ~360 m from cut; ground surface 23.8 mAHD; screened 12 – 19 mBGS. | Cut and bore in different aquifers. Ground elevation at bore is below base of cut elevation. Risk of unacceptable impact to groundwater levels at RN14310245 is negligible. |
| 30.7 – 31.0 | 308.6 | 65 | RN133518 – Alluvium; ~540 m from cut; ground surface 52.2 mAHD; top of screen 11 mBGS; depth of bore 17 m. | Cut and bore in different aquifers and ground elevation at bore is below base of cut elevation. Risk of unacceptable impact to groundwater levels at RN133518 is negligible. |
| | | | RN14310277 – Alluvium; ~600 m from cut; ground surface 55 mAHD; screened 11 – 18 mBGS. | Cut and bore in different aquifers. Ground elevation at bore is below base of cut elevation. Risk of unacceptable impact to groundwater levels at RN14310277 is negligible. |
| 32.5 – 32.6 | 70.6 | 65 | RN154100 – Alluvium; ~360 m from cut; ground surface 59.9 mAHD; top of screen 3 mBGS; depth of bore 15 m. | Cut and bore in different aquifers. Ground elevation at bore is below base of cut elevation. Risk of unacceptable impact to groundwater levels at RN154100 and RN154101 is negligible. |
| | | | RN154101 – Alluvium; ~500 m from cut; ground surface 62.6 mAHD; screened 10 – 11 mBGS. | |

³ Preliminary estimate using Theis approximation; cutting floor 5 m below water table, hydraulic conductivity of 5 m/d, storage coefficient of 0.1 (unconfined aquifer) at 365 days (assumed stabilised drawdown impacts).

| Deep cut chainage | Length | Minimum base of cut elevation ¹ (mAHD) | Registered bores | Comment ² |
|-------------------|--------|---|--|--|
| 34.5 – 34.8 | 301.9 | 70 | RN120512 – Marburg Subgroup; ~750 m from cut; ground surface 104.2 mAHD; depth of bore 10 m | Distance from cut suggests limited potential for unacceptable impact to groundwater levels at RN120512 and RN120513. Confirmation of final cut design, bore location, bore construction, and groundwater levels at cut and/or bore would further refine assessment. |
| | | | RN120513 – Alluvium; ~750 m from cut; ground surface 112.2 mAHD; top of screen 4 mBGS; depth of bore 10 m. | |
| 43.9 – 44.0 | 146.7 | 80 | No registered bores within 1 km. | No potential for impact to groundwater levels at registered groundwater bores. |
| 44.8 – 45.1 | 364.6 | 70 | | |
| 46.7 – 46.9 | 57.0 | 60 | | |
| 47.3 – 47.4 | 128.6 | 57 | | |
| 47.8 – 47.9 | 42.0 | 55 | | |
| 49.1 – 49.2 | 58.8 | 55 | | |
| 51.6 – 51.6 | 19.2 | 45 | RN152848 – Marburg Subgroup; ~430 m from cut; ground surface 35.5 mAHD; screened 25 – 27 mBGS. | Ground elevation at bore is below base of cut elevation. Risk of unacceptable impact to groundwater levels at RN152848, RN152849 and RN152850 is negligible. |
| | | | RN152849 – Marburg Subgroup; ~180 m from cut; ground surface 34 mAHD; top of screen 14 mBGS; depth of bore 18 m. | |
| | | | RN152850 – Marburg Subgroup; ~470 m from cut; ground surface 34.2 mAHD; top of screen 18 mBGS; depth of bore 29 m. | |
| 53.6 – 53.7 | 65.9 | 45 | No registered bores within 1 km. | No potential for impact to groundwater levels at registered groundwater bores. |
| 53.8 – 53.9 | 95.3 | 40 | | |

Table notes:

1 Approximate elevation from GIS analysis

2 Approximate bore elevations from BoM NGIS (<http://www.bom.gov.au/water/groundwater/ngis/>)

Based on a review of information currently available for proposed cut construction and/or elevation of ground surface at registered bores compared to proposed base of deep cut elevations, there appears to be limited potential for unacceptable impacts to registered groundwater bores from the reduced groundwater levels due to seepage into free draining cuts. Confirmation of final cut design, bore location, bore construction, and groundwater levels at cuts and/or registered bores would further refine the assessment; in particular for registered bores RN22039 and RN22040, and RN120512 and RN120513 and nearby cuts.

The potential aquatic and terrestrial GDEs in the groundwater study area are largely associated with groundwater supplied by alluvial aquifers, and occur in lower lying topography. Floor elevations of the deep cuts are above the elevation of potential GDEs and therefore reduced groundwater levels due to free draining cuts are not anticipated to be observed at the lower lying potential GDEs.

The potential loss of local recharge to registered bores and GDEs due to drainage of the deep cuts is considered to be negligible. The deep cuts will locally drain rock formations (largely the Walloon Coal Measures). Recharge to the potential GDEs and alluvial aquifer bores will be via the alluvial aquifers, with relatively negligible contribution from adjacent rock formations (in which the cuttings will be constructed). Where registered bores are present in the same formation as a nearby cutting (for example bores RN138180, RN22040 and RN120512) the depth of construction suggests that recharge will be via deeper, intermediate to regional groundwater flowpaths, rather than shallower flows recharged locally.

Preliminary estimates of groundwater inflows and drawdowns have been carried out to inform assessment of the potential to construct the Teviot Range tunnel and portals as permanently drained structures (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report). There are no registered bores within the predicted area of drawdown extent, however there are a number of potential aquatic and terrestrial GDEs within the predicted drawdown extent (refer Figure 9, Figure 10 and Figure 14). Ongoing and further investigations are anticipated to confirm that risks posed to potential GDEs are acceptable. Should this not be the case, works will be completed during subsequent phases (i.e. detailed design and early works) to develop mitigation and management strategies that achieve acceptable residual risks.

11.2.1.5 Vegetation removal and surface disturbance

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

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

Groundwater quality indicates it can only be sourced for earthworks and track works; however, groundwater is not the only, or preferred source of construction water for the Project.

Water will be required for dust control, site compaction and reinstatement during construction. Overall quantities of water have been estimated to be 950 ML (total for earthworks and trackworks, including material conditioning and dust suppression. ARTC recognises water sourcing and availability is critical to supporting the construction program for the Project. Sources of construction water (including potable water demand) will be finalised as the construction approach is refined during the detail design and tender phases of the Project (post-EIS) and will be dependent on:

- Climatic conditions in the lead up to construction
- Confirmation of private water sources made available to the Project by landholders under private agreement
- Confirmation of access agreement with local governments for sourcing of mains water.

The hierarchy of preference for accessing of construction water is generally anticipated to be as follows:

- a) 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 licensed 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 (e.g. camps require potable water)
- Water quality requirement for the activity
- Source location relative to the location of need.

The current estimated water demand is expected to be met using existing water sources, however further options may need to be investigated depending on engagement with water resource owners.

An appropriate quality of water will be sourced for each use. For instance, non-potable water is suitable for soil conditioning and dust suppression, while potable water must be sourced for the construction offices and amenities. Prior to sourcing any construction water, the necessary approvals and licences will be obtained.

The buying or sharing of groundwater from existing water license/entitlement/permit is an option to be considered in the instance bore water is selected as a preferred source of construction water.

Temporary water permits could provide a suitable water supply option for the construction phase of the proposal. 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.

In the instance a temporary water permit is warranted during construction, the licensed volume is expected to be within the allowable extraction limits for the relevant Water Plan. Therefore, the Project is not expected to impact on, or alter, the identified relevant Water Plans or other plans under the Water Act outside of their designated use and objectives.

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 floodplain alluvial sediments are typically dominated by clays and silty clays which will impede vertical infiltration to groundwater.

11.2.2.2 Contamination

During the construction phase there will be potential sources of contamination to groundwater from:

- Accidental spills and leaks of hydrocarbons (oils, fuels and lubricants) and other chemical associated with plant and equipment
- Water mixtures and emulsions related to washdown areas.

Leaching of contaminated embankment fill could impact groundwater quality and affect EVs. It is proposed that cut volumes provide the source for embankment fill. Any impacts would be local to embankments and limited in extent due to the disturbance footprint. In areas of low relief where groundwater is shallower and hence more vulnerable, the floodplain alluvial sediments are typically dominated by clays and silty clays which will impede vertical infiltration to groundwater.

11.2.2.3 Acid rock drainage/acid sulphate soils

The intersection of sulphide-bearing rocks in cuts and the Teviot Range 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 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 sulphate levels. Potential Acid Sulphate Soils (PASS) also present a risk through excavation of cuts in soils susceptible to acid forming conditions.

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

- Alluvium – generally low risk due to young age and lack of sulphide minerals
- Main Range Volcanics – the Tertiary Main Range Volcanics are considered low risk given their primary mineralogy is sulphide poor
- Sedimentary units – the Jurassic age Walloon Coal Measures, Koukandowie Formation and Gatton Sandstone, in which cuts and tunnel are proposed, may host disseminated sulphide minerals (i.e. pyrite).

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

11.2.2.4 Bridge pilings

Changes to groundwater quality (for example pH and salinity) may occur during installation of pilings for bridge construction. Any such changes are likely to be temporary, localised and small.

11.2.2.5 Discharge of groundwater seepage

Long term inflows to free draining cuttings, portals and the Teviot Range tunnel would require appropriate management. The potential effects of discharging groundwater seepage to receiving waterbodies have been assessed in Chapter 13: Surface Water and Hydrology of the EIS, and is not considered further as part of the groundwater study.

11.3 Operational phase potential impacts

Many of the potential impacts with respect to groundwater are considered temporary in nature and primarily associated with the construction phase of the Project. Impacts on groundwater resources during the operation phase of the Project are considered limited to groundwater seepage from ongoing dewatering of the tunnel and the management thereof.

11.3.1 Water resources

11.3.1.1 Access to registered groundwater bores

There are several registered bores located within, or near to, the groundwater study area. Bores within the Project footprint will be decommissioned to enable construction of the Project. The potential exists for these to become inaccessible due to rail corridor restrictions after construction.

11.3.1.2 Embankments

Surface loading from embankments can cause a damming effect due to increased groundwater levels and/or reduced ability to transmit groundwater through compressed shallow sediments (i.e. due to reduced hydraulic conductivities). Depths to groundwater in the alluvial sediments are typically greater than 5 m and thicknesses of the main alluvial channels greater than 15 m thick. The risk is therefore considered low, however shallower groundwater may be present locally (with depths of 1 to 3 m also measured in the groundwater study area). Further assessment of embankment loading on alluvial sediments and groundwater levels would refine understanding of this potential impact and inform final construction.

11.3.1.3 Seepage to cuts and tunnel

Lowered groundwater levels due to long term seepage into cuts and the Teviot Range tunnel has the potential to impact groundwater users (e.g. registered bores and surface water flows). Long-term dewatering via the Teviot Range tunnel may also have the potential to impact vegetation such as deep-rooted trees.

Maximum drawdowns due to the seepage at cuttings are unlikely to exceed 0.5 m at 200 m from cuttings⁴, based on the limited data currently available. As discussed in Section 11.2.1.4, there is limited potential for unacceptable impacts at registered bores based on comparison of deep cut floor elevations and the construction and/or location of registered bore locations. Confirmation of final cut design, bore location, bore construction, and groundwater levels at cuts and/or registered bores would further refine the assessment; in particular for registered bores RN138180 and RN22040, and RN120512 and RN120513, which are located near proposed deep cuts.

Preliminary estimates of groundwater inflows and drawdowns have been carried out to inform assessment of the potential to construct the Teviot Range tunnel and portals as permanently drained structures (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report). There are no registered bores within the predicted area of drawdown extent of the tunnel and portals, however there are a number of potential aquatic and terrestrial GDEs within the predicted drawdown extent (refer Figure 9, Figure 10 and Figure 14). Ongoing and further investigations are anticipated to confirm that risks posed to potential GDEs are acceptable. Should this not be the case, works will be completed during subsequent phases (i.e. detailed design and early works) to develop mitigation and management strategies that achieve acceptable residual risks.

It is currently assumed that cuttings, portals and the Teviot Range tunnel will be free draining and dewatering effects will be ongoing/long term. Final design construction could mitigate 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 local 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 Discharge of dewatering activities

It is currently assumed that cuttings and the tunnel will be free draining and that ongoing inflows to cuttings, portals and the Teviot Range tunnel would require appropriate management. Preliminary assessment of tunnel dewatering suggests that salinity and total nitrogen concentrations of tunnel inflows could exceed criteria for receiving surface water bodies (refer Appendix A: Calvert to Kagaru Preliminary Hydrogeological Interpretive Report). Further, evaporation of the estimated low groundwater seepage rates into cuts (refer Section 10.2.2) may lead to salt residue on the faces of some cuts and the potential for increased salinity of discharge water in the short-term immediately following a 'first flush' rainfall event.

⁴ Preliminary estimate using Theis approximation; cutting floor 5 m below water table, hydraulic conductivity of 5 m/d, storage coefficient of 0.1 (unconfined aquifer) and assumed steady state at 365 days

12 Mitigation

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 measures of relevance to groundwater

| Aspect | Initial design measures |
|-----------------|---|
| Water resources | <p>The Project is generally located within the existing Southern Freight Rail Corridor, which was gazetted as a future rail corridor in 2010. 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.</p> <p>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).</p> <p>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.</p> |
| Water quality | <p>The disturbance footprint defined in Project design has aimed to minimise clearing extents to that required to construct and operate the works.</p> |

12.2 Proposed mitigation measures

In order to manage Project risks during construction, a number of mitigation measures have been proposed for implementation in future phases of Project delivery, as presented in Table 12.2. These proposed mitigation measures have been identified to address Project specific issues and opportunities, address 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.

EIS Chapter 23: Draft Outline Environmental Management Plan provides further context and the framework for implementation of these proposed mitigation and management measures.

Table 12.2 Groundwater mitigation measures

| Delivery phase | Aspect | Proposed mitigation measures |
|--------------------------------|-----------------|--|
| Detail design | Water resources | <p>Undertake additional investigations and assessment of potential drainage/dewatering impacts associated with the tunnel through the Teviot Range, portals and deep cut sections to further refine current understanding, inform detailed design, identify potential for impacts to and mitigation measures for groundwater users. This will also inform requirements for monitoring during construction and potentially operation.</p> <p>Refine seepage analysis for deep cuts to inform detailed design (for example drainage blanket specifications, shotcrete and weep hole specifications.).</p> <p>Review the proposed groundwater monitoring network to ensure locations are accessible during pre-construction, construction, commissioning and operation of the Project. Continue collection of baseline groundwater monitoring data (levels and quality) to confirm seasonal variation and inform detailed design and the development of the final Groundwater Monitoring and Management Plan (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.</p> <p>Engage with relevant landholders to confirm the location of existing bores, identification/confirmation of new monitoring bore locations, and procure access agreements to existing registered groundwater bores included in the GMMP.</p> <p>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 and engage with licensed users to determine an appropriate mitigation strategy.</p> <p>Undertake field 'truing' of identified potential aquatic and terrestrial GDEs within the groundwater study area that can potentially be impacted by the Project and confirm their status.</p> <p>Confirm source(s) for construction water requirements via consultation with relevant stakeholders (including landholders/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 license requirements and/or private landholder agreements are met.</p> |
| | Water quality | <p>Undertake detailed geotechnical investigations at deep cut sections to inform design and location specific construction management of groundwater.</p> <p>Risks associated with dewatering (i.e. water table lowering) and environmental management requirements during construction are identified through appropriate baseline groundwater monitoring, modelling and analysis.</p> |
| Pre-construction | Water resources | <p>Continue collection of baseline groundwater monitoring data (levels and quality) to confirm seasonal variation and inform detailed 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.</p> |
| | Water quality | <p>Undertake site inspections prior to the construction of cuts, including visual examination of surface outcrops for sulfide minerals or evidence of sulfide mineralisation. Utilise the information from these inspections to inform the management of potential acid rock drainage (ARD) from cuttings prior to Project works.</p> |
| Construction and commissioning | Water resources | <p>Implement the CEMP and the construction GMMP with appropriate groundwater level and quality monitoring criteria based on the baseline groundwater monitoring, modelling analysis and regulatory requirements; with make-good arrangements with the owners of groundwater bores as necessary.</p> <p>Opportunities to re-use/recycle groundwater water drawn from tunnel and cuttings where encountered, are identified and implemented where feasible during construction.</p> |

| Delivery phase | Aspect | Proposed mitigation measures |
|----------------|-----------------|--|
| | Water quality | <p>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.</p> <p>Personnel involved in ground-disturbing works are familiar with hazardous spill management procedures.</p> <p>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.</p> <p>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.</p> <p>Imported fill material will be clean, certified contaminant free and be required to comply with regulatory guidelines for the intended use.</p> <p>Material won from site will be tested and assessed for suitability prior to use within proximity to potential groundwater infiltration sites.</p> <p>Any excavated material which is suspected to contain sulfides 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.</p> <p>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.</p> <p>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.</p> <p>Implement the construction GMMP.</p> <p>Any groundwater supply and/or monitoring that require decommissioning will be undertaken in accordance with the Minimum Construction Requirements for Water Bores in Australia – Edition 3 (Feb 2012).</p> |
| Operation | Water resources | Implement operational phase GMMP. |
| | Water quality | <p>Appropriate controls are to be in place to prevent environmental incidents including leaks/spills from refuelling activities and locomotive operations and to protect the environment in the event of an incident.</p> <p>In the event of a spill, all necessary actions will be taken to contain the spill and follow ARTC emergency response protocols.</p> <p>Teviot Range tunnel and potential deep cut seepage water will be monitored and discharged in accordance with the surface water monitoring framework and the Surface Water Sub-plan as confirmed during detailed design.</p> <p>Groundwater quality will be monitored in accordance with the operational phase GMMP, assessed against trigger levels and contingency measures followed (as required).</p> <p>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).</p> |

12.3 Groundwater monitoring and management program

The GMMP provides for an ongoing assessment of the potential impacts identified in Section 11. The GMMP incorporates principles of performance assessment and adaptive management, a structured, iterative process for decision making. The GMMP will be assessed and updated after each phase of works (pre-construction/baseline, construction, and operation) such that the GMMP for subsequent phases is based on the outcomes of the previous phase.

The indicative pre-construction/baseline GMMP's primary objective is to develop a robust baseline dataset from which all subsequent monitoring will be assessed against to identify impacts. This dataset will also inform the proposal-specific WQO trigger values. The pre-construction/baseline GMMP will be developed and implemented during the detail design stage to inform proposal-design aspects and ensure a suitable groundwater baseline dataset is established before starting any works.

The baseline/pre-construction dataset is to be the reference dataset for future groundwater monitoring and, as such, may be supplemented with existing groundwater data inclusive of, but not limited to, representative data from local councils, recent studies, etc. The baseline dataset will be compiled, and the construction GMMP developed, prior to the commencement of the construction phase of the proposal.

The pre-construction (baseline) GMMP is discussed in the following subsections. The construction phase GMMP will be developed prior to commencement of construction. Groundwater baseline monitoring should commence as soon as practicable to provide information on seasonal variation. The baseline monitoring program will be completed in enough time prior to commencement of construction works to allow for assessment of the data, including trends, develop groundwater level and quality thresholds (warning and action levels) and inform the development of the construction phase GMMP.

An indicative network of monitoring bores in proximity to the deep cuts is summarised in Table 12.3. In addition to the existing bores, it may be beneficial to install dedicated environmental monitoring bores in areas where materials will be stored and in locations identified to intersect groundwater, in order to provide adequate coverage up and down the hydraulic gradient of these areas. The monitoring network will be subject to landholder negotiations and access and will be refined during the detailed design phase.

12.3.1 Groundwater level monitoring

Groundwater levels for bores within the indicative minimum network are to be monitored using automated pressure transducers/level loggers to record measurements at least every six hours. Particularly this is required to establish the baseline groundwater dataset from which potential impacts can be assessed during construction and operation of the Project.

Manual measurements on all bores is proposed monthly during establishment of the baseline groundwater dataset as this will be the basis of comparison for the Project. Pressure transducer data will be downloaded on a bimonthly basis, during the baseline program, to coincide with quality monitoring, as discussed below. The baseline groundwater monitoring program will be continuously ongoing so as to account for natural (seasonal) or anthropogenic fluctuations of groundwater levels prior to construction. This is pertinent for the alluvial sediments in particular, as the water levels in these sediments are key to the design, construction, and operation of the Project.

In addition, the baseline groundwater level dataset will allow for identification of outside influences on groundwater levels. This information is important to capture to allow for discernibility between the impacts of the Project and those from non-project influences.

The baseline monitoring program will be completed in sufficient time prior to commencement of construction works to allow for assessment of the data, including trends, to develop groundwater level thresholds (warning and action levels); the construction phase GMMP will also be developed at this time. Groundwater level measurements are to remain ongoing in the transition from detail design into construction.

After completion of baseline monitoring program, and with consideration of the final detail design, the frequency and location of level measurements can be reviewed and amended for suitability to achieve the objectives of the groundwater monitoring Program for the construction stage of the Project. The shallow aquifer data will be considered together with regular surface water level monitoring data to inform the local hydraulic connectivity between surface water and shallow groundwater in the disturbance footprint.

Table 12.3 Indicative minimum groundwater monitoring network

| Chainage (km) | Bore ID | Deep cut chainage (km) | Aquifer | Screen interval (mbgl) |
|---------------|--------------|------------------------|-------------------------------------|------------------------|
| 1.6 | RN120194 | 9.7 – 10.2 | Alluvium | 16.2 – 21.7 |
| 12.0 | RN138180 | 10.3 – 10.5 | Walloon Coal Measures | 135.0 – 147.0 |
| 16.0 | RN22039 | 15.5 – 16.2 | Walloon Coal Measures | Unknown |
| 16.0 | RN22040 | 15.5 – 16.2 | Walloon Coal Measures | Unknown |
| Ch 17.6 | RN14310245 | 15.5 – 16.2 | Alluvium | 17.1 – 18.6 |
| 29.6 | RN133518 | 30.7 – 31.0 | Alluvium | 11.1 – 17.1 |
| Ch 31.2 | RN14310277 | 30.7 – 31.0 | Alluvium | 17.0 – 18.0 |
| 33.2 | RN154100 | 32.5 – 32.6 | Alluvium | 8.3 – 14.3 |
| 33.4 | RN154101 | 32.5 – 32.6 | Alluvium | 6.7 – 11.2 |
| 34.0 | RN120512 | 34.5 – 34.8 | Marburg Subgroup – undifferentiated | 8.0 – 10.0 |
| 34.0 | RN120513 | 34.5 – 34.8 | Alluvium | 7.6 – 10.0 |
| 51.4 | RN152848 | 51.6 – 51.6 | Marburg Subgroup – undifferentiated | 22.6 – 28.6 |
| 51.4 | RN152849 | 51.6 – 51.6 | Marburg Subgroup – undifferentiated | 11.1 – 17.1 |
| 51.4 | RN152850 | 51.6 – 51.6 | Marburg Subgroup – undifferentiated | 16.0 – 27.8 |
| Ch 31.1 | BH-04 | 30.7 – 31.0 | Koukandowie Formation | 10.9 - 16.9 |
| Ch 44.8 | BH-05 | - | Gatton Sandstone | 18.97 - 24.97 |
| Ch 39.8 | BH-07 | - | Gatton Sandstone | 29.5 - 35.5 |
| Ch 40.0 | 340-1-BH2101 | - | Gatton Sandstone | 112 - 124 |
| Ch 17.4 | 340-1-BH2215 | - | Alluvium | 19 - 25 |
| Ch 25.4 | 340-1-BH2220 | - | Koukandowie Formation | 16 - 25 |
| Ch 35.2 | 340-1-BH2224 | - | Walloon Coal Measures | 16 - 25 |
| Ch 36.6 | 340-1-BH2225 | - | Alluvium | 19 - 25 |
| Ch 37.2 | 340-1-BH2226 | - | Koukandowie Formation | 17 - 26 |
| Ch 46.4 | 340-1-BH2229 | - | Koukandowie Formation | 11 - 20 |
| Ch 52.8 | 340-1-BH2233 | - | Alluvium and Gatton Sandstone | 16 - 25 |
| Ch 35.0 | 340-1-BH2303 | - | Gatton Sandstone | 22 - 31 |

12.3.2 Groundwater quality monitoring

The baseline groundwater monitoring program is to include the indicative bores in Table 12.3 at a minimum to characterise the local groundwater quality prior to construction activities. The quality data collected during the baseline program will be used to assess potential impacts of the Project on local groundwater resources through all stages of the Project. Groundwater quality samples are to be collected for field and laboratory analyses on a bimonthly basis (to coincide with the manual groundwater level measurement baseline program).

The baseline groundwater quality program will be continuously ongoing to account for and allow characterisation of natural (seasonal) and/or anthropogenic variation prior to commencement of construction activities. This is especially applicable to the shallow aquifers hydraulically connected to surface water as after the dry season (negligible recharge) a first-flush/flow of recharge to these sediments can result in markedly different quality from data collected within and after the wet season. In addition, the baseline quality dataset will indicate the potential for ARD prior to construction works and inform the suitability of local groundwater suitability for construction water purposes.

Field parameters to be collected during sampling include pH, EC, temperature, redox potential, and dissolved oxygen. The following analytical suite is suggested for laboratory analyses for the baseline groundwater quality dataset and is considered sufficient to identify potential ARD and suitability of groundwater for construction water purposes:

- pH, EC and TDS
- Major anions (bicarbonate, chloride, sulphate)
- Major cations (calcium, magnesium, sodium, potassium and silicon)
- Dissolved and total metals (aluminium, arsenic, boron, cadmium, chromium, copper, manganese, lead, nickel, selenium, molybdenum, silver, zinc, iron, and mercury)
- Nutrients (ammonia, nitrite, nitrate, total nitrogen, total phosphorus).

The baseline monitoring program will be completed in sufficient time prior to commencement of construction works to allow for assessment of the data, including trends, to develop groundwater quality trigger levels (warning and action levels); the construction phase GMMP will also be developed at this time. Groundwater quality monitoring events are to remain ongoing between project phases.

After completion of baseline monitoring program, and with consideration of the final detail design, the frequency and location of groundwater quality sample events can be reviewed and amended for suitability to achieve the objectives of the groundwater monitoring program for the construction stage of the Project. The shallow aquifer data will be considered together with regular surface water quality monitoring data to inform the local hydraulic connectivity between surface water and shallow groundwater in the disturbance footprint.

Groundwater quality data (post-baseline) will be analysed for trends and compared to the baseline dataset to identify potential impacts of the Project on groundwater quality.

Groundwater monitoring and sample collection will be conducted in accordance with recognised groundwater sampling guidelines such as Monitoring and sampling manual (DES 2018) and Groundwater Sampling and Analysis – A Field Guide (Geoscience Australia 2009) unless an updated version is available prior to commencement of the baseline monitoring program.

12.3.3 Data management and reporting

The following data and reporting requirements would be implemented:

- All groundwater data will be validated with suitable quality assurance and quality control (quality assurance/quality control (QA/QC)) protocols applied
- Monitoring data will be assessed on a quarterly basis initially to identify trends and compare to trigger levels (baseline and pre-construction)
- After baseline, where consecutive data points for the same bore(s) over a six-month period indicate divergence from the baseline trends or previous data, consideration of verification sampling to confirm the accuracy of the data will be undertaken and the bore data will be further investigated to determine appropriate actions. This may include more rigorous monitoring or trigger a re-assessment of impacts/or mitigation measures.
- Reporting will be completed on an annual basis and present the assessment of water levels and water quality trends, including hydrographs and hydrochemical plots. The annual assessment will recommend if the location and frequency of monitoring needs to be modified to ensure the objectives of the monitoring plans for the relevant stage of the Project are achieved.

12.3.4 Summary

A summary of the monitoring and requirements of the GMMP is presented in Table 12.4.

Table 12.4 Summary of Groundwater Monitoring and Management Program requirements

| GMMP requirements | Pre-construction (baseline) | Construction | Operation |
|--------------------------------|--|---|---|
| Groundwater level monitoring | <ul style="list-style-type: none"> ■ Pressure transducers/level loggers record measurements six hourly intervals ■ Pressure transducer data downloaded every two months ■ Manual measurements monthly | Subject to DNRME/DES approval of the GMMP | Subject to DNRME/DES approval of the GMMP |
| Groundwater quality monitoring | <ul style="list-style-type: none"> ■ Every two months | Subject to DNRME/DES approval of the GMMP | Subject to DNRME/DES approval of the GMMP |
| Reporting | <ul style="list-style-type: none"> ■ Quarterly data comparison ■ Annual reporting | Subject to DNRME/DES approval of the GMMP | Subject to DNRME/DES approval of the GMMP |

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 and EIS Chapter 4: Assessment Methodology.

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

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 measures) factored into the design phase (refer Table 13.1) have been implemented.

Proposed mitigation measures, including those listed in relevant subplans (including the GMMP), were then applied as appropriate to the phase of the project to reduce the level of potential impact and are detailed in Section 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.

13.1 Temporary impacts

Many of the potential impacts with respect to groundwater are considered temporary in nature and primarily associated with the construction phase of the Project. The likelihood of a material impact on current groundwater conditions and users is considered to be low.

Final construction design, engineering controls and monitoring are generally considered to be adequate to mitigate potential impacts to groundwater. However, it is noted that additional investigations and assessment of potential drainage/dewatering impacts associated with the Teviot Range tunnel and deep cut sections is proposed to further refine current understanding and inform detailed design and reduce potential impacts.

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/drainage of the Teviot Range 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 be adequate to mitigate potential impacts to groundwater. However, it is noted that additional investigations and assessment of potential drainage/dewatering impacts and potential loading impacts near significant embankments is proposed to further refine current understanding, inform detailed design, and refine the long-term monitoring approach.

Table 13.1 Significance assessment summary for groundwater

| Potential impact | Phase | Initial significance ¹ | | | Application of proposed mitigation measures presented in Table 12.2, by aspect ² | Residual significance ³ | |
|---|--------------|-----------------------------------|-----------|--------------|---|------------------------------------|--------------|
| | | Sensitivity | Magnitude | Significance | | Magnitude | Significance |
| Loss of registered bores (through destruction, damage or lack of access) | Construction | Moderate | Moderate | Moderate | Water resources (pre-construction and construction) | Low | Low |
| | Operations | | Moderate | Moderate | | Low | Low |
| Subsidence/consolidation due to groundwater extraction, dewatering or loading | Construction | Moderate | Moderate | Moderate | Water resources (detailed design, pre-construction, construction) Water quality (pre-construction) | Low | Low |
| | Operations | | Low | Low | | Low | Low |
| Altered groundwater levels (increase or decrease) affecting groundwater users (incl. impacts due to embankments and seepage to cuts) | Construction | Moderate | Moderate | Moderate | Water resources (detailed design, pre-construction, construction) | Moderate | Moderate |
| | Operations | | Moderate | Moderate | | Moderate | Moderate |
| Reduced groundwater levels affecting groundwater users – due to drained tunnel (Teviot Range tunnel) | Construction | Moderate | High | High | Water resources (detailed design, pre-construction, construction) | Moderate | Moderate |
| | Operations | | High | High | | Moderate | Moderate |
| Altered groundwater flow regime | Construction | Moderate | Low | Low | - | Low | Low |
| | Operations | | Low | Low | - | Low | Low |
| Contamination or water quality degradation of vulnerable groundwater resources requiring remediation (spills or induced flow, bore hole intersections. Upwards leakage along pile/soil interface) | Construction | Moderate | High | High | Water quality (detailed design, pre-construction, construction) | Moderate | Moderate |
| | Operations | | Low | Low | | Low | Low |
| ARD from cuts and tunnel impacts on EVs (i.e. GDEs) | Construction | Moderate | Moderate | Moderate | Water quality (pre-construction, construction) | Low | Low |
| | Operations | | Low | Low | | | |
| Vegetation removal and surface alteration affecting recharge/ discharge, increasing associated salinity risks | Construction | Moderate | Moderate | Moderate | Water resources (pre-construction) | Low | Low |
| | Operations | | Low | Low | | Low | Low |

Table notes:

- 1 Includes implementation of initial mitigation measures specified in Table 12.1
- 2 Proposed mitigation measures and controls, as identified in Table 12.2.
- 3 Assessment of residual significance once the initial and additional mitigation measures have been applied.

13.3 Cumulative impacts

Cumulative impacts are the successive, incremental and combined impacts of an activity when added to other existing or planned projects and activities (IFC 2013). For the Project, a CIA was undertaken where potential groundwater impacts of the Project were assessed together with existing or planned surrounding activities (as outlined in Section 3.3.4).

