APPENDIX

N

Hydrology and Flooding Technical Report

PART 1 OF 3

Main Report, Appendices A and B

CALVERT TO KAGARU ENVIRONMENTAL IMPACT STATEMENT

INLAND RAIL

ARTC

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

IR_1381

Inland Rail Calvert to Kagaru EIS

Appendix N – Hydrology and Flooding Technical Report

Australian Rail Track Corporation

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Contents

Appendices

Figures

Tables

Glossary

The following terms and acronyms are used within this document:

Term or Acronym	Description
AAToS	Annual Average Time of Submergence (hrs/year)
AEP	Annual Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR 2016	Australian Rainfall and Runoff Guidelines – 2016 edition
ARTC	Australian Rail Track Corporation
Backwater	Upstream movement of water from a downstream catchment in flood
BCC	Brisbane City Council
BoM	Bureau of Meteorology
BRCFS	Brisbane River Catchment Flood Study
CC	Climate change
CL	Continuing loss rate (mm/hr)
C2K	Calvert to Kagaru
DCDB	Digital Cadastral Data Base
DEA	Design Event Approach
DEM	Digital Elevation Model
Developed Case	Hydraulic modelling case with Project in place
Disturbance footprint	The Project disturbance footprint includes the rail corridor and other permanent works associated with the Project (e.g. where changes to the road network are required) as well as the construction footprint where only temporary disturbance is proposed (e.g. laydown areas and compound sites).
DNRME	Department of Natural Resources, Mines and Energy
Existing Case	Hydraulic modelling case pre-Project
FFA	Flood Frequency Analysis
FFJV	Future Freight Joint Venture
GIS	Geographic Information System
ICC	Ipswich City Council
IFD	Intensity-Frequency-Duration (rainfall)
IL	Initial loss (mm)
ILSAX	Hydrologic model
km	kilometres
LCC	Logan City Council
LiDAR	Light Detection and Ranging
MCS	Monte Carlo Simulation
m	metres
mm	millimetres
m AHD	metres above Australian Height Datum
PMF	Probable Maximum Flood
QLD	Queensland
QR	Queensland Rail

Term or Acronym	Description
RAATM	Requirements Analysis Allocation Traceability Matrix
RCBC	Reinforced concrete box culvert
RCP	Reinforced concrete pipe
RFFE	Regional Flood Frequency Estimation
SRRC	Scenic Rim Regional Council
The Project	The Calvert to Kagaru Project
TOI	Time of Inundation
ToR	Terms of Reference
ToS	Time of Submergence (hrs)
URBS	Rainfall runoff routing software
WWTP	Wastewater Treatment Plant

Executive summary

Inland Rail is a once-in-a-generation Program connecting regional Australia to domestic and international markets, transforming the way we move freight around the country. It will complete the ‘spine’ of the national freight network between Melbourne and Brisbane via regional Victoria, New South Wales and Queensland. This new 1,700 kilometres (km) line is the largest freight rail infrastructure project in Australia and is expected to commence operations in 2025.

The Inland Rail Calvert to Kagaru Project (the ‘Project’) provides a connection between the eastern end of the Helidon to Calvert (H2C) Project and the ARTC Sydney to Brisbane Interstate Line at Kagaru. At the eastern end the Project connects to the existing West Moreton Line which runs between Calvert and Rosewood towards Brisbane. At the south-western end, the Project diverges to provide a connection heading north towards Brisbane and a second connection heading south towards Bromelton.

There are four major waterway catchments that the Project alignment crosses, being the Bremer River, Warrill Creek, Purga Creek and Teviot Brook. Detailed hydrologic and hydraulic assessments have been undertaken due to the catchment size and substantial floodplain flows associated with each of these watercourses. Bremer River, Warrill Creek and Purga Creek all form part of the larger Brisbane River system. Teviot Brook is a tributary of the Logan River system.

The purpose of this investigation was to better understand and quantify the existing flooding characteristics of the each of the high-risk waterways in the vicinity of the Project alignment and to assess and mitigate any potential impacts on properties and infrastructure. The key objectives of the Report are to provide information on the data investigation, development and calibration of the hydrology and hydraulic models, document impacts and mitigation measures and to provide comment on the performance on the Project design.

Available background information including existing hydrologic and hydraulic models, survey, streamflow data, available calibration information and anecdotal flood data was collected and reviewed. This data was sourced from a wide range of stakeholders and was used to develop calibrated hydrologic and hydraulic models for each waterway. These models were calibrated against multiple historical events and validated through stakeholder and community feedback.

Design flood estimation techniques in accordance with Australian Rainfall and Runoff 2016 (ARR 2016) were applied to the hydrologic and hydraulic models to determine Existing Case flood conditions on each of the four floodplains. This modelling was undertaken for a range of design events from the 20% Annual Exceedance Probability (AEP) event up to the 1 in 10,000 AEP event and the Probable Maximum Flood (PMF).

A Developed Case was prepared using the Existing Case models and incorporating the Project design. The Developed Case models were run for the same range of design events with results compared to determine impacts on peak water levels, flows, flood flow distribution, velocities and duration of inundation on each floodplain and, in particular, upon identified flood sensitive receptors.

The refinement of the Project design was guided using hydraulic design criteria and flood impact objectives (refer Table 1) that were developed for the Project. The flood impact objectives were initially developed based on a review of objectives used for other large infrastructure projects in rural and urban areas as well as consideration of industry practice and use of engineering judgement.

Table 1 Flood impact objectives

Parameter	Objectives				
Change in peak water levels[1]	Existing habitable and/or commercial and industrial buildings/premises (e.g. dwellings, schools, hospitals, shops)	Residential or commercial/industrial properties/lots where flooding does not impact dwellings/buildings (e.g. yards, gardens)	Existing non-habitable structures (e.g. agricultural sheds, pump-houses)	Roadways	Agricultural and grazing land/forest areas and other non-agricultural land
	≤ 10 mm	≤ 50 mm	≤ 100 mm	≤ 100 mm	≤ 200 mm with localised areas up to 400 mm
	Changes in peak water levels are to be assessed against the above proposed limits. It is noted that changes in peak water levels can have varying impacts upon different infrastructure/land and flood impact objectives were developed to consider the flood sensitive receptors in the vicinity of the Project. It should be noted that in many locations the presence of existing buildings or infrastructure limits the change in peak water levels.				
Change in duration of inundation[1]	Identify changes to time of inundation through determination of time of submergence (ToS). For roads, determine Annual Average Time of Submergence (AATOS) (if applicable) and consider impacts on accessibility during flood events. Justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors.				
Flood flow distribution[1]	Aim to minimise changes in natural flow patterns and minimise changes to flood flow distribution across floodplain areas. Identify any changes and justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors.				
Velocities[1]	Maintain existing velocities where practical. Identify changes to velocities and impacts on external properties. Determine appropriate scour mitigation measures taking into account existing soil conditions. Justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors.				
Extreme event risk management	Consider risks posed to neighbouring properties for events larger than the 1% AEP event to ensure no unexpected or unacceptable impacts.				
Sensitivity testing	Consider risks posed by climate change and blockage in accordance with ARR 2016. Undertake assessment of impacts associated with Project alignment for both scenarios.				

Table note:

1 These flood impact objectives apply for events up to and including the 1% AEP event

Detailed hydrologic and hydraulic modelling was undertaken to meet the hydraulic design criteria and flood impact objectives, with a series of iterations undertaken to incorporate design refinement and stakeholder and community feedback.

The hydrologic and flooding assessment undertaken has demonstrated that the Project is predicted to result in impacts on the existing flooding regime that generally comply with the flood impact objectives and that the Project design meets the hydraulic design criteria.

A comprehensive consultation exercise has been undertaken to provide the community with detailed information and certainty around the flood modelling and the Project design. The consultation with stakeholders, including landholders, was undertaken at key stages including validation of the performance of the modelling in replicating experienced historical flood events and presentation of the design outcomes and impacts on properties and infrastructure. In future stages, ARTC will:

- Continue to work with landowners concerned with hydrology and flooding throughout the detailed design, construction and operational phases of the Project
- Continue to work with directly impacted landowners affected by the alignment throughout the detailed design, construction and operational phases of the Project
- Continue to work with local Councils and State government departments throughout the detailed design, construction and operational phases of the Project.

1 Introduction

1.1 Inland Rail Program

Inland Rail is a once-in-a-generation Program connecting regional Australia to domestic and international markets, transforming the way we move freight around the country. It will complete the 'spine' of the national freight network between Melbourne and Brisbane via regional Victoria, New South Wales and Queensland.

This new 1,700 kilometre (km) line is the largest freight rail infrastructure project in Australia and is expected to commence operations in 2025.

1.2 Calvert to Kagaru Project

The Inland Rail section between Calvert and Kagaru (the 'Project') provides a connection between the eastern end of the Helidon to Calvert (H2C) project, adjacent to the existing Queensland Rail (QR) West Moreton Line, and the ARTC Sydney to Brisbane Interstate Line (K2ARB) at Kagaru. At the western end there is a connection between the Project and the existing West Moreton Line that runs between Calvert and Rosewood towards Brisbane. At the south-eastern end, the Project diverges to provide a connection heading north towards Brisbane and a second connection heading south towards Bromelton (refer Figure 1.1).

Key features of the Project include:

- 53 km of new single track dual gauge railway (trains travelling in both directions share the same track)
- A 1,015 metre (m) long tunnel to be constructed through the Teviot Range
- Bridges to accommodate topographical variation, crossings of waterways and other infrastructure
- Reinforced concrete pipe culverts and reinforced concrete box culverts
- Rail crossings including level crossings, grade separations/rail or road overbridges, occupational/private crossings and fauna crossing structures.

ARTC are applying for approval to build infrastructure to accommodate trains up to 1,800 m in length, however, infrastructure will be designed such that the future extension of some crossing loops to accommodate 3,600 m trains is not precluded. Although ARTC intend to acquire the land for the future 3,600 m crossing loop extension with the initial land acquisition, 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 m train lengths has not been included in the flood modelling.

1.3 Objectives of this report

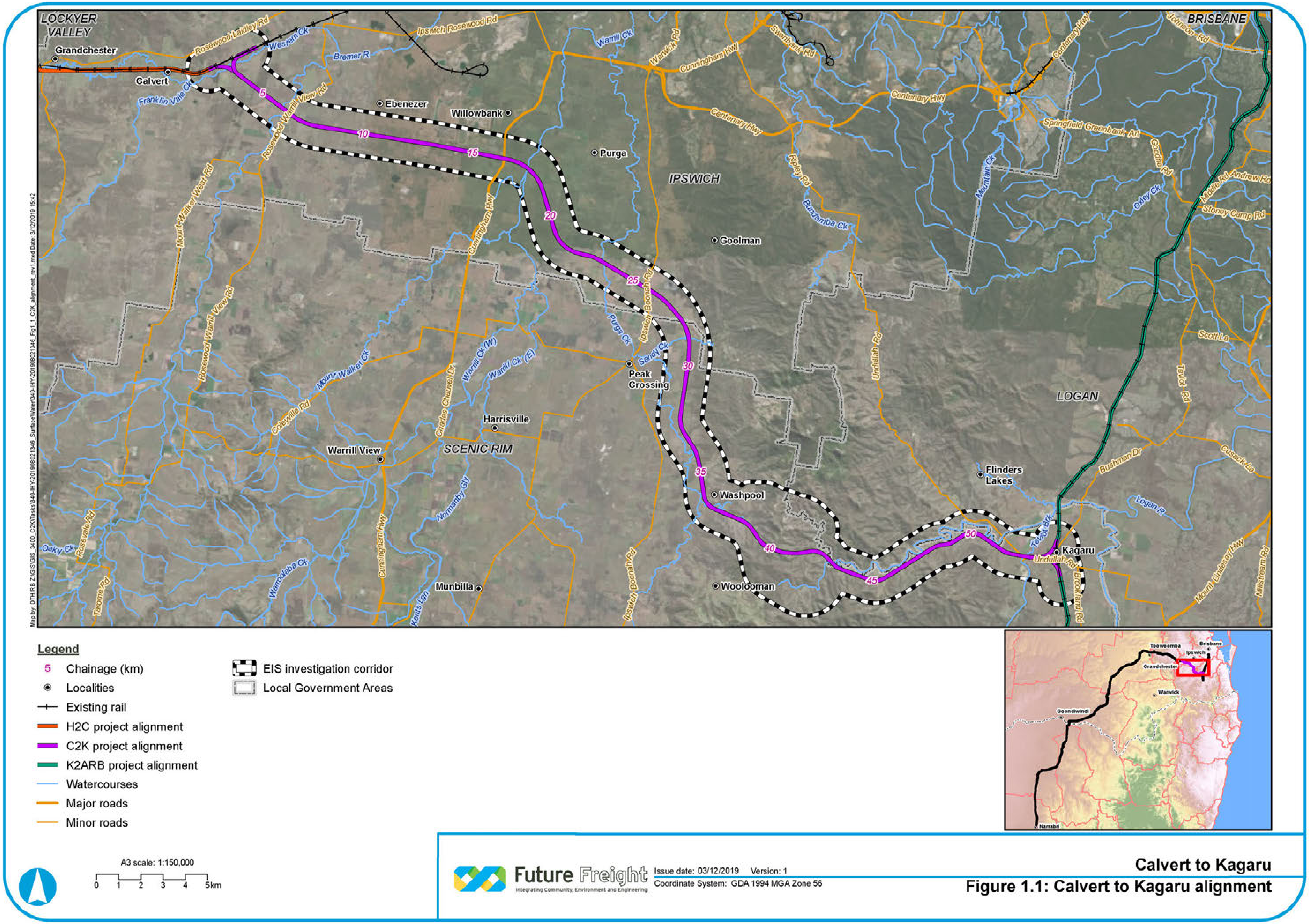
This investigation has been undertaken to firstly identify high-risk watercourse crossings or floodplain locations that may be impacted by the Project alignment. Secondly a detailed quantitative assessment has been undertaken to better understand and quantify the existing flooding characteristics of each of the high-risk waterways in the vicinity of the Project alignment and to assess and mitigate any potential impacts associated with the Project alignment on the existing flooding regime of each waterway.