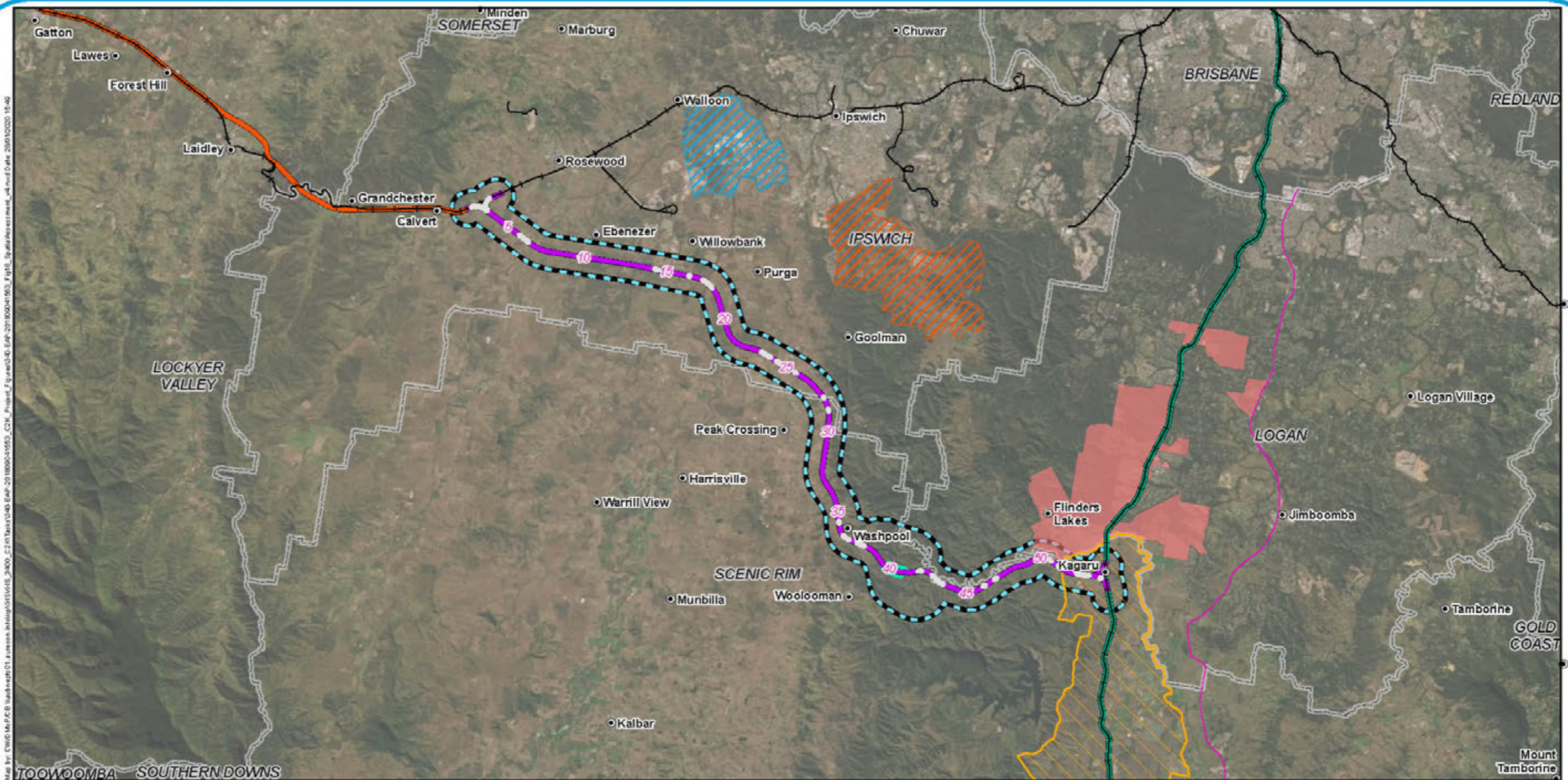
It is noted that no cumulative impacts on agricultural groundwater users are anticipated as no potentially significant effects were identified for individual groundwater bores carried out as part of this groundwater study (refer Section 11). For a full assessment of cumulative impacts refer EIS Chapter 22: Cumulative Impacts.

13.3.1 Surrounding projects and timeline relationships

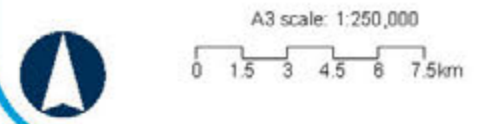
Projects and operations surrounding the groundwater study area are depicted on Figure 18. Due to the localised potential groundwater impacts associated with the alignment, only applicable projects and operations (with potential impacts on groundwater) in Table 13.2 have been considered for this CIA. Other projects are considered too distant compared to the localised nature of potential groundwater impacts, and/or the scope of the surrounding projects were such that there is negligible potential to impact on groundwater.

Table 13.2 Applicable projects and operations considered for the Cumulative Impact Assessment

| Project and proponent | Location | Description | EIS status | Timeline | Relationship to the Project |
|---|---|---|---------------------|--|---|
| Kagaru to Acacia Ridge and Bromelton (K2ARB) (ARTC) | Rail corridor from Kagaru to Acacia Ridge and Bromelton | Enhancing and connecting the existing rail corridor (approximately 49 km) from North-east of Kagaru to Acacia Ridge and from south of Kagaru to Bromelton | Project Feasibility | Construction: 2023 to 2025 Operation: >50 years | Potential overlap of construction for C2K and K2ARB |
| Helidon to Calvert (H2C) (ARTC) | Rail alignment from Helidon to Calvert | <ul style="list-style-type: none"> ■ 47 km single-track dual-gauge freight rail line to accommodate double stack freight trains up to 1,800 m long ■ 850 m tunnel through the Little Liverpool Range ■ Construction of rail infrastructure, culverts, bridges, viaducts and crossing loops ■ Connection to the existing West Moreton Railway Line ■ Ancillary works including road and public utility crossings and realignments | EIS in preparation | Construction: 2021 to 2026 Operation: >50 years | Potential overlap of construction for H2C and C2K |



- Legend**
- Localities
 - 5 Chainage (km)
 - Bridges
 - Existing rail
 - C2K project alignment
 - Tunnel
 - Groundwater study area
 - Local Government Areas
- Projects**
- ▨ Ripley Valley Priority Development Area
 - ▨ RAAF Base Amberley
 - ▨ State Development Area Boundary - Bromelton
 - ▨ South West Pipeline
 - ▨ Priority Development Area Boundary - Greater Flagstone
 - H2C project alignment
 - K2ARB project alignment



Calvert to Kagaru
Figure 18: Location of projects included in the cumulative impact assessment

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 13.3.

Table 13.3 Summary of potential cumulative impacts

| Project | Potential cumulative impact | |
|--------------------------------------|---|---|
| | Groundwater levels | Groundwater quality/contamination |
| Calvert to Kagaru | Potential overlap of impacts from dewatering and cuttings which intersect shallow aquifers. 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 the shallow aquifer from spills/leaks from heavy machinery, drill rigs. |
| Kagaru to Acacia Ridge and Bromelton | | |
| Helidon to Calvert | | |

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) to 3 (high) to the potential cumulative impacts for each of the following aspects:

- The probability of the impact
- The duration of the impact
- The magnitude/intensity of the impact
- The sensitivity of receiving environment.

The significance of the cumulative impact is then determined by summing the relevance factors. The impact categories are as follows:

- *Low (relevance sum 1-6)* – Negative impacts should be managed by standard environmental procedures. Special approval conditions are unlikely. Monitoring required as part of the general project monitoring.
- *Medium (relevance sum 7-9)* - Mitigation measures likely required and specific management practices to be applied. Specific approval conditions are likely.
- *High (relevance sum 10-12)* - Alternative actions should be considered and/or mitigation measures applied to demonstrate improvement. Specific approval conditions are likely and targeted monitoring is required.

Based on the above methodology the cumulative groundwater impacts for the Project is summarised in Table 13.4.

Table 13.4 Summary of the cumulative impact assessment

| Cumulative impact | Aspect | Relevance factor | Sum of relevance factors | Impact significance | Comments | Mitigation measures |
|---------------------------------------|--------------------------------------|------------------|--------------------------|---------------------|--|---|
| Change in groundwater levels | Probability of impact | 1 | 6 | Low | <ul style="list-style-type: none"> ■ Localised impacts on shallow groundwater levels considered unlikely to be compounded northern and southern ends of the Project alignment with either ARTC projects exist ■ Overlap of construction activities at the northern and southern ends of the alignment with either ARTC projects exist. | <ul style="list-style-type: none"> ■ Adherence to dewatering and water supply mitigation measures discussed in Section 12. ■ Adherence to the CEMP to respond effectively to groundwater level drawdown triggers. |
| | 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 | <ul style="list-style-type: none"> ■ 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 northern and southern ends of the Project alignment with either ARTC projects exist. | <ul style="list-style-type: none"> ■ Implementation of the groundwater monitoring program to identify and respond to triggers being breached. ■ Adherence to the CEMP to prevent and respond effectively to spills and leaks. |
| | Duration of the impact | 2 | | | | |
| | Magnitude/ intensity of the impact | 1 | | | | |
| | Sensitivity of receiving environment | 2 | | | | |

14 Summary

This groundwater technical report has been prepared to evaluate potential impacts of the Project on groundwater. The Project will comprise approximately 53 km of new track between the towns of Calvert and Kagaru in south-east Qld, including bridges, embankments, cuts and the 1,015 m Teviot Range tunnel beneath the Teviot Range.

The Project is located within the Ipswich City Council, Logan City Council and Scenic Rim Regional Council local government area in south-east Qld. The alignment is oriented generally northwest to south-east, traversing the Bremer River catchment area (west of the Teviot Range) and Logan River catchment area (east of the Teviot Range). The alignment traverses a number of defined watercourses including Western Creek, Bremer River, Warrill Creek, Purga Creek and Teviot Brook.

Much of the groundwater study area is located to the west of the Teviot Range and is underlain by the Jurassic-aged Walloon Coal Measures. Relatively thin deposits of Quaternary alluvial sediments are associated with the primary surface water features inclusive of that flow through the west side of the groundwater study area. The alluvial sediments are limited in extent, both laterally and vertically, away from the watercourses. The central portion of the groundwater study area is underlain by Gatton Sandstone which forms the topographic high known as the Teviot Range. The eastern extent of the groundwater study area is underlain by the Koukandowie Formation and Walloon Coal Measures, which are overlain in some parts by alluvial sediments associated with Teviot Brook.

The two main aquifer systems considered relevant to the groundwater study area are the Cainozoic to recent alluvium and volcanic formations – including shallow alluvial systems along river valleys within the Basin (underlying approximately 39 per cent of the alignment), and volcanic formations including Cainozoic basalt aquifers) and Jurassic to Cretaceous sandstones – including the Walloon Coal Measures, Koukandowie Formation and Gatton Sandstone (underlying approximately 61 per cent of the alignment).

The water table is typically a subdued version of topography, with the depth to groundwater increasing beneath topographic highs (for example the Teviot Range), and shallower groundwater in lower lying reaches (such as close to surface water drainage lines). The water table will occur in the alluvial sediments or outcropping Walloon Coal Measures across much of the groundwater study area west and east of the Teviot Range. The Gatton Sandstone of the Teviot Range will form the upper (water table) aquifer in the central portion of the groundwater study area.

Depths to groundwater in the alluvial sediments are anticipated to be between 5 m and 15 m but have been measured at less than 5 m in several locations across the groundwater study area. Shallow groundwater in the alluvial sediments will typically occur in low lying areas near to watercourses where fill/embankments and/or bridges are proposed, with no cuttings proposed through the alluvial sediments. Significant embankments in areas of shallow groundwater and compressible materials (i.e. alluvial sediments in low lying areas) may create groundwater mounding.

In the main outcrop areas of Walloon Coal Measures (Ch 8 km to Ch 13 km and Ch 18 km to Ch 23 km) the water table might be expected to be at least 5 m, and greater than 10 m beneath higher relief; where deeper cuts are proposed. There are limited water table elevation data available for the Gatton Sandstone and Koukandowie. Data from a geotechnical site investigation monitoring well indicates that some cuts could intersect groundwater. The full length of the Teviot Range tunnel and associated portals are also expected to intersect groundwater within the Gatton Sandstone (that form the Teviot Range).

Where groundwater levels are above the base of cut elevations, consideration will be required with respect to potential geotechnical implications (such as wall failure and floor heave), reduced groundwater levels and flow at receptors, and the quality of groundwater discharge (for example to surface water courses). It is noted that only the 2018 geotechnical monitoring bore 340-1-BH2303 was constructed near a proposed cutting, with all others targeting the proposed sites of bridges (seven bores) and the tunnel (one bore).

Water quality data for the Clarence-Moreton Basin and baseline groundwater sampling at eight of the geotechnical monitoring bores (Golder 2018) indicates variable water quality within and across the key hydrogeological formations; with groundwater in the alluvial sediments generally fresher than the underlying sediments (primarily the Walloon Coal Measures in the groundwater study area).

Evaluation of groundwater EVs in the groundwater study area indicates that groundwater associated with the sedimentary rock formations are of limited value for most uses. Groundwater associated with the alluvium is sporadic and seasonal and is not considered to provide sufficient (sustainable) supply in the groundwater study area to allow for evaluation. The only recognised groundwater EV to be enhanced or protected within the groundwater study area is stock watering. Aquatic ecosystems may also be relevant based on the presence of potential GDEs within the groundwater study area.

A significance assessment was carried out for identified potential impacts on groundwater resources in terms of groundwater levels, groundwater flow, and water quality. The significance of impacts is considered low to moderate across the majority of the proposed alignment if the recommended mitigation measures are adopted.

Potential residual risks were identified as being moderate for groundwater users (that is groundwater bore users and potential GDEs) from lowering of groundwater levels due to permanent seepage from a free draining Teviot Range Tunnel and deep cuts. Ongoing and further investigations are anticipated to confirm that risks posed to groundwater users are acceptable. Should this not be the case, works will be completed during subsequent phases (i.e. detailed design and early works) to develop mitigation and management strategies that achieve acceptable residual risks. Key locations for further investigations include:

- Significant embankments overlying alluvial sediments with shallow groundwater
- Drawdowns and inflow rates to deep cuts intersecting groundwater
- Teviot Range tunnel.

A CIA was undertaken where potential groundwater impacts of the Project were assessed together with existing or planned surrounding activities. Those relevant to groundwater were the adjoining ARTC projects (K2ARB and H2C). Other projects are considered too distant compared to the localised nature of potential groundwater impacts, and/or the scope of the surrounding projects were such that there is negligible potential to impact on groundwater. A qualitative significance assessment was used to evaluate cumulative impacts from the Project and surrounding projects. The CIA identified low potential impact significance for changes in groundwater levels and groundwater quality; primarily due to the physical distance of each project from the Project and the proposed adoption and implementation of recommended mitigation measures.

An indicative groundwater monitoring program is outlined in this report to provide an on-going assessment of the potential impacts of the proposal on groundwater users (that is groundwater bore users and GDEs), and in particular the relevant groundwater EVs of stock watering and aquatic ecosystems. The program includes an adaptive management approach and indicative monitoring bore network for periodic water level and groundwater quality monitoring. Selected bores will be equipped with automated pressure transducers which record water levels. The proposed groundwater monitoring program will be refined subsequent to post-EIS investigations and detailed design to ensure a comprehensive approach to monitoring.

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APPENDIX

0

Groundwater Technical Report

Appendix A Calvert to Kagaru Preliminary Hydrogeological Interpretative Report

CALVERT TO KAGARU ENVIRONMENTAL IMPACT STATEMENT



REPORT

**Inland Rail Section 340 - Calvert to Kagaru Preliminary
Hydrogeological Interpretative Report**
Feasibility Design Stage

Submitted to:

Future Freight Joint Venture

Submitted by:

Golder Associates Pty Ltd

147 Coronation Drive, Milton, Queensland 4064, Australia

+61 7 3721 5400

1893803-018-R-Rev7

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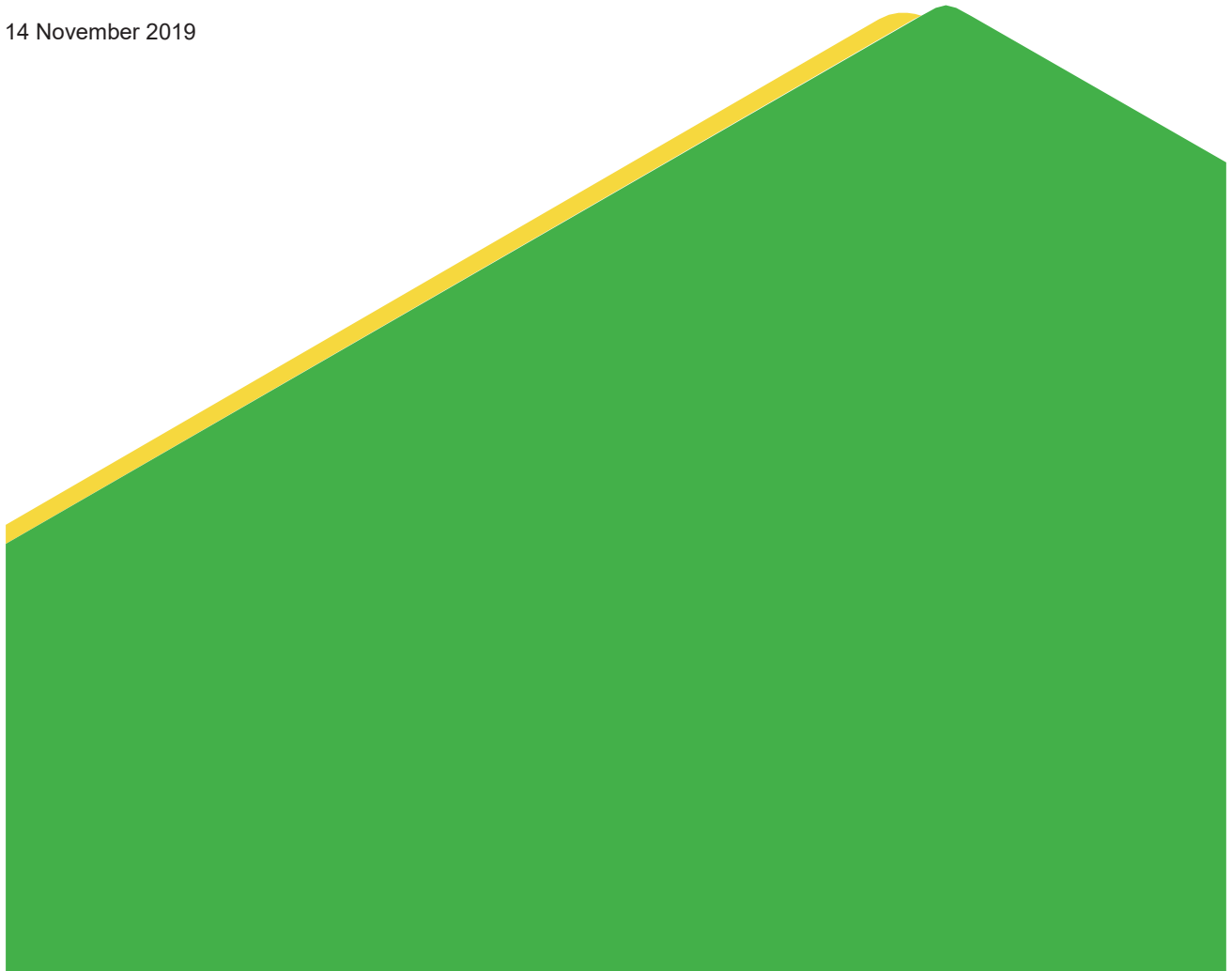


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APPENDIX B

Groundwater Chemistry

APPENDIX C

Groundwater Level with Relation to Earth Works and Bridge Locations

APPENDIX D

Inferred Groundwater Chemistry at Proposed Bridge Locations

APPENDIX E

Important Information Relating to this Report

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 Calvert to Kagaru (C2K) section (Section 340 between Kilometrage 0.0 to 56.200 km) comprises approximately 56 kilometres of new dual gauge rail line which diverts from the West Moreton rail line near Calvert and connects to the existing Sydney to Brisbane interstate rail line at Kagaru.

1.2 Objective

This report provides 100% 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 C2K Section 340 of works. This version of the report supersedes Technical Memoranda Golder, 2018a and Golder, 2018b.

1.3 Alignment

The Calvert to Kagaru project area consists of an approximately 56-kilometre route that extends in an east-south-easterly direction between Calvert (western terminus) and Kagaru (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 330 – Helidon to Calvert at the west and Section 350 – Kagaru to Acacia Ridge/Bromelton at the east.

2.0 REVIEWED INFORMATION

For the Feasibility Study of the C2K section ARTC is undertaking a geotechnical investigation (the C2K FS SI) to gain an understanding of the ground conditions along the alignment. Work completed at time of reporting includes:

- Rotary and core drilling at:
 - 7 bridge locations
 - 1 cut locations and
 - 1 location near the Woollooman tunnel
- Installation of 9 groundwater monitoring bores equipped with standpipe piezometers and automatic water level probes recording groundwater level at half hourly intervals
- Borehole permeability testing including
 - water pressure testing of the Gatton Sandstone at two depth intervals below and above the tunnel invert level
 - slug testing in 1 monitoring bore
- Groundwater sampling for water chemistry analysis.

Data records and information gained from the investigation are reported in the C2K 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 (DNRME, 2018)
- 6) ARTC Phase 1 Geotechnical Investigations (ARTC, 2016)

In addition to the data sources listed above, a hydrogeological investigation was undertaken by Golder in 2009 for the Wyaralong dam site on behalf of Queensland Water Infrastructure. The dam site is located 10 km to the southeast of the Teviot Range section in an area with similar geology to parts of the C2K alignment. It will be necessary to prepare a Request for Information (RFI) formally requesting permission to use the data collected in that investigation which is recommended to be pursued for the next phase of design.

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 Amberly AMO BoM weather station (040004) is the nearest station to the Section 340 alignment which has long-term statistical climate data (1941-2018). For this station the mean maximum and minimum daily temperatures are 26.8 and 13.1 degrees Celsius respectively (calculated as annual statistics). The monthly mean maximum daily temperatures range from 21.3 degrees Celsius in July to 31.2 degrees Celsius in January. The monthly mean minimum daily temperatures range from 5.4 degrees Celsius in July to 19.6 degrees Celsius in January. Table 1 provides long-term mean monthly rainfall summary statistics for the Amberly AMO BoM station. For this station, a mean annual rainfall of 864.0 mm and a median annual rainfall of 882.5 mm are reported.

Table 1: Long-term mean monthly rainfall summary statistics for ‘Amberly AMO’ Australian Bureau of Meteorology station number 040004 for the years between 1941 and 2018. Source: Bureau of Meteorology (2018)

| Statistic | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|-----------|-------|-------|-------|-------|-------|-------|-------|------|-------|-------|-------|-------|--------|
| Mean | 116.9 | 121.2 | 85.5 | 54.5 | 52.8 | 46.9 | 37.6 | 28.6 | 33.3 | 73.3 | 81.5 | 119.4 | 864.0 |
| Lowest | 0.0 | 13.0 | 6.7 | 2.4 | 0.0 | 0.0 | 0.5 | 0.0 | 0.0 | 6.6 | 5.9 | 27.3 | 391.8 |
| 10th %ile | 40.6 | 33.8 | 17.8 | 9.0 | 9.1 | 4.0 | 3.8 | 4.8 | 3.1 | 20.2 | 22.4 | 46.0 | 587.6 |
| Median | 94.0 | 102.8 | 74.2 | 33.4 | 32.4 | 27.1 | 26.2 | 24.6 | 24.0 | 66.3 | 67.3 | 105.3 | 94.0 |
| 90th %ile | 206.1 | 209.7 | 169.5 | 108.7 | 137.5 | 111.8 | 74.8 | 57.0 | 69.1 | 141.4 | 155.2 | 210.4 | 206.1 |
| Highest | 635.2 | 434.9 | 282.8 | 362.6 | 429.2 | 389.1 | 214.1 | 93.7 | 119.9 | 319.5 | 280.4 | 394.4 | 1398.1 |

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

The Harrisville Mary Street weather station (040094) is located closer to the alignment than the Amberly station and has a longer period of rainfall record with records available from 1896 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, indicating a similar pattern of rainfall to that recorded for Amberly. The nearest available evaporation data was reported as mean daily evaporation for each month from 1992 to 2014 at the Gatton DAFF Research weather station (040436), reported on Figure 1.

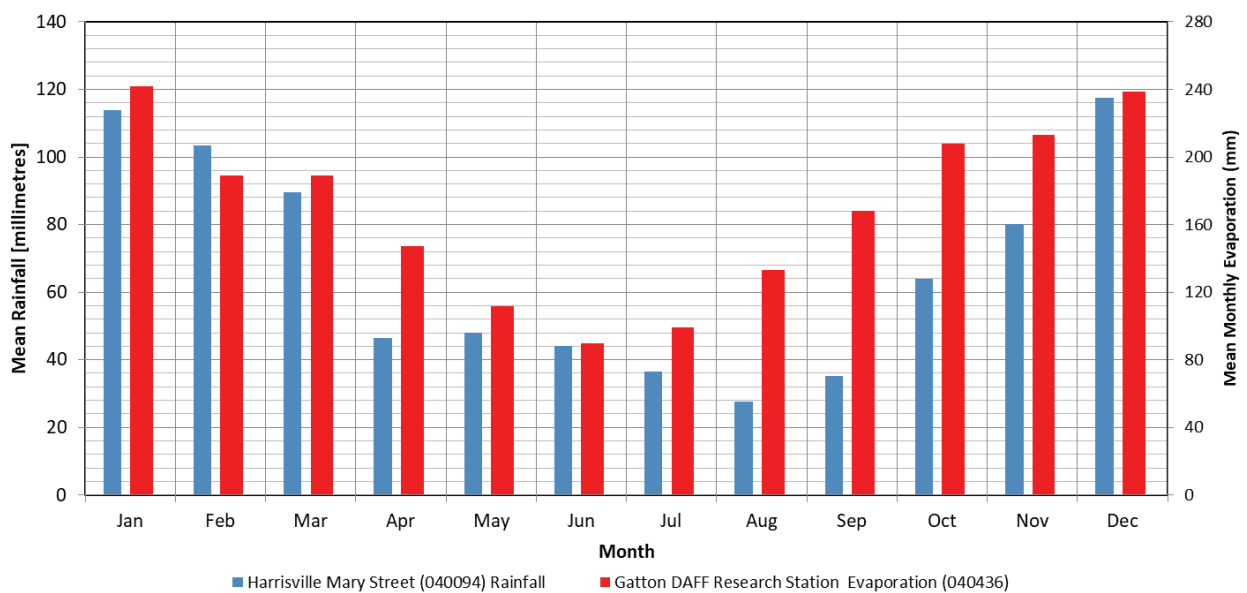


Figure 1: Monthly rainfall statistics for ‘Harrisville Mary Street’ Australian Bureau of Meteorology station number 040094 and mean daily evaporation for each month from the Gatton DAFF Research station number (040436).

Annual rainfall records were used to calculate rainfall residuals and the CRD, for the ‘Harrisville Mary Street’ BoM station (Figure 2). The CRD shows the long-term trends in rainfall patterns. A rising trend in slope in the CRD plot indicates periods of above average rainfall, whilst a declining slope indicates periods when rainfall is below average. CRD and groundwater level data are generally well correlated, with groundwater levels expected to rise during periods of rising CRD (regional scale groundwater recharge) while those recorded during periods of declining CRD expected to decline (drought conditions).

Clear long-term trends occur at Harrisville and likely along the entire rail corridor. The CRD underwent multiple cycles, generally increasing from 1943 to 1956 and generally decreasing from 1956 until 2013 with a few wetter than average periods during this time. Negative CRD was experienced resulting in drought conditions between 1997 until 2010 until wetter than average rainfall was observed. Similarly, the CRD graph shows a negative trend from 1991 until 2007, indicating the area had below-average rainfall during this period. Since the beginning of 2014, the graph shows slight increase despite data gaps in the CRD, indicating above average rainfall conditions.

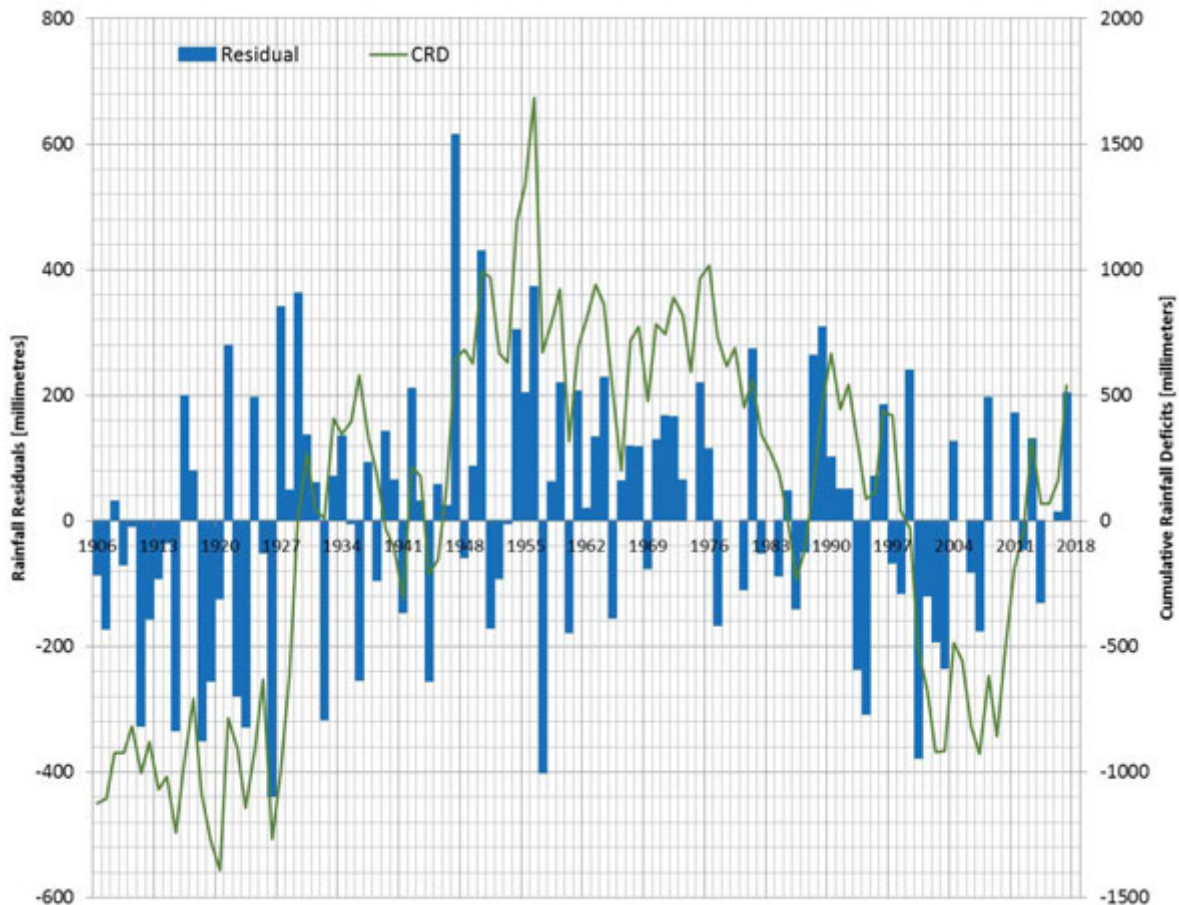


Figure 2: Annual residual rainfall and cumulative residual deficit (cumulative deviation from average) for ‘Harrisville Mary Street’ Australian Bureau of Meteorology station number 040094, record period between 1896 and 2018.

3.2 Topography and Drainage

The rail alignment runs from the east side of the Little Liverpool Range near Calvert to the base of Teviot range near Peaks Crossing. The area is dominated by the alluvial floodplain of the Bremer River and its tributaries, which is a relatively flat to slightly undulating broad flood plain containing a series of meandering watercourses with localised slopes. The Bremer River originates in the Main Range National Park and flows to the northeast toward Ipswich where it joins the Brisbane River. The Bremer River has multiple tributaries, which includes Warill Creek and Purga Creek which also flow to the northeast to converge with the Bremer River near Ipswich. The watercourses in the valley are generally slow flowing meandering channels which have generated fluvial terrace complexes with localised slopes or stepped slopes. The watercourses are prone to flooding during the wet season.

The rail alignment crosses the Teviot Range to the east of Peaks Crossing and is generally aligned with fluvially incised valleys between the peaks of Teviot Range. The range has a series of north-northwest trending ridges aligned with the main regional geological features. Locally, elevations can reach up to 680 m AHD (Flinders Peak). Teviot Range acts as a catchment divide separating the alluvial plains of the Bremer River and the alluvial plains of the Logan River. To the east of Teviot Range in the alluvial plains of the Logan River, Woollaman Creek is a tributary of Logan River and flows to the northeast. The Wyaralong Dam was constructed to the south of Mt Joyce and Mount Flintoff within Teviot Range on Teviot Brook.

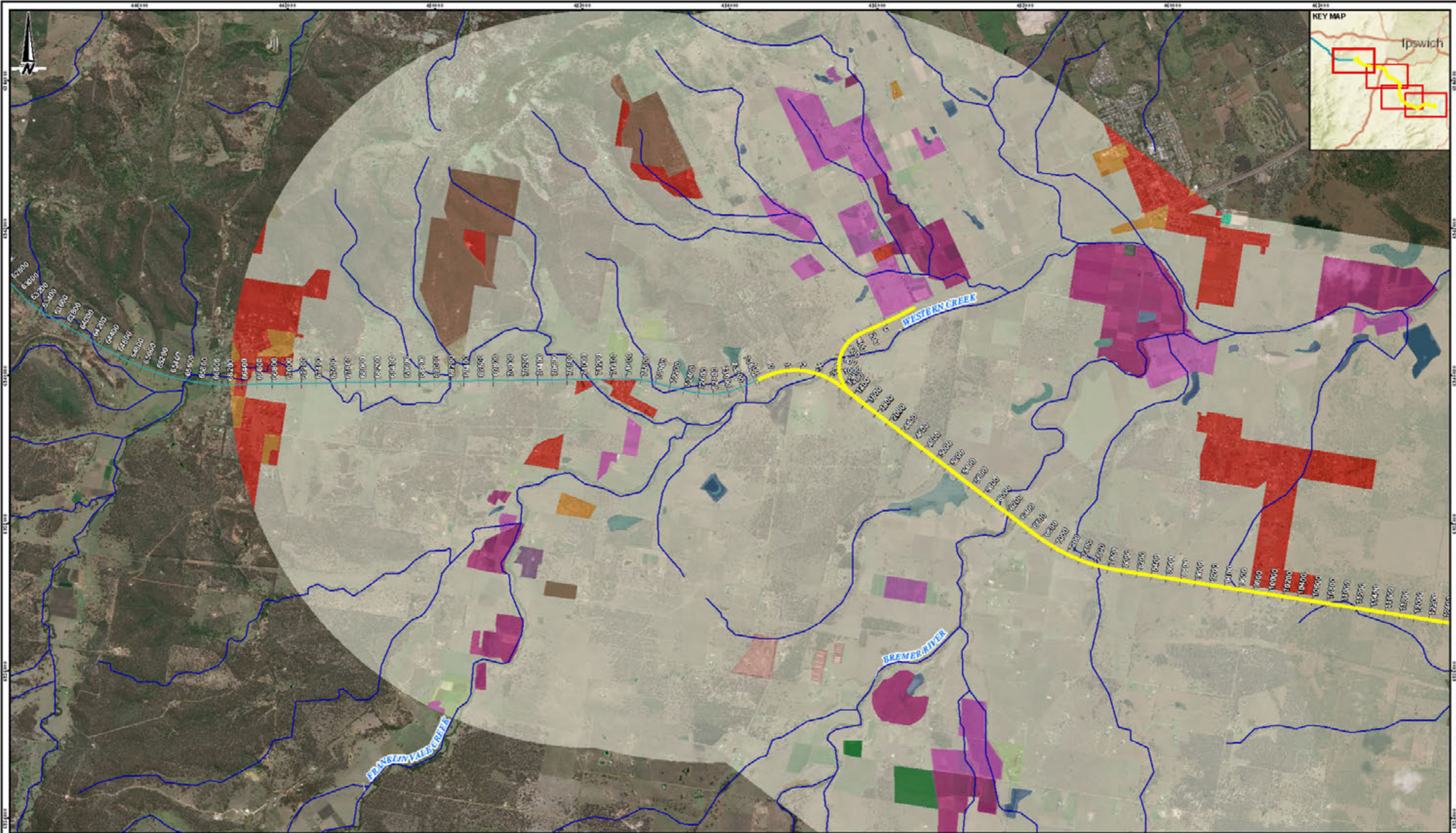
3.3 Land Use and Cover

The C2K rail corridor extends west to east through the northern portion of the Clarence-Moreton Bioregion. Remnant land cover in the northern portion of the Clarence-Moreton Bioregion primarily comprises scattered woody vegetation, including native shrubs and trees.

The C2K rail corridor is traversed by a number of perennial river systems (e.g. the Bremer River in the northwest and the Logan River and Teviot Brook in the southeast). The primary land use within 5 kilometres of the rail alignment comprises grazing native vegetation (84.8% of the total area). Irrigated cropping and modified pastures occur in close proximity to river systems and comprise approximately 4.5% of the total area within a 5-kilometre corridor. Irrigated areas may contribute to excess recharge along river systems. Additional land use types within a 5 km corridor are listed in Table 2 and displayed on Figure 3.

Table 2: Percent land use by area (within 5-kilometre corridor of C2K alignment)

| Land Use Type (Secondary) | Sum Area (Square Metres) | Percent of Total |
|---|--------------------------|------------------|
| Grazing native vegetation | 529174655 | 84.8% |
| Irrigated modified pastures / Irrigated Cropping | 26052642 | 4.2% |
| Other minimal use | 12980793 | 2.1% |
| Nature conservation | 12178357 | 2.0% |
| Residential | 11586849 | 1.9% |
| Reservoir/dam, Marsh/Wetland | 7385454 | 1.2% |
| Grazing modified pastures | 5838680 | 0.9% |
| Mining | 5331253 | 0.9% |
| Services, Transportation and Communication | 5222163 | 0.8% |
| Land in transition | 2464753 | 0.4% |
| Plantation forestry | 1974600 | 0.3% |
| Irrigated perennial horticulture | 1800328 | 0.3% |
| Others (incl. intensive animal production, cropping, managed resource protection, perennial horticulture, manufacturing and industrial, waste treatment and disposal, Intensive horticulture) | 2107511 | 0.3% |



- LEGEND**
- Watercourse
 - Inland Rail Alignment Section
 - C2K - Calvert to Kagaru
 - H2C - Helidon to Calvert
 - Land use (5km Buffer of Alignment)**
 - Nature conservation
 - Managed resource protection
 - Other minimal use
 - Grazing native vegetation
 - Grazing modified pastures
 - Cropping
 - Land in transition
 - Irrigated modified pastures
 - Irrigated cropping
 - Irrigated seasonal horticulture
 - Intensive animal husbandry
 - Manufacturing and industrial
 - Residential
 - Services
 - Waste treatment and disposal
 - Reservoir/dam
 - Marsh/wetland

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



CLIENT
FUTURE FREIGHT JOINT VENTURE

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| PREPARED | BO | |
| REVIEWED | NMC | |
| APPROVED | DB | |

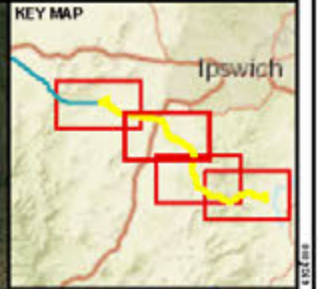
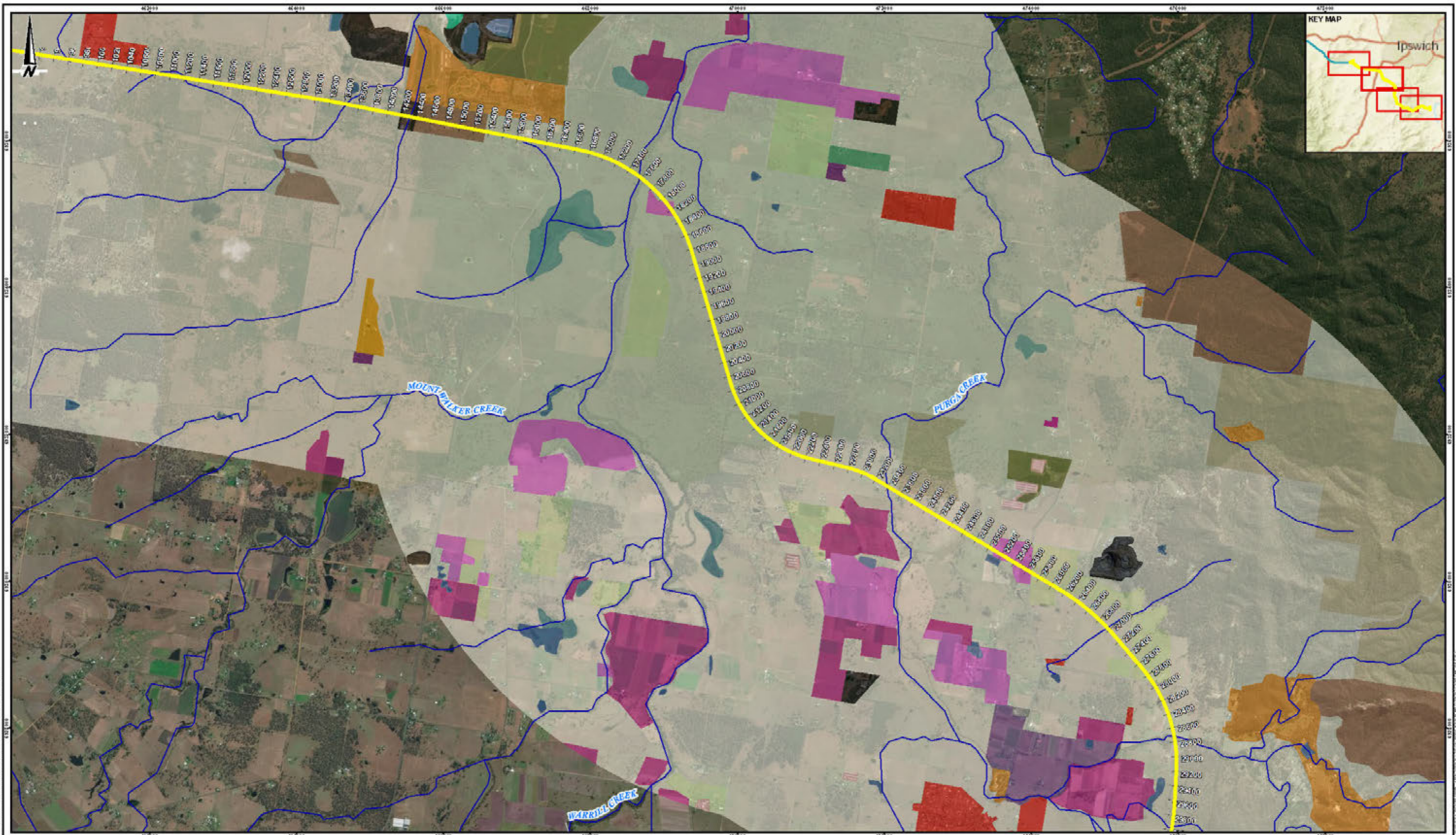
NOTE(S)
 Service Layer Credits: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, © OpenStreetMap contributors, and the GIS User Community

REFERENCE(S)
 1. **Watercourses:** Geoscience Australia
 2. **Alignment:** Provided by FFJV on 7th Dec 2018
 3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2018

PROJECT
INLAND RAIL SECTION 340 C2K

TITLE
LAND USE OF THE CALVERT TO KAGARU RAIL CORRIDOR

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| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 3-1 |



LEGEND

| | | |
|---|----------------------------------|---------------|
| Watercourse | Land in transition | Mining |
| Inland Rail Alignment Section | Irrigated modified pastures | Reservoir/dam |
| C2K - Calvert to Kagaru | Irrigated cropping | Marsh/wetland |
| Land use (5km Buffer of Alignment) | Irrigated perennial horticulture | |
| Nature conservation | Irrigated seasonal horticulture | |
| Managed resource protection | Intensive horticulture | |
| Other minimal use | Intensive animal husbandry | |
| Grazing native vegetation | Manufacturing and industrial | |
| Plantation forestry | Residential | |
| Grazing modified pastures | Services | |
| Perennial horticulture | Transport and communication | |

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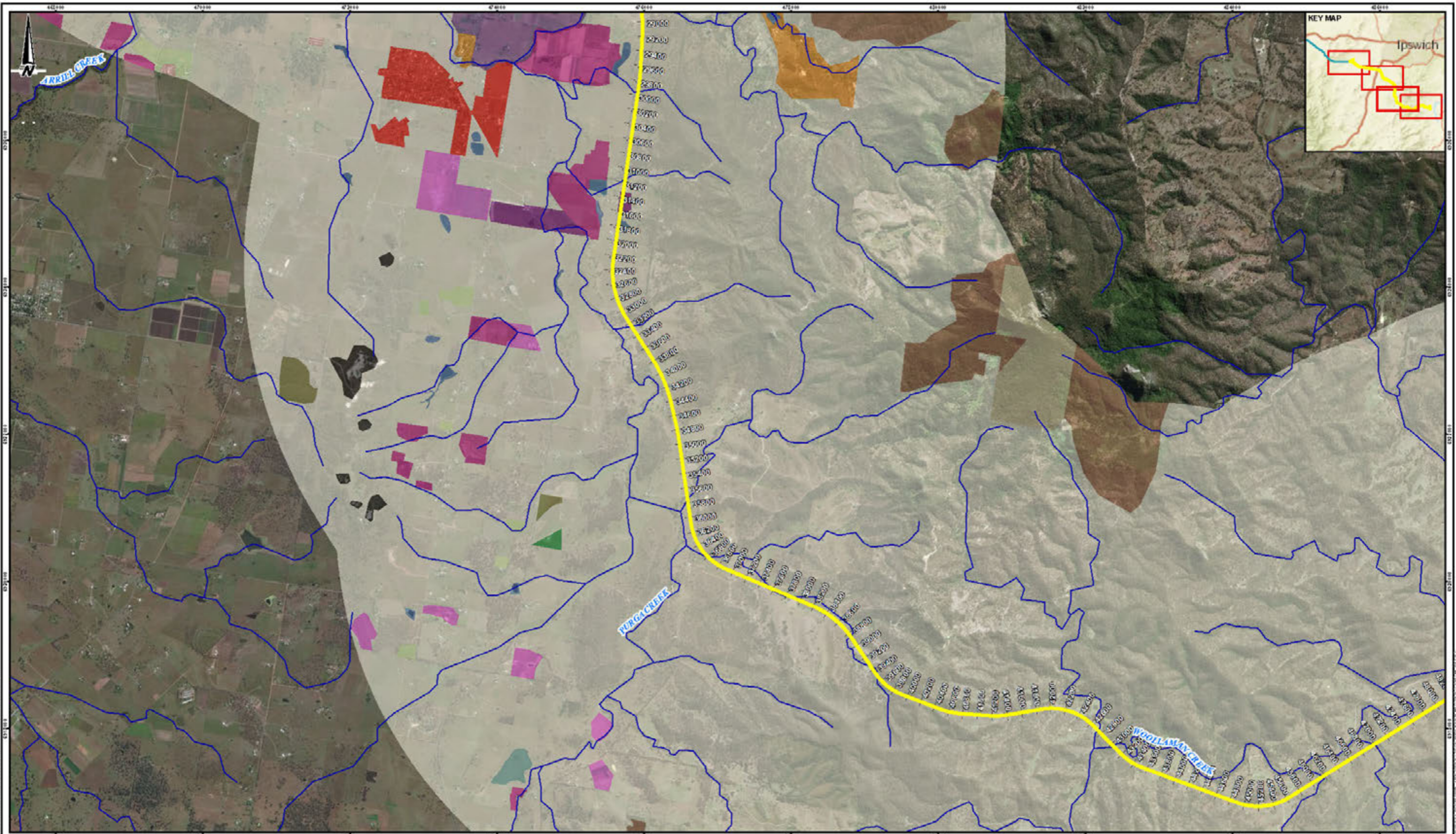
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PROJECT
 INLAND RAIL SECTION 340 C2K

TITLE
 LAND USE OF THE CALVERT TO KAGARU RAIL CORRIDOR

| | | | |
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| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 3-2 |



- LEGEND**
- Watercourse
 - Inland Rail Alignment Section
 - C2K - Calvert to Kagaru
 - Land use (5km Buffer of Alignment)**
 - Nature conservation
 - Other minimal use
 - Grazing native vegetation
 - Plantation forestry
 - Grazing modified pastures
 - Cropping
 - Irrigated modified pastures
 - Irrigated cropping
 - Irrigated perennial horticulture
 - Irrigated seasonal horticulture
 - Intensive animal husbandry
 - Residential
 - Services
 - Mining
 - Reservoir/dam
 - Marsh/wetland

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

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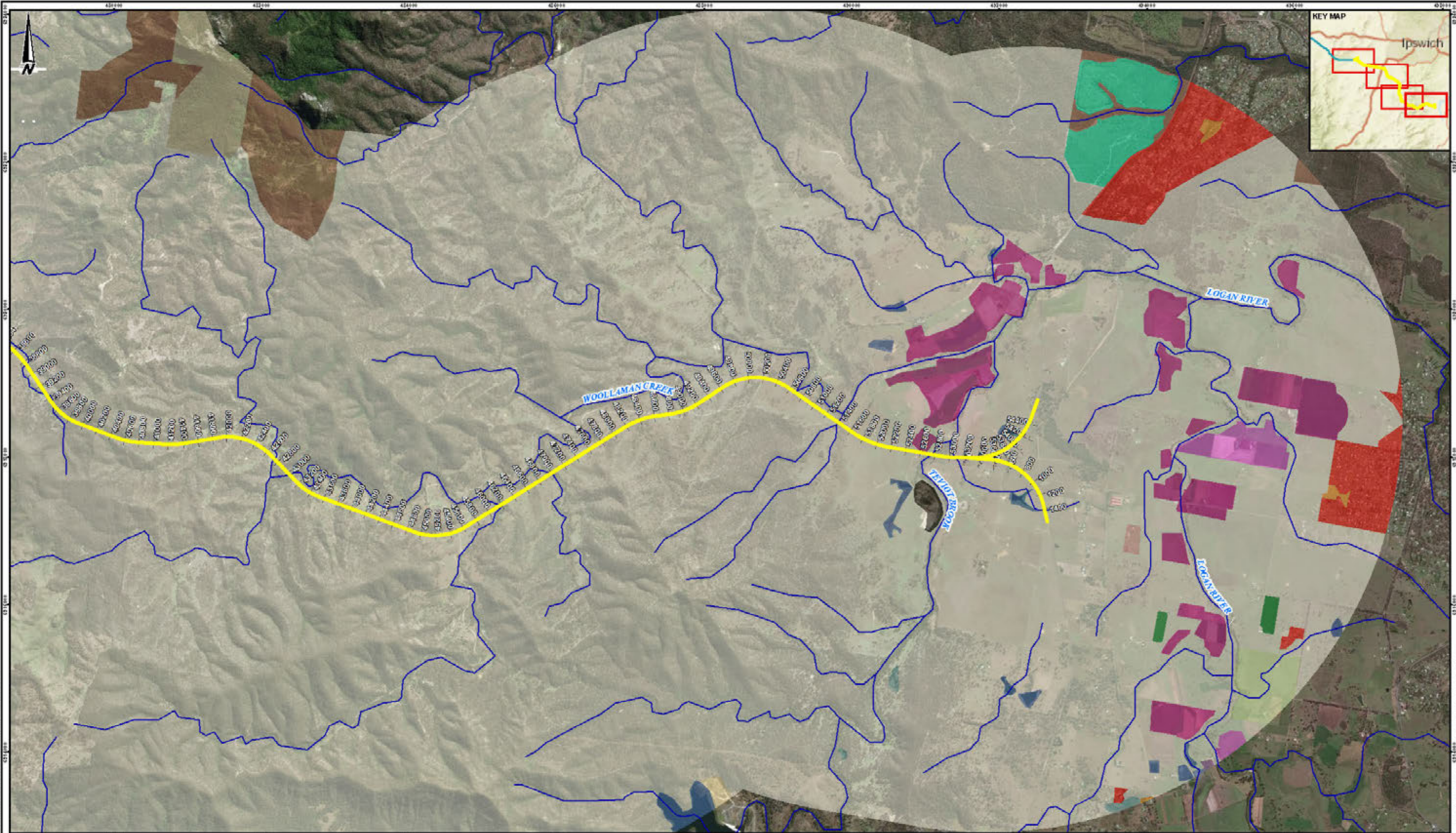
NOTE(S)
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PROJECT
INLAND RAIL SECTION 340 C2K

TITLE
LAND USE OF THE CALVERT TO KAGARU RAIL CORRIDOR

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|-------------|---------|------|--------|
| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 3-3 |



- LEGEND**
- Watercourse
 - Inland Rail Alignment Section**
 - C2K - Calvert to Kagaru
 - Land use (5km Buffer of Alignment)**
 - Nature conservation
 - Other minimal use
 - Grazing native vegetation
 - Grazing modified pastures
 - Cropping
 - Land in transition
 - Irrigated modified pastures
 - Irrigated cropping
 - Irrigated seasonal horticulture
 - Intensive animal husbandry
 - Residential
 - Services
 - Utilities
 - Mining
 - Reservoir/dam
 - Marsh/wetland

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



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 FUTURE FREIGHT JOINT VENTURE

| CONSULTANT | DATE | DESCRIPTION |
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REFERENCE(S)
 1. **Watercourses:** Geoscience Australia
 2. **Alignment:** Provided by FFJV on 7th Dec 2018
 3. **Landuse:** State of Queensland (Department of Science, Information Technology and Innovation), September 2016

| PROJECT | | TITLE | |
|-----------------------------|---------|---|--------|
| INLAND RAIL SECTION 340 C2K | | LAND USE OF THE CALVERT TO KAGARU RAIL CORRIDOR | |
| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 3-4 |

4.0 STRATIGRAPHY AND GEOLOGICAL PROCESSES

The geological units throughout the C2K rail corridor are reported below. This section has been quoted directly from FFJV, 2018, except for the alluvium and colluvium unit which has been included to complement the geological description in the FFJV report that focusses on the Woolooman Tunnel in Teviot Range and excludes this unit.

Gatton Sandstone

Gatton Sandstone is the lower member of the Marburg Subgroup and comprises mainly labile and feldspathic labile sandstone with minor interlaminated shale, siltstone and mudstone with clay matrix. Minor beds of granule, pebble and cobble polymictic conglomerate occur. The sandstone is predominantly fine grained, grey in colour and high strength when fresh.

Other than primary bedding and laminations that dip gently to the west, joints are typically poorly developed and widely spaced (larger than 1200 mm). The texture is typically massive but crossbedding also occurs. When weathered, the sandstone is typically pale brown.

Exposures in road cuttings, both along the Boonah Beaudesert Road and the Wyaralong Dam Access Road indicate that the sandstone is typically massive, moderately to thickly bedded. In a quarry located south of the Boonah Beaudesert Road, massive Gatton Sandstone is quarried to produce blocks and slabs for construction, decoration, landscape and other purposes. The waste product of the block cutting is used as lower quality road base and structural fill.

Gatton Sandstone is anticipated to underlie the proposed C2K alignment between approximately kilometrage 37.000 and 50.000 km.

Koukandowie Formation

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

The Heifer Creek Sandstone is commonly cliff forming with interbedded weaker units that forms 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 Koukandowie Formation is not anticipated to occur in the vicinity of the Woolooman Tunnel.

Woogaroo Subgroup

The Ripley Road Sandstone of the Woogaroo Subgroup outcrops around the Wyaralong Dam inundation area. It appears that due to the uplift associated with the South Moreton Anticline, the Gatton Sandstone has been eroded from the topographic high area and the underlying, older Ripley Road Sandstone became exposed.

The Ripley Road Sandstone comprises mainly cross-bedded quartzose sandstone with few fine grained interbeds and is not anticipated to occur in the vicinity of the Woolooman Tunnel.

Walloon Coal Measures

The Walloon Coal Measures 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 over bank deposits within highly sinuous fluvial systems and the upper part of the unit was deposited as coal swamps. The Walloon Coal Measure rocks form gently undulating terrain and are unlikely to be present in the vicinity of the Woolooman Tunnel.

Tertiary Age Volcanics

From reference to the published geological data, it appears that the mainly alkali basaltic volcanics occur some distance to the north from the proposed WT alignment. However, magnetic imagery indicates the presence of localised anomalies, which may be related to small scale intrusive rocks, such as dykes or plugs.

Alluvium and Colluvium

Parts of the alignment are within the alluvial plains of the Bremer River and Warrill Creek, and their tributaries, and to the east of the range is within the alluvial plains of the Logan River. 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 sand, silt and clay sediments.

Colluvium deposit and residual soils may be located at the base of the Teviot Range 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.

4.1 Geological Structures

The Woogaroo and Marburg Subgroups formed in the Clarence-Moreton Basin that developed on a basement cut by major long-lived strike slip faults. Movement along these faults followed by thermal relaxation and subsidence led to the development of the basin in the Late Triassic. Sedimentation continued until the Late Jurassic. The Bremer River Catchment likely contains more than 2000 m of fluvial and lacustrine siliciclastic rocks and coal, with the WCM comprising the upper 400 to 600 m (Cui *et. al.*, 2018).

The Woolooman Tunnel lies west of the West Ipswich Fault (a near-vertical network of normal faults dipping to the west) which forms part of the Great Moreton Fault System. The fault was active until deposition of the Gatton Sandstone in the early Jurassic and was locally reactivated during the mid-Cretaceous (Ingram and Robinson, 1996). Based on reviewed literature (Wells and O'Brien, 1994), the FFJV, 2018 reports that the South Moreton Anticline is likely to encounter the C2K alignment at approximately kilometrage 47.500 km, while the West Ipswich Fault may be encountered at 46.800 km.

To the east of the West Ipswich Fault lies the South Moreton Anticline (a fold, generally convex upward whose core contains stratigraphically older rocks). This is a major geological structure that extends in a north-south direction over 250 km. It is a compressional structure that resulted from Late Jurassic to Early Cretaceous uplift and its form varies along strike. To the south (Rathdowney area), it is recognised as an east facing faulted monocline and in New South Wales it is referred to as the East Richmond Fault. The anticline is overlain by Late Triassic and Jurassic aged units which thin toward the anticlinal axes from depths of 2000 m to the surface. Near Rathdowney, the anticline is associated with reverse faulting and is characterised by gently dipping strata to the west (less than 20°) and steep dips to the east (40 to 60°).

A geotechnical investigation conducted by FFJV (2018) assesses the regional geological structures and fault zone analysis. This report should be read to supplement the detailed understanding of structural geology in the region surrounding Woolooman Tunnel.

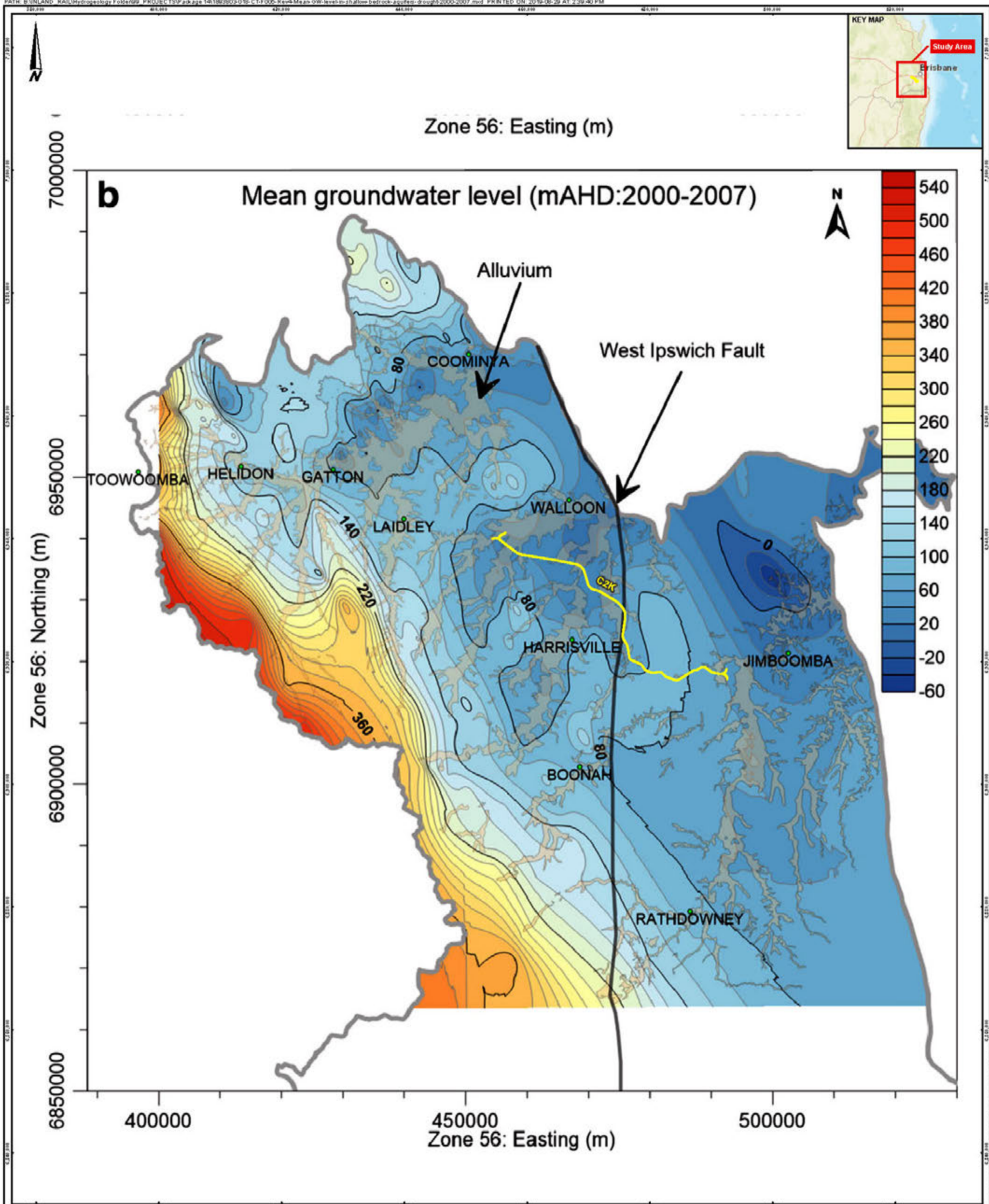
5.0 REGIONAL HYDROGEOLOGY

5.1 Hydrostratigraphy

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

To the west of Teviot Range the alignment is located within the alluvial plains of the Bremer River and Warrill Creek, and their tributaries, and to the east of the range is located within the alluvial plains of the Logan River. 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 in these areas. The areas surrounding the watercourse which are floodplains of the watercourses are conceptualised to possess sediment deposits containing smaller particles 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 Teviot Range 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. 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 which are located in colluvium may occur intermittently following rainfall.



LEGEND
 Inland Rail Alignment Section
 C2K - Calvert to Kagaru

NOTE(S)
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REFERENCE(S)
 1. Alignment: Provided by FFJV on 7th Dec 2018.
 2. Mean Groundwater Level Image: Sourced from Cui, T., Raiber, M., Pagendam, D., Gilfedder, M., Rassim, D. (Cui et al., 2018). Response of groundwater level and surface-water/groundwater interaction to climate variability: Clarence-Morston Basin, Australia. Journal of Hydrogeology, 2018, Volume 26 pages 593 to 614. DOI 10.1007/s10040-017-1653-6

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 Projection: Transverse Mercator
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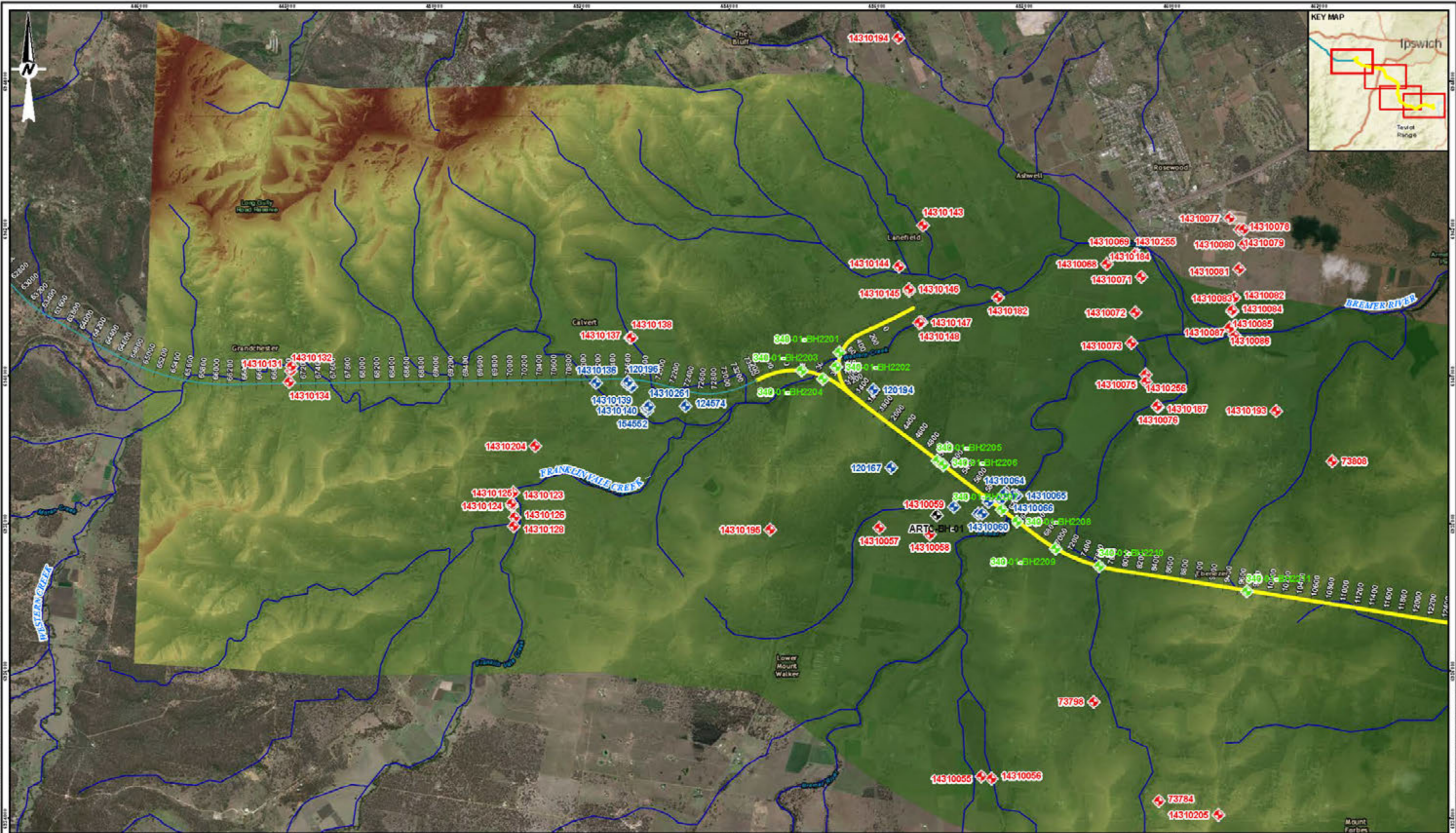
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CONSULTANT: GOLDER

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| REVIEWED | NMC |
| APPROVED | DB |

TITLE: MEAN GROUNDWATER LEVEL IN SHALLOW BEDROCK AQUIFERS DURING THE DROUGHT PERIOD BETWEEN 2000 TO 2007 (CUI ET AL., 2018)

| | | | |
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| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 5 |



- LEGEND**
- Bores**
- ◆ ARTC 2016 - Geotech
 - ◆ Golder 2018 - Geotech
 - ◆ Registered Bores (Water Levels)
 - ◆ Registered Bores (Water Quality)
 - Watercourse

- Inland Rail Alignment Section**
- C2K - Calvert to Kagaru
 - H2C - Helidon to Calvert
- C2K Digital Elevation Model 1 meter**
- High : 469.509
 - Low : -26.179

Coordinate System: ODA 1994 MGA Zone 56
 Projection: Transverse Mercator
 Datum: GDA 1984
 Scale: 1:50,000@A3



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REFERENCE(S)

1. Alignment, 1m DEM: Provided by FFJV on 7th Dec. 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

PROJECT
INLAND RAIL SECTION 340 C2K

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SECTION 340 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

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| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 6-1 |



- LEGEND**
- Bores**
- ARTC 2016 - Geotech
 - Golder 2018 - Geotech
 - Golder 2018 - Groundwater
 - Registered Bores (Water Levels)
 - Registered Bores (Water Quality)
 - Watercourse

Inland Rail Alignment Section

C2K - Calvert to Kagaru

C2K Digital Elevation Model 1 meter

High : 469.509

Low : -26.179

Coordinate System: ODA 1994 MGA Zone 56
 Projection: Transverse Mercator
 Datum: GDA 1984

Scale: 1:50,000 @ A3

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FUTURE FREIGHT JOINT VENTURE