The key purpose of this report is to provide details of investigation undertaken including data collection and review, development and calibration of hydrology and hydraulic models, design event modelling, impact assessment of the Project alignment, development of mitigation measures and to provide comment on the performance of the Project design. Consultation with stakeholders and the community has been progressively undertaken with feedback used to inform the development and calibration of the models and to refine the Project design.

Key objectives of the hydrology and flooding investigation were to:

- Consult with local authorities regarding existing flood studies relevant to the design and consider these previous flood studies in the design
- Consult with landholders, stakeholders and government agencies to obtain flood data to assist in model development and calibration, and to discuss impacts associated with the Project
- Undertake detailed hydrologic and hydraulic modelling for each major catchment to establish the Base Case (or Existing Case) flood conditions for the range of floods up to 1% Annual Exceedance Probability (AEP) as well as the 1 in 2,000 AEP, 1 in 10,000 AEP and Probable Maximum Flood (PMF) events
- Determine existing flood conditions including flood levels, flows and velocities
- Analyse the Project design including the alignment design, drainage infrastructure and associated infrastructure works
- Assess the impacts of the Project design on neighbouring properties, infrastructure and the surrounding environment
- Identify and assess potential mitigation measures. The requirement for mitigation was based on the magnitude of impacts and how this aligned with the flood impact objectives.

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



Future Freight
Integrating Community, Environment and Engineering

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Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure 1.1: Calvert to Kagaru alignment

2 Assessment methodology

The hydrology and flooding investigation involved the following activities:

- Collation and review of available background information including existing hydrologic and hydraulic models, survey, rainfall and streamflow data, calibration information and anecdotal flood related data. This review established which datasets were suitable to use for the Project design.
- Determination of critical flooding mechanisms for waterways and drainage paths in vicinity of the Project alignment, i.e. regional flooding versus local catchment flooding
- Determination of high-risk watercourses that the alignment crosses qualitatively considering:
  - The catchment size, resulting flood flows and velocities
  - The land use in the vicinity of the rail alignment
  - The extent and depth of flood inundation
  - The duration of flood events and catchment response time
  - The proximity to and nature of flood sensitive receptors (eg houses, sheds, roads etc)
- Development of tailored hydrologic and hydraulic models for key waterways
- Validation of the hydrologic and hydraulic models against recorded data for historical flood events
- Community and stakeholder engagement to validate model performance and gain acceptance of modelling and calibration outcomes. Anecdotal flood event information such as flood photography, recorded flood markers and personal observations from landholders were sourced to validate the calibration of the hydrologic and hydraulic models.
- Update of hydrologic models to include Australian Rainfall and Runoff 2016 (ARR 2016) design events. ARR 2016 was adopted for this Project as ARR 2019 was not released when this investigation commenced
- Simulation of ARR 2016 design events for the Existing Case and comparison to previous studies to confirm drainage paths, waterways, and associated floodplain areas, and establish the existing flood regime in the vicinity of the Project
- Inclusion of Project alignment and drainage structures (Developed Case) in the hydraulic models and simulation of ARR 2016 design events including the 20%, 10%, 5%, 2%, 1%, 1 in 2,000, 1 in 10,000 AEP and Probable Maximum Flood (PMF) events
- Assessment of impacts of Project alignment using the suite of design flood events including consideration of change in flood levels, flow distributions, velocities and inundation periods
- Determination of appropriate mitigation measures to manage potential impacts including refinement of location and dimensions of drainage structures under the Project alignment. Iterations were undertaken in the hydraulic models to achieve a design that addresses the flood impact objectives.
- Sensitivity analysis on the design for factors including climate change and blockage risk.

The hydrology and hydraulic impact assessment provided key inputs to the Project design where the alignment is located within the modelled flood extents. Key dependencies for the Project design include:

- Modelling of the Existing Case 1% AEP event to ascertain existing conditions and inform the flood immunity for the Project alignment and to size drainage structures
- Modelling of 1 in 2,000 AEP event to provide inputs for bridge design and wider resilience assessment
- Modelling of rare flood events (1 in 10,000 AEP and PMF events) to assist in consideration of overtopping risk
- Modelling the full range of flood events to quantify potential impacts and inform mitigation measures

- Input to drainage design including scour protection design – water levels, flows and velocities from this assessment have been used to inform the design of scour protection
- Input to structure selection and design for culverts and bridges.

3 Existing environment

The Project alignment traverses both the Bremer River and Logan River catchments. Details of each catchment and local waterways are outlined in the following sections.

3.1 Bremer River catchment

The Bremer River catchment is situated west of Brisbane within the local government boundaries of Ipswich City Council (ICC) and the Scenic Rim Regional Council (SRRC) and expands to an area of approximately 2,030 square kilometres (km^2) with the main Bremer River channel surrounded by smaller sub-catchments. The stream network length is approximately 4,425 km. Dominant land uses within the Bremer catchment include grazing, native bushland, intensive agricultural and urban. The lower catchment is mostly urbanised, where the rest of the catchment is rural with the majority of the catchment cleared for cattle grazing.

There are three major waterways that the Project alignment crosses being the Bremer River (including Western Creek), Warrill Creek and Purga Creek. Detailed hydrologic and hydraulic modelling has been undertaken due to the catchment size and substantial floodplain flows associated with each of these watercourses. Bremer River, Warrill Creek and Purga Creek all form part of the larger Brisbane River system. Details on each of these catchments are outlined in the following sections.

3.1.1 Bremer River and Western Creek

The Bremer River, a major tributary of the Brisbane River, joins the Brisbane River near the city of Ipswich approximately 80 km downstream of Wivenhoe Dam. There are three key tributaries of the Bremer River in the vicinity of the Project alignment being Western Creek, Warrill Creek and Purga Creek. The confluence between the Bremer River and Western Creek occurs immediately downstream of the Project alignment.

3.1.2 Warrill Creek

The Warrill Creek catchment is the largest of the three Bremer River tributaries and has a catchment area of 902 km^2 to the Amberley gauge. The major waterways in the catchment are Warrill Creek and Reynolds Creek. Other significant tributaries include Warrolaba Creek, Mount Walker Creek and Ebenezer Creek.

Moogerah Dam, completed in 1960, is a large reservoir on Reynolds Creek in the upper Warrill Creek catchment. It has a catchment area of 226 km^2 (25 per cent of the catchment area to Amberley). The dam has an uncontrolled spillway and provides some flood attenuation, particularly when reservoir levels are low, but no controlled flood regulation. Further downstream, several smaller weirs (Kalbar, Junction) provide offtakes for water harvesting but do not represent significant water storages.

3.1.3 Purga Creek

The Purga Creek catchment is the smallest of the three Bremer River tributaries with a catchment area of 209 km^2. Purga Creek is the main watercourse in the catchment and joins Warrill Creek approximately 3 km downstream of Amberley and 2.5 km upstream of the Warrill Creek and Bremer River confluence.

3.2 Logan River catchment

The Logan River catchment is situated to the south of Brisbane with its headwater in the McPherson and Main Ranges. The majority of the catchment features in the local government areas of the SRRC and Logan City Council (LCC) but also includes small sections of other local government areas. The catchment area expands over 3,076 km^2 with approximately 5,500 km of stream network. The dominant land uses within the Logan catchment include grazing, native bush, rural residential and intensive agriculture. The upper catchment has been cleared for agriculture, grazing and dairying while the mid and lower catchment flows through rural, residential and urban areas. The Project alignment intersects the sub-catchment of Lower Teviot Brook with details on the waterway provided below.

3.2.1 Teviot Brook

Teviot Brook is a tributary of the Logan River with the downstream confluence at Yarrahapinni. The upper reaches of the Teviot Brook catchment extend to Mount Roberts. The catchment is predominantly rural particularly in its upper reaches. Wyaralong Dam is a water supply dam located on the Teviot Brook. It is a mass concrete gravity dam with an un-gated spillway. The dam was constructed in 2011 and has a catchment area of approximately 546 km^2.

The Project alignment crossing location is backwater affected by flooding from the Logan River. The Logan River is a large river system which discharges into Moreton Bay with its upstream catchment boundary at the Queensland/New South Wales border between Mount Lindesay and Mount Ernest.

3.3 Floodplain infrastructure

Existing infrastructure on the floodplains that the Project alignment crosses includes:

- West Moreton Rail Line
- Waters Road
- Washpool Road
- Wild Pig Creek Road
- Undullah Road
- Levees and dams from farming practices.

The Project alignment connects into the West Moreton Rail Line which is operated by QR. The QR rail line runs parallel to Western Creek and has multiple cross drainage structures. During a 1% AEP event, the QR rail line is inundated by Western Creek. Running parallel to the QR rail line is Waters Road. This road is flood prone and is inundated by Western Creek during frequent flood events.

Washpool Road is within the Purga Creek catchment. This road is also flood prone and inundated frequently. As part of the Project, it is proposed to realign part of Washpool Road.

Wild Pig Creek Road and Undullah Road are within the Teviot Brook catchment. It is proposed that Wild Pig Creek Road will be realigned as part of the Project. In the vicinity of Teviot Brook, Undullah Road runs on the upstream side of the proposed alignment and is inundated by frequent flood events.

4 Design requirements, standards and guidelines

4.1 Hydraulic design criteria

Table 4.1 outlines the hydraulic design criteria that have guided the Project design. Detailed hydrologic and hydraulic modelling has been undertaken to meet these design criteria with a series of iterations undertaken to incorporate design refinement and stakeholder and community feedback. The resulting design outcomes relative to these design criteria are detailed in Section 9.

Table 4.1 Project hydraulic design criteria

Performance criteria	Requirement
Flood immunity	Rail line – 1% AEP flood immunity with 300 mm freeboard to formation level. Tunnel portals – 1 in 10,000 AEP event flood immunity.
Hydraulic analysis and design	Hydrologic and hydraulic analysis and design to be undertaken based on ARR 2016 and State/local government guidelines. ARR 2016 interim climate change guidelines are to be applied with an increase in rainfall intensity to be considered. No sea level change consideration required due to location outside tidal zone. ARR 2016 blockage assessment guidelines are to be applied.
Scour protection of structures	All bridges and culverts should be designed to reduce the risk of scour with events up to 1% AEP event considered. Mitigation to be achieved through providing appropriate scour protection or energy dissipation or by changing the drainage structure design.
Structural design	1 in 2,000 AEP event to be modelled for bridge design purposes.
Extreme events	Damage resulting from overtopping to be minimised.
Flood flow distribution	Locate structures to ensure efficient conveyance and spread of floodwaters.
Sensitivity testing	Consider climate change and blockage in accordance with ARR 2016. Understand risks posed and Project design sensitivity to climate change and blockage of structures.

4.2 Flood impact objectives

The impact of the Project upon the existing flood regime was quantified and compared against flood impact objectives as detailed in Table 4.2. These objectives have been used to guide the Project design. Acceptable impacts will ultimately be determined on a case by case basis with interaction with stakeholders/landholders through the community engagement process using these objectives as guidance. This will take into account flood sensitive receptors and land use within the floodplain. The resulting design outcomes relative to these flood impact objectives are detailed in Section 9.