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| REVIEWED | NMC |
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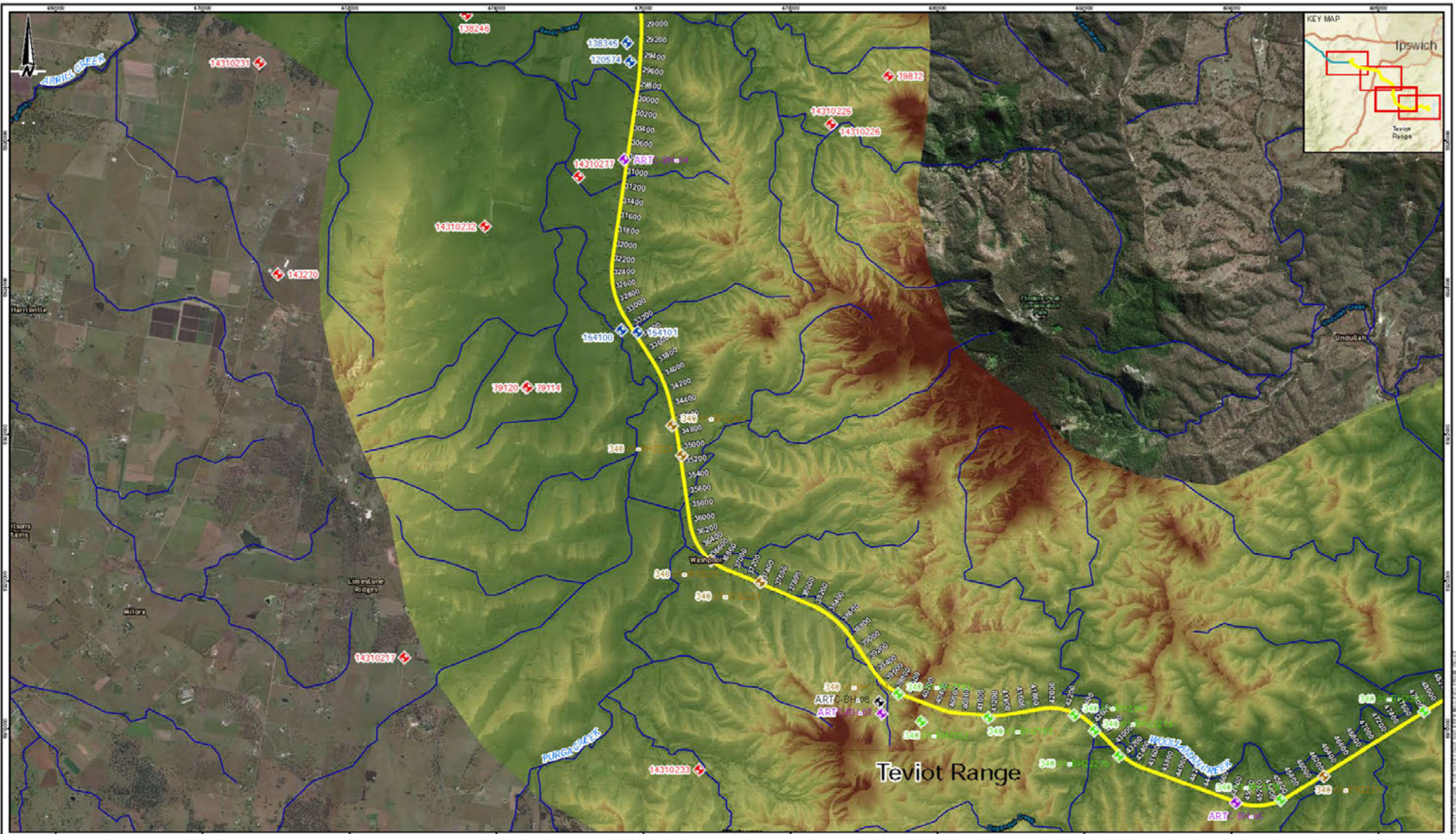
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- Alignment, 1m DEM: Provided by FFJV on 7th Dec 2018, and derived from LIDAR data provided by FFJV respectively.
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- ARTC Geotech and Groundwater Bores: Retrieved from ARTC's 01-3400-PD-P00-DE-0009_2 C2K Concept Geotechnical Factual Report Aug 2016
- Watercourse: Geoscience Australia

PROJECT
INLAND RAIL SECTION 340 C2K

TITLE
SECTION 340 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

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| PROJECT NO. | CONTROL | REV. | FIGURE |
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- LEGEND**
- Bores**
- ARTC 2016 - Geotech
 - ARTC 2016 - Groundwater
 - Golder 2018 - Geotech
 - Golder 2018 - Groundwater
 - Registered Bores (Water Levels)
 - Registered Bores (Water Quality)
 - Watercourse

Inland Rail Alignment Section

C2K - Calvert to Kagaru

C2K Digital Elevation Model 1 meter

High : 469.509

Low : -26.179

Coordinate System: ODA 1994 MGA Zone 56
 Projection: Transverse Mercator
 Datum: GDA 1984

0 500 1,000 1,500 2,000
 1:50,000@A3 METRES

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FUTURE FREIGHT JOINT VENTURE

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PROJECT
INLAND RAIL SECTION 340 C2K

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SECTION 340 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

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| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 6-3 |



- LEGEND**
- Bores**
- ARTC 2016 - Geotech
 - ARTC 2016 - Groundwater
 - Golder 2018 - Geotech
 - Golder 2018 - Groundwater
 - Registered Bores (Water Levels)
 - Registered Bores (Water Quality)
 - Watercourse

Inland Rail Alignment Section

C2K - Calvert to Kagaru

C2K Digital Elevation Model 1 meter

High : 469.509

Low : -26.179

Coordinate System: ODA 1994 MGA Zone 56
 Projection: Transverse Mercator
 Datum: GDA 1984

0 500 1,000 1,500 2,000
 1:50,000@A3 METRES

CLIENT
FUTURE FREIGHT JOINT VENTURE

CONSULTANT

| | |
|------------|-----------|
| YYYY-MM-DD | 14-DEC-18 |
| DESIGNED | BO |
| PREPARED | BO |
| REVIEWED | NMC |
| APPROVED | DO |

GOLDER

NOTES

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

REFERENCE(S)

1. Alignment, 1m DEM: Provided by FFJV on 7th Dec 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

PROJECT
INLAND RAIL SECTION 340 C2K

TITLE
SECTION 340 FFJV INVESTIGATION AND REGISTERED BORE LOCATIONS

| | | | |
|-------------|---------|------|--------|
| PROJECT NO. | CONTROL | REV. | FIGURE |
| 1893803 | 018 | 4 | 6-4 |

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| Age | | Major stratigraphic unit | Stratigraphic subdivision | Depositional environment | Generalised hydraulic characteristics ² |
|------------------------------|------------------------|---|--|--|--|
| 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 ¹ | | Aquicludes? |
| | | | Piora Member ¹ | | Aquifer/Aquitard ¹ |
| | Late Jurassic | Orara Formaton ¹ (Kangaroo Creek Sandstone) | Bungawalbin Member ¹ | Fluvial to low-energy overbank | Aquicludes? |
| | | | Kangaroo Creek Sst Member ¹ Maclean Sandstone Member | Fluvial channel | Aquifer/Aquitard ¹ |
| | Middle Jurassic | Walloon Coal Measures | | Sinuuous meandering streams and backswamps | Aquifer/Aquitard ¹ |
| | | | Koukandowie Formation | Heifer Creek Sandstone Member | Sandy bedload channels |
| | | | Ma Ma Creek Sandstone Member | Lacustrine environment | |
| | | | Towallum Basalt | | |
| | Early Jurassic | Gatton Sandstone | | Stacked channel sands in low-sinuosity streams | Low permeability aquifer/aquitard |
| | | | Calamia Member | Low-energy fluvial system | |
| Koreelah Conglomerate Member | | | Valley-fill sediments | | |
| Triassic | Late Triassic | Woogaroo Subgroup | Ripley Road Sandstone | Point bars and channel fills | Good aquifer |
| | | | Raceview Formation | Mixed fluvial environment | |
| | | | Aberdare/Laytons Range conglomerates | Braided river and alluvial fan | |
| | Early-Middle Triassic | Ipswich Coal Measures | Redcliffe Coal Measures | | Aquifer/Aquitard ¹ |
| | | | Evans Head Coal Measures | | Aquifer/Aquitard ¹ |
| | Nymboida Coal Measures | | | Aquifer/Aquitard ¹ | |

¹proposed stratigraphic revision by Doig and Stanmore (2012)

²further discussed in Chapter 1.1.4 Hydrogeology and groundwater quality

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

Within the project alignment, Walloon Coal Measures (WCM) overlie the Koukandowie Formation and the Gatton Sandstone which are formations of the Marburg Subgroup. 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, coal seams and geological structures such as faulting may locally increase the potential for groundwater movement and storage. The WCM are considered a Great Artesian Basin (GAB) aquifer in the Water Resource GAB Plan (2006) despite the 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 will likely result in low long-term seepage rates.

The Koukandowie Formation is comprised of two members occupying the lower part of the formation and an undifferentiated succession of interbedded argillaceous lithic sandstones, carbonaceous siltstones and shales (Ingram and Robinson, 1996). The two lower members are the basal Ma Creek Member and the Heifer Creek Sandstone Member (Ingram and Robinson, 1996). The Ma Creek Member conformably overlies the Gatton Sandstone and consists of thinly interbedded siltstones, claystones and fine-grained sandstones generally 10 to 20 m thick (Ingram and Robinson, 1996). The Heifer Creek Sandstone Member comprises interbedded sandstone, siltstone and shale with minor coal. The sandstones are quartzose, fine- to coarse-grained, thin- to very thick-bedded with a variable amount of lithic grains, clay and calcareous cement and coarsen upwards with less frequent siltstone and shale layers which are typically carbonaceous (Ingram and Robinson, 1996). This member 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 (IESC, 2014) and is generally described as low permeability aquifers and aquitards. The Heifer Creek Sandstone 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 Creek Sandstone and the Ma Creek Member are considered together and referred to as the Koukandowie Formation.

The Gatton Sandstone conformably underlies the Ma Ma Creek Member of the Koukandowie Formation at a conformable, sharp contact between siltstones of these geological units. The Gatton Sandstone is described by Wells and O'Brien (1994) as primarily thick bedded, relatively uniform, medium and coarse grained, quartz-lithic and feldspathic sandstone commonly with argillaceous matrix and cements rich in sodium, calcium and magnesium carbonates (McTaggart, 1963). Pebble beds, carbonised wood fragments and large-scale planar and crossbedding are characteristic of this formation. 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). The formation contains water, but overall, is of low to moderate permeability and the water is of poor quality with saline water at depth in places. Due to the lack of spatially continuous beds of low permeability rock or a thick low permeability soil layer, groundwater in the Gatton Sandstone is believed to be unconfined below ridges and mostly unconfined elsewhere.

The C2K alignment is anticipated to encounter the Walloon Coal Measures and Quaternary alluvium in low lying areas between 0.0 and 22.900 km and between 53.200 and 56.200 km and the Marburg Subgroup (Koukandowie Formation, and the Gatton Sandstone) in the Teviot Range between 22.900 and 53.200 km. At the location of the Woollooman Tunnel (between Kilometrage 39.500 and 41.280 km) the Gatton Sandstone is locally exposed at the surface or blanketed by a thin layer of red and yellow podzolics, lithosols and solodic soils, typical for soils of steep hills on sandstone (Queensland Globe 1:100 000 soil map; DNRME, 2018).

5.2 Groundwater Level and Flow

Regional groundwater flow in the Bremer River valley has been assessed by CSIRO (Cui *et. al*, 2018) to determine the response of groundwater levels and surface-groundwater interactions as a result of climate variability. The mean groundwater level in shallow bedrock aquifers during the drought period between 2000 to 2007 is reported on Figure 5 and 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.

The Bremer River Catchment is adjacent to the major regional fault system, the north-south trending West Ipswich Fault at the Teviot Range. At the eastern margin of the Bremer River sub-basin, the Clarence-Moreton Basin sedimentary sequence terminates against low permeability basement rock juxtaposed by the West Ipswich Fault (Cui *et. al.*, 2018). This may result in an upward flow direction from the WCM and underlying stratigraphic units, discharging into shallow aquifers or nearby wetlands or alluvia which will then follow the shallow bedrock flow direction to the northeast. The locations of groundwater levels bores from the ARTC C2K Phase 1 site investigations (ARTC, 2016), the C2K FS SI and registered groundwater bores (DNRME, 2018) within 500 m of the alignment and with recorded groundwater levels between 2000 and 2018 are reported in Figure 6. Registered groundwater bores with water quality data within 5 km is also reported on Figure 6.

As of 15 March 2019, thirteen groundwater monitoring bores were installed during Phase 2 geotechnical site investigations (Golder, 2018c). Pressure transducers (water level data loggers) were installed in the C2K FS SI groundwater monitoring bores to continuously monitor groundwater levels on at hourly intervals with a barometric pressure correction applied to monitored data. Hydrographs for bores installed during C2K FS SI investigations are reported in APPENDIX A.

Basic groundwater level statistics from all available groundwater bores are reported in Table 3.

Historical groundwater levels were reported for 340-BH-04, 340-BH-05 and 340-BH-07 during the ARTC C2K Phase 1 investigation in 2016. No hydrographs are available for these bores. Seventeen registered groundwater bores are located within 500 m of the alignment, 10 in alluvium and 4 in the WCM and 3 in the Marburg Subgroup (Undifferentiated). Hydrographs for registered bores constructed within alluvium are reported on Figure 7, while bores completed in either the WCM or the Marburg subgroup (Undifferentiated) are reported on Figure 8. The peak of high rainfall climatic events since the 2011 floods have been reported on Figure 7 and Figure 8 to indicate groundwater responses to these events (noting, however, that the resolution of the water level measurements is not sufficient to assess short-term response).

Table 3: Groundwater levels statistics for 2018 FFJV investigation bores and registered groundwater bores (DNRME, 2018) within 500 m of the Section 340 alignment

| Bore ID | Formation | Kilometrage (Km) | Groundwater Level (m AHD) | | | | | | |
|----------------------------|-------------------------------|------------------|---------------------------|------------|-------|-------|--------|-------|-------|
| | | | Date From | Date To | Min | Max | Median | Mean | Count |
| 340-BH-04 | Koukandowie Formation | 30.800 | 29/06/2016 | 29/06/2016 | - | - | 73.4 | - | 1 |
| 340-BH-05 | Gatton Sandstone | 44.800 | 29/06/2016 | 29/06/2016 | - | - | 82.6 | - | 1 |
| 340-BH-07 | Gatton Sandstone | 40.000 | 29/06/2016 | 29/06/2016 | - | - | 117.8 | - | 1 |
| 340-01-BH2101 | Gatton Sandstone | 40.000 | 28/09/2018 | 24/10/2018 | 141.1 | 145.9 | 145.6 | 145.2 | 1156 |
| 340-01-BH2203 ¹ | Alluvium | 0.600 | - | - | - | - | - | - | - |
| 340-01-BH2224 | WCM | 35.200 | 4/09/2018 | 25/10/2018 | 64.7 | 64.9 | 64.8 | 64.8 | 1172 |
| 340-01-BH2225 | Alluvium | 36.600 | 12/09/2018 | 23/10/2018 | 68.7 | 69.0 | 68.8 | 68.8 | 973 |
| 340-01-BH2233 | Alluvium and Gatton Sandstone | 52.800 | 28/09/2018 | 24/10/2018 | 23.3 | 24.8 | 23.4 | 23.5 | 907 |
| 340-01-BH2215 | Alluvium | 17.400 | 14/09/2018 | 24/10/2018 | 23.0 | 23.2 | 23.1 | 23.1 | 955 |
| 340-01-BH2220 | Koukandowie Formation | 25.400 | 26/09/2018 | 23/10/2018 | 38.6 | 43.3 | 38.7 | 38.7 | 652 |
| 340-01-BH2303 | Gatton Sandstone | 35.000 | 27/09/2018 | 24/10/2018 | 72.8 | 80.3 | 73.5 | 74.3 | 644 |
| 340-01-BH2229 | Koukandowie Formation | 46.400 | 28/09/2018 | 24/10/2018 | 47.2 | 48.1 | 47.3 | 47.3 | 573 |
| 340-01-BH2226 ² | Koukandowie Formation | 37.200 | 10/09/2018 | - | - | - | 72.7 | - | - |
| 340-01-BH2213 | WCM | 14.400 | 09/11/2018 | 11/02/2019 | 33.6 | 36.1 | 33.7 | 33.7 | 2277 |
| 340-01-BH2214 | WCM | 16.300 | 06/11/2018 | 11/02/2019 | 38.5 | 45.1 | 42.3 | 42.3 | 2324 |

| Bore ID | Formation | Kilometrage (Km) | Groundwater Level (m AHD) | | | | | | |
|---------------|------------------------|------------------|---------------------------|------------|------|------|--------|------|-------|
| | | | Date From | Date To | Min | Max | Median | Mean | Count |
| 340-01-BH2301 | Koukandowie Formation | 15.800 | 09/11/2018 | 11/02/2019 | 54.3 | 62.6 | 54.3 | 54.5 | 2252 |
| RN120167 | WCM | 4.600 | 10/12/2003 | 10/12/2003 | - | - | 10.9 | - | 1 |
| RN120194 | Western Creek Alluvium | 3.800 | 16/10/2003 | 16/10/2003 | - | - | 38.7 | - | 1 |
| RN120574 | Sandy Creek Alluvium | 29.600 | 07/08/2004 | 07/08/2004 | - | - | 51.8 | - | 1 |
| RN138345 | WCM | 29.200 | 15/03/2008 | 15/03/2008 | - | - | 46.9 | - | 1 |
| RN14310062 | Bremer River Alluvium | 6.000 | 03/12/2002 | 06/02/2012 | 33.0 | 34.2 | 33.4 | 33.5 | 14 |
| RN14310063 | Bremer River Alluvium | 6.000 | 03/12/2002 | 06/02/2012 | 32.4 | 34.0 | 33.0 | 33.2 | 15 |
| RN14310066 | Bremer River Alluvium | 6.200 | 03/12/2002 | 21/12/2017 | 32.1 | 34.0 | 33.4 | 33.2 | 48 |
| RN14310148 | Western Creek Alluvium | 0.000 | 04/12/2002 | 19/07/2010 | 36.5 | 38.2 | 37.6 | 37.4 | 20 |
| RN14310173 | Warrill Creek Alluvium | 17.200 | 20/04/2000 | 03/05/2007 | 22.0 | 23.6 | 22.6 | 22.7 | 36 |
| RN14310223 | WCM | 23.000 | 18/08/2004 | 13/12/2017 | 31.4 | 33.1 | 32.3 | 32.4 | 34 |
| RN14310224 | WCM | 27.800 | 18/08/2004 | 13/12/2017 | 43.0 | 45.1 | 44.1 | 44.0 | 32 |
| RN14310245 | Marburg | 17.200 | 13/04/2007 | 18/12/2017 | 21.6 | 22.6 | 21.8 | 22.1 | 44 |
| RN14310262 | Western Creek Alluvium | 0.000 | 22/03/2010 | 21/12/2017 | 37.6 | 43.0 | 41.5 | 41.3 | 28 |
| RN143683 | WCM | 20.200 | 24/09/2009 | 11/11/2009 | - | - | 28.1 | - | 1 |
| RN152848 | Marburg | 51.200 | 24/07/2014 | 24/07/2014 | - | - | 20.9 | - | 1 |

| Bore ID | Formation | Kilometrage (Km) | Groundwater Level (m AHD) | | | | | | |
|----------|------------------------|------------------|---------------------------|------------|-----|-----|--------|------|-------|
| | | | Date From | Date To | Min | Max | Median | Mean | Count |
| RN152849 | Marburg | 51.400 | 20/07/2014 | 20/07/2014 | - | - | 23.7 | - | 1 |
| RN154100 | Purga Creek Alluvium | 33.200 | 01/06/2010 | 01/06/2010 | - | - | 56.1 | - | 1 |
| RN154101 | Purga Creek Alluvium | 33.400 | 04/06/2010 | 04/06/2010 | - | - | 57.4 | - | 1 |
| RN120194 | Western Creek Alluvium | 3.800 | 16/10/2003 | 16/10/2003 | - | - | 38.7 | - | 1 |

Note:

1 340-01-BH2203 was installed after the final issue date of this report. As such, any data collected from this borehole has not been included in downgradient interpretations.

2 Groundwater level data is not available because property access was denied at the time of reporting.

Of the 10 alluvial bores with water level data, only RN14310262 and RN14310066 records contain time-series data during climatic events with a resolution able to show a response in groundwater levels. The frequency of the data is sufficient to show broad trends in groundwater levels during wet periods in 2011 and 2013. During 2011 flooding, RN14310262 experienced a relatively rapid response to the 2011 flood events with an increase in groundwater levels of about 3.0 m and an increase of about 1.5 m during Cyclone Oswald in 2013. RN14310066 indicated a groundwater level increase of about 1.2 m following 2011 flooding and a 0.3 m increase during Cyclone Oswald in 2013. Wet periods after 2014 may not have reached inland far enough to have had an influence at these locations.

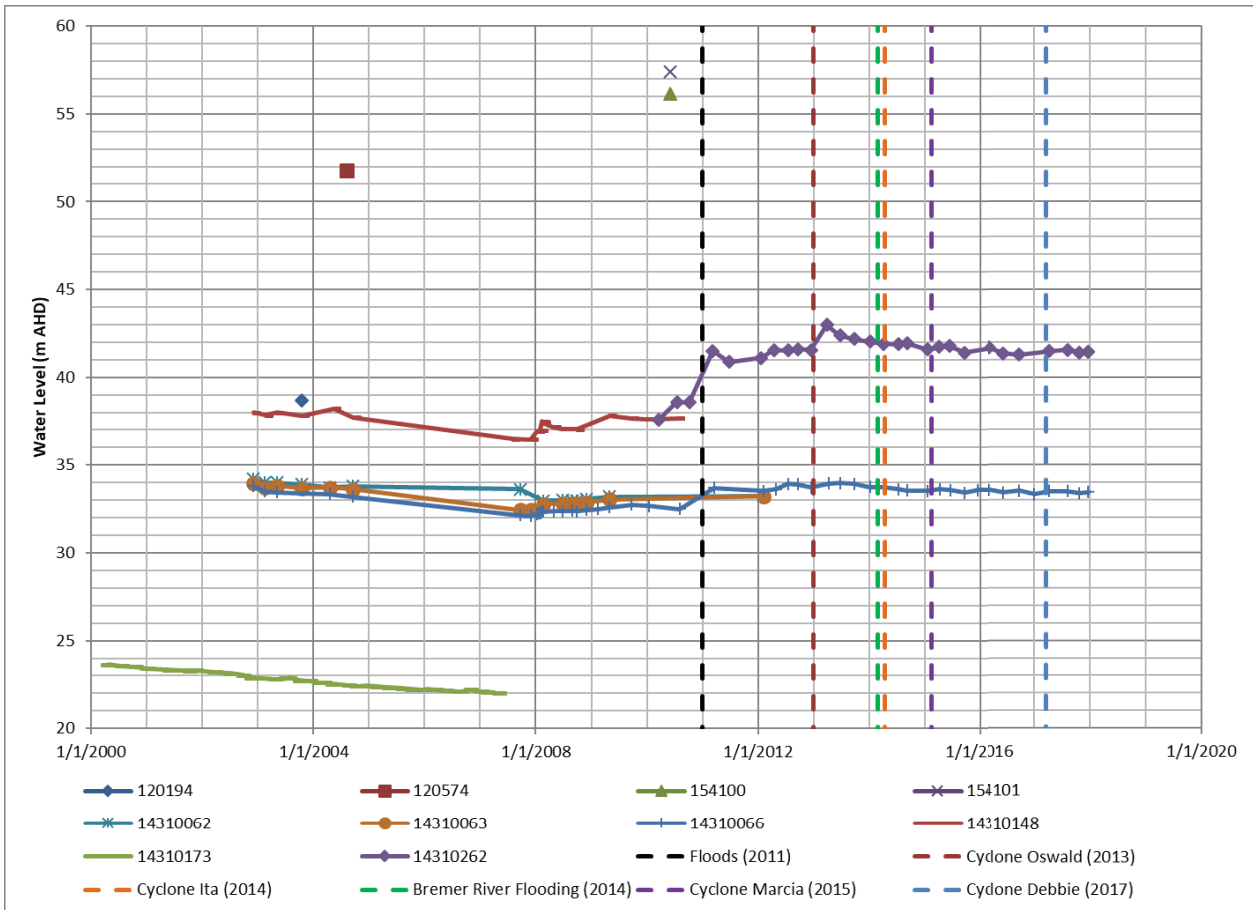


Figure 7: Water levels of registered groundwater bores completed in alluvium within 500 m of the rail alignment (DNRME, 2018) from 2000 until 2017 and climatic events since 2011 flooding

Registered bore RN14310223 monitors groundwater level in the WCM and reports a decrease of about 0.5 m from 32 m AHD to 31.5 m AHD between 2004 and 2008 with a subsequent increase of nearly 1.5 m from 2008 to 2017. Registered bore RN14310224 monitors water level in the WCM and reports a decrease in groundwater level of about 2 m from 2005 to 2011 and an increase of 2 metres between 2011 and 2017. Water levels in 2017 were at 45 m AHD. Registered bore 14310245 is monitoring groundwater levels in the Marburg Subgroup (Undifferentiated) and reports an increase in groundwater levels from 2005 to 2018 of about 1 m from 21.7 to 22.7 m AHD. While no short-term influences of climatic events were observed, long-term fluctuations indicated a potential time-delayed increase in groundwater levels in each of the monitored bores indicating a time-delayed response to climatic events. It is difficult to determine a correlation with climatic events in the groundwater bores completed within rock due to the limited groundwater level data near each event.

An increase in groundwater level was observed in site investigation boreholes 340-01-BH2225 and 340-01-BH2229 (0.2 m and 0.15 m respectively) as a result of rainfall events in early to mid-October 2018. No other bores were visibly impacted by these rainfall events.

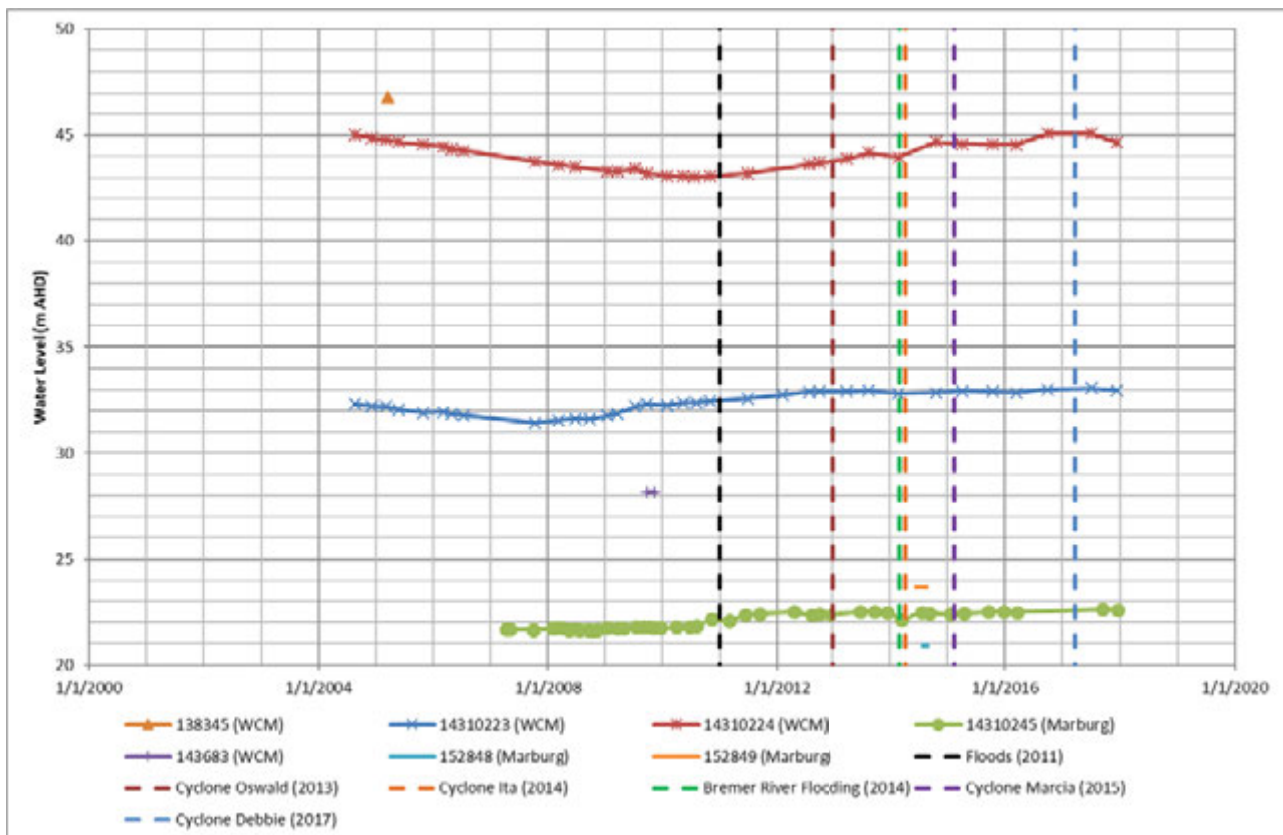


Figure 8: Water levels of registered groundwater bores completed in rock within 500 m of the rail alignment (DNRME, 2018) from 2000 until 2017 and climatic events since 2011 flooding

5.3 Groundwater Recharge

In areas with alluvial or colluvial materials, recharge is anticipated to be supplied by direct infiltration of rainfall, and by seepage from ephemeral streams during periods of flow following rainfall. 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 average evaporation exceeds annual average rainfall), and on average a deficit for each month of the year (Figure 2). Direct infiltration of rainfall to groundwater is unlikely during dry periods, when light rainfall events will be absorbed by soil moisture only to be subsequently lost to evapotranspiration. Recharge is likely to occur in response to higher or more continuous rainfall events, and overall net recharge rates at the site are expected to be low.

A response of historical groundwater levels in alluvia to climate variability was reported by Cui *et. al.*, 2018 for the Bremer River valley, indicating a decrease in the median of 0.3 m/year during drought conditions and an increase of 0.5 m/year during wet periods, though the results for the wet period may have been influenced by the extreme conditions from the 2011 floods.

These rates are less pronounced in sedimentary rock units with the median levels 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 an increase of as much as 0.7m/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 and Gatton Sandstone, was estimated using chloride mass balance. Statistical parameters for groundwater recharge are reported in Table 4.

Table 4: Clarence-Moreton bioregion rainfall recharge estimates (Australian Government, 2014)

| Formation | Number of Samples/ Tests | Lower (mm/year) | Typical (mm/year) | Upper (mm/year) |
|--|--------------------------|-----------------|-------------------|-----------------|
| Alluvium | 2677 | 3.9 | 10.6 | 32.5 |
| WCM | 90 | 1.3 | 3.5 | 9.7 |
| Marburg Subgroup (Koukandowie Formation) | 6 | 1.6 | 2.7 | 25.7 |
| Marburg Subgroup (Gatton Sandstone) | 242 | 1.1 | 3.5 | 10.2 |

Note: Values are obtained from ranges presented in Clarence-Moreton Basin (Australian Government, 2014). 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 is a total of 232 samples from 92 groundwater monitoring bores within 5 km of the proposed rail alignment. Collected samples span a range of 61 years, with the earliest samples collected in 1957 and the most recent collected as part of the C2K Site Investigation. Water chemistry data has been obtained from the QLD registered bores database, reviewed documents and in the C2K Geotechnical Site Investigation Report (Golder, 2018c). Water chemistry data is summarised in APPENDIX B.

Of these monitoring bores, 64 contain a complete set of cation and anion analytical records; 38 of which are screened in the Quaternary alluvium, 14 in the WCM, and 5 in the Marburg Subgroup (Undifferentiated). A Piper Diagram was generated to determine hydrogeochemical classification of each formation tested and is shown in Figure 9. The milliequivalents percentage of major cations and anions are shown by separate ternary plots to the lower left and right of the diagram. The apexes of the cation plot are calcium, magnesium and sodium plus potassium cations. The apexes of the anion plot are sulphate, chloride and carbonate plus hydrogen carbonate anions. The two ternary plots are then projected onto the central diamond field, which provides the overall character of the water.

Groundwater sampling data from the C2K FS SI is only available for 340-01-BH2101 at the time of reporting. Analytical results from remaining C2K FS SI bores will be included in subsequent submissions of the report.