Table 4.2 Flood impact objectives

Parameter	Objectives				
Change in peak water levels[1]	Existing habitable and/or commercial and industrial buildings/premises (e.g. dwellings, schools, hospitals, shops)	Residential or commercial/industrial properties/lots where flooding does not impact dwellings/buildings (e.g. yards, gardens)	Existing non-habitable structures (e.g. agricultural sheds, pump-houses)	Roadways	Agricultural and grazing land/forest areas and other non-agricultural land
	≤ 10 mm	≤ 50 mm	≤ 100 mm	≤ 100 mm	≤ 200 mm with localised areas up to 400 mm

Parameter	Objectives
	Changes in peak water levels are to be assessed against the above proposed limits. It is noted that changes in peak water levels can have varying impacts upon different infrastructure/land and flood impact objectives were developed to consider the flood sensitive receptors in the vicinity of the Project. It should be noted that in many locations the presence of existing buildings or infrastructure limits the change in peak water levels.
Change in duration of inundation[1]	Identify changes to time of inundation through determination of time of submergence (ToS). For roads, determine Annual Average Time of Submergence (AATOS) (if applicable) and consider impacts on accessibility during flood events. Justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors.
Flood flow distribution[1]	Aim to minimise changes in natural flow patterns and minimise changes to flood flow distribution across floodplain areas. Identify any changes and justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors.
Velocities[1]	Maintain existing velocities where practical. Identify changes to velocities and impacts on external properties. Determine appropriate scour mitigation measures taking into account existing soil conditions. Justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors.
Extreme event risk management	Consider risks posed to neighbouring properties for events larger than the 1% AEP event to ensure no unexpected or unacceptable impacts.
Sensitivity testing	Consider risks posed by climate change and blockage in accordance with ARR 2016. Undertake assessment of impacts associated with Project alignment for both scenarios.

Table note:

1 These flood impact objectives apply for events up to and including the 1% AEP event.

4.3 Project nomenclature for design events

The flood analysis adopts the latest approach to design flood terminology as detailed in ARR 2016.

Accordingly, all design events are quoted in terms of AEP using percentage probability. An extract of Figure 1.2.1 from Book 1 (shown in Table 4.3) details the relationship between Average Recurrence Interval (ARI) and AEP for a range of design events.

Table 4.3 Event nomenclature (taken from ARR 2016 Book 1)

Exceedances per year (EY)	AEP (%)	AEP (1 in x)	Average Recurrence Interval (ARI)
0.22	20.00	5	4.48
0.20	18.13	5.52	5.00
0.11	10.00	10	9.49
0.05	5.00	20	20
0.02	2.00	50	50
0.01	1.00	100	100
0.01	0.50	200	200
0.002	0.20	500	500
0.0005	0.05	2,000	2,000
0.0001	0.01	10,000	10,000

In line with ARR 2016 recommendations, the following terminology has been adopted for the simulated design events:

- 20% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- 1 in 2,000 AEP
- 1 in 10,000 AEP
- PMF.

4.4 Relevant standards and guidelines

The design standards applicable for the hydrologic and hydraulic analysis are listed below:

- AS7637:2014: Railway Infrastructure – Hydrology and Hydraulics
- Austroads (2013). Guide to Road Design Part 5: Drainage – General and Hydrology Considerations, Sydney
- Commonwealth of Australia. (2016). Australian Rainfall and Runoff: A Guide to Flood Estimation. Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors).
- Evaluating Scour at Bridges, Hydraulic Engineering Circular Number 18 (HEC-18), Fourth Edition, US Department of Transport – Federal Highway Administration, Virginia, USA, Richardson, EV and Davis, SR**:** 2001
- Hydraulic Design of Energy Dissipaters for Culverts and Channels, Hydraulic Engineering Circular Number 14 (HEC-14), Third Edition US Department of Transport – Federal Highway Administration, Virginia, USA, Thompson, PL & Kilgore, RT; 2006
- Department of Transport and Main Roads (2013) Bridge Scour Manual http://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Bridge-scour-manual.

5 Data collection and review

Available background information including existing hydrologic and hydraulic models, survey, streamflow data, available calibration information and anecdotal flood data has been gathered. Data was sourced from a wide range of stakeholders including:

- Local government authorities including ICC, SRRC and LCC
- The Bureau of Meteorology (BoM) – rainfall and stream gauging data
- Department of Natural Resources, Mines and Energy (DNRME) – stream gauging data
- QR – existing infrastructure details
- Queensland Reconstruction Authority (QRA) – Brisbane River Catchment Flood Study.

The following sections detail the existing information sourced and reviewed for use in the hydrologic and hydraulic assessment.

5.1 Previous studies

A number of previous hydrology and hydraulic studies were sourced as part of this study. A review of each study was undertaken to determine suitability for use on the Project as documented in the following sections.

5.1.1 Bremer River and Western Creek

5.1.1.1 Aurecon (2015), Brisbane River Catchment Flood Study (BRCFS) Hydrology Phase Final Report

This report covers a study area which includes the entire Brisbane River catchment; more specifically, the modelling includes the Bremer River and its tributaries. Hydrologic models of each of these sub-catchments were developed and calibrated against a range of recent historical flood events and these models were used to determine design flood estimates. Key aspects of the hydrologic component of the study included:

- Review and update of stream gauge flow ratings
- Recalibration of the existing Brisbane River hydrologic models
- Estimate of streamflows and volumes using hydrologic/rainfall based methods (Design event approach in accordance with ARR (1987) and Monte-Carlo Simulation)
- Flood frequency analysis at key stream gauge locations throughout the catchment
- Reconciliation of flows predicted by the different methods to produce design flow estimates to be adopted for the Brisbane River catchment.

Key review findings were:

- The hydrologic model was well calibrated against a range of recent flood events including the 1974, 1996, 1999, 2011 and 2013 flood events
- The hydrologic models would need to be modified to produce estimates at the location of the proposed rail corridor
- The resultant hydrologic models would need to be updated to be compliant with the hydraulic design requirements (Section 4.1).

5.1.1.2 Bremer River Flood Study, BMT (draft provided in early 2020)

ICC commissioned BMT to undertake a joint hydrologic and hydraulic calibration of the entire Bremer River catchment. This modelling covers Western Creek, Bremer River, Warrill Creek and Purga Creek. The ICC study was in progress at the time of this current investigation with no reporting available until a draft report was issued in early 2020. This was after finalisation of the modelling for the Project alignment.

ICC advised that the hydrologic assessment for the study was undertaken using the BRCFS URBS hydrologic model with a TUFLOW hydraulic model developed for the hydraulic assessment. ICC provided the material files that were to be used in the TUFLOW hydraulic model for the ICC study.

As part of the Detailed Design stage, the hydrologic and hydraulic modelling for Western Creek, Bremer River, Warrill Creek and Purga Creek will be reviewed and updated to consider the current Ipswich City Council hydrologic and hydraulic modelling completed in early 2020.

5.1.1.3 Western Creek, Engeny 2014

This report covers the Project alignment that runs parallel to Western Creek. The hydraulic modelling was undertaken in a 2D modelling software package. The model was calibrated to the 2011 historical event, but the calibration methodology was not outlined in the report.

5.1.1.4 Halliburton, KBR (2002), Ipswich Flood Studies, Phase 3 Final Report

This report covers the Bremer River, Western Creek, Franklyn Vale Creek and Purga Creek and involved both the development and calibration of hydrologic models and 1D hydraulic models of these catchments. The study is however based upon design flood hydrology inputs derived from Australian Rainfall and Runoff (1987) and so therefore the design flood estimates are not consistent with ARR 2016.

5.1.1.5 Maunsell, (2008), SFRC Study – Draft Impact Assessment Report - Technical Paper 4, Revision A

This report covers the alignment of the proposed Southern Freight Rail Corridor and includes the Bremer River and Western Creek catchments. The study involved the development of both hydrologic and 1D hydraulic models which were calibrated to historical flood events, principally January 1974. The design flood hydrology was based upon Australian Rainfall and Runoff (1987) and so design flood estimates are not consistent with ARR 2016.

5.1.2 Warrill Creek

5.1.2.1 Aurecon (2016), Warrill Creek Flood Study Final Report, April 2016

This report covers the SRRC area of the upper reaches of the Warrill Creek from Tarome (Warrill Creek) and Moogerah (Reynolds Creek) to Peak Crossing. The study involved the development of a hydrologic model and a 2D hydraulic model of the study area. The hydrologic and hydraulic models have been calibrated against a range of historic flood events including the January 2011 flood event. The design flood hydrology was based upon Australian Rainfall and Runoff (1987) and so design flood estimates are not consistent with ARR 2016.

5.1.3 Purga Creek

5.1.3.1 Aurecon (2016), Purga Creek Flood Study Final Report, July 2016

This report covers the SRRC area of the upper reaches of the Purga Creek from Teviotville to Peak Crossing. The study involved the development of a hydrologic model and a 2D hydraulic model of the study area. The hydrologic and hydraulic models have been calibrated against a range of historic flood events including the January 2011 flood event. The design flood hydrology was based upon Australian Rainfall and Runoff (1987) and so design flood estimates are not consistent with ARR 2016.

5.1.4 Teviot Brook

5.1.4.1 Aurecon (2016), Teviot Brook Creek Flood Study Final Report, July 2016

This report covers the SRRC area of Teviot Brook from its headwaters to downstream of Yarrahapinni to Carneys Creek. The study involved the development of a hydrologic model and a 2D hydraulic model of the study area. The hydrologic and hydraulic models have been calibrated against a range of historic flood events including the January 2011 flood event. The design flood hydrology was based upon Australian Rainfall and Runoff (1987) and so design flood estimates are not consistent with ARR 2016.

5.1.4.2 Aurecon (2016), Logan River Flood Study Final Report, July 2016

This report covers the SRRC area of Logan River. The study involved the development of a hydrologic model and a 2D hydraulic model of the study area. The hydrologic and hydraulic models have been calibrated against a range of historic flood events including the January 2011 flood event. The design flood hydrology was based upon Australian Rainfall and Runoff (1987) and so design flood estimates are not consistent with ARR 2016.

5.2 Survey data

ARTC provided LiDAR data from 2015 as 1 m grid Digital Elevation Model (DEM) tiles. Using GIS software, a DEM) was generated with a 1 m grid resolution for use in the Project based on the 2015 dataset. This was used for modelling within the disturbance footprint and up to the full extent of the 2015 LiDAR where relevant.

Additional LiDAR data was required to model downstream boundary conditions and facilitate calibration against streamflow gauges. In areas that were not covered by the LiDAR provided by ARTC, LiDAR tiles were sourced from Geoscience Australia. The DEM datasets utilised for modelling were based on survey flown between 2009 and 2015, with preference given to the most recent data available.

5.3 Aerial imagery

Aerial imagery was provided by ARTC and has been used to identify and confirm topographic and vegetative characteristics of catchment areas. Aerial imagery captured in 2015 was provided. Additional imagery for areas not covered in the provided aerial imagery was sourced from QGIS imagery in an open source format.

5.4 Existing drainage structure data

Drainage structure geometry information was obtained from the following sources:

- Previous studies
- Site inspection

- Field survey.

Details of existing drainage structures and sources are outlined in Section 6.

5.5 Stream gauge data

Stream gauges are used to provide a record of observed stream levels. These were originally manually recorded staff levels (typically recorded on a daily basis with more frequent records during flood events) with modern gauges providing a continuous automated record.

Although levels may be adequate for flood warning services, hydrologic investigations are usually more interested in streamflow. A rating curve is required to convert recorded levels into an equivalent stream discharge. The most reliable source of data for deriving a rating curve are actual in stream flow measurements taken during flood events. These are often difficult/dangerous to obtain during major flood events unless the gauge site is located near an appropriate structure spanning the waterway (e.g. a high-level bridge), and so are often only available for low to moderate flows. The rating must therefore be extrapolated to higher flows. This is often based on simple power-law best fit through the available data, however ideally the extrapolation is based on more reliable means, such as a hydraulic model calibrated to the reliable part of the rating curve.

Other factors can also influence the short- and long-term reliability of the rating curve. Changes to channel bed or roughness, either long-term or during a flood event, can change the hydraulic properties and hence the rating curve. Gauges are preferably located at a hydraulic control, either natural or artificial, (e.g. a weir), or where the bed material has low erodibility. The gauge location may also not produce a singular relationship between flow and level. This may occur in areas where there is significant floodplain storage, and hence the level is dependent on the duration and rate of change of the flow, or the gauge location may be affected by backwater from a downstream tributary.

5.5.1 Bremer River and Western Creek

The primary stream gauge for calibration of the Bremer River hydrologic and hydraulic models is located at Walloon. The site has a long historical record and over 150 recorded flow measurements, although the majority are for low discharges. The maximum recorded gauging is 835 cubic metres per second (m^3/s). The rating was confirmed and extended during the BRCFS using a calibrated hydraulic model. The rating is derived for local Bremer River tributary flows. However, review of Brisbane River hydraulic flood modelling undertaken by Brisbane City Council identified that the gauge location is potentially affected by backwater during major Brisbane River flood events.

BoM flood warning gauges are located upstream of Walloon at Five Mile Bridge and Rosewood. The Rosewood gauge has a significantly longer flood record than Walloon, (dating back to 1922 compared to 1962). These gauges have no rating curves or recorded flow data and therefore provide only level data, making them of limited use for the hydrologic assessment. The gauge levels can be correlated to those at Walloon, and a rating curve was derived for the Rosewood gauge during the BRCFS but is considered to have a lower reliability than the Walloon gauge.