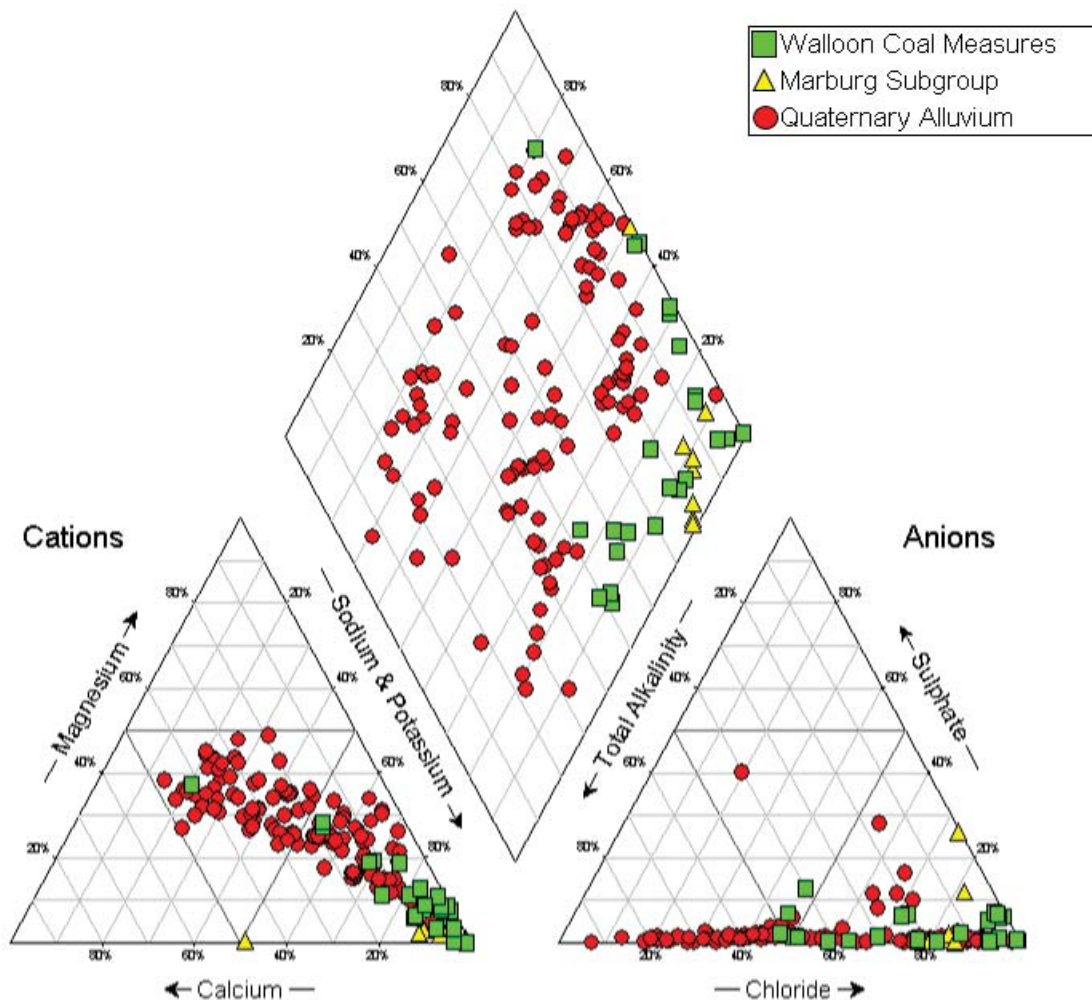


Figure 9: Piper Diagram of groundwater of hydrostratigraphic units

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, subcropping rocks and proximity to roads or topographic highs. Groundwater in the Marburg Subgroup (Undifferentiated) is primarily of Na-Cl type, while water in the WCM varies between Na-Cl and Na-CO₃ 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 8.4.

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 Bremer River valley. Groundwater supply to wetland, marsh areas and springs utilise groundwater in the natural environment. There is no groundwater use anticipated in the Teviot ranges.

To the east of Teviot Range, the alignment is within the Logan River catchment where groundwater is utilised for irrigation, cropping and residential purposes at the town of Kagaru.

The Environmental Impact Assessment (C2K – 2-0001-340-EAP-10-RP-0114) will provide further detail on groundwater use.

6.0 CONCEPTUAL HYDROGEOLOGICAL MODELS

Conceptualisations for the Woollooman 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 C2K FS SI along the proposed C2K alignment (Golder, 2018c) and the Clarence-Moreton Bioregional Assessment database (Australian Government, 2018). 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.

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 C2K FS SI. At the time of this report, slug test results were only available for 340-01-BH2101 (drilled close to the location of the Woollooman Tunnel), in addition to results for water pressure testing carried out during drilling of this bore. The remaining slug tests analysis will be incorporated in subsequent report revisions. These tests are reported in Golder, 2018c.

Hydraulic conductivity values from testing carried out for the project are summarised in Table 5. The water pressure test in borehole 340-01-BH2101 was conducted from 80 to 85 m bgl over a competent section of the Gatton Sandstone with two recorded geotechnical defects. The result of this test provides an indication of the hydraulic conductivity of a slightly weathered to fresh section of the Gatton Sandstone. Despite the proximity to the West Ipswich Fault complex and the South Moreton Anticline, the rock in borehole 340-01-BH2101 appears to be unaffected by the faulting or significant folding; however, small scale folding or faulting may affect zones several metres wide within the rock mass (FFJV, 2018). An additional geotechnical borehole, 340-01-BH2102, is planned to be drilled in the area which will be used to extend the understanding of the Gatton Sandstone surrounding Woollooman Tunnel.

Hydraulic parameters derived from site specific testing and the results of relevant other studies as listed above are summarised in Table 5. The “typical” values provided in this table may not be representative of conditions at specific locations along the project alignment considering the large value range. Further assessment may be required after results of further testing become available.

Table 5: Hydraulic test results summary from FFJV 2018 investigations (Golder, 2018c)

| Bore | Test Interval (m bgl) | Test Method | Lithology | Analytical Method | Hydraulic Conductivity (m/s) | Lugeon Value (L) |
|---------------|-----------------------|---------------------|--------------------------------|-------------------|------------------------------|------------------|
| 340-01-BH2101 | 104 to 124 | Falling Head Test | Sandstone / Breccia / Mudstone | Hvorslev | 4.5×10^{-10} | NA |
| | | | | KGS Model | 1.1×10^{-9} | |
| 340-01-BH2101 | 80 to 85 | Water Pressure Test | Sandstone | - | 2.9×10^{-9} | 0.026 |
| 340-01-BH2224 | 13 to 25 | Falling Head Test | Sandstone | NR | NR | NR |
| 340-01-BH2225 | 16 to 25 | Falling Head Test | Sandstone | NR | NR | NR |
| 340-01-BH2233 | 14 to 25 | Falling Head Test | Alluvium / Coal / Sandstone | NR | NR | NR |
| 340-01-BH2215 | 16 to 25 | Falling Head Test | Alluvium | NR | NR | NR |
| 340-01-BH2220 | 13 to 25 | Falling Head Test | Sandstone | NR | NR | NR |
| 340-01-BH2303 | 19 to 31 | Falling Head Test | Sandstone | NR | NR | NR |
| 340-01-BH2229 | 9 to 20 | Falling Head Test | Sandstone | NR | NR | NR |
| 340-01-BH2226 | 15 to 26 | Falling Head Test | Sandstone | NR | NR | NR |

Note: One Lugeon is equal to 1×10^{-7} m/s. NA – Bore not tested with the specified, NR – Information not reported because the tests had not been completed by the time of this report's delivery.

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 two tests carried out in 340-01-BH2101 as discussed above, a total of 78 test results are available for the Gatton Sandstone for locations across the Clarence-Moreton basin, with results ranging between 9×10^{-9} to 2×10^{-5} m/s. Of these 78 permeability test records, 40 are above 1×10^{-7} m/s and 19 are above 1×10^{-6} m/s. A statistical distribution of permeability test results for the Gatton Sandstone including all 80 tests is shown in Figure 10 and statistical parameters for the test records are summarised in Table 6. 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^{-8} has been used as a typical value for the Gatton Sandstone for modelling to assess tunnel inflow. 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 isotropic¹ 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. Anisotropy² ratios adopted for this assessment are reported in Table 6.

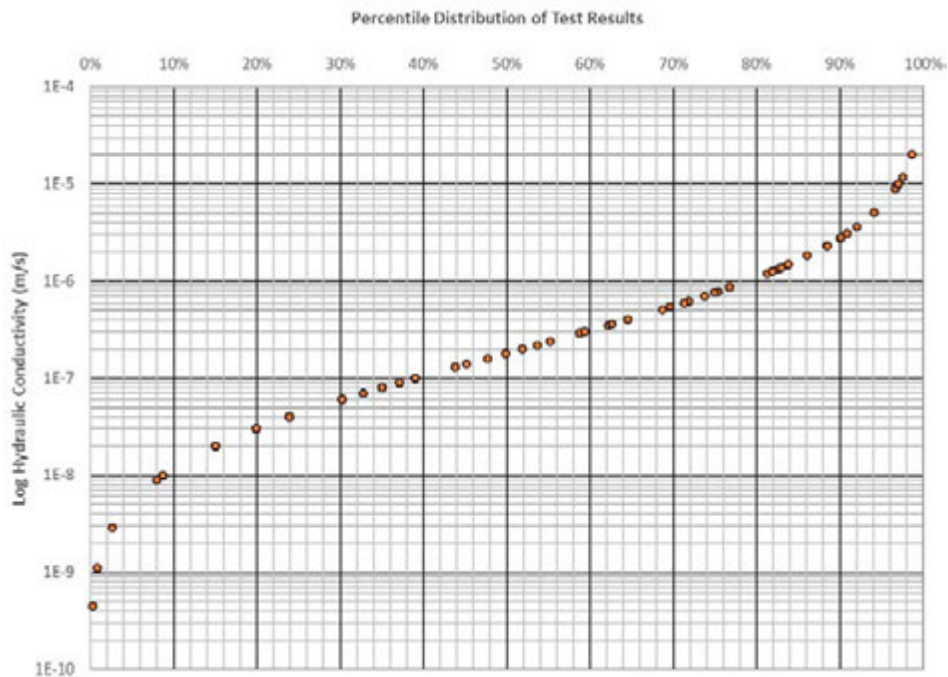


Figure 10: Statistical distribution of permeability test results for the Gatton Sandstone of the Clarence Moreton Basin.

There are no specific yield values³ available for the Gatton Sandstone 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 and Precipice Sandstone) in previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011). The argillaceous matrix and carbonate cementation of the Gatton Sandstone which is believed to have reduced the effective porosity and thus the capacity of the sandstone to store water has been considered in the reduced value range for specific yield of the Gatton Sandstone. Lower, typical and upper specific yield estimates are provided in Table 6.

¹ Transverse isotropy relates to a material with identical properties within a plane which is different than properties perpendicular to that plane. For example, the properties in any directions along bedding are the same while the properties transverse to bedding is different.

² Anisotropy refers to the condition of having different properties in different directions, as in geological strata that transmit water with different velocities in different directions but at the same pressure gradient along the respective directions

³ Specific yield refers to the amount of water available within the pore spaces of a rock that may be drained under the influence of gravity.

Koukandowie Formation and Walloon Coal Measures

Hydraulic conductivity of the Koukandowie Formation range between 2.8×10^{-9} and 2.2×10^{-4} m/s based mostly on specific capacity test records; 20 are above 1×10^{-7} m/s and 10 are above 1×10^{-6} m/s. Results of 79 permeability tests are available for the WCM. Values range between 2×10^{-11} and 8×10^{-4} m/s; 59 are above 1×10^{-7} m/s and 28 are above 1×10^{-6} m/s.

The test records indicate that the hydraulic conductivity of the WCM and Marburg Subgroup (Undifferentiated, Koukandowie Formation and Gatton Sandstone) are 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.

There are no specific yield values derived from field testing for the Koukandowie Formation and Walloon Coal Measures. A range of specific yield values has been estimated from previous modelling studies conducted in the Surat Basin by the University of Southern Queensland (2011) for similar sandstones (Hutton Sandstone and Precipice Sandstone) and from the New Acland EIS for the Walloon Coal Measures in 2013 (Barnett, 2013). Lower, typical and upper specific yield estimates are provided in Table 6.

Alluvium

A total of 96 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 strongly bias towards the high end of the conductivity range due to tested bores mostly drilled for irrigation purpose 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 6: Preliminary hydrogeological design parameters

| Formation | Hydraulic Property/year | Number of Samples/Tests | Lower | Typical | Upper |
|---|---|-------------------------|----------------------|----------------------|----------------------|
| Marburg Subgroup (Gatton Sandstone) | Hydraulic Conductivity (m/s) ^A | 80 | 1.0×10^{-9} | 1.5×10^{-7} | 8.2×10^{-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 | 242 | 1.1 | 3.7 | 10.2 |
| Marburg Subgroup (Koukandowie Formation) | Hydraulic Conductivity (m/s) ^A | 26 | 4.7×10^{-8} | 6.7×10^{-7} | 9.5×10^{-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 | 6 | 1.7 | 2.3 | 25.7 |

| Formation | Hydraulic Property/year | Number of Samples/Tests | Lower | Typical | Upper |
|-----------------------|---|-------------------------|----------------------|----------------------|----------------------|
| Walloon Coal Measures | Hydraulic Conductivity (m/s) ^A | 79 | 2.5×10^{-9} | 1.6×10^{-7} | 1.1×10^{-5} |
| | K_h/K_v ^B | Estimate | 20 | 100 | 500 |
| | Specific Yield ^C | Estimate | 0.005 | 0.035 | 0.05 |
| | Rainfall Recharge (mm/year) ^D | 90 | 1.3 | 3.5 | 9.7 |
| Alluvium | Hydraulic Conductivity (m/s) ^A | 96 | 1×10^{-6} | 1×10^{-5} | 1.7×10^{-2} |
| | K_h/K_v | Estimate | 1 | 10 | 100 |
| | Specific Yield ^C | Estimate | 0.05 | 0.10 | 0.15 |
| | Rainfall Recharge (mm/year) ^D | 2677 | 3.9 | 10.6 | 32.5 |

Note: ^A Lower, typical and upper values are represented by $\mu - \sigma$, μ , $\mu + \sigma$ of hydraulic test records with μ , median, and σ , standard deviation, of the logarithmized test values. Tests were conducted at locations across the Clarence-Moreton Basin.

^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 for monitoring groundwater levels. Water level measurements available at the time of reporting are summarised in Table 3.

Water level records of the monitoring bores will be updated in subsequent report revisions when available.

Groundwater levels along the Woolooman tunnel alignment, earthworks and bridge locations have been estimated based on available water level data within the same rock formation, similar ground relief and land use. Estimates were derived using statistical methods based on the correlation between depth to water table and ground surface elevation. These estimated groundwater levels in various parts of the alignment are discussed below.

Woollooman Tunnel

A groundwater monitoring bore (340-01-BH2101) equipped with a standpipe piezometer has been installed about 260 m to the southwest of CH 40.400 km within the C2K tunnel alignment at the top of the ridge. This bore currently has a groundwater level data logger installed, with the most recent groundwater level reported at 145.94 m AHD on 24 October 2018 (APPENDIX A Figure A1). As part of the ARTC Phase 1 Investigation, standpipe piezometer 340-BH-07 was installed about 360 m Southwest of CH 39.800 and reported a groundwater level on 29 June 2016 of 117.8 m AHD.

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 11. 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.

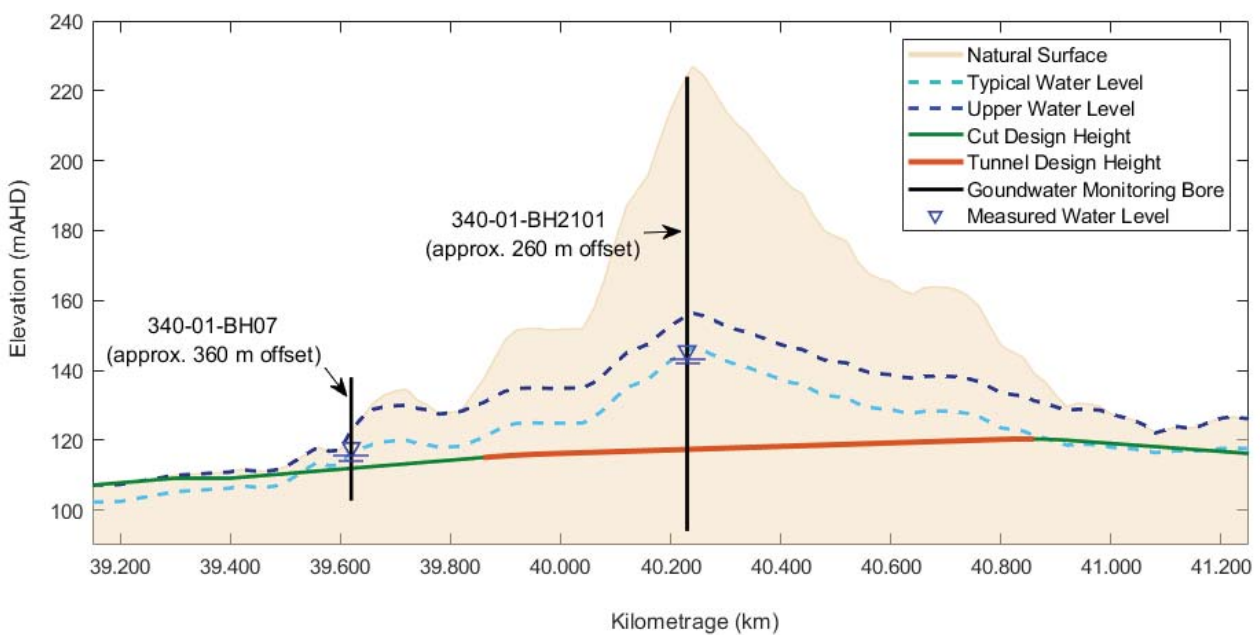


Figure 11: Preliminary estimates of pre-development groundwater level along the alignment between Kilometrage 39.150 to 41.250 km prior to tunnel construction

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

Table 7: Summary of preliminary estimates of groundwater level along the alignment between Kilometrage 39.500 to 41.280 km prior to tunnel construction

| Kilometrage (Km) | Estimated Groundwater Level | | Kilometrage (Km) | Estimated Groundwater Level | |
|------------------|-----------------------------|---------------------|------------------|-----------------------------|---------------------|
| | Typical Level (m AHD) | Upper Level (m AHD) | | Typical Level (m AHD) | Upper Level (m AHD) |
| 39.500 | 113 | 117 | 40.500 | 132 | 142 |
| 39.600 | 119 | 129 | 40.600 | 129 | 139 |
| 39.700 | 120 | 130 | 40.700 | 128 | 138 |
| 39.800 | 118 | 128 | 40.800 | 124 | 134 |
| 39.900 | 124 | 134 | 40.900 | 119 | 129 |
| 40.000 | 125 | 135 | 41.000 | 118 | 127 |
| 40.100 | 132 | 142 | 41.100 | 117 | 126 |
| 40.200 | 143 | 153 | 41.200 | 117 | 126 |
| 40.300 | 143 | 153 | 41.280 | 101 | 106 |
| 40.400 | 137 | 147 | | | |

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 one cut location along the C2K alignment, groundwater level records are available for the period between September 2018 to October 2018 (Table 3). 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 within the same rock formation, similar ground relief and land use. A summary of estimates of preliminary groundwater level at deep cuts relative to cut elevations is presented in Table 8.

Groundwater level and cut elevations for the remaining cuts are provided in APPENDIX C.

Based on a review of available information, groundwater is anticipated to be encountered in at least 21 of the 30 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 Along Cut (m AHD) | Median GW Level at Cut (m AHD) | Maximum GW Level at Cut (m AHD) | Assumed Geology from Desktop Review and Nearby FFJV Groundwater Bores |
|---------|------------|----------|-------------|---------------------------------------|--------------------------------|---------------------------------|---|
| 340-C1 | 3800 | 4410 | 0.610 | 55.9 | 52.8 | 56.3 | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C2 | 9.140 | 11.030 | 1.890 | 68.7 | 69.7 | 83.2 | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C4 | 15.080 | 16.850 | 1.770 | 43.6 | 48.0 | 58.5 | Tertiary Basalt and Claystone / Siltstone / Sandstone / Dolomite. Alluvium (~Kilometrage 16.570 to 18.180); becoming Tertiary Amberley Basin over Walloon Coal Measures. Nearby groundwater bore 340-01-BH2301. |
| 340-C8 | 21.870 | 22.830 | 0.960 | 45.9 | 42.1 | 48.8 | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C9 | 26.110 | 26.950 | 0.840 | 60.3 | 60.2 | 63.7 | Tertiary Intrusions: Dolerite / Basalt (~Kilometrage 26.000 to 26.400); Walloon Coal Measures. Nearby groundwater bore 340-01-BH2220. |
| 340-C11 | 29.410 | 29.710 | 0.300 | 65.5 | 64.1 | 67.8 | Koukandowie Formation; Walloon Coal Measures. Nearby registered groundwater bore RN120574. |
| 340-C12 | 29.980 | 31.120 | 1.140 | 64.6 | 63.0 | 88.8 | Koukandowie Formation; Alluvium. Nearby groundwater bore 340-BH04. |
| 340-C13 | 31.340 | 32.010 | 0.670 | 64.3 | 60.5 | 64.5 | Koukandowie Formation; Alluvium. Nearby registered groundwater bore RN14310277 |
| 340-C14 | 32.360 | 33.150 | 0.790 | 65.0 | 65.4 | 73.3 | Alluvium. No nearby groundwater bores. |
| 340-C15 | 33.460 | 33.650 | 0.190 | 67.0 | 67.4 | 71.2 | Koukandowie Formation. No nearby groundwater bores. |
| 340-C16 | 34.470 | 35.140 | 0.670 | 72.2 | 76.0 | 93.1 | Koukandowie Formation; Alluvium. Nearby groundwater bores 340-01-BH2303 and 340-01-BH2224. |

| Name | Start (km) | End (km) | Length (km) | Median CL Elevation Along Cut (m AHD) | Median GW Level at Cut (m AHD) | Maximum GW Level at Cut (m AHD) | Assumed Geology from Desktop Review and Nearby FFJV Groundwater Bores |
|----------|------------|----------|-------------|---------------------------------------|--------------------------------|---------------------------------|--|
| 340-C18a | 39.150 | 39.855 | 0.705 | 110.3 | 116.0 | 123.8 | Gatton Sandstone. Nearby groundwater monitoring bores 340-01-BH2101 and 340-BH-07. |
| 340-C18b | 40.870 | 41.350 | 0.480 | 117.7 | 124.7 | 128.0 | Gatton Sandstone. Nearby groundwater bore 340 01 BH2102. |
| 340-C19 | 42.350 | 42.470 | 0.120 | 102.8 | 102.6 | 105.2 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C20 | 43.850 | 44.070 | 0.220 | 85.0 | 93.6 | 104.3 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C21 | 44.570 | 45.450 | 0.880 | 72.9 | 80.0 | 106.3 | Gatton Sandstone. Nearby groundwater bore 340-01-BH2229 and 340-BH5. |
| 340-C22 | 46.670 | 46.900 | 0.230 | 62.5 | 63.2 | 67.9 | Gatton Sandstone. Nearby groundwater bore 340-01-BH2229 |
| 340-C23 | 47.110 | 47.510 | 0.400 | 59.9 | 60.4 | 71.8 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C24 | 47.780 | 48.270 | 0.490 | 56.4 | 61.2 | 68.9 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C25 | 48.450 | 48.850 | 0.400 | 54.5 | 56.0 | 57.2 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C26 | 49.030 | 49.260 | 0.230 | 53.0 | 54.0 | 56.6 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C27 | 51.510 | 51.720 | 0.210 | 45.6 | 44.4 | 49.5 | Heifer Creek Sandstone. Nearby registered groundwater bores RN152848 and RN152849. |

7.0 GROUNDWATER DRAWDOWN AND INFLOW MODELLING

7.1 Woollooman 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 Woollooman Tunnel and adjacent cuts as permanently drained structures. The analysis has been based on the alignment for design option 3405 for Section 340 C2K, preliminary hydrogeological parameters listed above Table 8 and preliminary groundwater levels provided in Table 7.

7.1.1 Design Assumptions

The Woollooman Tunnel alignment of design option 3405 for Section 340 C2K is located between Kilometrage 39.860 km and 40.860 km (Kilometrages of the tunnel design portals). The approximate length of the single-track tunnel is 1 km. The tunnel invert elevation varies between 115.0 m AHD and 120.3 m AHD and design height of the tunnel is 10 m throughout the alignment. Maximum rock thickness above tunnel crown is approximately 100 m at Kilometrage 40.240 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 690 m and a depth of up to approximately 20 m. At the eastern tunnel portal, the cut has a depth of up to approximately 17 m and extends for approximately 470 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;
- The modelled tunnel alignment and portal cuts is between Kilometrage 39.150 to 41.350 km, with the tunnel itself located between Kilometrage 39.860 to 40.860 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 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 11., 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 variations⁴.

7.1.2 Methodology

The estimates of groundwater inflows and drawdown were derived using the Perrochet analytical method (Maréchal et. al., 2014) and a numerical modelling approach using SEEP/W. The Perrochet analytical method can simulate transient discharge into 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.

⁴ Although groundwater levels will generally reflect topographic variations and will be generally be 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.

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 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.

To account for structural elements in the modified Perrochet analysis, the analysis was divided into 20 m intervals along the tunnel alignment. As indicated by FFJV, 2018, the location of any structurally affected zones will only be identified during tunnel excavation; however, it was recommended that for cost estimate purposes, analysis be allowed for three zones of structurally affected areas within the tunnel alignment, each up to 10 m in length. Therefore, within the analysis, three sections containing elevated hydraulic conductivity values were incorporated to account for uncertainties relating to the extent and random distribution of structurally affected areas.

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

- The modelled tunnel and portal cuts are between Kilometrage 39.540 to 40.960 km, over which length the bottom elevation of the construction is lower than the estimated groundwater level.
- Tunnel excavation will start from west to east with the approximate tunnel construction rate of 4 m per day. Duration of tunnel construction is 250 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 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 1×10^{-8} m/s has been adopted for the horizontal hydraulic conductivity for the Gatton Sandstone. Hydraulic conductivity is assumed to be isotropic in the Perrochet method of analysis.

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 12. The inflow and drawdown analysis are based on the following assumptions:

- The modelled cross section is located at Kilometrage 40.240 km where the rock thickness above the tunnel crown is at its maximum;
- Three geological units have been included in the model according to the Woollooman Tunnel Geotechnical Desktop Assessment Report (2-0001-340-IGE-20-RP-0002): highly weathered rock with an average thickness of 8.6 m, moderately weathered rock with an average thickness of 7.1 m and fresh rock with the thickness of greater than 100 m;
- The boundaries to the North and South are located 5 km away from the tunnel. Constant heads of 141.9 m and 137.5 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 recharge rates have been adjusted in order to get a better match with the observed and inferred typical groundwater levels illustrated in Figure 11. Recharge rates adopted for the Gatton Sandstone after model calibration range between 1.46 and 3.65 mm/year and are well within the range of recharge rates reported in Table 6.
- A regional groundwater flow divide has been interpreted from groundwater level contours which have been estimated using the correlation between groundwater level and ground surface elevation. Figure 13 which shows the interpreted groundwater level contours and the interpreted flow directions. 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 12).
- An anisotropy ratio of 100:1 (horizontal to vertical) has been used, as referenced in Table 6. The value of horizontal hydraulic conductivity for fresh rock has been modified to get a good match with the observed and inferred typical groundwater levels, yielding a value of 5.8×10^{-8} m/s for horizontal hydraulic conductivity.

| Color | Name | Category | Kind | Parameters |
|-------|-----------------------|-----------|---------------------|---------------------|
| ■ | Drainage | Hydraulic | Water Pressure Head | 0 m |
| ■ | Head boundary (north) | Hydraulic | Water Total Head | 141.87 m |
| ■ | Head boundary (south) | Hydraulic | Water Total Head | 137.47 m |
| ■ | Lateral flow (valley) | Hydraulic | Water Rate | 0 m ² /d |
| ■ | Recharge (general) | Hydraulic | Water Flux | 1e-05 m/d |
| ■ | Recharge (middle top) | Hydraulic | Water Flux | 4e-06 m/d |
| ■ | Recharge (valley) | Hydraulic | Water Flux | 4e-07 m/d |

| Color | Name | Model | Sat Kx (m/d) |
|-------|---------------------------|----------------|--------------|
| ■ | Highly weathered rock | Saturated Only | 0.00864 |
| ■ | Moderately weathered rock | Saturated Only | 0.00864 |
| ■ | Slightly weathered rock | Saturated Only | 0.005 |
| ■ | Tunnel | (none) | |

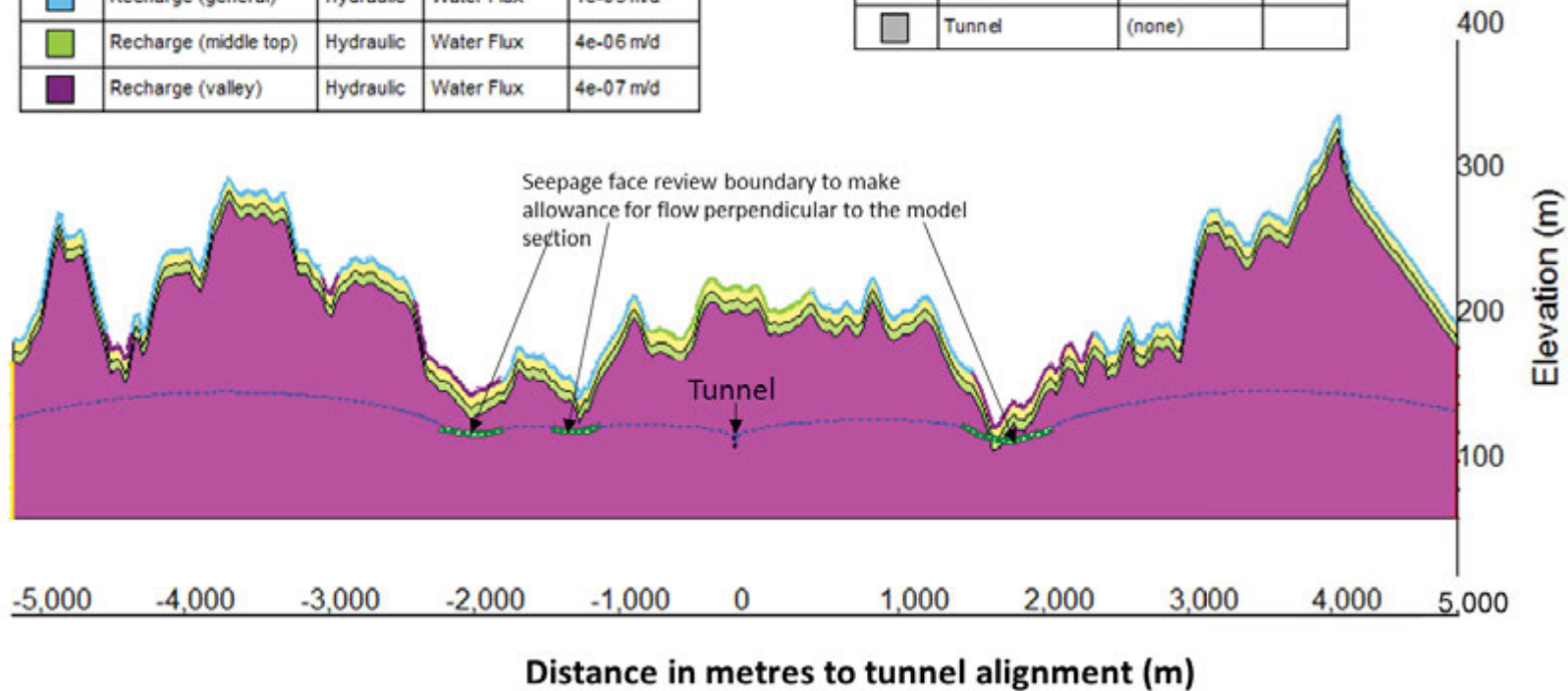


Figure 12: Woollooman Tunnel cross section at Kilometrage 40.240 km (SEEP/W model)

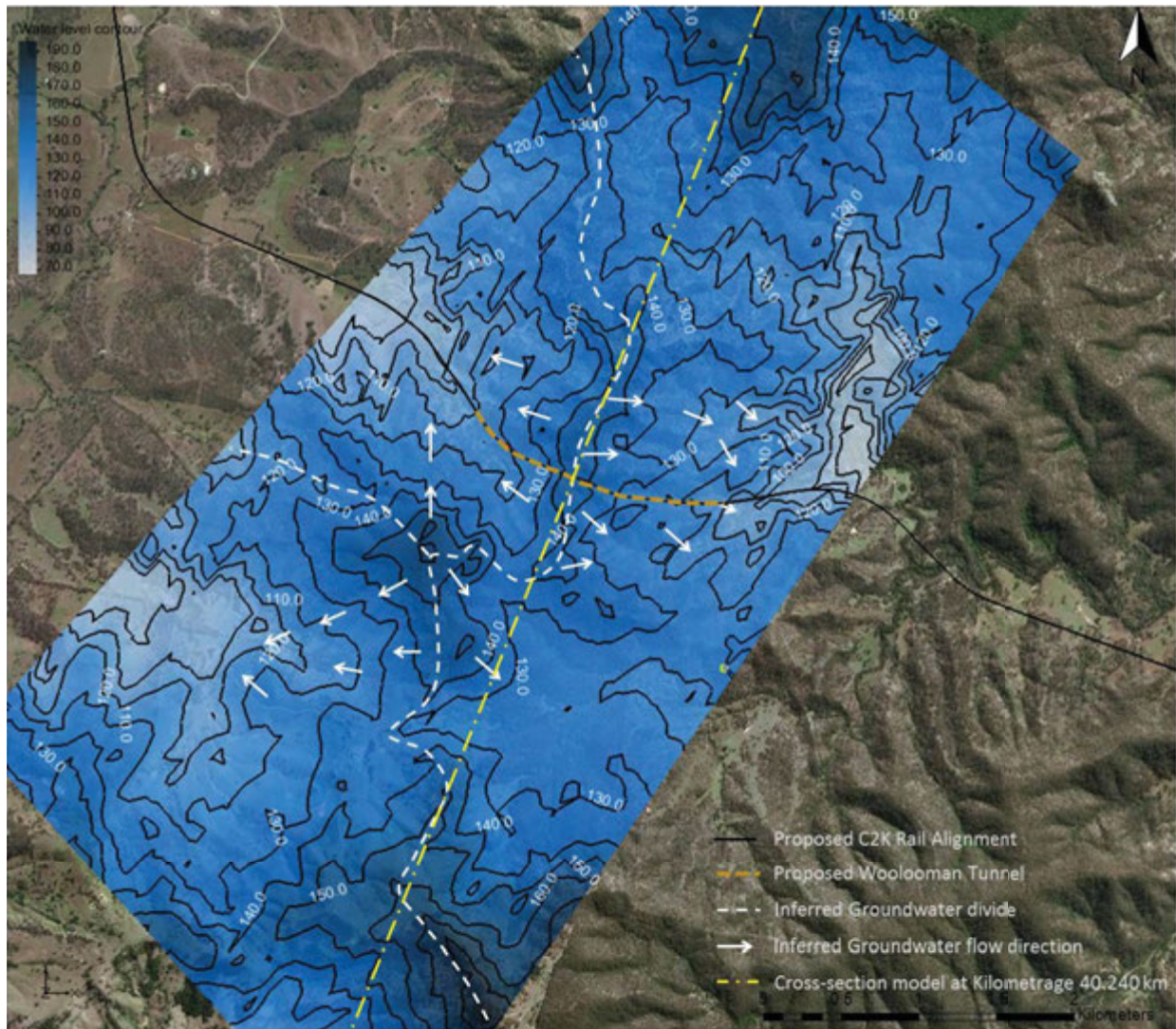


Figure 13: Groundwater level contours and groundwater flow divide. White dash lines show groundwater flow divide. Arrows indicate the groundwater flow direction

7.1.3 Groundwater Inflow Estimates

A long-term inflow of about 0.1 L/s has been estimated under drained conditions for the 1 km 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 40.240 km computed by the SEEP/W model is 0.014 L/s per 100 m of tunnel. The predicted inflow using the analytical method for the 100 m section between Kilometrage 40.160 to 40.260 is 0.01 L/s (refer to Table 9). The results from the two models are similar, with the results indicating that the analytical model may slightly under-predict inflow rates.