The DNRME gauge at Adams Bridge in the upper Bremer River catchment has a relatively reliable rating but captures only 20 per cent of the catchment.

A number of other gauges throughout the catchment also provided limited information. On Western Creek, BoM has flood warning gauges at Rosewood Wastewater Treatment Plant (WWTP) upstream of the confluence with Bremer River, and further upstream at Kuss Road (although this gauge failed to register the 2011 flood). DNRME also operates a stream gauge at Kuss Road although it has only been operational since September 2011.

The Bremer River stream gauge locations are presented in Appendix A Figure A1-B.

5.5.2 Warrill Creek

The primary stream gauge used for calibration on the Warrill Creek is located at Amberley. This gauge has a good period of record and over 200 flow gaugings, with a maximum gauged record of 9.81 m gauge height corresponding to 914 m^3/s, giving good confidence in the flow rating.

Two-dimensional modelling of the gauge site was undertaken for the BRCFS to confirm and extend the rating. This modelling identified a complicating issue with the gauge site. During larger flood events (in excess of ~700 m^3/s), a proportion of the higher flows bypass around the gauge site, breaking out of Warrill Creek upstream of the Amberley gauge site and flowing westwards into Purga Creek downstream of the Loamside gauge site. The flows in Warrill Creek at the gauge location are therefore not the total flows coming from Warrill Creek. Since the primary purpose of the gauge is to estimate total creek flows, the gauge rating was adapted to relate the recorded level at the Amberley gauge to the total creek flow (ie including the breakout flow).

Moogerah Dam on Reynolds Creek in the upper Warrill Creek catchment has been in operation since 1960. It has well defined storage relationship and outflow is via an uncontrolled ogee crest spillway. Seqwater conducted reverse reservoir routing of the Moogerah Dam levels to determine hydrographs in Reynolds Creek upstream of the dam for the BRCFS calibration events.

Although several other gauges are located within the Warrill Creek catchment, they do not provide reliable flow data. Seqwater operated water resource assessment gauges are located at Junction and Kalbar Weirs, and Churchbank Weir, while BoM flood warning gauges are located at Kalbar, Harrisville and Green's Road. These are water level gauges and do not have flow gauging or ratings. Although Seqwater has conducted an assessment of the Junction and Kalbar Weirs, review of the derived rating during the BRCFS suggested that the flow conditions (influence of tailwater control) did not provide a consistent flow rating.

The Warrill Creek stream gauge locations are presented in Appendix B Figure B1-B.

5.5.3 Purga Creek

Purga Creek has only two stream gauges. The primary gauge is at Loamside where the gauge has a reasonable period of record and over 130 flow gaugings up to a maximum of 46.5 m^3/s. During the BRCFS, the gauge rating was confirmed and extended using the same hydraulic model as the Amberley Gauge. Purga Creek has a small narrow channel within a much wider floodplain and the gauge rating becomes relatively sensitive to changes in level at high flows and care should be taken when considering levels above the highest flow gauging.

As discussed in Section 5.5.2, breakout flows from Warrill Creek transfer into Purga Creek downstream of the Loamside Gauge. Although it is theoretically possible that under rare conditions the additional flows could have backwater effects at the gauge site, this would require a flow in Warrill Creek of much greater magnitude (in terms of both flow and rarity) than the concurrent event in Purga Creek. This occurrence is considered unlikely and there is no obvious evidence of it having occurred in the gauge record of the model calibration events.

The BoM gauge on Purga Creek at Peak Crossing is a flood warning gauge with no rating or flow measurements. Peak Crossing also has a relatively short flood history and few hydrologic model results available. For the BRCFS, a flow rating was estimated for the site using Manning's Equation and a cross-section extracted from LiDAR survey at the gauge location. The normal-depth flow calculations were adjusted to match predictions of the hydrologic model (calibrated to Loamside) and are not considered a reliable check of absolute levels/flows but may be used to provide qualitative feedback on the timing/shape of the predicted hydrograph.

The Purga Creek stream gauge locations are presented in Appendix C Figure C1-B.

5.5.4 Teviot Brook

Teviot Brook is a tributary of the Logan River upstream of Yarrahapinni. The upper reaches of the Teviot Brook catchment extend to Mount Roberts. The Yarrahapinni alert gauge is located north of Cedar Grove on the Logan River. The gauge is in a partially suburban area surrounded primarily by pasture and some housing. The Overflow gauge is located at the wall of Wyaralong Dam. This gauge is in a rural area and is primarily surrounded by dense vegetation. The Teviot Brook stream gauge locations are presented in Appendix D Figure D1-B.

5.6 Rainfall data

Rainfall data for all historical events modelled was embedded within the previous BRCFS and SRRC hydrologic models. The embedded historical rainfall data was adopted for this assessment.

Design rainfall data for the Existing Case and Developed Case modelling is outlined in Section 8.1.2.

5.7 Anecdotal flood data

Anecdotal flood data for the historical flood events has been collected from many sources including:

- Previous studies
- Local Government Authorities
- Landholders and stakeholders.

Anecdotal data includes information obtained from a wide range of sources and as such it is of varying levels of accuracy and reliability. The anecdotal data has been used to assess the performance of the hydraulic model to replicate historical flood conditions.

5.8 Site inspection

A site inspection was undertaken during February 2018. During the site inspection, all proposed major waterway crossings were inspected with photographs taken and details recorded of the crossing, existing drainage structures and surrounding catchment and waterway environment. An assessment of the relative roughness and blockage potential was undertaken during the site inspection. The site visit confirmed that the catchment conditions were consistent with the LiDAR and aerial imagery provided.

6 Development of models

6.1 Summary

A summary of the modelling approach for each catchment is listed in Table 6.1. Although the Logan River does not cross the Project alignment it influences the Teviot Brook through backwater effects. A sub-model of the Logan River hydraulic model (Aurecon, 2016) has been prepared to extract tailwater conditions for the Teviot Brook hydraulic model. All hydrologic and hydraulic modelling was undertaken with the guidance of a qualified engineer. Validation with historical data was undertaken where available and sensitivity checks were undertaken to test assumptions. The development of these models is outlined in the sections below.

Table 6.1 Hydrologic and hydraulics modelling approach summary

Catchment	Hydrologic modelling approach	Hydraulic modelling approach
Bremer River	Adopted the BRCFS hydrology (URBS) and updated to be ARR 2016 compliant.	Created a TUFLOW model of Bremer River (including Western Creek) using data from the Bremer River study (BMT, Current)
Warrill Creek	Adopted the BRCFS hydrology (URBS) and updated to be ARR 2016 compliant.	Created a TUFLOW model using information and data from Warrill Creek Flood Study Final Report (Aurecon, 2016) and Bremer River Flood Study (BMT, Current)
Purga Creek including Sandy Creek	Adopted the BRCFS hydrology (URBS) and updated to be ARR 2016 compliant.	Created a TUFLOW model of using information and data from Purga Creek Flood Study Final Report (Aurecon, 2016) and Bremer River Flood Study (BMT, Current)
Teviot Brook	Adopted Teviot Brook RAFTS model and updated to be ARR 2016 compliant.	Created TUFLOW model of Teviot Brook using information and data from Teviot Brook Flood Study Final Report (Aurecon, 2016)
Logan River	Adopted Logan River RAFTS model and updated to be ARR 2016 compliant.	Created a sub-model of the Regional Logan River hydraulic model (Aurecon, 2016).

6.2 Hydrologic models

6.2.1 Bremer River, Warrill Creek and Purga Creek

For the Bremer River, Warrill Creek and Purga Creek, the hydrologic modelling from the BRCFS (Aurecon 2015) has been adopted. This modelling is the most robust and up-to-date and has been accepted by ICC, SRRC and LCC.

The BRCFS undertook a detailed hydrologic assessment of the Brisbane River catchment, followed by hydraulic modelling of the Brisbane River (downstream of Wivenhoe Dam) and lower tributaries. Hydrologic modelling for the BRCFS was undertaken using the URBS software package. The hydrologic models were originally developed by Seqwater but were reviewed and revised as part of the BRCFS in response to changes to the gauge ratings and (preliminary) hydraulic modelling of the lower Brisbane River undertaken by Brisbane City Council.

The Brisbane River hydrologic model configuration separates the catchment into seven separate sub-models – the Upper Brisbane (upstream of Wivenhoe), its major tributary Stanley River (upstream of Somerset Dam), the Lower Brisbane, Lockyer Creek, the Bremer River and two of its tributaries, Warrill Creek and Purga Creek, which join upstream of Ipswich. Three of these hydrologic sub-models have been used for the current investigation. Minor modifications were made to the hydrologic models to produce flow estimates at locations of interest along the Project alignment.

6.2.2 Teviot Brook

The Teviot Brook Flood Study undertaken in 2016 for SRRC is the most recent study of Teviot Brook. The 2016 study involved the development of calibrated RAFTS hydrologic and TUFLOW hydraulic models. The Teviot Brook RAFTS model was adapted from a model originally developed by LCC as part of the 2014 hydrology study analysing the Teviot Brook, Albert and Logan catchments.

6.2.3 Logan River

The Logan River Flood Study (Aurecon 2016) undertaken for SRRC is the most recent study of Logan River. The 2016 study involved the development of calibrated RAFTS hydrologic and TUFLOW hydraulic models. The Logan River RAFTS model was adapted from a model originally developed by LCC as part of the 2014 hydrology study analysing the Teviot Brook, Albert and Logan catchments.

6.3 Bremer River hydraulic model

6.3.1 Model setup

The Bremer River hydraulic model was set up on a 10 m grid and run in TUFLOW HPC. The model incorporates Western Creek which is a tributary of the Bremer River. The TUFLOW model set up is presented in Appendix A Figure A1-C. Gully lines have been used to model continual flow paths along the invert of the main channels. The hydraulic model has been extended downstream to incorporate the Walloon gauge for calibration purposes.

6.3.2 Hydraulic structures

Existing structure data was provided by ICC from their previous studies, Bremer River Flood Study (BMT, ongoing) and Western Creek (Engeny, 2014). Further to this, survey of structures along the QR line was incorporated in the model. Combined this structure information provided sufficient detail for the hydraulic modelling.

6.3.3 Roughness

Refer to Section 7.8 for details on hydraulic roughness parameters.

6.3.4 Boundary conditions

The BRCFS URBS model outputs were applied as inflows into the TUFLOW model. Total inflows from catchments upstream of the hydraulic model extents were applied at the upstream model boundary and local inflows from areas within the TUFLOW model were applied throughout the hydraulic model. A normal depth boundary condition was applied at the downstream boundary. By testing a range of conditions, it was confirmed the downstream boundary was located sufficiently downstream so as to not influence flow conditions at the Project alignment.

6.4 Warrill Creek hydraulic model

6.4.1 Model setup

The Warrill Creek hydraulic model was set up on a 10 m grid and run in TUFLOW HPC. The TUFLOW model set up is presented in Appendix B Figure B1-C. Gully lines have been used to model continual flow paths along the invert of the main channels. The model has been extended downstream to incorporate the Amberley gauge for calibration purposes.

6.4.2 Hydraulic structures

ICC provided structure existing data within the hydraulic model area. This structure information was sufficient for the hydraulic modelling.

6.4.3 Roughness

Refer to Section 7.9 for details on hydraulic roughness parameters.

6.4.4 Boundary conditions

The BRCFS URBS model outputs were applied as inflows into the TUFLOW model. Total inflows from catchments upstream of the hydraulic model extents were applied at the upstream model boundary and local inflows from areas within the TUFLOW model were applied throughout the model. A normal depth boundary condition was applied at the downstream boundary. By testing a range of conditions, it was confirmed the downstream boundary was located sufficiently downstream so as to not influence flow conditions at the Project alignment.

6.5 Purga Creek hydraulic model

6.5.1 Model setup

The Purga Creek hydraulic model was set up on a 10 m grid and run in TUFLOW HPC. The TUFLOW model set up is presented in Appendix C Figure C1-C. Gully lines have been used to model continual flow paths along the invert of the main channels. The model has been extended downstream to incorporate the Loamside stream gauge for calibration purposes.

6.5.2 Hydraulic structures

Only limited information for bridges and cross-drainage structures was available. ICC provided structure existing data within the hydraulic model area.

6.5.3 Roughness

Refer to Section 7.9 for details on hydraulic roughness parameters.

6.5.4 Boundary conditions

The BRCFS URBS model outputs were applied as inflows into the TUFLOW model. Total inflows from catchments upstream of the hydraulic model extents were applied at the upstream model boundary and local inflows from areas within the TUFLOW model were applied throughout the model. A normal depth boundary condition was applied at the downstream boundary. By testing a range of conditions, it was confirmed the downstream boundary was located sufficiently downstream so as to not influence flow conditions at the Project alignment.