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 0.6 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 0.6 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 in the tunnelling.

For the cuts at the portals of the tunnel, long-term seepage flows of 0.02 L/s and less than 0.01 L/s respectively have been estimated for the western and eastern portals.

Table 9: Preliminary estimates of inflow to the Woolooman tunnel from Kilometrage 39.540 to 40.960 km (Perrochet method)

| Kilometrage (km) | Estimated Long term Operational Groundwater Inflows (L/s) ^A |
|------------------|--|
| 39.540 to 39.660 | Less than 0.01 |
| 39.660 to 39.760 | Less than 0.01 |
| 39.760 to 39.860 | Less than 0.01 |
| 39.860 to 39.960 | Less than 0.01 |
| 39.960 to 40.060 | Less than 0.01 |
| 40.060 to 40.160 | 0.01 |
| 40.160 to 40.260 | 0.01 |
| 40.260 to 40.360 | 0.01 |
| 40.360 to 40.460 | Less than 0.01 |
| 40.460 to 40.560 | Less than 0.01 |
| 40.560 to 40.660 | Less than 0.01 |
| 40.660 to 40.760 | Less than 0.01 |
| 40.760 to 40.860 | Less than 0.01 |
| 40.860 to 40.960 | Less than 0.01 |
| Total | 0.11 |

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

^A Based on “typical” estimate groundwater level as shown in Figure 11.

7.1.4 Groundwater Drawdown Estimates

Queensland’s Water Act 2000 specifies a trigger threshold for drawdown of 5 m at locations of bores in consolidated aquifers (such as the Gatton Sandstone). The approximate extent of the predicted long-term drawdown associated with the drained tunnel and portal cuts is illustrated on Figure 14, indicating the predicted drawdown contour based on the Perrochet analysis. The width of 5 m groundwater table drawdown envelope is up to 400 m in the direction perpendicular to the tunnel alignment. It is noted that the maximum drawdown does not align with the tunnel along the eastern tunnel section.

This is due to topographic effects with the inferred water table to the south of the tunnel being higher in this area than at the tunnel or to the north of the tunnel.

Because of this asymmetry of groundwater levels across the section perpendicular to the tunnel and the greater potential drawdown between the existing groundwater level and the tunnel elevation in the area to the south, drawdown to the southern side of tunnel is larger compared to the drawdown at the alignment or at the same distance to the north. The long-term tunnel drainage is anticipated to reduce groundwater levels below the ridge to the elevation of the tunnel invert and thus potentially reducing availability of groundwater to deep rooted trees in the areas of relatively lower topography near the portals and to the north and south of the tunnel.

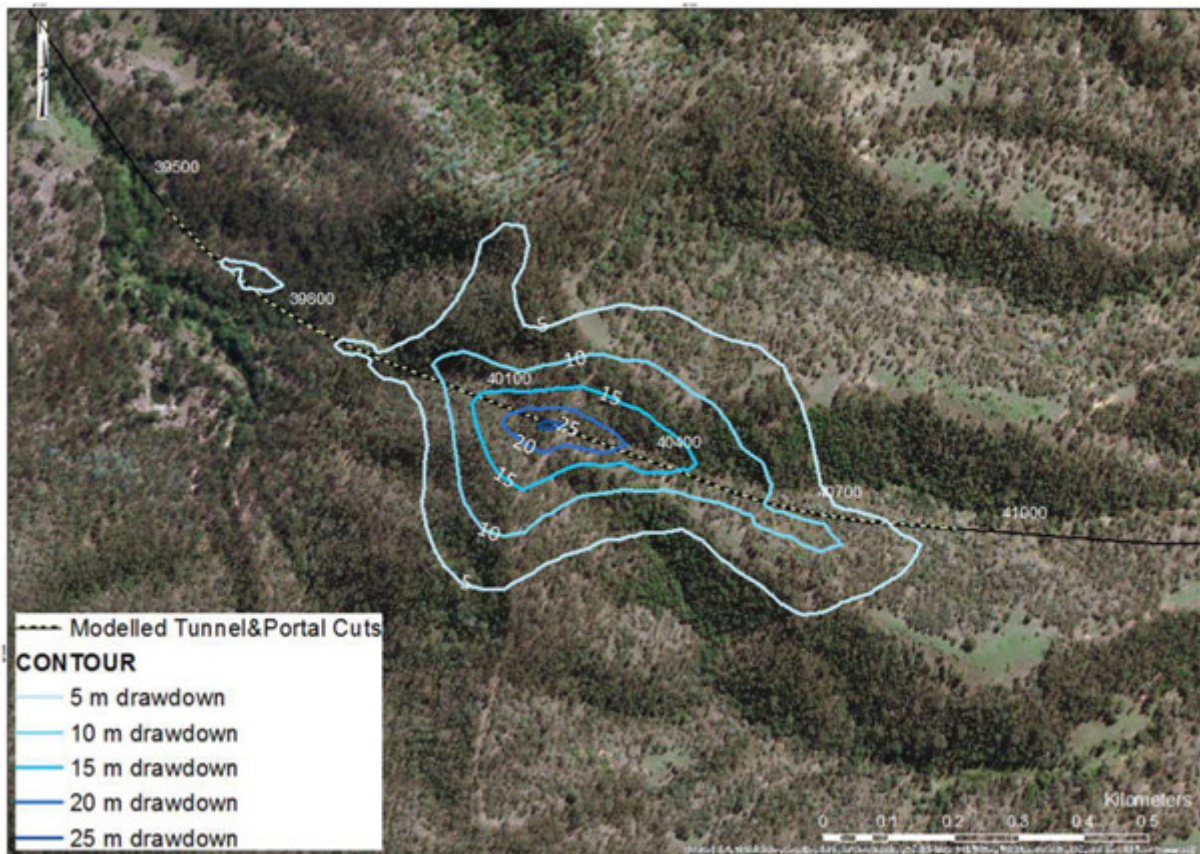


Figure 14: Estimated drawdown of groundwater table between Kilometrage 39.540 and 40.960 km due to drainage of tunnel (Perrochet method).

The estimated long-term groundwater table drawdown along the cross section at Kilometrage 40.240 km is shown in Figure 15, comparing the predictions of the analytical model with the SEEP/W model. Both the Perrochet method and SEEP/W model suggests the width of estimated 5 m drawdown in long-term are approximately 0.8 km at the southern side. At the northern side, the width of 5 m drawdown is approximately 1.4 km in SEEP/W model but estimated to 0.8 km by the analytical solution. This discrepancy between the two modelling approaches may be due to the lateral flow along the valley north of the tunnel which was partially accounted for in the SEEP/W model but was not included in the analytical model.

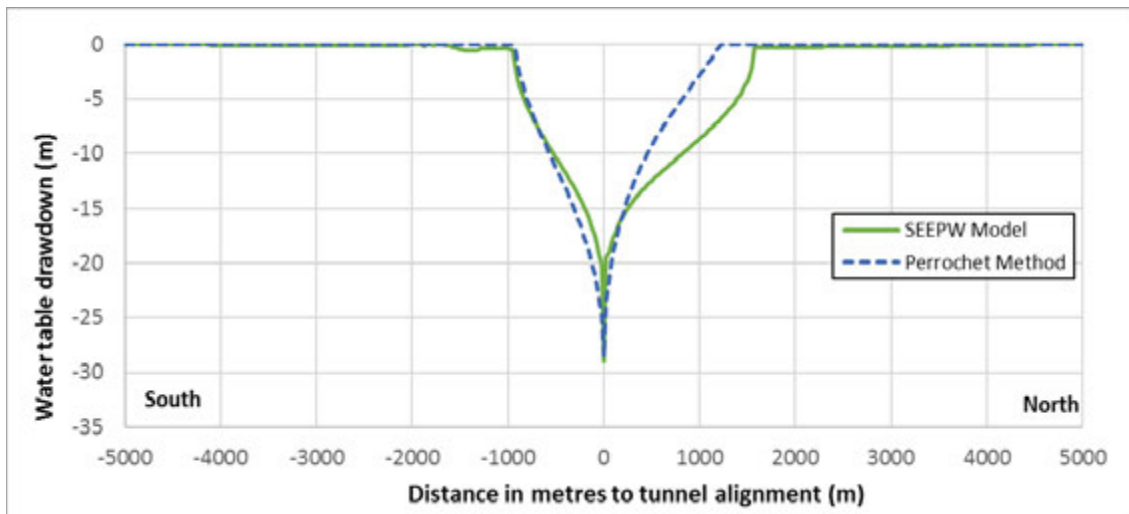


Figure 15: Comparison of modelled groundwater table drawdown along the cross section at Kilometrage 40.240 km

7.1.5 Uncertainty Analysis

An uncertainty analysis has been carried out to account for the effects of higher pre-existing groundwater levels and structural features on groundwater inflow and drawdown by using the model based on the Perrochet analytical method.

The Woolooman Tunnel Geotechnical Desktop Assessment Report (2-0001-340-IGE-20-RP-0002) suggests the presence of two or three structurally affected zones of 10 m width along the tunnel section. The location of such structurally affected zones is not confirmed. The following assumptions have been made for the uncertainty analysis:

- Three structurally affected zones have been included in the model. It is assumed that the tunnel will encounter the structurally affected zones at Kilometrage 40.240 km (where the groundwater level is highest), 40.050 km (midpoint between western portal and Kilometrage 40.240 km) and 40.550 km (midpoint between eastern portal and Kilometrage 40.240 km).
- 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 upper value of hydraulic conductivity (8.2×10^{-7} m/s) 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 three structurally affected zones; and
- An elevated groundwater level with three 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 | 0.17 |
| 2 | 3 | Typical water level | 0.13 |
| 3 | 3 | Elevated water level | 0.23 |

When the water level is elevated by 10 m, the total long-term inflow for 1 km length of tunnel increases from 0.11 L/s to 0.17 L/s. Structural features cause a slight increase in the long-term inflow rate from 0.11 to 0.13 L/s.

The approximate extents of the predicted long-term drawdown under the three scenarios are illustrated in Figure 16, Figure 17 and Figure 18. The width of the 5-m groundwater table drawdown is up to 700 m under elevated water level (Figure 16). When structural features have been considered, the estimated drawdown significantly develops along the structurally affected zones (Figure 17 and Figure 18).

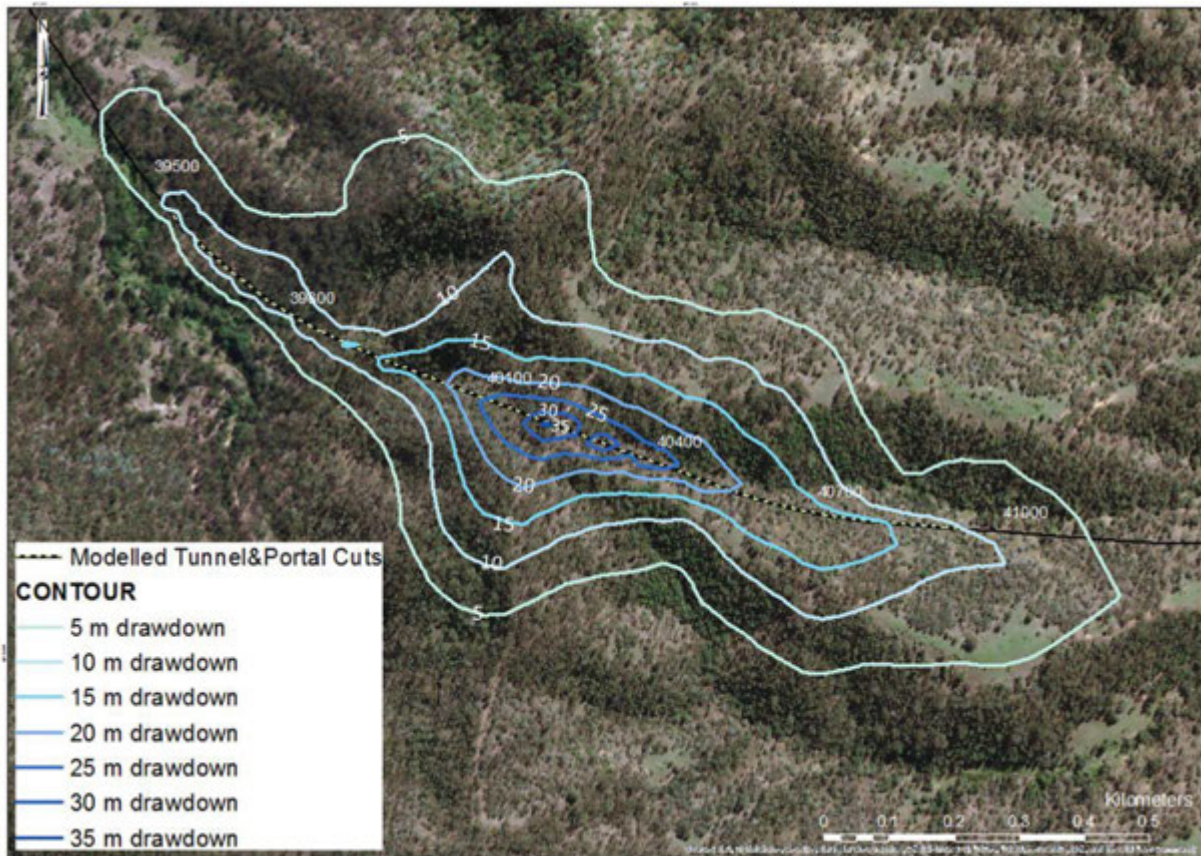


Figure 16: Estimated drawdown of groundwater table between Kilometrage 39.540 and 40.960 km due drainage of the Woolooman tunnel and portal cuts (Scenario 1).

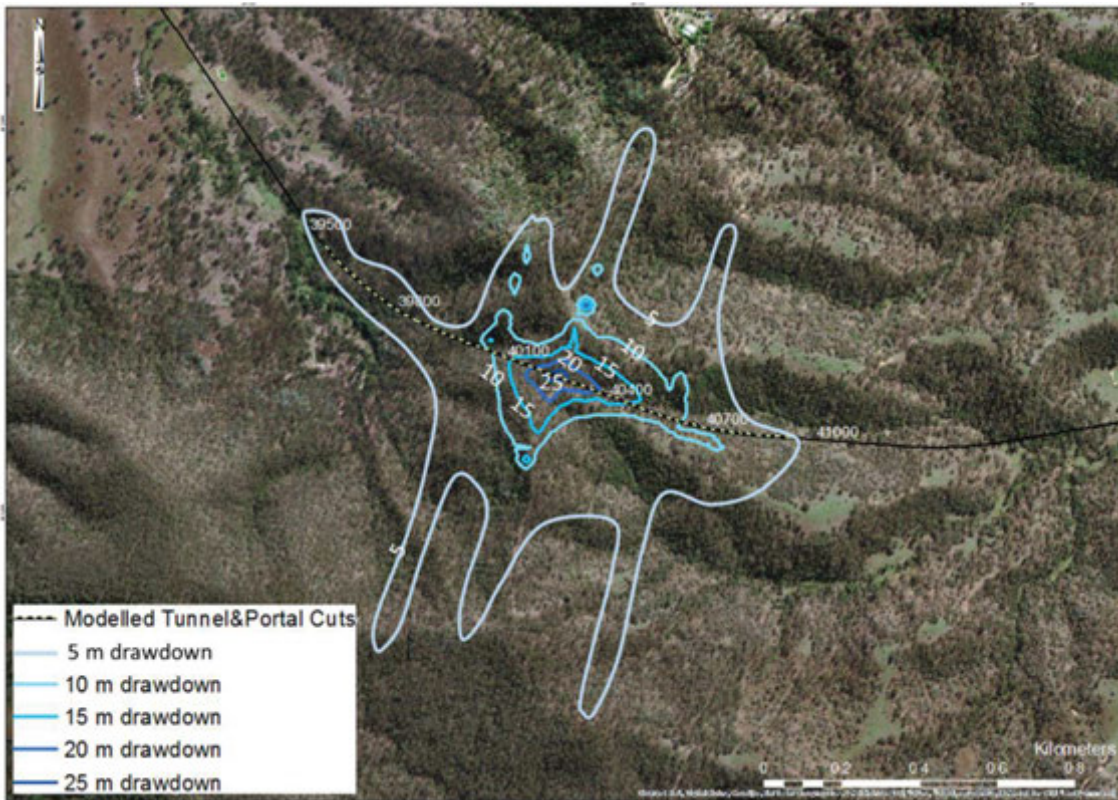


Figure 17: Estimated drawdown of groundwater table between Kilometrage 39.540 and 40.960 km due to drainage of the Woolooman tunnel and portal cuts (Scenario 2).

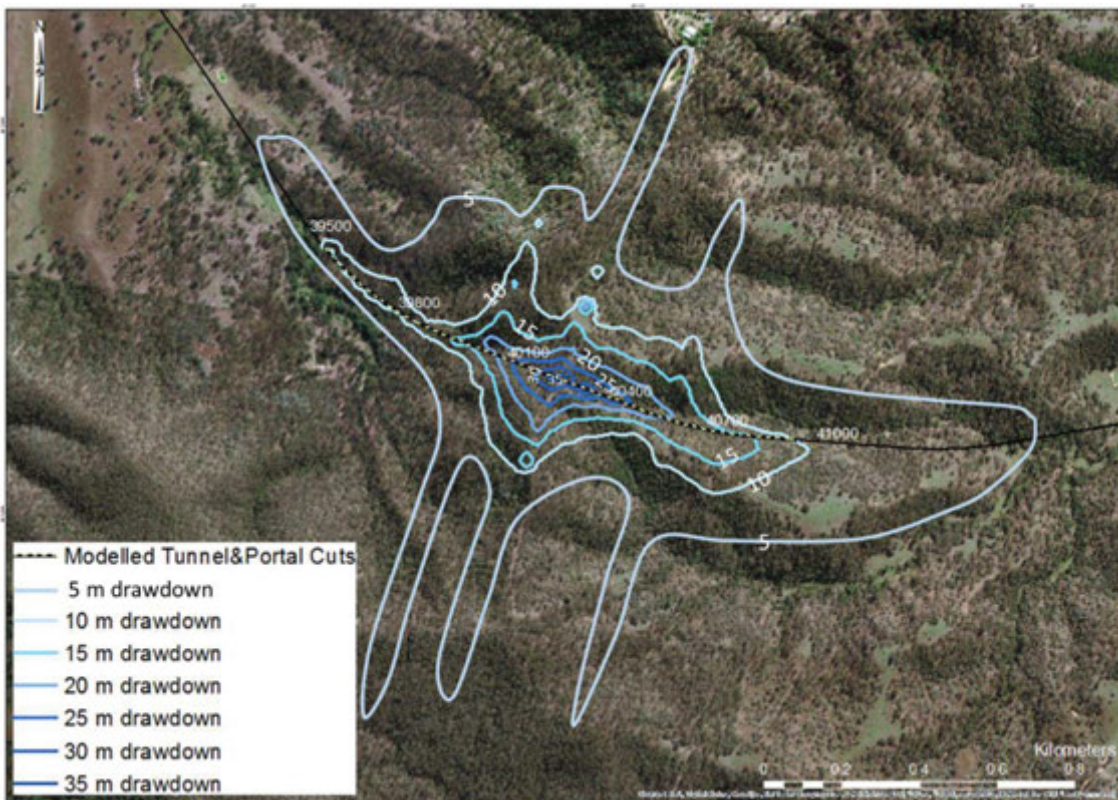


Figure 18: Estimated drawdown of groundwater table between Kilometrage 39.540 and 40.960 km due to drainage of the Woolooman tunnel and portal cuts (Scenario 3).

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 6 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.

7.2 Cuts Along the Alignment

7.2.1 Design Assumptions

The requirements for earthworks and bridges for design option 3405 of Section 340 C2K comprise 30 cuts, 30 embankments and 30 bridges, 3 of which are road bridges. Cuts range from 120 m up to 1890 m in length while embankments range from 150 m up to 4730 m in length. The bridges are in areas where there are waterways and range from 60 m up to 1817 m in length.

Location of deep cuts anticipated to experience groundwater seepage are summarised in APPENDIX C.

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 6
- 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 C2K 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 19. Seepage was calculated using inferred groundwater levels at ten-metre intervals along the length of each cut.

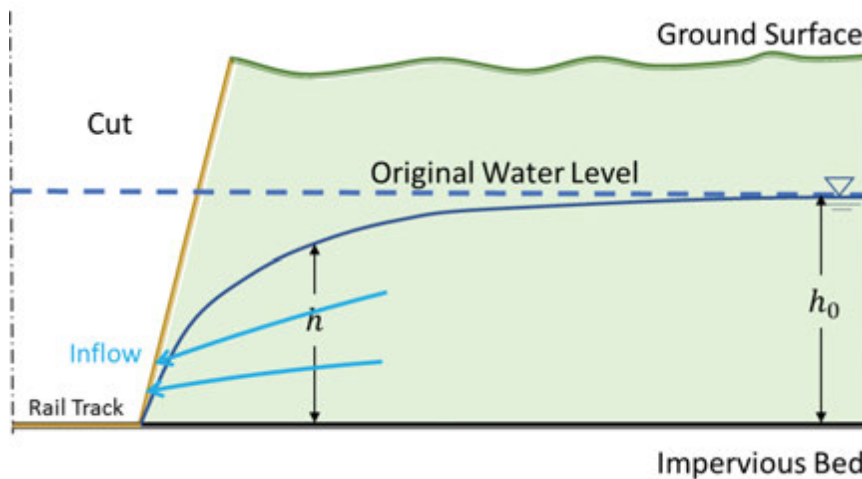


Figure 19: Seepage flow analytical model for cuts along the C2K rail track alignment where h_0 is the undisturbed (ambient) piezometric water level and h is the piezometric head

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 0.8 L/s. Estimated steady state seepage rates range from less than 0.1 L/s to 0.1 L/s. Seepage rate estimates for each cut are reported in Table 11.

The following points are noted:

- Two cuts (340-C12 and 340-C14) are inferred to intersect alluvial, colluvial sediment deposits or weathered rock along part of their length near the base of the escarpments. High inflow rates of up to approximately 1 L/s at one-year post construction and up to 0.1 L/s in the long-term are estimated for these cuts. The high inflow is derived from the alluvial sediment deposits, and inflows would be significantly less if the length of the slope cut intersecting the alluvial sediment deposits is less than assumed for the assessment.
- 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 C2K alignment

| Cut Name | Length (m) | Geology | Total Seepage Rate (L/s) | |
|----------|------------|-----------------------|---------------------------|---------------|
| | | | 1 year after construction | Long term |
| 340-C1 | 610 | Walloon Coal Measures | Less than 0.1 | Less than 0.1 |
| 340-C2 | 1890 | Walloon Coal Measures | 0.2 | Less than 0.1 |
| 340-C4 | 1770 | Walloon Coal Measures | 0.2 | Less than 0.1 |
| 340-C8 | 960 | Walloon Coal Measures | Less than 0.1 | Less than 0.1 |
| 340-C9 | 840 | Walloon Coal Measures | Less than 0.1 | Less than 0.1 |
| 340-C11 | 300 | Koukandowie Formation | Less than 0.1 | Less than 0.1 |

| Cut Name | Length (m) | Geology | Total Seepage Rate (L/s) | |
|----------|------------|-----------------------|---------------------------|---------------|
| | | | 1 year after construction | Long term |
| 340-C12 | 1140 | Alluvium | 0.8 | 0.1 |
| 340-C13 | 670 | Koukandowie Formation | Less than 0.1 | Less than 0.1 |
| 340-C14 | 790 | Alluvium | 0.2 | Less than 0.1 |
| 340-C15 | 190 | Koukandowie Formation | Less than 0.1 | Less than 0.1 |
| 340-C16 | 670 | Koukandowie Formation | 0.2 | Less than 0.1 |
| 340-C19 | 120 | Gatton Sandstone | Less than 0.1 | Less than 0.1 |
| 340-C20 | 220 | Gatton Sandstone | Less than 0.1 | Less than 0.1 |
| 340-C21 | 880 | Gatton Sandstone | 0.2 | Less than 0.1 |
| 340-C22 | 230 | Gatton Sandstone | Less than 0.1 | Less than 0.1 |
| 340-C23 | 400 | Gatton Sandstone | Less than 0.1 | Less than 0.1 |
| 340-C24 | 490 | Gatton Sandstone | 0.1 | Less than 0.1 |
| 340-C25 | 400 | Gatton Sandstone | Less than 0.1 | Less than 0.1 |
| 340-C26 | 230 | Gatton Sandstone | Less than 0.1 | Less than 0.1 |
| 340-C27 | 210 | Koukandowie Formation | Less than 0.1 | Less than 0.1 |

7.2.4 Limitations

The following limitations of this method are noted:

- The assumption of an impervious bed below the rail track may 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.

8.0 HYDROGEOLOGICAL DESIGN CONSIDERATIONS

8.1 Water Quality and Durability Considerations for Woollooman Tunnel

Data records on groundwater characteristics retrieved from the Queensland registered bore database for an approximately 5.0 km wide corridor along the track alignment between Kilometrage 39.860 km and 40.860 km are limited to a single record for electrical conductivity with a value of 6 140 $\mu\text{S}/\text{cm}$. Site specific data was obtained from 340-01-BH2101, for which the following results were recorded for a sample collected on 13 September 2018:

- An electrical conductivity of 10 200 $\mu\text{S}/\text{cm}$.
- A pH of 11.1. The high pH indicates potential influence of grout bleeding on the sample
- A concentration of ammonia as nitrogen of 0.69 milligrams per litre (mg/L).

Borehole 340-01-BH2101 is screened from 105 to 117 mbgl in sandstone. Hydraulic conductivity of the screened section is very low ($<2 \times 10^{-8} \text{m/s}$), therefore complete development could not be implemented at the time of drilling. Access restrictions prevented a return to the site to complete development. It is highly likely that the high pH value is a result of the drilling process and limited well development, but this interpretation cannot be confirmed at this point in time.

The concentrations of ammonia as nitrogen is above the Water Quality Objective (WQO) for upland freshwater ecosystems which has a trigger value of 0.01 mg/L. Groundwater in environments with forestry like those found within the area above the tunnel and adjacent to the cuts at the two portals are potentially affected by lignin, tannin and their decomposition by-products leached from forest litter as water passes through it. Lignin and tannins don't present a health hazard but are likely to cause groundwater to have background concentration of organic nitrogen above the Limit of Reporting.

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. However, salinity of groundwater drainage may exceed salinity of receiving streams and total nitrogen may exceed the 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 an extended search radius of 25 km and for 340-01-BH2101. A total of 14 registered bores screened in the Marburg Subgroup with water quality results relevant to the durability assessment were identified within this radius, ranging in distance from the tunnel from 180 m to 20 km (9 with magnesium, 14 with EC and 10 with all water quality characteristics). The results are interpreted to indicate a wide range of water quality parameters for the Marburg Subgroup, and it is not possible at this stage to give more specific information on groundwater characteristics at the site.

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

| Characteristic ^A | Unit | Registered bores within 25 km radius ^B | 340 01 BH2101 |
|----------------------------------|-------|---|---------------|
| Number of Samples | - | 14 | 1 |
| Sulphate | mg/L | 8 to 75 | 505 |
| Chloride | mg/L | 438 to 3 300 | 3 000 |
| Carbonate | mg/L | 0 to 71 | 113 |
| Bicarbonate | mg/L | 2 to 584.0 | <1 |
| Calcium | mg/L | 4 to 145 | 229 |
| Magnesium | mg/L | 0 to 175 | 20 |
| Magnesium/Calcium Ratio | - | 0 to 2.5 | 0.1 |
| pH | - | 6.5 to 11.6 | 11.1 |
| Electric Conductivity | µS/cm | 300 to 9 200 | 10 200 |
| Langelier Saturation Index (LSI) | - | -2.1 to 2.7 | 3.4 |
| Ryznar Stability Index (RSI) | - | 6.1 to 11.0 | 4.4 |

Note: ^A Records retrieved from the Queensland registered bore database for an approximately 25 km wide corridor of the track alignment between Kilometrage 39.500 and 41.280 km.

^B Magnesium concentration data records from 9 locations, EC from 14 locations and all other data records from 10 locations. LSI and RSI have been estimated based on data records of 9 locations.

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 260 to 26 500 µS/cm). Water quality estimates are based on records from the Queensland Registered Bores Database (DNRM, 2018) and for one SI borehole drilled at deep cut 340-C11 (between CH 29.410 km and 29.710 km). For cut number 340-C11, SI borehole 340-01-BH2303 suggests water quality is brackish, with an EC measurement of 4464 µS/cm and a pH value of 7.94.

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 embankments:

- overlying geological formations with a low specific yield may result in a potential groundwater rise of 5 m immediately following large rainfall or flood events.
- overlying areas with deep alluvium with a higher specific yield may result in a potential increase of groundwater levels by 1.5 m following large rainfall or flood events.

As the majority of embankments are located in low-lying areas underlain by alluvium, most are susceptible to potential increases in groundwater level in response to wet season heavy rainfall and flood events. 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 | Estimated Surface Elevation (mAHD) ¹ | Estimated GW Level (mAHD) ² | Estimated GW Level (mbgl) | Potential Mounded GW Level (m bgl) |
|----------------|---|--|---------------------------|------------------------------------|
| 340-E18 | 79.0 | 72.2 | 6.8 | 1.1 |
| 340-E19 | 86.1 | 79.8 | 6.3 | 0.5 |
| 340-E20 | 66.0 | 58.3 | 7.7 | 2.0 |

Note: GW = Groundwater, ¹Estimated surface elevation calculated based on the typical value for elevation along the proposed rail alignment (RL), ²Estimated 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, Marburg Subgroup (Undifferentiated) and WCM) within 5 km of the proposed alignment. For the purposes of this assessment, the Gatton Sandstone and Koukandowie Formation have been reported as part of the Marburg Subgroup (Undifferentiated) due to limited information available. Results of current data analysis across three formations indicate a broad range of water quality parameters for the Quaternary alluvium, WCM, and Marburg Subgroup (Undifferentiated). In general, lower values of Mg and Ca were reported for the Marburg Subgroup (Undifferentiated), while higher values of Cl and EC were reported for the WCM.

Factual information is available in the Geotechnical Factual Report (2-0001-340-IGE-10-RP-001), however due to timing of the site investigation completion the data was not available for inclusion in this interpretive report. Table 14 provides results for bridge locations which are located near a Golder SI bore, while a complete set of results is provided in APPENDIX D.

Table 14: Estimated characteristics of groundwater at proposed bridge locations along the C2K rail alignment to inform durability assessment

| Bridge Location | SO ₄ ^A [mg/L] | Cl ^A [mg/L] | CO ₃ ^A [mg/L] | HCO ₃ ^A [mg/L] | Ca [mg/L] | Mg [mg/L] | Mg/Ca [] | pH ¹ [] | EC ¹ [µS/cm] | T ^{1,B} (C°) | LSI [] | RSI [] |
|-----------------|--|---------------------------|--|---|--------------|--------------|-------------|-----------------------|----------------------------|--------------------------|-----------|-----------|
| 340-BR14 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.89 | 27380 | 24.9 | 7.12 | -0.11 |
| 340-BR14 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.91 | 5408 | 22.4 | 7.19 | -0.14 |
| 340-BR15 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.91 | 5408 | 22.4 | 7.19 | -0.14 |
| 340-BR16 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.91 | 5408 | 22.4 | 7.19 | -0.14 |
| 340-BR22 | 25 | 1185 | 2.55 | 297.5 | 47.15 | 11 | 0.01 | 7.02 | 7916 | 21.6 | 8.12 | -0.55 |
| 340-BR27 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.41 | 8412 | 21.3 | 7.74 | -0.66 |
| 340-BR28 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.41 | 8412 | 21.3 | 7.74 | -0.66 |
| 340-BR29 | 13.8 | 488 | 2.8 | 520.2 | 88.35 | 74.8 | 0.15 | 6.41 | 8412 | 21.3 | 7.74 | -0.66 |

Note: ^A Records retrieved from the Queensland registered bore database for an approximately 5 km wide corridor of the proposed C2K rail alignment. ^B T = Temperature. ¹Recorded field water 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 Gatton Sandstone higher than estimated in Section 7.1 and consequently groundwater inflows to the tunnel and portal cuts and groundwater level drawdown higher than expected. | 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 or dykes allowing preferential groundwater flow and consequently tunnel drainage is higher than expected. | 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, |

| Risk/Issue | Proposed Mitigation |
|--|---|
| | extent and hydrogeologic characteristic of geological structures along the tunnel alignment. |
| Hydraulic conductivity of the Marburg Subgroup, Walloon Coal Measures or alluvial sediment deposits lower or higher than estimated 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 where borehole data indicates that the groundwater level is above the base of the cut. |
| Groundwater recharge higher than estimated 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 cut locations where borehole data indicates that the groundwater level is above the base of the cut.. 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. |
| Magnesium concentrations higher than estimated in Table 12 and Table 14 and consequently impact of groundwater on concrete durability larger than expected. | Repeated groundwater sampling along the tunnel alignment and bridge locations and testing for magnesium and calcium concentration. |
| Groundwater aggressivity and scaling potential of tunnel drainage higher than expected. | Repeated groundwater sampling of the Gatton Sandstone along the tunnel alignment and testing for aggressivity and scaling potential parameters prior to final design and construction. |

10.0 IMPORTANT INFORMATION RELATING TO THIS REPORT

Your attention is drawn to the document - "Important Information Relating to this Report", which is included in APPENDIX E 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.