6.6 Teviot Brook hydraulic model

6.6.1 Model setup

A sub-model of the regional Teviot Brook hydraulic model (Aurecon, 2016) was prepared for this study. The model was upgraded to TUFLOW HPC and modelled on a 10 m grid size. The hydraulic roughness was also refined, and the latest topographic information provided by ARTC was incorporated. Gully lines have been used to model continual flow paths along the invert of the main channels. The model extents are outlined in Appendix D Figure D1-C.

6.6.2 Hydraulic structures

Structures from SRRC's regional Teviot model were incorporated in the Teviot Brook sub-model.

6.6.3 Roughness

Refer to Section 7.11 for details on hydraulic roughness parameters.

6.6.4 Boundary conditions

The Teviot Brook RAFTS model outputs were applied as inflows into the TUFLOW model. Total inflows from catchments upstream of the hydraulic model extents were applied at the upstream model boundary and local inflows from areas within the TUFLOW model were applied throughout the model.

Teviot Brook is influenced by backwater from the Logan River. To model this phenomenon a water surface level with time boundary condition was applied at the downstream boundary. As per the regional Teviot Brook hydraulic model this boundary condition was extracted from the Logan River hydraulic model.

6.7 Logan River hydraulic model

6.7.1 Model setup

A hydraulic sub-model of the regional Logan River hydraulic model (Aurecon, 2016) was prepared for this study. The hydraulic results of this model were used to provide tailwater conditions for the Teviot Brook hydraulic model (time varying water surface level). The sub-model was upgraded to TUFLOW HPC and the hydraulic roughness was refined in the calibration of the model as outlined in Section 7.9. The model extents are outlined in Appendix E Figure E1-A.

6.7.2 Hydraulic structures

There were no structures in the regional hydraulic model and as such no hydraulic structures were incorporated in the hydraulic sub-model.

6.7.3 Roughness

Refer to Section 7.9 for details on hydraulic roughness parameters.

6.7.4 Boundary conditions

The Logan River Brook RAFTS model outputs were applied as inflows into the TUFLOW model. Total inflows from catchments upstream of the hydraulic model extents were applied at the upstream model boundary and local inflows from areas within the TUFLOW model were applied throughout the model.

A normal depth boundary condition was applied at the downstream boundary. This boundary condition is unchanged from the Logan River Regional Model.

6.8 Implementation of baseflow

Baseflow parameters for each URBS model were estimated as part of the hydrologic model calibration process. The baseflow is not routed through the hydrologic model, but rather is calculated at a specific location of interest and then added to the routed flow at that location. The assumed baseflow at a location is therefore not the sum of the baseflow from the upstream sub-catchments routed through the model. This makes it difficult to achieve exact equivalence between the hydrologic model (empirical baseflow at a point location) and hydraulic model (flow at a point is cumulative routing of upstream inflows).

For the historical calibration events, baseflow has been estimated using the URBS model at each of the major tributary inflows and included in the inflows. The baseflow from the boundary inflows is routed through the hydraulic model and may therefore affect slightly the attenuation of the combined flows. URBS does not calculate baseflow contribution from the local sub-catchments; these are therefore not included in the hydraulic model. Overall, baseflow represents a relatively small component of the peak flow. Since the focus of the calibration is to confirm the hydraulic model routing and level-flow relationships rather than match an exact flow, these minor differences will have no impact on the outcome of the TUFLOW calibration.

No baseflow was used in the Teviot Brook or Logan River RAFTS hydrologic models. ARR 2016 does not mandate the implementation of baseflow.

7 Joint calibration

7.1 Introduction

The hydraulic models developed generally cover the mid to lower portion of the hydrologic models. Routing and attenuation of the hydrologic model is therefore partially replicated within the hydraulic model. The hydraulic model inflows therefore consist of total reach flows where the hydraulic model boundary intersects any major tributary (more than one upstream catchment) and local sub-catchment flows where the catchment centroid lies inside the hydraulic model boundary.

Hydrologic models are based on simplistic empirical runoff routing equations using coefficients determined primarily by calibration to a specific point of interest. By contrast, hydraulic models are more physically based, providing a (relatively) realistic representation of the catchment geometry and solving equations of motion within the model domain. Some differences between the hydrologic and hydraulic routing must realistically be expected. Nevertheless, the hydraulic model should closely replicate the flow characteristics (attenuation, timing etc.) that have been validated in the hydrologic model by calibration to historical flood events.

The hydraulic model must also produce flood levels consistent with the flows. This can be confirmed by comparison with flood levels recorded during historical flood events, although the reliability is dependent upon the accuracy of the modelled flows, which are in turn dependent on the accuracy of the recorded rainfall. Further validation across a wide range of flows can be achieved by comparison of the modelled level-flow relationships at the stream gauge sites with the gauge ratings, which allows the level-flow relationship to be confirmed without necessarily having to exactly match a specific flow.

The TUFLOW hydraulic models have been validated using historical events. The primary objectives of the calibration process have been:

- To confirm hydraulic model roughness factors required to match level-flow relationships at the stream gauges, particularly those where the ratings are well defined by in-streamflow measurements
- To confirm that the flood routing through the TUFLOW hydraulic model reasonably matches the hydrologic model (TUFLOW physically represents storage and other catchment characteristics that are represented in hydrology software by empirical coefficients) and that the adopted roughness parameters do not adversely affect the timing or attenuation of the flood routing.

The historical events were selected to represent a range of magnitudes and duration. A summary of each event is outlined in the sections below.

7.2 Calibration events – Bremer River, Warrill Creek and Purga Creek

7.2.1 January 1974

January 1974 was a major flood event that affected much of the Brisbane River catchment, typified by a single flood peak of similar magnitude and duration to the major peak of the 2011 flood in much of the mid- and lower Lockyer catchment, but without the preceding flash floods in the upper catchment (refer discussion below). The 1974 flood remains the largest recorded in the Bremer River catchment.

7.2.2 January 2011

January 2011 was a major flood event affecting the Brisbane River catchment and causing major damage within the Lockyer, Bremer River and Brisbane River catchments. The event was typified by several separate bursts of very heavy rainfall over several days resulting in a flow hydrograph in the downstream catchment with a series of sharp peaks. Initial rainfall bursts were concentrated over the upper Lockyer catchment causing extreme flash flooding in Helidon and Grantham, followed by more widespread flooding across the catchment that caused higher peaks at Gatton and in the southern Lockyer catchment and the Bremer River.

7.2.3 January 2013

January 2013 was a moderate flood across much of the Brisbane River catchment (although mitigation by Wivenhoe minimised impacts in the lower Brisbane River). More spatially and temporally consistent rainfall produced a single broad flood peak, allowing a good hydrologic calibration to be achieved across much of the catchment.

7.3 Calibration events – Teviot Brook

The Teviot Brook modelling was validated for the 1974, 1990 and 2013 events using the historical information from the previous studies. The 1974 event was the largest event recorded in the catchment at the Project alignment.

7.4 Review of BRCFS hydrologic investigation

The hydrologic models developed and calibrated by Seqwater were revised and recalibrated as part of the BRCFS. The recalibration process focussed initially on five flood events: January 1974, May 1996, February 1999, January 2011 and January 2013. These events were selected as they represent moderate to major floods and they also contain the best recent records in terms of spatial and temporal rainfall and streamflow information. The calibration parameters were then validated against a further 38 historical flood events, (28 events from between 1955 and 2013 and ten older events dating back to 1887). Events prior to 1955 have limited pluviograph data and so the temporal representation of these events is generally less reliable.

Recommended parameters derived from the calibration/validation process are listed in Table 7.1. Model results using the recommended parameters were compared across the full range of verification events, generally showing a good correlation between calculated and rated peak flow rates and event volumes with no obvious flow rate related bias at all the examined flow gauges.

Table 7.1 Tributary sub-model adopted parameters

Sub-catchment	Alpha	Beta	m	n
Bremer River	0.79	2.8	0.8	0.85
Warrill Creek	0.79	2.5	0.8	0.85
Purga Creek	0.93	3.8	0.8	0.85

For each of the tributary hydrologic sub-models, the calibration process focussed on achieving a good match of the flow hydrograph at the primary calibration gauge site (refer Section 5.5), typically at or near the downstream end of the catchment. The calibration parameters are therefore not necessarily optimised for individual tributaries or areas in the upper catchments.

For calibration events, losses can act to make up for inaccuracies in the rainfall data. The calibration rainfall data are recorded at isolated gauge sites and then interpolated across the catchment. If the rainfall was concentrated around the gauge site, therefore leading to an overestimate of the actual rainfall across the catchment, this can be compensated for by increasing losses, and vice versa. Forty-eight historical rainfall/flood events were simulated during the BRCFS to calibrate/validate the hydrologic models. The median Initial Losses (IL) and Continuing Losses (CL) are shown in Figure 7.1 and Figure 7.2 respectively. The 25^{th} and 75^{th} percentile losses are shown to give an indication of variability.

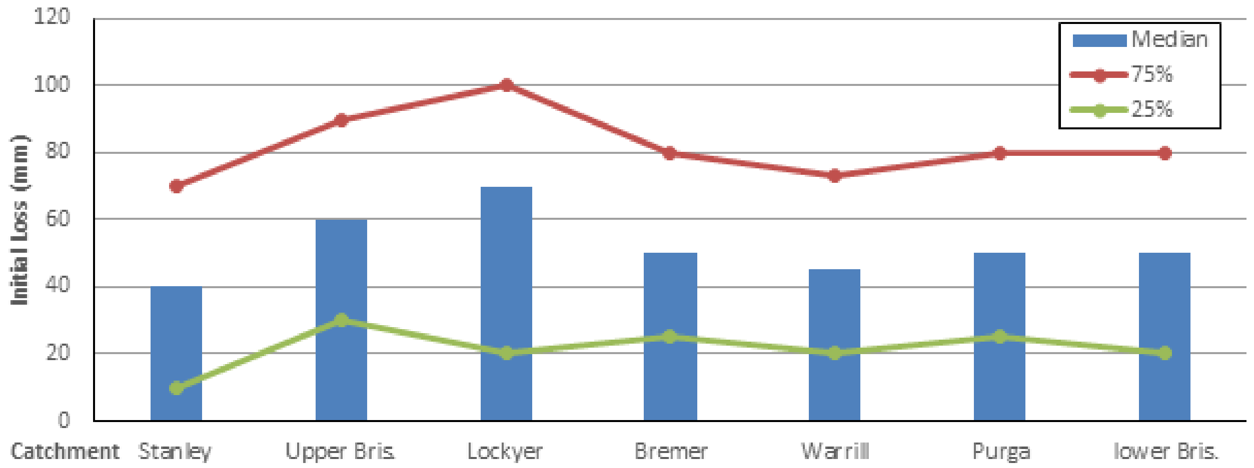


Figure 7.1 **BRCFS calibration event initial losses**

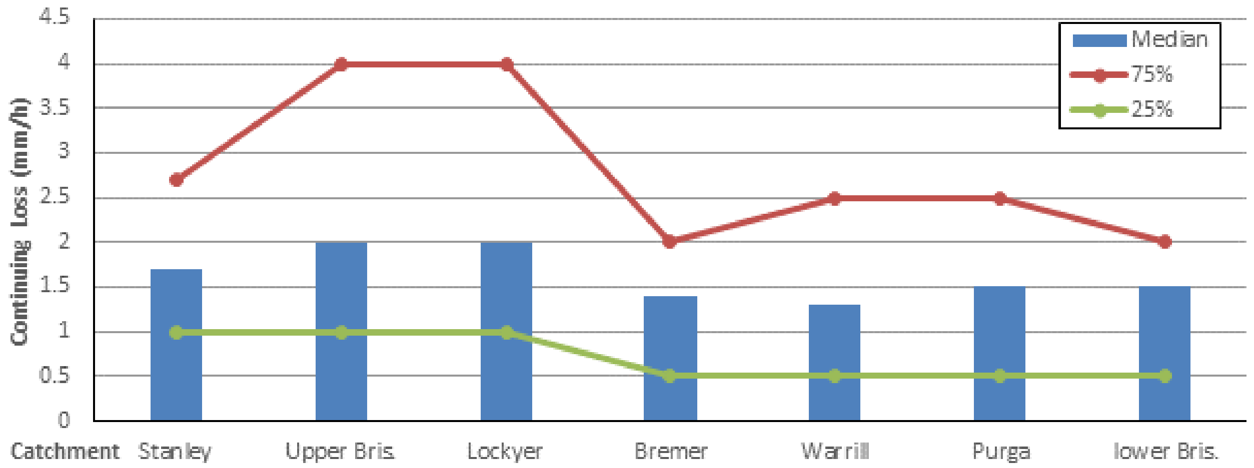


Figure 7.2 **BRCFS calibration event continuing losses**

7.5 Review of Teviot Brook and Logan River RAFTS models

As noted above the adopted LCC Teviot Brook and Logan River hydrologic models were calibrated to the 1974, 1990 and 2013 flood events. The LCC RAFTS model flood routing utilised the Muskinghum-Cunge channel routing method. This method specifies the storage constant and weighting factors (k and x) to be applied between nodes. It is noted that the source calculations for the storage factors applied to the LCC RAFTS model were not available for verification.

The LCC RAFTS also includes a storage coefficient factor ‘Bx’. This uniformly modifies all sub-catchment Storage Time Delay Coefficient values. The parameters applied to the LCC RAFTS model for storage factors, ‘k’, ‘x’ and ‘Bx’ were assumed appropriate and adopted for use in this study. Review of the hydrographs from the LCC RAFTS model against historic gauge records shows a reasonable match in terms of flood time lag supporting the use of the previously developed storage factors. For all models a standard “x” value of 0.25 has been used. The “k” lag parameter is unique to each link and is proportional to its length.

The parameters adopted for the LCC RAFTS model for the Teviot Brook and Logan River calibration events are outlined in Table 7.2 and Table 7.3 respectively.

Table 7.2 Logan City Council Teviot Brook RAFTS model calibration event parameters

Event	Calibration parameters		
	Initial loss (mm)	Continuing loss rate (mm/hr)	Bx
1974	75	1.75	1.4
1990	42	2.00	1.4
2013	100	3.50	1.4

Table 7.3 Logan City Council Logan River RAFTS model calibration event parameters

Event	Calibration parameters		
	Initial loss (mm)	Continuing loss rate (mm/hr)	Bx
1974	50.0	0.50	1.4
1990	10.0	2.20	1.4
2013	130.0	2.50	1.4

7.6 Hydrologic modelling calibration process

Detailed calibration of the hydrologic models was undertaken for the BRCFS catchments (Bremer River, Warrill Creek and Purga Creek) and Logan (Teviot Brook and Logan River). These models have been adopted for the current study with minimal change. No additional calibration of the hydrologic models has been undertaken.

7.7 Hydraulic modelling calibration process

The primary calibration parameter for the TUFLOW models is the hydraulic roughness, represented in TUFLOW as a Manning's roughness coefficient, *n*. Calibration of the hydraulic models involved:

- Comparison of the TUFLOW prediction of the relationship between level and flow with stream gauge ratings. As discussed in Section 5.5, a detailed review of the stream gauge ratings was undertaken for a number of key gauges in the Bremer River catchments, which provide a relationship between observed flows and levels that are consistent.
- Comparison of TUFLOW level and flow hydrographs for the calibration events to confirm that they match both the shape and timing of observed flow
- Comparison of TUFLOW levels with anecdotal flood level data from Councils and the community.

The Bremer River, Warrill Creek and Purga Creek TUFLOW hydraulic models cover a significant proportion of the middle of the catchment. These models use inflows taken from the URBS hydrologic model as both total channel flows at creek inflows at the hydraulic model boundary and local sub-catchment flows at points within the model boundary. Initial comparisons of the URBS hydrologic routing and TUFLOW hydraulic routing identified that the TUFLOW flows tended to lag the URBS flows. The sub-catchment hydrographs that are input into TUFLOW include attenuation and lag due to local catchment storage routing from URBS. Because a real catchment does not have a distinct interface between sub-catchment and main-stream routing, this carries the risk of double-counting storage in the lower sub-catchment tributaries. It was found that reducing the sub-catchment lag parameter, β, improved the match between the two models. Note that this modification is applied to the inflows within the TUFLOW model domain, not the calibrated URBS model. For input into the hydraulic modelling the Beta values in Table 7.4 were updated and adopted.

Table 7.4 Updated values for hydraulic modelling

Sub-catchment	Beta, β
Bremer River	1.5
Warrill Creek	1.0
Purga Creek	1.5

7.8 Bremer River joint calibration results

Initial estimates for roughness were based on the BMT (current) Bremer River Flood Study and confirmed using aerial imagery. The TUFLOW model set up is presented Appendix A Figure A1-C. The roughness values were then refined to achieve the desired relationship between flow and level at the stream gauges. Typical roughness parameters adopted for Bremer River are summarised in Table 7.5 and are indicative of the conditions present in each creek. It should be noted that, as with the ratings, these values are understood to be indicative of typical creek/catchment conditions and may be different during any individual flood event.

Table 7.5 Bremer River Manning's roughness parameters

Land use	Manning's n
Non-Tidal Waterway	0.030
Grassland (Long)	0.040
Light Vegetation	0.040
Agricultural Fields/Parks	0.035
Dense Vegetation	0.080
Very Dense Vegetation	0.120
Rough Pasture/Light Brush	0.060
Roads/Car Parks	0.025
Medium Density Urban Block	0.100
Mining	0.070

Appropriate roughness parameters for the Bremer River TUFLOW model were determined by comparing the model flow-depth relationship with the rating at the Walloon gauge. Figure 7.3 shows the relationship between level and flow for the 1974 flood hydrograph. Walloon has a reliable rating curve that is based on flow measurements up to ~900 m³/s and extended using a MIKE 21 model for the BRCFS. The TUFLOW model identifies minor hysteresis effects above ~500 m³/s, however in general shows excellent agreement with the BRCFS rating curve.

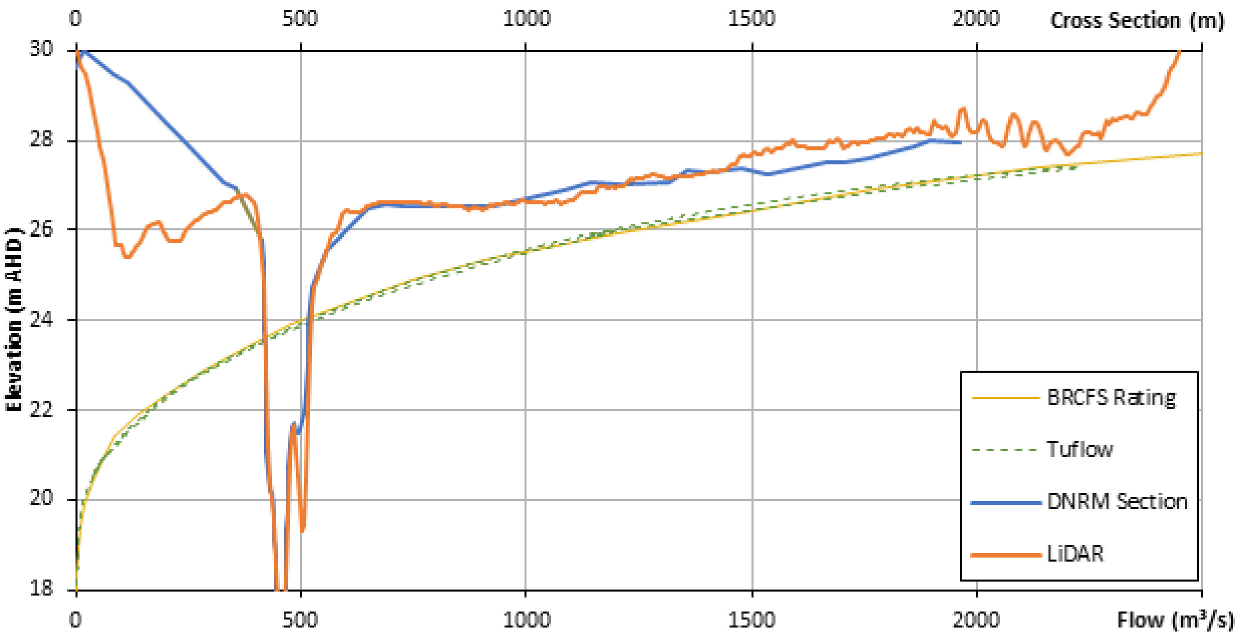


Figure 7.3 Comparison of TUFLOW flow-depth relationship with Walloon rating

The BoM Alert gauge at Rosewood does not have any streamflow measurements or an official flow rating curve. A validation rating curve was developed for the BRCFS by fitting a power-law relationship through estimated event peak flows in the Bremer River at Rosewood (from the URBS model calibrated to Walloon) with corresponding peak levels observed at the Walloon gauge. The rating was developed using data from 17 historical events, typically between 100 m³/s and 1,200 m³/s, noting that the rating reliability decreases away from this range. Comparison between the derived rating and the TUFLOW level-flow relationship is shown in Figure 7.4. Although this does not provide independent confirmation of the modelled flows, it does identify a good consistency between the modelled flows and the observed flood levels.

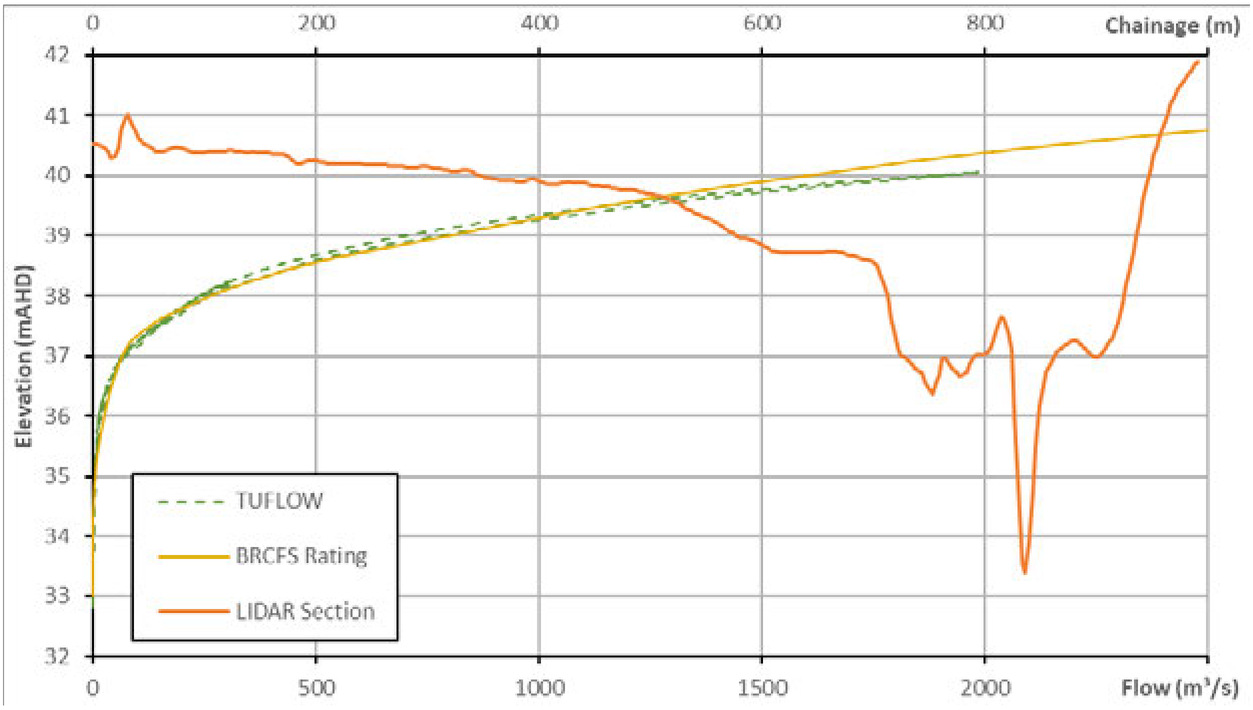


Figure 7.4 **Comparison of TUFLOW flow-depth relationship with Rosewood rating**

The DNRME Kuss Road stream gauge in the upper Western Creek catchment has only been operational since September 2011. A BoM gauge site was located at the site prior to this but only limited peak water level records are available. The DNRME gauge rating curve is based on a maximum measured flow at site of 120 m³/s at 52.5 metres above Australian Height Datum (m AHD), recorded during the 2013 flood. Review of the cross-section suggests that flow capacity would increase significantly above this level, so extrapolation beyond this level is highly uncertain. The DNRME rating and the TUFLOW level-flow relationship are shown in Figure 7.5. Also shown in the figure are the flood levels recorded at the DNRME gauge for the 2013 flood plotted against flow modelled in URBS and older historical flood peaks recorded at the BoM gauge against the peak flow predicted by the URBS model.

The TUFLOW level-flow relationship shows very good agreement with the DNRME rating up to 50.5 m AHD. Above this level it appears to show good consistency with the BoM historic flood peaks but not the DNRME gauge levels. Review of historical aerial photographs identified that the bridge and approach road underwent a significant upgrade at some time between 1997 and 2002. The current bridge level is 53 m AHD, and interference of the bridge deck is a likely cause for the discrepancy between the BoM gauge record (1974 and 1996) and the current DNRME gauge records (2013). This bridge is not included in the TUFLOW model. The TUFLOW model parameters are considered to give a good representation of the channel characteristics excluding impacts of the bridge. Considering the hydraulic grade during flood events, these are expected to be localised to several hundred metres upstream of the bridge and should decrease during major flood events when large flows are conveyed outside the channel.