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Signature Page

Golder Associates Pty Ltd



Cristian Loddo
Associate, Geotechnical Group Leader

DB,YZ,NMC,HG/SF-DB/db/ow/rw

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APPENDIX A

Hydrographs from 2018 FFJV Investigations

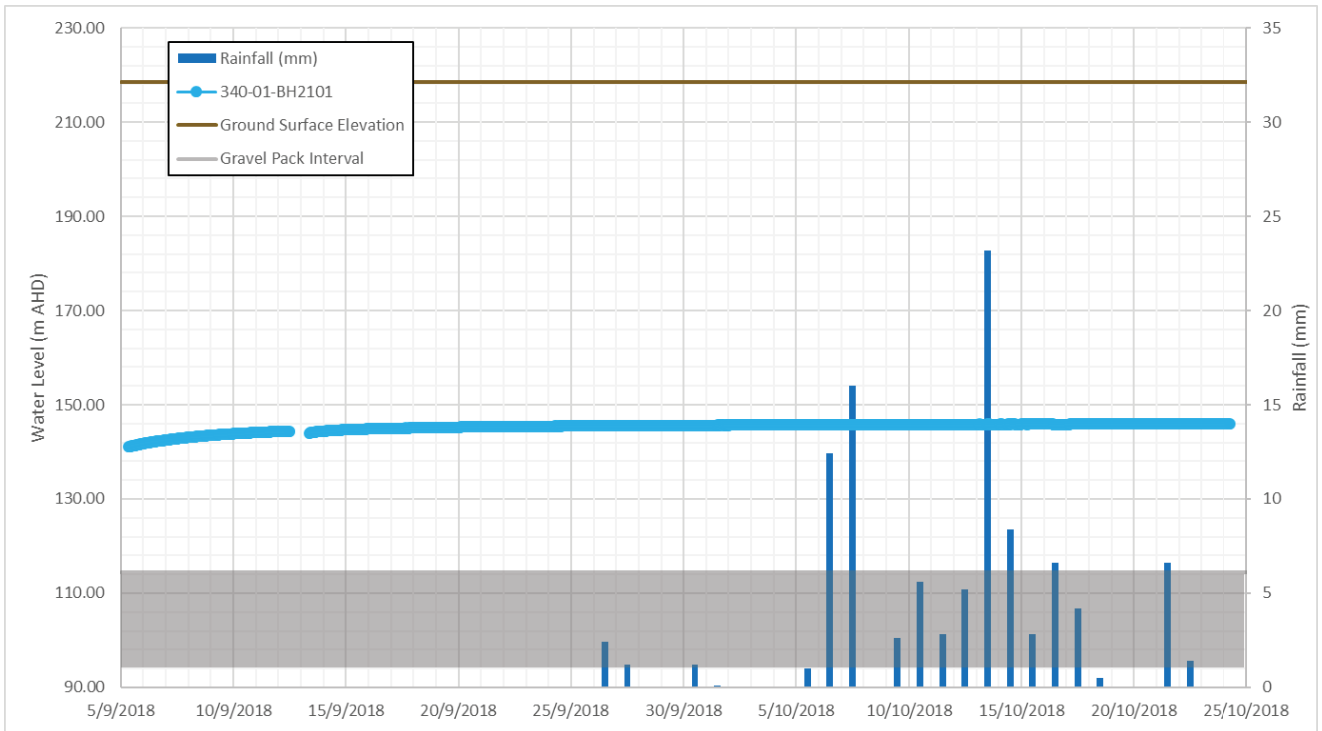


Figure A1: Hydrograph of 340-01-BH2101, rainfall from the Harrisville Mary Street weather station (Station 040094)

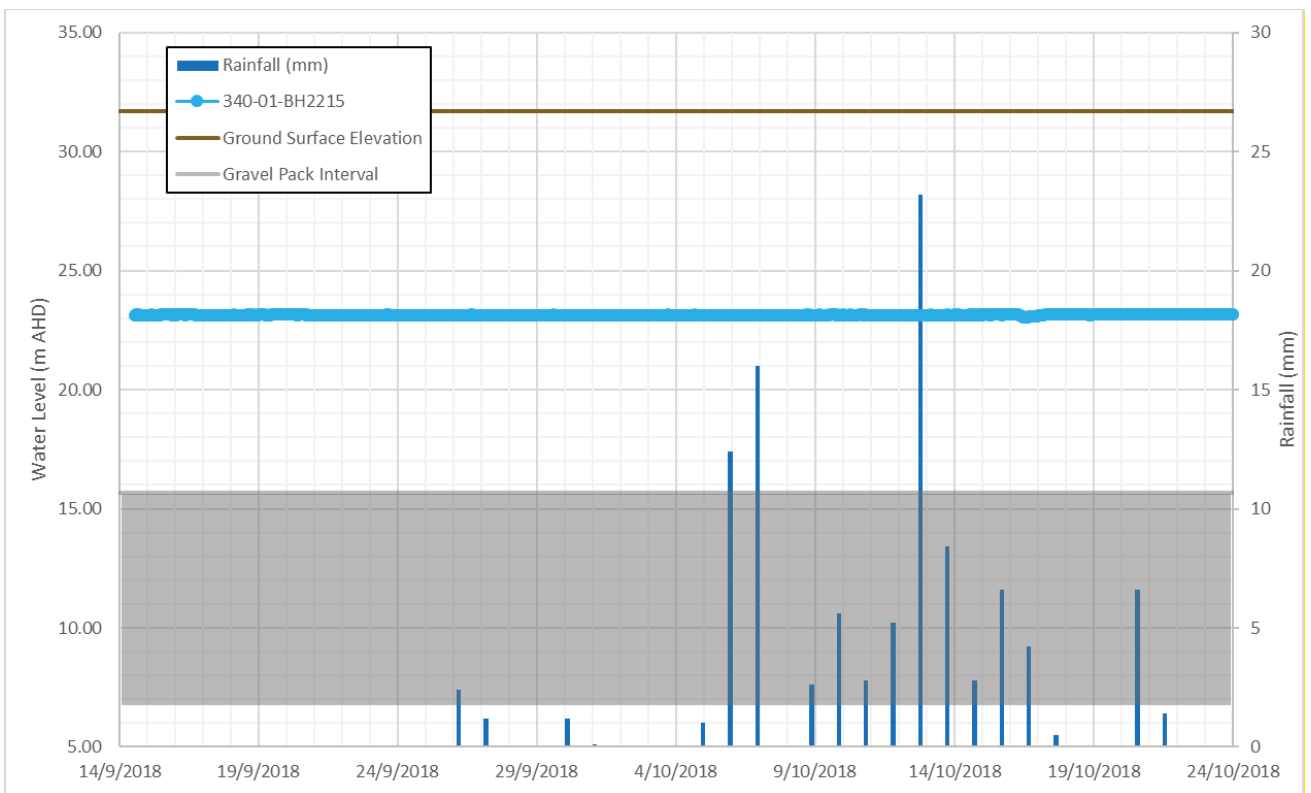


Figure A2: Hydrograph of 340-01-BH2215, rainfall from the Harrisville Mary Street weather station (Station 040094)

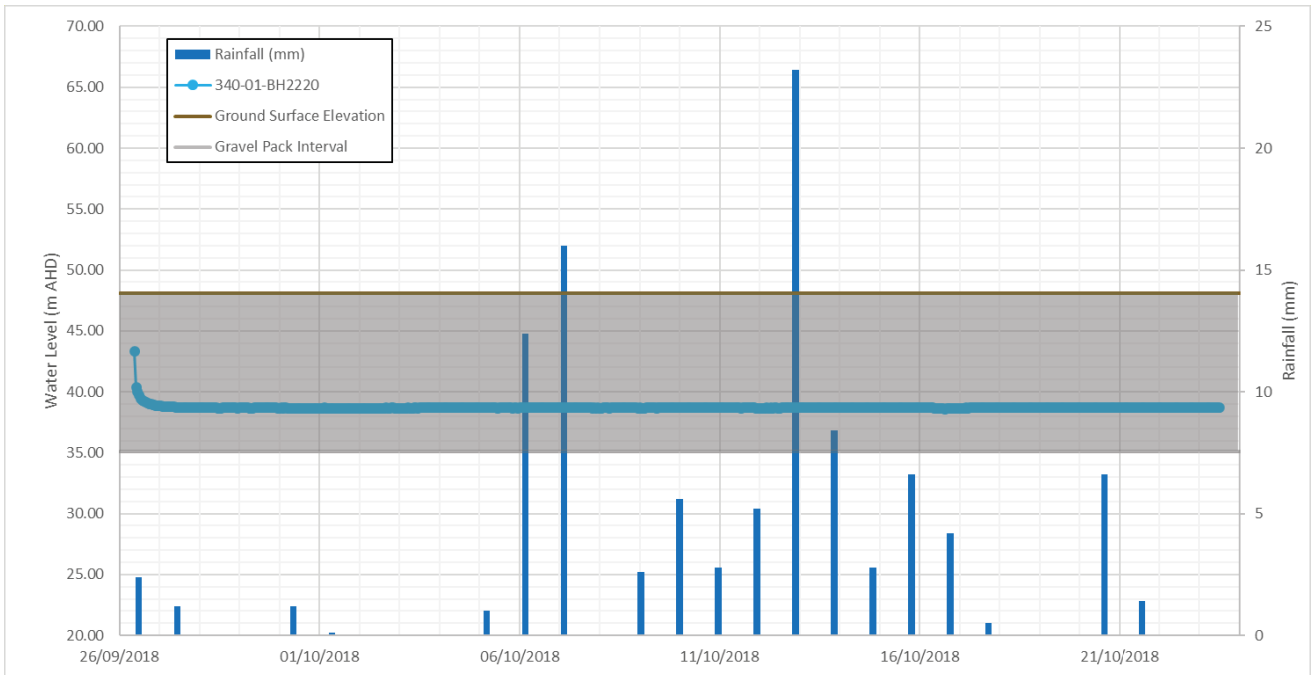


Figure A3: Hydrograph of 340-01-BH2220, rainfall from the Harrisville Mary Street weather station (Station 040094)

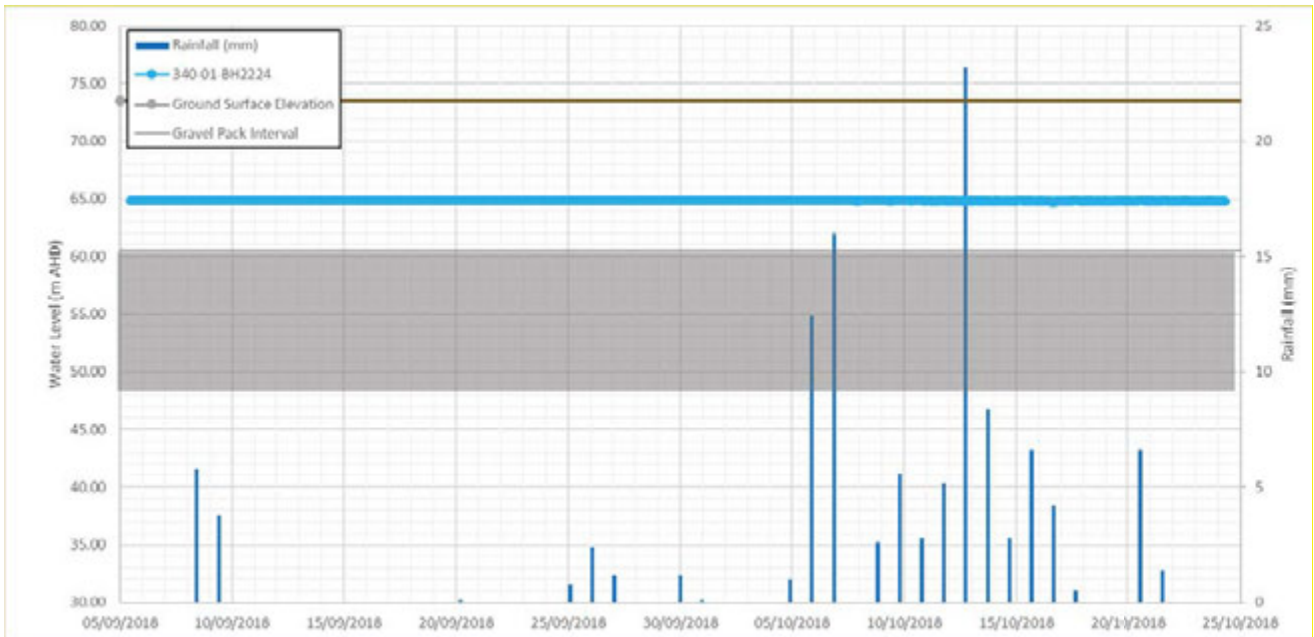


Figure A4: Hydrograph of 340-01-BH2224, rainfall from the Harrisville Mary Street weather station (Station 040094)

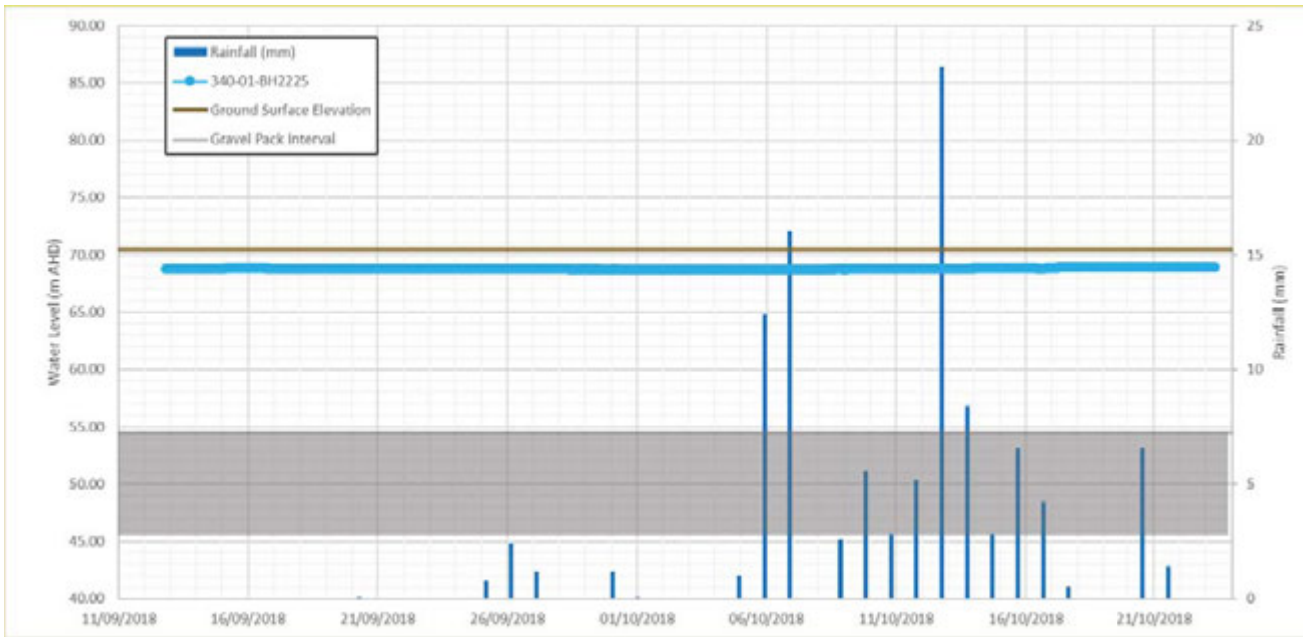


Figure A5: Hydrograph of 340-01-BH2225, rainfall from the Harrisville Mary Street weather station (Station 040094)

Not available at the time of reporting

Figure A6: Hydrograph of 340-01-BH2226, rainfall from the Harrisville Mary Street weather station (Station 040094)

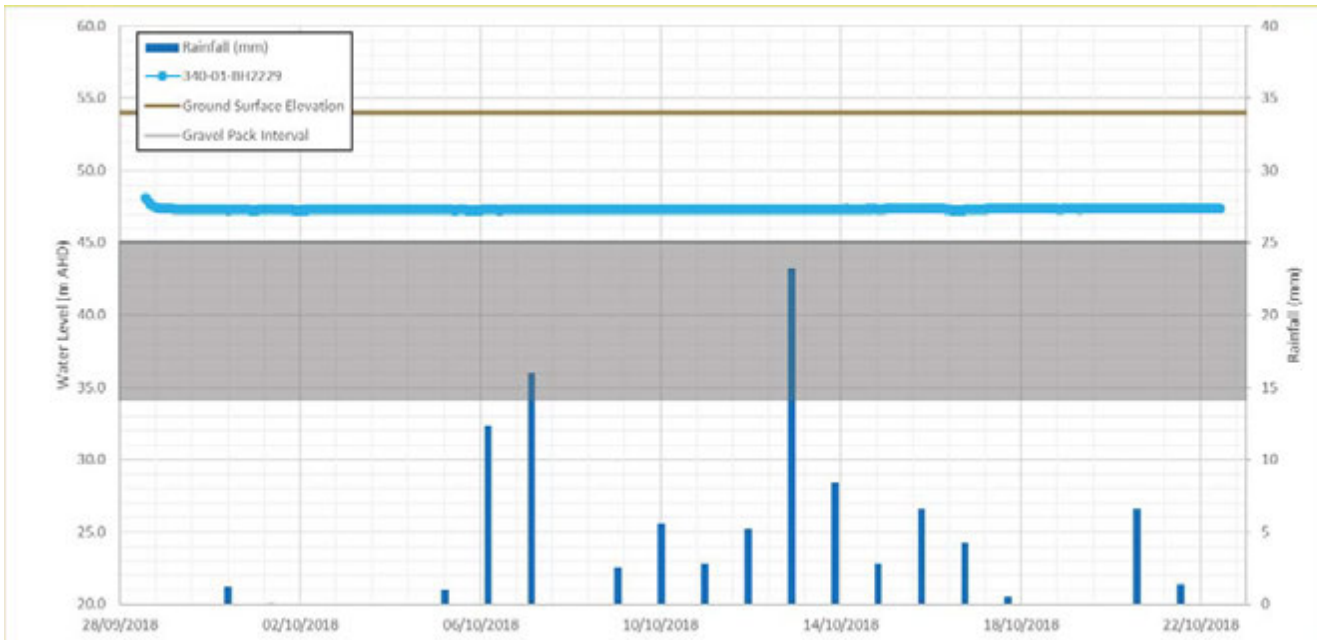


Figure A7: Hydrograph of 340-01-BH2229, rainfall from the Harrisville Mary Street weather station (Station 040094)

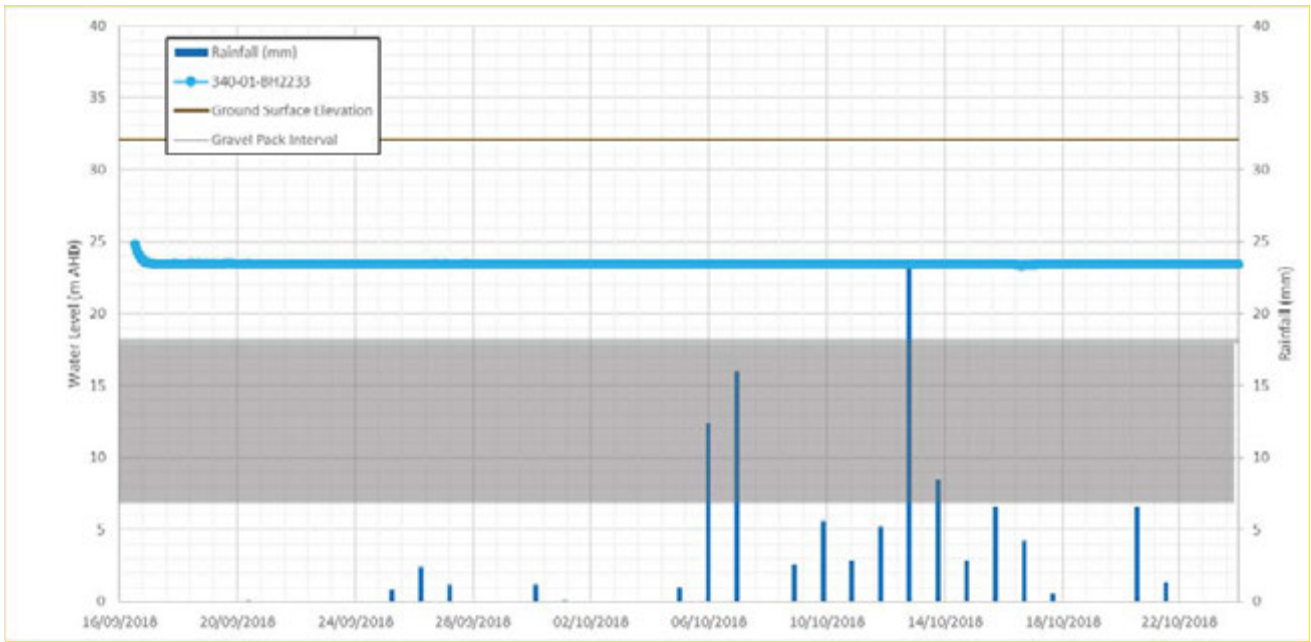


Figure A8: Hydrograph of 340-01-BH2233, rainfall from the Harrisville Mary Street weather station (Station 040094)

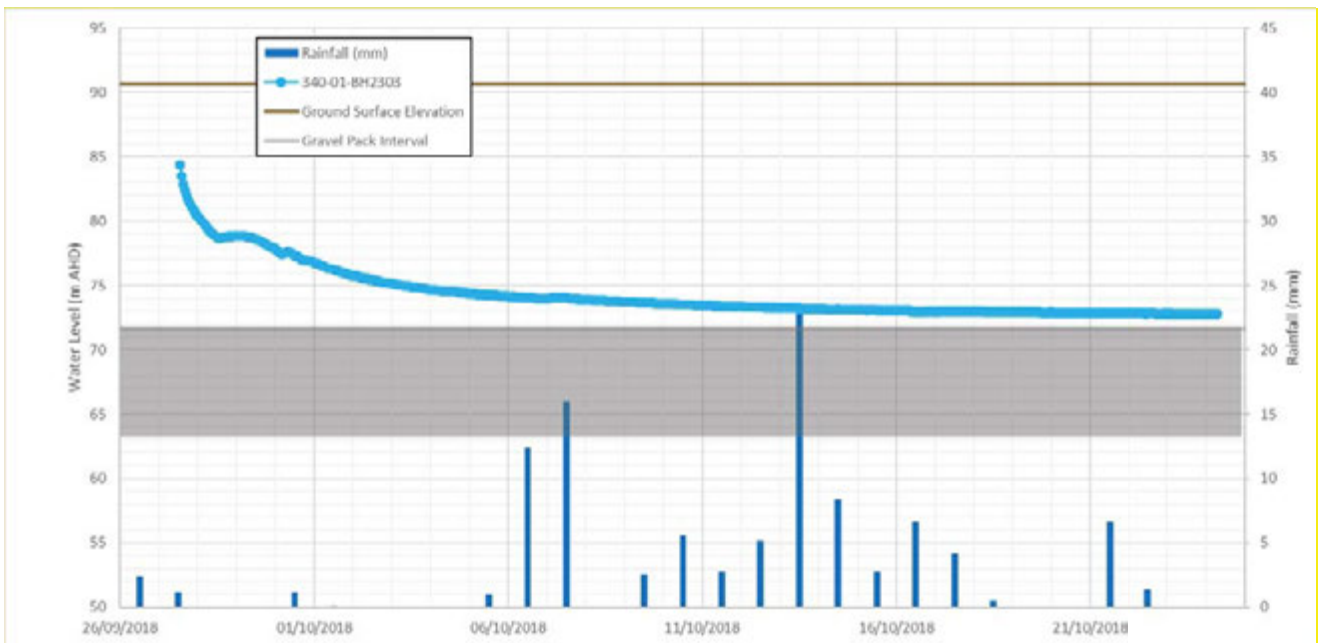


Figure A9: Hydrograph of 340-01-BH2303, rainfall from the Harrisville Mary Street weather station (Station 040094)

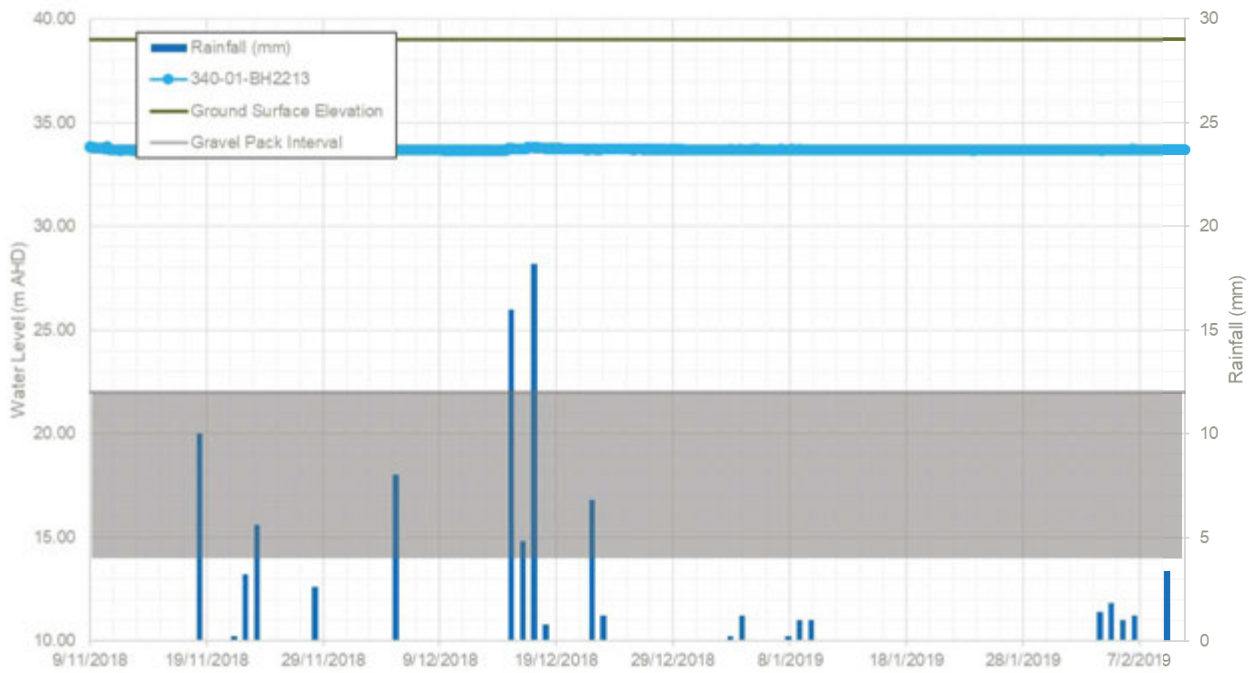


Figure A10: Hydrograph of 340-01-BH2213, rainfall from the Harrisville Mary Street weather station (Station 040094)

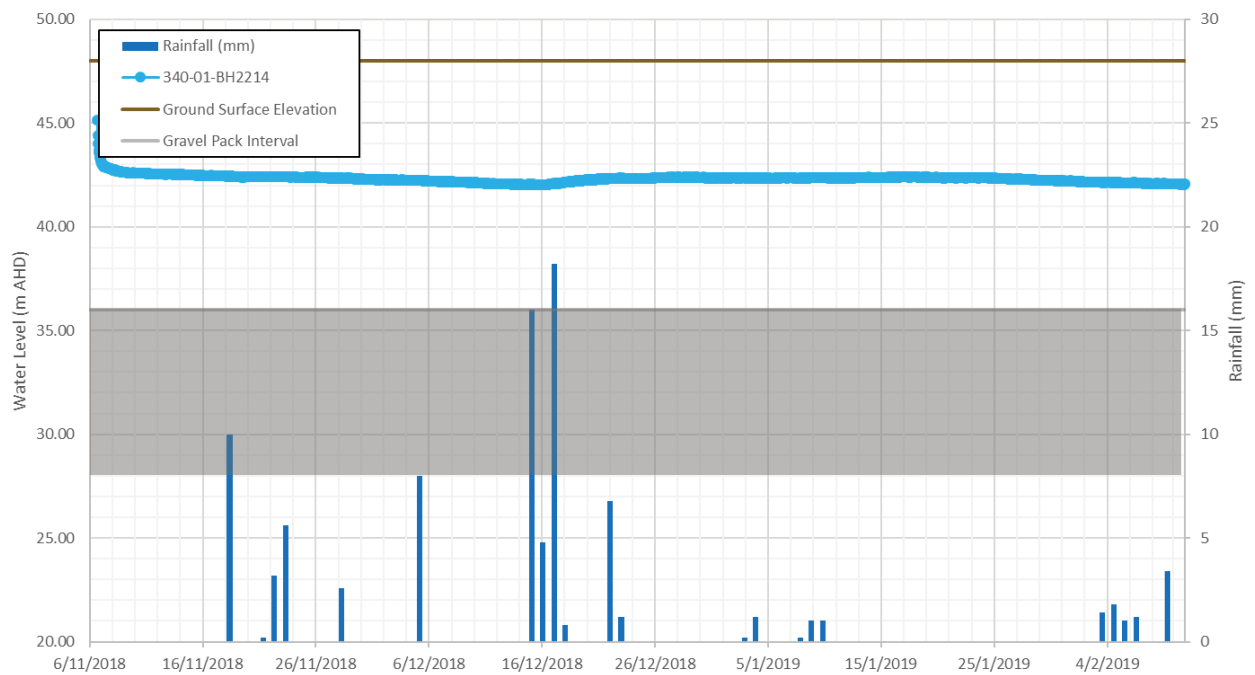


Figure A11: Hydrograph of 340-01-BH2214, rainfall from the Harrisville Mary Street weather station (Station 040094)

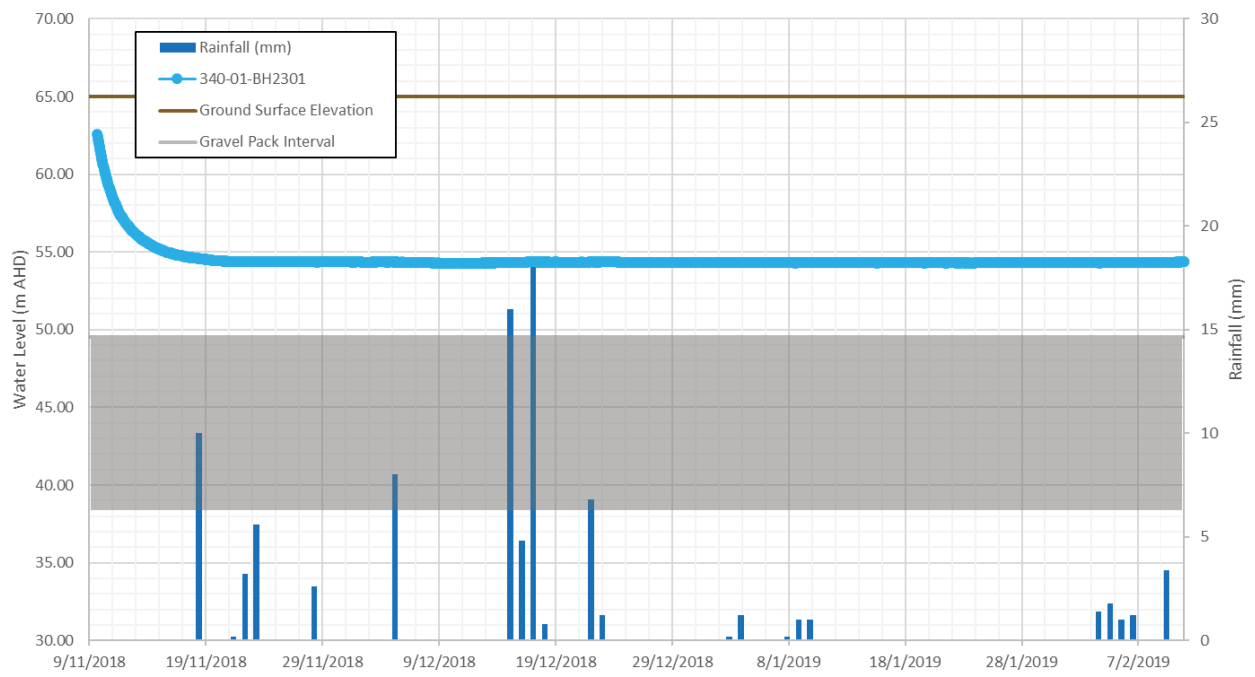


Figure A12: Hydrograph of 340-01-BH2301, rainfall from the Harrisville Mary Street weather station (Station 040094)