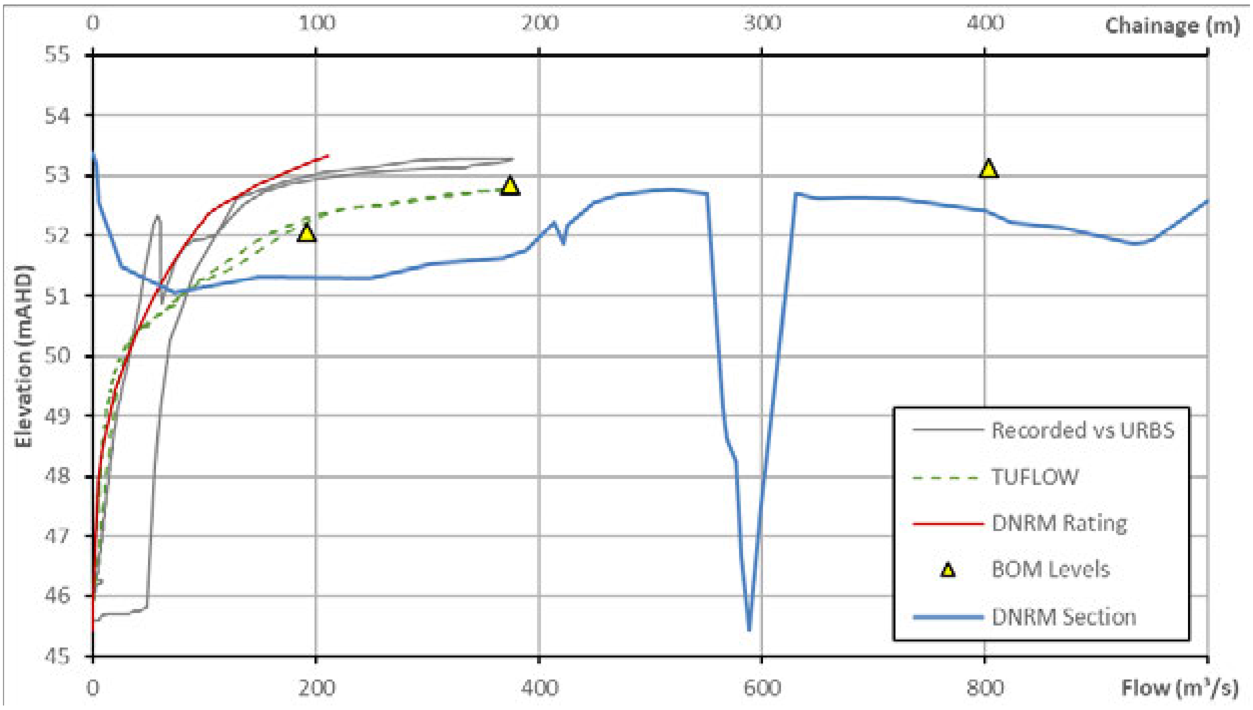


Figure 7.5 Comparison of TUFLOW flow-depth relationship with Kuss Road rating

7.8.1 January 1974

The 1974 flood is the largest flood known to have occurred in the Bremer River catchment, exceeding even the 1893 floods (the largest recorded Brisbane River floods) which were caused by heavy rainfall in the Upper Brisbane and Stanley River catchments. Unfortunately, the continuous stream gauge at Walloon was not operational during the 1974 flood and only a flood peak flood level is available, reducing the usefulness of the event for calibration purposes. Rainfall losses for the event were estimated based on adjacent catchments. The only site at which continuous stream gauge data is available is at Adam's Bridge in the upper Bremer River. Comparison between the URBS hydrologic model and rated stream gauge flows is shown in Figure 7.6. Although the hydrologic model overestimates the flow at the start and end of the event, the timing, shape and magnitude of the main peak are considered a reasonable match given the small size of the catchment and limited rainfall data.

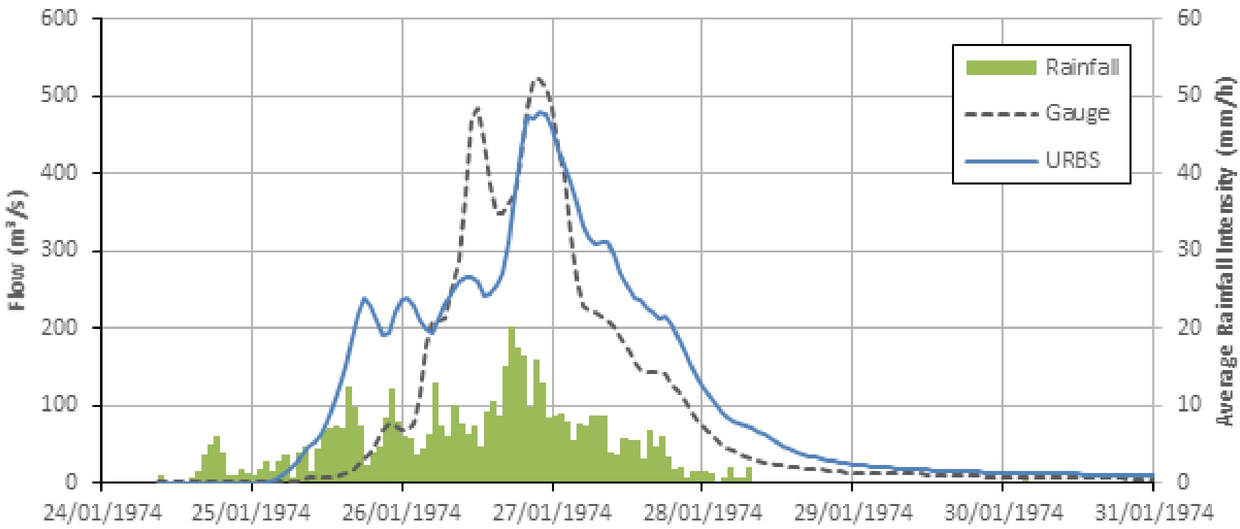


Figure 7.6 Comparison of URBS and stream gauge hydrographs at Adam's Bridge for the 1974 event

The flow hydrographs for the 1974 flood event produced by the URBS hydrologic model and TUFLOW hydraulic model at Kuss Road and Walloon are compared in Figure 7.7 and Figure 7.8 respectively. These demonstrate that although there are a few minor differences in timing, the overall shape and peak of the hydrograph are very similar at both locations. At Kuss Road the timing differences are negligible, while at Walloon the mid-range (between 300 m^3/s and 1,200 m^3/s) TUFLOW flows tend to lag behind URBS by around 2 hours, particularly on the rising limb, but agree relatively well for lower and higher flows including the peak.

According to the peak flood level information the Walloon gauge had a rated flow of 2,810 m^3/s during the 1974 event. The hydrologic model flows (and consequently the hydraulic model) underestimate the rated peak flow at Walloon by approximately 500 m^3/s (note that this corresponds to only 0.44 m difference in gauge height). There are several potential causes for this, including rating error and sensitivity, variability of floodplain vegetation, or simply a shortfall in the recorded rainfall. Alternatively, the gauge site is also suspected to have some minor backwater influence from the downstream confluence with Warrill and Purga Creeks during major events, which would cause the flood level (and corresponding rated flow) to increase.

A peak level of 53.12 m AHD was recorded at the BoM alert gauge at Kuss Road. The TUFLOW model reaches a peak of 53.17 m AHD, only 50 mm higher (Figure 7.5).

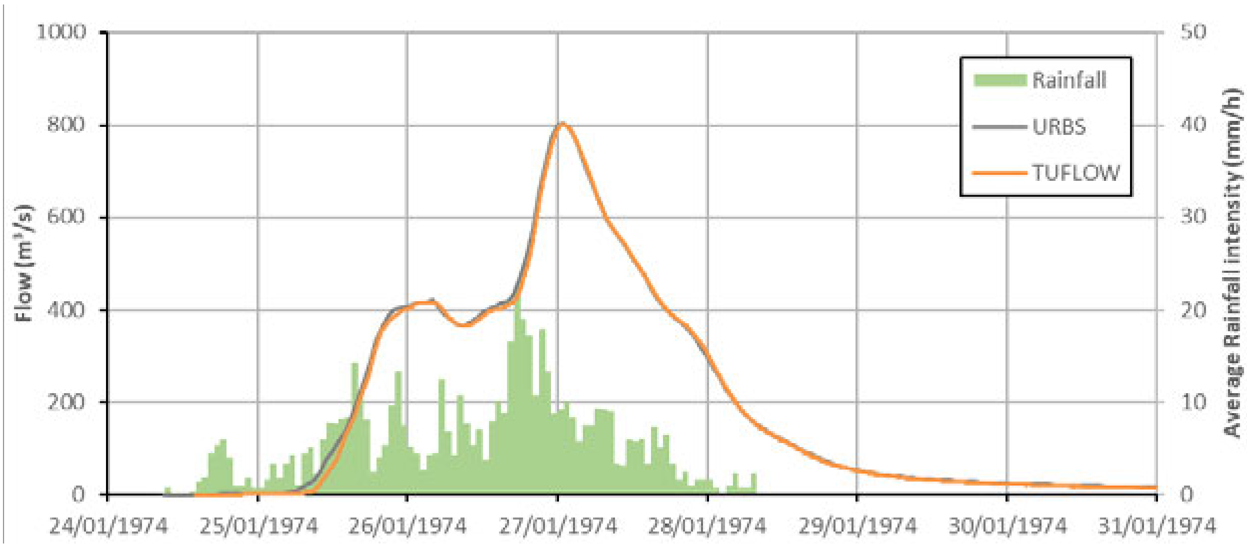


Figure 7.7 Comparison of URBS and TUFLOW hydrographs at Kuss Road for the 1974 event

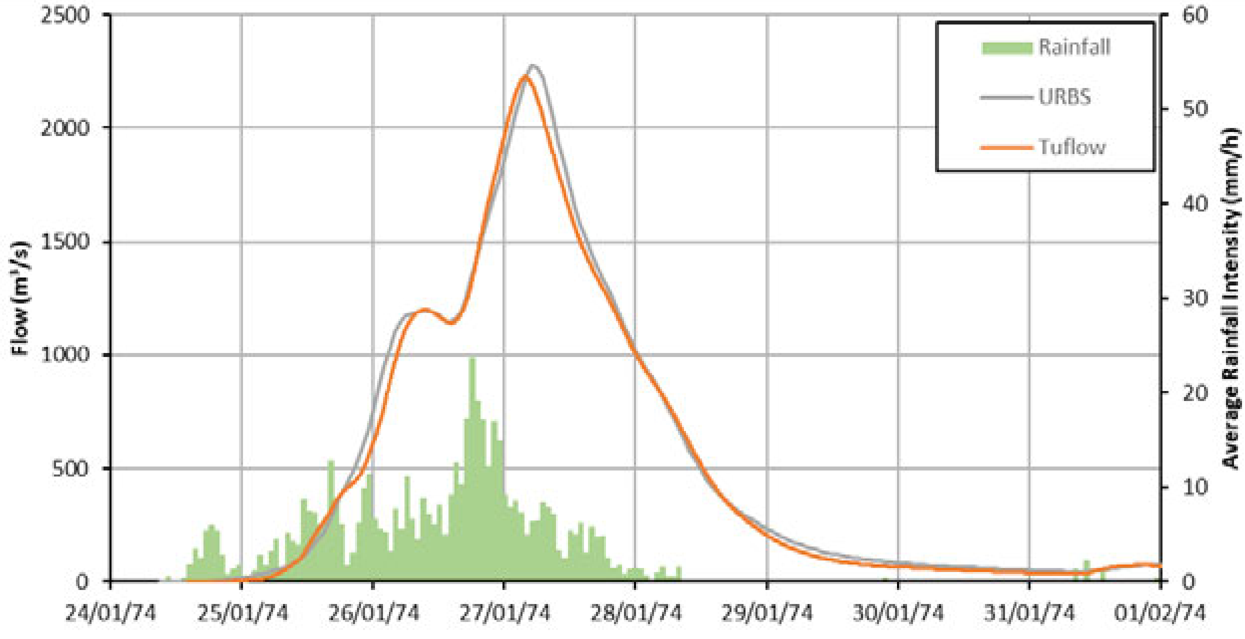


Figure 7.8 Comparison of URBS and TUFLOW hydrographs at Walloon for the 1974 event

7.8.2 January 2011

The 2011 flood is the largest recorded flood in the upper Bremer River at Adam's Bridge, but peaked slightly lower than 1974 in the lower Bremer River. The overall event was the combination of several distinct rainfall bursts across the 10th and 11th of January. Comparison of URBS model and rated flows at Adam's Bridge in Figure 7.9 demonstrates that the URBS model replicates the timing, shape and approximate magnitude of the hydrographs in the upper catchment, noting that the model calibration considered the wider Bremer and Brisbane River model calibration, hence the overall shape and volume of the hydrograph was as, or more important, than the absolute peak at this location.