APPENDIX B

Groundwater Chemistry

APPENDIX C

**Groundwater Level with Relation to
Earth Works and Bridge Locations**

Appendix C Table 1: Groundwater Levels at Cuts

| Cut Name | Start (km) | End (km) | Length (km) | Median CL | Median GW | Maximum | Total Seepage | | Assumed Geology from Desktop Review and Nearby FFJV Groundwater Bores |
|----------|------------|----------|-------------|-------------------------|---------------------|------------------------|----------------------------------|------------------------------------|---|
| | | | | Elevation at Cut (mAHD) | Level at Cut (mAHD) | GW Level at Cut (mAHD) | Total Seepage after 1 year (L/s) | Total Seepage after 50 Years (L/s) | |
| 340-C1 | 3800 | 4410 | 610 | 55.9 | 52.8 | 56.3 | Less than 0.1 | Less than 0.1 | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C2 | 9140 | 11030 | 1890 | 68.7 | 69.7 | 83.2 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C3 | 12140 | 12830 | 690 | 59.0 | 54.1 | 58.1 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C4 | 15080 | 16850 | 1770 | 43.6 | 48.0 | 58.5 | 0.2 | Less than 0.1 | Tertiary Basalt and Claystone / Siltstone / Sandstone / Dolomite. Alluvium (~CH16570-18180); becoming Tertiary Amberley Basin over Walloon Coal Measures. Nearby groundwater bore 340-01-BH2301 |
| 340-C5 | 18630 | 19320 | 690 | 35.7 | 28.5 | 29.0 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C6 | 19620 | 20240 | 620 | 37.6 | 30.0 | 31.8 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C7 | 20860 | 21230 | 370 | 41.7 | 33.5 | 34.1 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C8 | 21870 | 22830 | 960 | 45.9 | 42.1 | 48.8 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C9 | 26110 | 26950 | 840 | 60.3 | 60.2 | 63.7 | - | - | Tertiary Intrusions: Dolerite / Basalt (~Kilometrage 26.000-26.400); Walloon Coal Measures. Nearby groundwater bore 340-01-BH2220 |
| 340-C10 | 28930 | 29160 | 230 | 66.0 | 61.4 | 62.6 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C11 | 29410 | 29710 | 300 | 65.5 | 64.1 | 67.8 | - | - | Koukandowie Formation; Walloon Coal Measures. No nearby groundwater bores. |
| 340-C12 | 29980 | 31120 | 1140 | 64.6 | 63.0 | 88.8 | 0.8 | 0.1 | Koukandowie Formation; Alluvium. No nearby groundwater bores. |
| 340-C13 | 31340 | 32010 | 670 | 64.3 | 60.5 | 64.5 | Less than 0.1 | Less than 0.1 | Koukandowie Formation; Alluvium. No nearby groundwater bores. |
| 340-C14 | 32360 | 33150 | 790 | 65.0 | 65.4 | 73.3 | 0.2 | Less than 0.1 | Alluvium. No nearby groundwater bores. |
| 340-C15 | 33460 | 33650 | 190 | 67.0 | 67.4 | 71.2 | Less than 0.1 | Less than 0.1 | Koukandowie Formation. No nearby groundwater bores. |
| 340-C16 | 34470 | 35140 | 670 | 72.2 | 76.0 | 93.1 | 0.2 | Less than 0.1 | Koukandowie Formation; Alluvium. Nearby groundwater bores 340-01-BH2303 and 340-01-BH2224. |
| 340-C17 | 37320 | 37480 | 160 | 83.4 | 80.4 | 81.8 | - | - | Alluvium; Gatton Sandstone. No nearby groundwater bores. |
| 340-C18a | 39150 | 39855 | 705 | 110.3 | 116.0 | 123.8 | * | * | Gatton Sandstone. Nearby groundwater monitoring bores 340-01-BH2101 and 340-BH-07. |
| 340-C18b | 40870 | 41350 | 480 | 117.7 | 124.7 | 128.0 | * | * | Gatton Sandstone. No nearby groundwater bores. |
| 340-C19 | 42350 | 42470 | 120 | 102.8 | 102.6 | 105.2 | - | - | Gatton Sandstone. No nearby groundwater bores. |
| 340-C20 | 43850 | 44070 | 220 | 85.0 | 93.6 | 104.3 | - | - | Gatton Sandstone. No nearby groundwater bores. |
| 340-C21 | 44570 | 45450 | 880 | 72.9 | 80.0 | 106.3 | 0.2 | Less than 0.1 | Gatton Sandstone. Nearby groundwater bore 340-01-BH2229 |
| 340-C22 | 46670 | 46900 | 230 | 62.5 | 63.2 | 67.9 | Less than 0.1 | Less than 0.1 | Gatton Sandstone. Nearby groundwater bore 340-01-BH2230 |
| 340-C23 | 47110 | 47510 | 400 | 59.9 | 60.4 | 71.8 | Less than 0.1 | Less than 0.1 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C24 | 47780 | 48270 | 490 | 56.4 | 61.2 | 68.9 | 0.1 | Less than 0.1 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C25 | 48450 | 48850 | 400 | 54.5 | 56.0 | 57.2 | Less than 0.1 | Less than 0.1 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C26 | 49030 | 49260 | 230 | 53.0 | 54.0 | 56.6 | Less than 0.1 | Less than 0.1 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C27 | 51510 | 51720 | 210 | 45.6 | 44.4 | 49.5 | Less than 0.1 | Less than 0.1 | Gatton Sandstone. No nearby groundwater bores. |
| 340-C28 | 51870 | 52220 | 350 | 44.3 | 41.3 | 43.0 | - | - | Heifer Creek Sandstone (~CH51790-52000); Walloon Coal Measures (~CH52000-52140). No nearby groundwater bores |
| 340-C29 | 53620 | 53830 | 210 | 48.3 | 42.0 | 43.0 | - | - | Walloon Coal Measures. No nearby groundwater bores. |
| 340-C30 | 54270 | 54620 | 350 | 49.8 | 43.3 | 45.6 | - | - | Walloon Coal Measures. No nearby groundwater bores. |

Note: *Seepage rates for tunnel portal cuts are provided in report Section 7.0

Appendix C Table 2: Groundwater Levels at Emba

| Type | Structure Name | Start Chainage | End Chainage | Length of Structure | Minimum Surface Elevation (mAHD) | Median Surface Elevation (mAHD) | Max Estimated WL (mAHD) | Median Estimated WL (mAHD) | Max Estimated WL (mbgl) | Median Estimated WL (mbgl) | Estimated GW Mounding at Embankments (m bgl) | Geological Formation at Structure |
|------------|----------------|----------------|--------------|---------------------|----------------------------------|---------------------------------|-------------------------|----------------------------|-------------------------|----------------------------|---|-----------------------------------|
| Embankment | 340-E1 | 2200 | 3800 | 1600 | 51.0 | 52.3 | 42.3 | 43.6 | 8.7 | 8.6 | 7.1 Alluvium | |
| Embankment | 340-E2 | 4410 | 9140 | 4730 | 42.1 | 47.5 | 32.8 | 38.5 | 9.3 | 9.0 | 7.5 Alluvium; Walloon Coal Measures | |
| Embankment | 340-E3 | 11030 | 12140 | 1110 | 52.8 | 58.7 | 44.2 | 50.5 | 8.6 | 8.2 | 3.2 Walloon Coal Measures | |
| Embankment | 340-E4 | 12830 | 15080 | 2250 | 37.4 | 43.2 | 27.8 | 33.9 | 9.7 | 9.3 | Walloon Coal Measures; slope wash / scree (~CH13100-4.3 13400); Alluvium (~CH13400-15040) | |
| Embankment | 340-E5 | 16850 | 18630 | 1780 | 32.0 | 33.2 | 22.0 | 23.3 | 10.0 | 9.9 | Alluvium (~CH16570-18180); Tertiary Amberley Basin | |
| Embankment | 340-E6 | 19320 | 19620 | 300 | 34.2 | 34.4 | 24.3 | 24.5 | 9.9 | 9.9 | 4.9 over Walloon Coal Measures | |
| Embankment | 340-E7 | 20240 | 20860 | 620 | 37.9 | 38.3 | 28.3 | 28.7 | 9.6 | 9.6 | 4.9 Walloon Coal Measures | |
| Embankment | 340-E8 | 21230 | 21870 | 640 | 40.2 | 41.1 | 30.7 | 31.7 | 9.5 | 9.4 | 4.6 Walloon Coal Measures | |
| Embankment | 340-E9 | 22830 | 26110 | 3280 | 38.8 | 42.8 | 29.2 | 33.5 | 9.6 | 9.3 | 4.4 Tertiary Amberley Basin | |
| Embankment | 340-E10 | 26950 | 28930 | 1980 | 58.4 | 61.2 | 50.2 | 53.1 | 8.2 | 8.0 | Alluvium and/or slope wash over WCM and Tertiary | |
| Embankment | 340-E11 | 29160 | 29410 | 250 | 63.5 | 64.6 | 55.7 | 56.8 | 7.9 | 7.8 | 4.3 Intrusions: Dolerite / Basalt (~CH25900-26050) | |
| Embankment | 340-E12 | 29710 | 29980 | 270 | 61.5 | 64.4 | 53.5 | 56.6 | 8.0 | 7.8 | Walloon Coal Measures; slope wash / scree (~CH28000-3.0 28400); Alluvium (~CH28400-28930) | |
| Embankment | 340-E13 | 31120 | 31340 | 220 | 61.5 | 63.6 | 53.5 | 55.7 | 8.0 | 7.9 | 2.8 Walloon Coal Measures | |
| Embankment | 340-E14 | 32010 | 32360 | 350 | 59.1 | 60.6 | 50.9 | 52.5 | 8.2 | 8.1 | Koukandowie Formation; Walloon Coal Measures; | |
| Embankment | 340-E15 | 33150 | 33460 | 310 | 61.1 | 61.8 | 53.1 | 53.8 | 8.0 | 8.0 | 2.8 Alluvium | |
| Embankment | 340-E16 | 33650 | 34470 | 820 | 60.0 | 62.1 | 51.9 | 54.2 | 8.1 | 8.0 | 2.9 Koukandowie Formation; Alluvium | |
| Embankment | 340-E17 | 35140 | 37320 | 2180 | 65.5 | 71.0 | 57.8 | 63.7 | 7.7 | 7.4 | 3.1 Alluvium (~CH31640-31700); Walloon Coal Measures | |
| Embankment | 340-E18 | 37480 | 39150 | 1670 | 79.0 | 89.7 | 72.2 | 83.6 | 6.8 | 6.1 | Koukandowie Formation; | |
| Embankment | 340-E19 | 41350 | 42350 | 1000 | 86.1 | 98.3 | 79.8 | 92.8 | 6.3 | 5.5 | 3.0 Alluvium towards the west. | |
| Embankment | 340-E20 | 42470 | 43850 | 1380 | 66.0 | 76.6 | 58.3 | 69.6 | 7.7 | 7.0 | 3.0 Koukandowie Formation; Alluvium | |
| Embankment | 340-E21 | 44070 | 44570 | 500 | 60.2 | 70.1 | 52.1 | 62.6 | 8.1 | 7.4 | 2.4 Koukandowie Formation; Alluvium | |
| Embankment | 340-E22 | 45450 | 46670 | 1220 | 48.1 | 61.4 | 39.1 | 53.3 | 8.9 | 8.0 | 1.1 Alluvium; Gatton Sandstone | |
| Embankment | 340-E23 | 46900 | 47110 | 210 | 50.9 | 56.1 | 42.2 | 47.7 | 8.7 | 8.4 | 0.5 Gatton Sandstone | |
| Embankment | 340-E24 | 47510 | 47780 | 270 | 45.1 | 52.9 | 35.9 | 44.3 | 9.1 | 8.6 | 2.0 Gatton Sandstone, Alluvium | |
| Embankment | 340-E25 | 48270 | 48450 | 180 | 45.5 | 49.0 | 36.4 | 40.1 | 9.1 | 8.9 | 2.4 Gatton Sandstone | |
| Embankment | 340-E26 | 48850 | 49030 | 180 | 43.9 | 47.3 | 34.6 | 38.3 | 9.2 | 9.0 | 3.0 Alluvium / Gatton Sandstone | |
| Embankment | 340-E27 | 49260 | 51510 | 2250 | 26.2 | 42.7 | 15.8 | 33.4 | 10.4 | 9.3 | 3.4 Alluvium, Gatton Sandstone | |
| Embankment | 340-E28 | 51720 | 51870 | 150 | 40.7 | 42.5 | 31.3 | 33.2 | 9.4 | 9.3 | 3.6 Gatton Sandstone | |
| Embankment | 340-E29 | 52220 | 53620 | 1400 | 28.0 | 38.1 | 17.7 | 28.4 | 10.3 | 9.6 | 3.9 Gatton Sandstone | |
| Embankment | 340-E30 | 53830 | 54270 | 440 | 38.3 | 41.8 | 28.7 | 32.5 | 9.6 | 9.4 | 4.0 Gatton Sandstone | |

Note: Groundwater mounding based on inferred effective porosity of underlying material

Appendix C Table 3: Groundwater Levels at Bridges

| Type | Structure Name | Start Chainage | End Chainage | Length of Structure | Surface | Surface | Estimated WL (mAHD) - Max | Estimated WL (mAHD) - avg | Estimated | Estimated | Estimated Formation | Estimated Depth of Formation |
|--------|----------------|----------------|--------------|---------------------|--------------------------|--------------------------|---------------------------|---------------------------|---------------------------------|---------------------------------|----------------------------------|---|
| | | | | | Elevation Minimum (mAHD) | Elevation Average (mAHD) | | | Depth to Water Table (mbgl) Max | Depth to Water Table (mbgl) Avg | | |
| Bridge | 340-BR02 | 458 | 1240 | | 782 | 48.6 | 50.5 | 39.7 | 41.7 | 8.9 | 8.8 Alluvium | ~20 m based on borelog for RN120194 |
| Bridge | 340-BR01 | 2472 | 3438 | | 966 | 48.7 | 51.2 | 39.8 | 42.5 | 8.9 | 8.7 Alluvium | ~20 m based on borelog for RN120195 |
| Bridge | 340-BR04 | 5887 | 6554 | | 667 | 43.4 | 44.1 | 34.1 | 34.8 | 9.3 | 9.2 Alluvium Over WCM, Sandstone | 12-17 m bgl |
| Bridge | 340-BR05 | 9750 | | | | 45.7 | 42.5 | 36.6 | 33.2 | 9.1 | 9.3 WCM | 45 m based on borelog for RN73798 |
| Bridge | 340-BR07 | 14340 | 14547 | | 207 | 79.2 | 79.5 | 72.4 | 72.8 | 6.8 | 6.8 Alluvium Over WCM | Depth unknown |
| Bridge | 340-BR08 | 16450 | | | | 40.2 | 40.7 | 30.8 | 31.3 | 9.5 | 9.4 Basalt | NA |
| Bridge | 340-BR09 | 17300 | 18013 | | 713 | 39.6 | 39.7 | 30.1 | 30.2 | 9.5 | 9.5 Alluvium over Basalt | 14-18 m bgl |
| Bridge | 340-BR10 | 23281 | 25098 | | 1817 | 39.1 | 39.1 | 29.5 | 29.5 | 9.6 | 9.5 Alluvium over WCM | NA |
| Bridge | 340-BR14 | 24750 | 25075 | | 325 | 40.2 | 41.0 | 30.7 | 31.6 | 9.5 | 9.4 Alluvium over Sandstone | 18.50 based on borelog (prelim) for 340-01-BH2 |
| Bridge | 340-BR11 | 25630 | 25709 | | 79 | 48.6 | 48.8 | 39.7 | 39.9 | 8.9 | 8.9 Alluvium over Sandstone | 18.50 based on borelog (prelim) for 340-01-BH2 |
| Bridge | 340-BR12 | 27904 | 27973 | | 69 | 29.1 | 30.8 | 18.9 | 20.7 | 10.2 | 10.1 Alluvium over WCM | 16 m bgl based on borelog for RN14310224 |
| Bridge | 340-BR13 | 28630 | 28837 | | 207 | 38.9 | 40.2 | 29.4 | 30.8 | 9.6 | 9.5 Alluvium | Depth unknown |
| Bridge | 340-BR14 | 35655 | 35770 | | 115 | 40.2 | 41.0 | 30.7 | 31.6 | 9.5 | 9.4 Alluvium over Koukandowie | 17 m bgl based on borelog (prelim) for 340-01-E |
| Bridge | 340-BR15 | 36560 | 36698 | | 138 | 46.7 | 47.5 | 37.7 | 38.6 | 9.0 | 9.0 Alluvium over Koukandowie | 18 m bgl based on borelog (prelim) for 340-01-E |
| Bridge | 340-BR16 | 36915.5 | 36984.5 | | 69 | 59.9 | 59.9 | 51.8 | 51.8 | 8.1 | 8.1 Alluvium over Koukandowie | 19 m bgl based on borelog (prelim) for 340-01-E |
| Bridge | 340-BR17 | 37497 | 37595 | | 98 | 53.7 | 58.8 | 45.2 | 50.6 | 8.5 | 8.2 Koukandowie Formation | Based on borelog (prelim) for 340-01-BH2226 |
| Bridge | New Bridge 1 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Bridge | 340-BR18 | 37800 | 37961 | | 161 | 70.2 | 70.3 | 62.8 | 62.9 | 7.4 | 7.4 Koukandowie Formation | Based on borelog (prelim) for 340-01-BH2226 |
| Bridge | New Bridge 2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| Bridge | 340-BR19 | 42716 | 42854 | | 138 | 70.4 | 72.1 | 63.0 | 64.8 | 7.4 | 7.3 Gatton Sandstone | NA |
| Bridge | 340-BR20 | 43012 | 43173 | | 161 | 72.6 | 73.2 | 65.3 | 66.0 | 7.3 | 7.2 Gatton Sandstone | NA |
| Bridge | 340-BR21 | 43306 | 43536 | | 230 | 81.0 | 81.5 | 74.3 | 74.9 | 6.7 | 6.6 Gatton Sandstone | NA |
| Bridge | 340-BR22 | 46160 | 46275 | | 115 | 81.9 | 83.3 | 75.3 | 76.8 | 6.6 | 6.5 10 m alluvium over Sandstone | Based on borelog for 340-01-BH2229 |
| Bridge | 340-BR23 | 46933 | 47094 | | 161 | 79.1 | 82.6 | 72.3 | 76.1 | 6.8 | 6.6 11 m alluvium over Sandstone | NA |
| Bridge | 340-BR24 | 50232 | 50301 | | 69 | 75.8 | 78.7 | 68.8 | 71.9 | 7.0 | 6.8 Gatton Sandstone | NA |
| Bridge | 340-BR25 | 50524 | 50731 | | 207 | 57.5 | 58.9 | 49.2 | 50.7 | 8.3 | 8.2 Gatton Sandstone/Koukandowie | NA |
| Bridge | 340-BR26 | 51264 | 51494 | | 230 | 52.5 | 53.2 | 43.9 | 44.7 | 8.6 | 8.6 Koukandowie (Marburg) | Based on borelog for RN152849 |
| Bridge | 340-BR27 | 52447 | 52916 | | 469 | 37.2 | 37.4 | 27.5 | 27.7 | 9.7 | 9.7 Alluvium over WCM | 20 m bgl based on borelog (prelim) for 340-01-E |
| Bridge | 340-BR28 | 52970 | 53200 | | 230 | 32.0 | 33.8 | 22.0 | 23.8 | 10.0 | 9.9 Alluvium over WCM | 21 m bgl based on borelog (prelim) for 340-01-E |
| Bridge | 340-BR29 | 773 | | | 773 | 31.7 | 32.5 | 21.7 | 22.5 | 10.1 | 10.0 Alluvium over WCM | 22 m bgl based on borelog (prelim) for 340-01-E |

Note: Formations estimated based on local Registered Bore lithology, SI data and surface geology (DNRM, 2018)

APPENDIX D

**Inferred Groundwater Chemistry
at Proposed Bridge Locations**



| Structure Name | SO4 | TDS | ALK | Cl | CO3 | HCO3 | Ca | Mg | Mg/Cl | pH | EC | T | LSI | RSI | Formation | Formation Depth |
|----------------|-------|---------|--------|---------|------|--------|-------|-------|-------|------|----------|-------|------|-------|------------------------------|--|
| 340-BR02 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium | ~20 m based on borelog for RN120194 |
| 340-BR01 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium | ~20 m based on borelog for RN120195 |
| 340-BR04 | 42.00 | 4588.89 | 613.50 | 2488.30 | 6.70 | 625.00 | 69.00 | 63.25 | 0.05 | 8.05 | 8230.00 | 19.95 | 6.20 | 0.92 | Alluvium Over WCM, Sandstone | 12-17 m bgl |
| 340-BR05 | 42.00 | 4588.89 | 613.50 | 2488.30 | 6.70 | 625.00 | 69.00 | 63.25 | 0.05 | 8.05 | 8230.00 | 19.95 | 6.20 | 0.92 | WCM | 45 m based on borelog for RN73798 |
| 340-BR07 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium Over WCM | Depth unknown |
| 340-BR08 | 42.00 | 4588.89 | 613.50 | 2488.30 | 6.70 | 625.00 | 69.00 | 63.25 | 0.05 | 8.05 | 8230.00 | 19.95 | 6.20 | 0.92 | WCM? | |
| 340-BR09 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium over Basalt | 14-18 m bgl |
| 340-BR10 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium over WCM | |
| 340-BR14 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.89 | 27380.00 | 24.90 | 7.12 | -0.11 | Alluvium over Sandstone | 18.50 based on borelog (prelim) for 340-01-BH2220 |
| 340-BR11 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium over Sandstone | 18.50 based on borelog (prelim) for 340-01-BH2221 |
| 340-BR12 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium over WCM | 16 m bgl based on borelog for RN14310224 |
| 340-BR13 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 7.60 | 2300.00 | 19.95 | 6.60 | 0.50 | Alluvium | Depth unknown |
| 340-BR14 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.91 | 5408.00 | 22.40 | 7.19 | -0.14 | Alluvium over Koukandowie | 17 m bgl based on borelog (prelim) for 340-01-BH2224 |
| 340-BR15 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.91 | 5408.00 | 22.40 | 7.19 | -0.14 | Alluvium over Koukandowie | 18 m bgl based on borelog (prelim) for 340-01-BH2224 |
| 340-BR16 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.91 | 5408.00 | 22.40 | 7.19 | -0.14 | Alluvium over Koukandowie | 19 m bgl based on borelog (prelim) for 340-01-BH2224 |
| 340-BR17 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Koukandowie Formation | Based on borelog (prelim) for 340-01-BH2226 |
| New Bridge 1 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 340-BR18 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Koukandowie Formation | Based on borelog (prelim) for 340-01-BH2226 |
| New Bridge 2 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| 340-BR19 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Gatton Sandstone | |
| 340-BR20 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Gatton Sandstone | |
| 340-BR21 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Gatton Sandstone | |
| 340-BR22 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 7.02 | 7916.00 | 21.60 | 8.12 | -0.55 | 10 m alluvium over Sandstone | Based on borelog for 340-01-BH2229 |
| 340-BR23 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | 11 m alluvium over Sandstone | |
| 340-BR24 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Gatton Sandstone | |
| 340-BR25 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Gatton Sandstone/Koukandowie | |
| 340-BR26 | 25.00 | 2269.92 | 281.00 | 1185.00 | 2.55 | 297.50 | 47.15 | 11.00 | 0.01 | 8.15 | 4975.00 | 19.95 | 7.05 | 0.55 | Koukandowie (Marburg) | Based on borelog for RN152849 |
| 340-BR27 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.41 | 8412.00 | 21.30 | 7.74 | -0.66 | Alluvium over WCM | 20 m bgl based on borelog (prelim) for 340-01-BH2233 |
| 340-BR28 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.41 | 8412.00 | 21.30 | 7.74 | -0.66 | Alluvium over WCM | 21 m bgl based on borelog (prelim) for 340-01-BH2233 |
| 340-BR29 | 13.80 | 1270.60 | 449.00 | 488.00 | 2.80 | 520.20 | 88.35 | 74.80 | 0.15 | 6.41 | 8412.00 | 21.30 | 7.74 | -0.66 | Alluvium over WCM | 22 m bgl based on borelog (prelim) for 340-01-BH2233 |

*Based on samples from registered bores within 5 km of alignment ok
 25 samples in WCM
 10 samples in Marburg subgroup
 216 samples in Alluvium
 Gatton and Koukandowie combined for purposes of this calculation

APPENDIX E

Important Information Relating to this Report

The document ("Report") to which this page is attached and which this page forms a part of, has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder's Client and persons acting on the Client's behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification

APPENDIX

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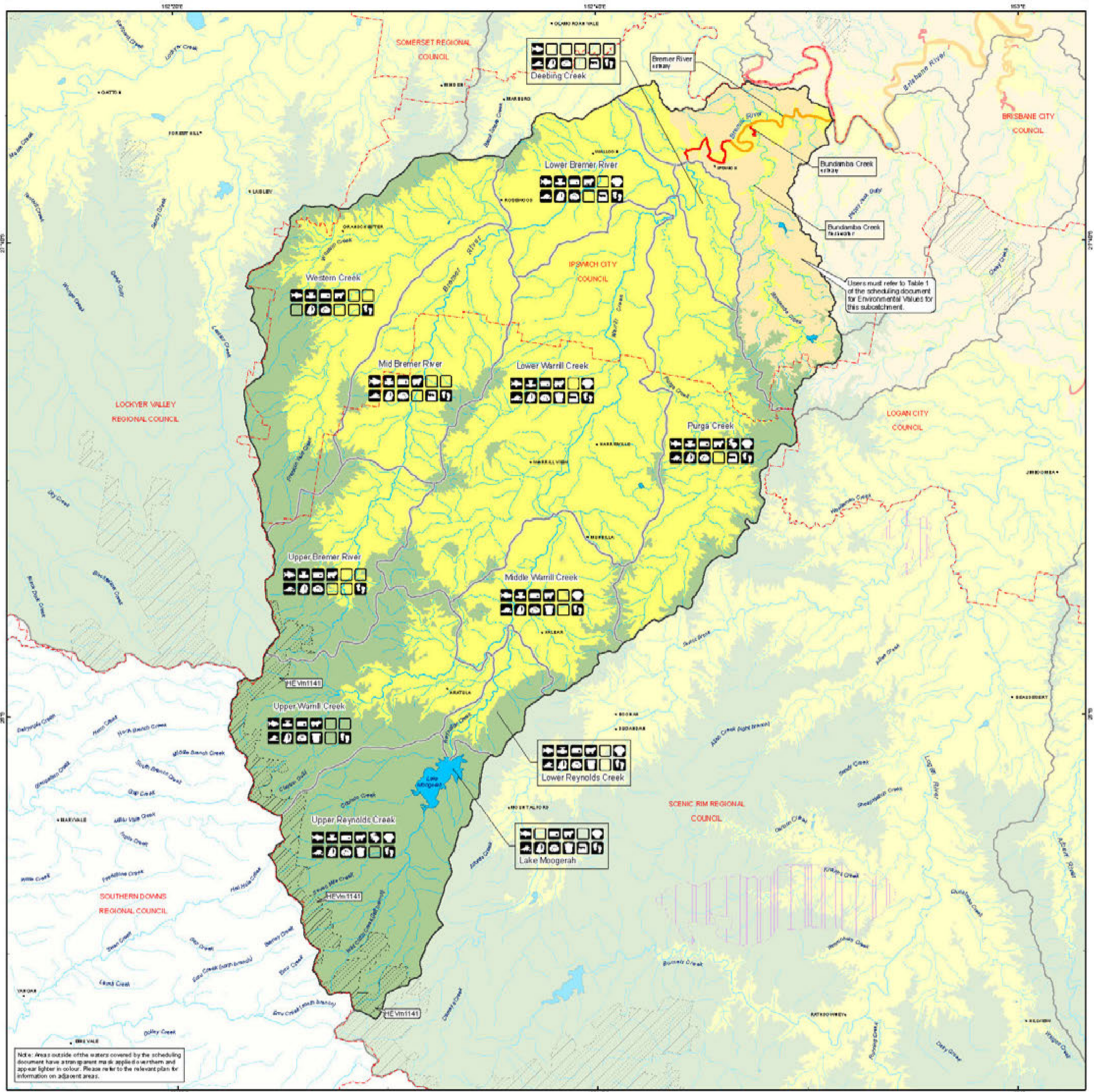
Groundwater Technical Report

Appendix B Relevant environmental value maps for the groundwater study area

CALVERT TO KAGARU ENVIRONMENTAL IMPACT STATEMENT

BREMER RIVER, INCLUDING ALL TRIBUTARIES OF THE RIVER

Part of Basin 143



Note: Areas outside of the waters covered by the scheduling document have a transparent mask applied to them and appear lighter in colour. Please refer to the relevant plan for information on adjacent areas.

Key to Environmental Values

| | |
|--|-----------------------------|
| | Aerial Photography |
| | Inundation |
| | Farm Safety |
| | Storm Water |
| | Aquaculture |
| | Nature Conservation |
| | Primary Production |
| | Secondary Production |
| | Visual Amenity |
| | Cultural Heritage |
| | Recreation |
| | Cultural & Spiritual Values |

Legend

| | |
|--|---------------------------------|
| | Well |
| | River/Creek |
| | State/Local Government Boundary |
| | Local Government Boundary |
| | Management Intent for Waters |
| | High Ecological Value (HES) |
| | High Cultural Value (HCV) |
| | Marine/Estuarine Waters |
| | Freshwaters |
| | Limited Freshwater |
| | Medium/Low Freshwater |
| | Coastal Freshwater |
| | Open Freshwater |
| | Urban Freshwater |

Note: Areas of the catchment that are not shown on this map are shown in a light grey colour. The map is intended to provide a general overview of the catchment and is not intended to be used for detailed planning or management purposes.

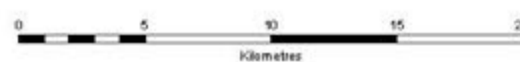
Environmental Protection (Water) Policy 2009 South-east Queensland Map Series PLAN WQ1436

Publication date: 21 July 2010

This plan forms part of the Bremer River Environmental Values and Water Quality Objectives scheduling document, prepared pursuant to the Environmental Protection (Water) Policy 2009.



Projection: Map Grid of Australia (MGA) Zone 56
Horizontal Datum: Geocentric Datum of Australia 1994 (GDA94)



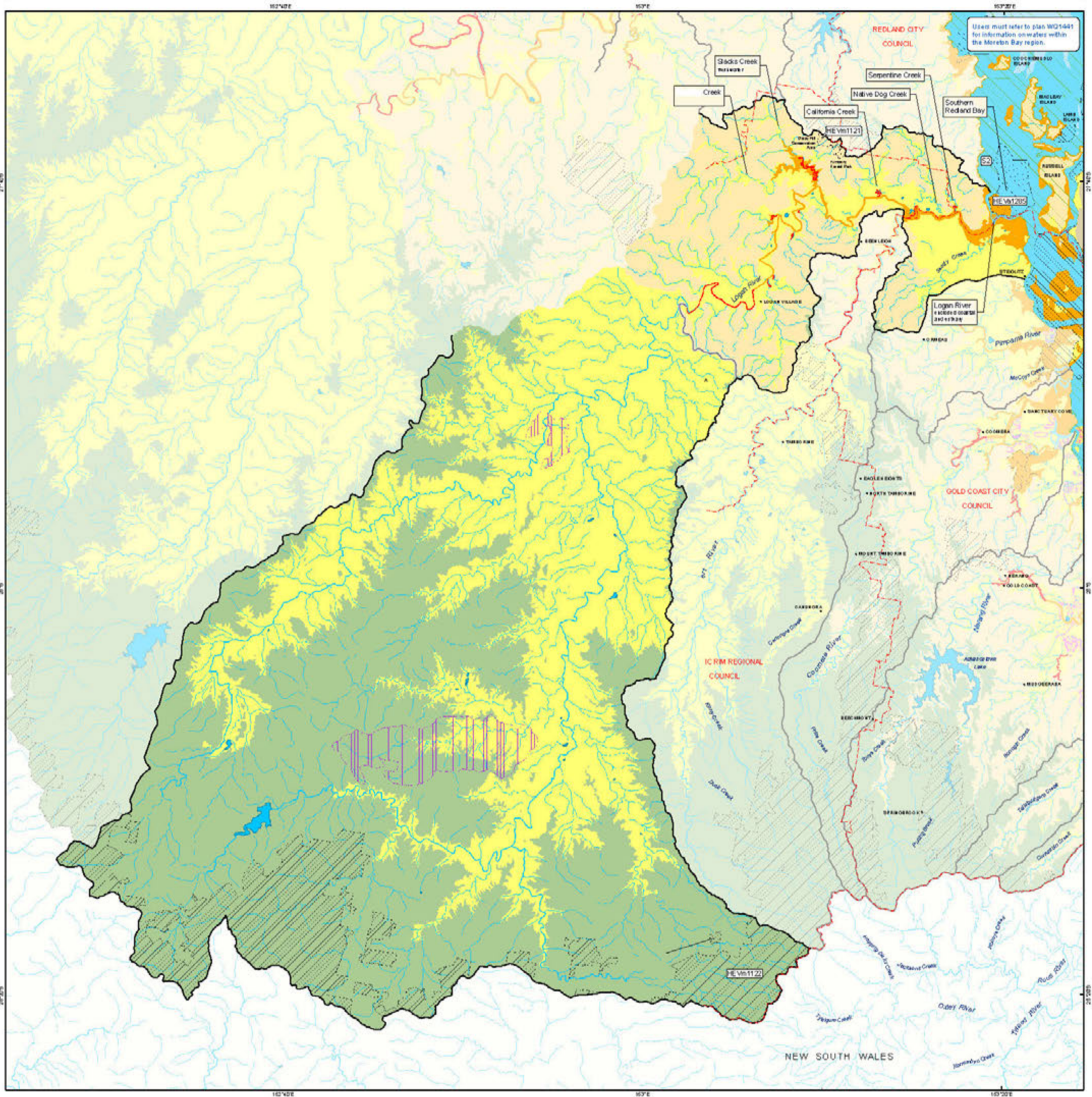
Scale of 1:100,000 (with projection)



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LOGAN RIVER, INCLUDING ALL TRIBUTARIES OF THE RIVER

Part of Basin 145



Key to Environmental Values

| | |
|--|---------------------------|
| | Aerial Environment |
| | Inhabitation |
| | Farm Land |
| | Shrub Water |
| | Aquaculture |
| | Marine Conservation |
| | Primary Production |
| | Secondary Production |
| | Visual Resources |
| | Cultural Values |
| | Recreation |
| | Quality & Cultural Values |

Management Intent for Waters

| | |
|--|--|
| | High ecological value water (freshwater) |
| | High ecological value water (estuarine/marine) |
| | Moderate Bay catchment |
| | High ecological value water (estuarine) |

Marine / estuarine waters

| | |
|--|---|
| | Open water |
| | Exposed mudflats / saltmarsh |
| | Shrub water |
| | Open water |
| | Turbidity / overbanked water / marine / saltmarsh |

Freshwaters

| | |
|--|-----------------------|
| | Lowland water |
| | Wetland / Shrub water |
| | Coastal water |
| | Upland water |
| | Lake / Reservoir |

Note: Areas of the catchment not shown on this map are being managed as high ecological value water.

Environmental Protection (Water) Policy 2009

South-east Queensland Map Series

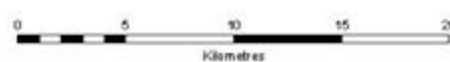
PLAN WQ1454

Revised 08/04/2010

This plan forms part of the Logan River Environmental Values and Water Quality Objectives scheduling document, prepared pursuant to the Environmental Protection (Water) Policy 2009.



Projection: Map Grid of Australia (MGA) Zone 56
Horizontal Datum: Geocentric Datum of Australia 1994 (GDA94)



Scale of 1:115,000 (MGA Zone 56)



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