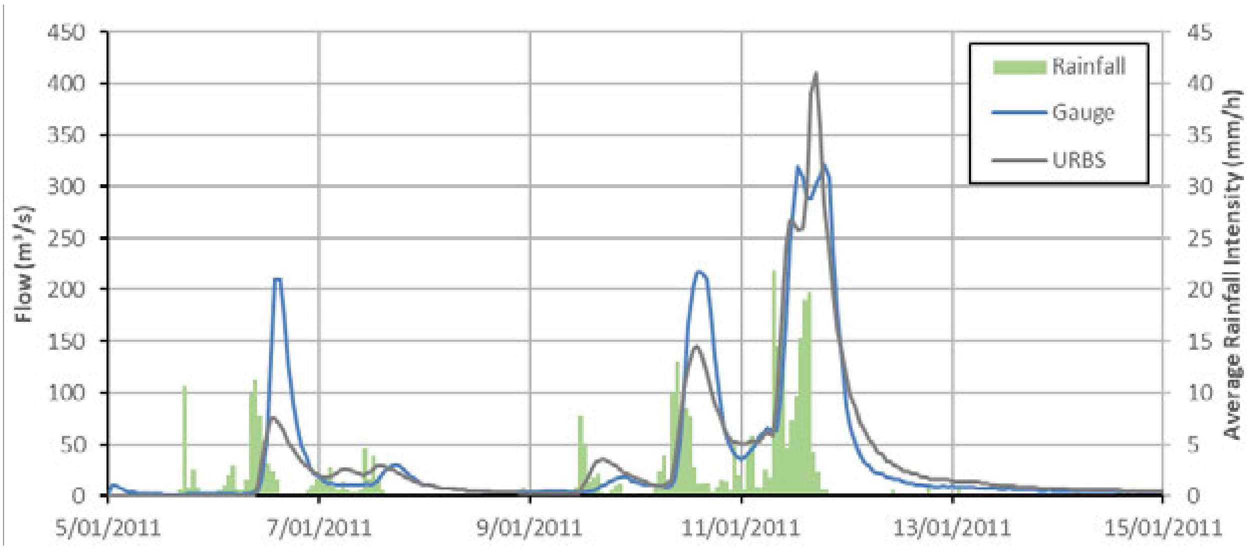


Figure 7.9 Comparison of URBS and stream gauge hydrographs at Adam's Bridge for the 2011 flood

The BoM gauge at Kuss Road on Western Creek failed during the 2011 event and did not capture the flood event, however flood levels for the 2011 event were recorded by the BoM ALERT gauge on Western Creek at the Rosewood WWTP, just upstream of the confluence with the Bremer River. There is no official gauge rating for the BoM gauge, and although Seqwater has estimated a rating based on comparison of URBS flows and recorded levels, the gauge has only been operational since 2001 and there are therefore few historical events and the rating has very low reliability. Widespread flooding also occurs around the confluence during large events and flow transfers between Western Creek and the Bremer River, making it difficult to define a specific 'Western Creek flow' for comparison. Water levels from the TUFLOW model are compared with gauge levels in Figure 7.10. The model nevertheless appears to replicate very well both the levels and timing of the recorded flood.

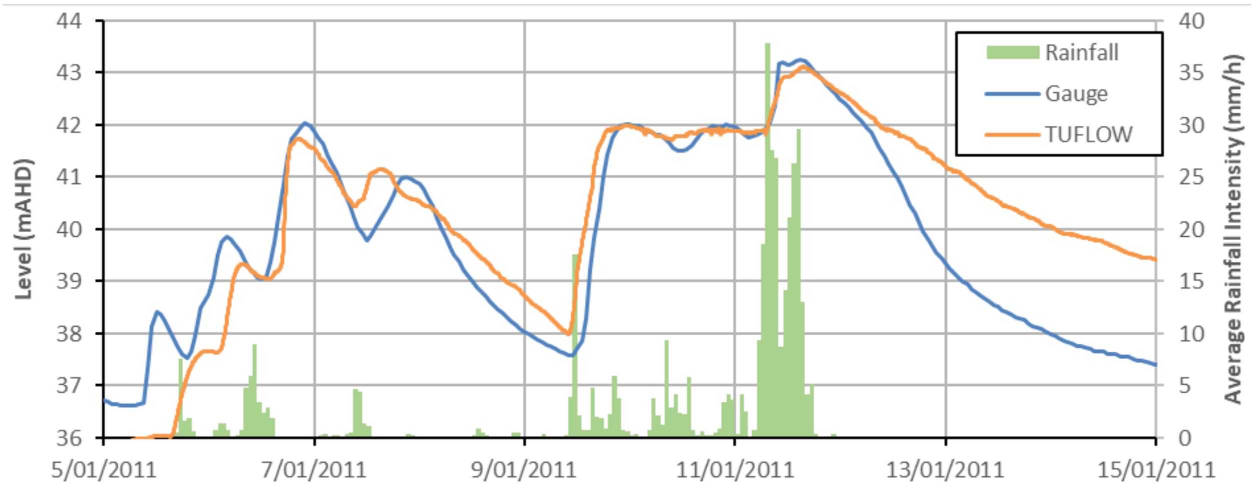


Figure 7.10 Comparison of TUFLOW and recorded water levels at Rosewood WWTP for the 2011 flood

The URBS and TUFLOW hydrographs for the 2011 flood at Walloon are compared in Figure 7.11. As with the other flood events, the TUFLOW hydrograph tends to lag behind the URBS hydrograph for flows between 300 m³/s and 1,500 m³/s but matches the peak. The modelled hydrographs generally match the shape of the observed hydrograph. The difference in timing between the recorded peak and modelled peaks is only 1 hour. The URBS flows, calibrated with consideration to gauges further upstream (Adam's Bridge) and downstream (Moggill, Centenary Bridge and Brisbane) do not match the exact peak of the event due to concerns the Walloon gauge level near the flood peak may have been influenced by backwater (e.g. backwater from Warrill Creek) and hence overestimated the rated flow.

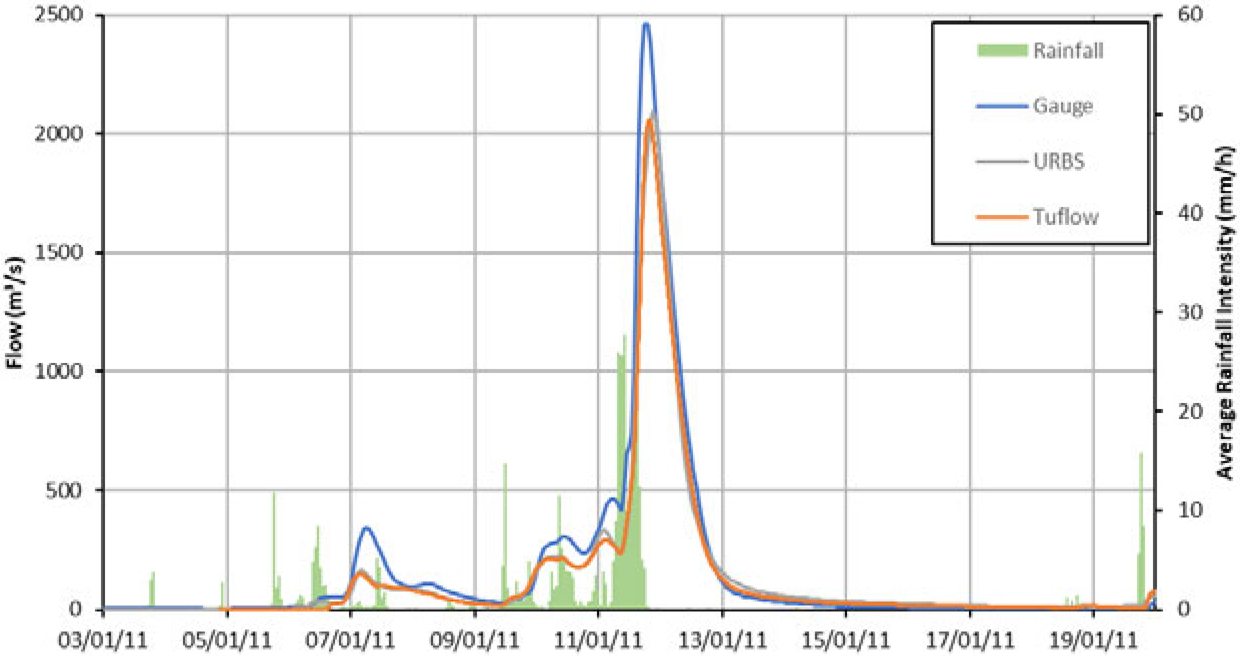


Figure 7.11 Comparison of URBS, TUFLOW and stream gauge hydrographs at Walloon for the 2011 flood

ICC provided a number of flood markers in the Bremer River catchment for the 2011 event. These recorded levels have a range of accuracies based on their source. Of these markers 47 were relevant for the Western Creek catchment. The flood markers are presented in Appendix A Figure A2-B.

In general, 74 per cent of the flood marker points are within 300 mm of the hydraulic results. Further to this 93 per cent of the flood markers are within 500 mm of the hydraulic results. The remaining three flood markers appear to be outliers. The distribution of these calibration points is outlined in Figure 7.12.

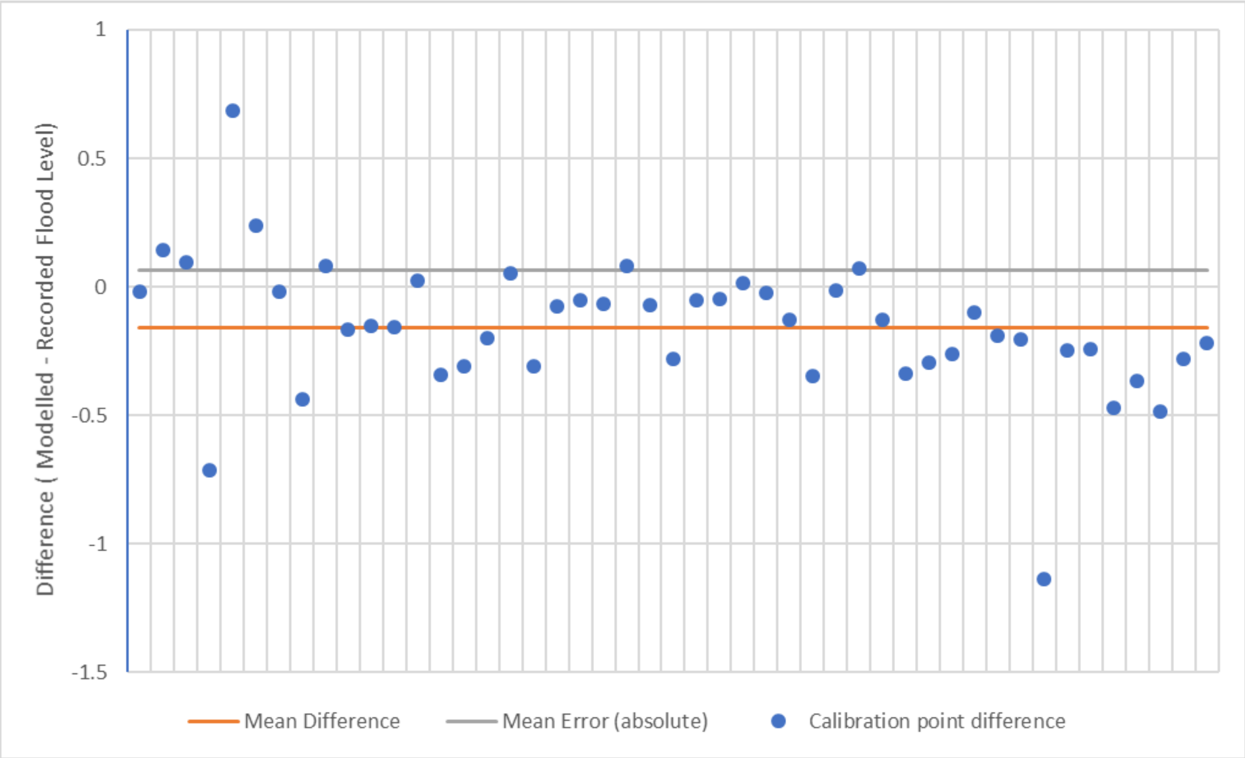


Figure 7.12 Western Creek 2011 – Flood Marker Difference

7.8.3 January 2013

The 2013 flood was caused by prolonged, wide-spread rainfall producing a single flood peak in the lower Bremer catchment. The rainfall event consisted of several days of light rainfall followed by nearly a day of relatively consistent rainfall. While moderate rainfall occurred several days prior to the 2011 flood, the 2013 flood occurred on a very dry catchment. Significant rainfall (>150 mm) occurred before any runoff was observed. The URBS and recorded hydrograph at the Adam's Bridge gauge in Figure 7.13 show good match of the hydrograph shape, noting that the loss parameters are not specifically selected for this site.

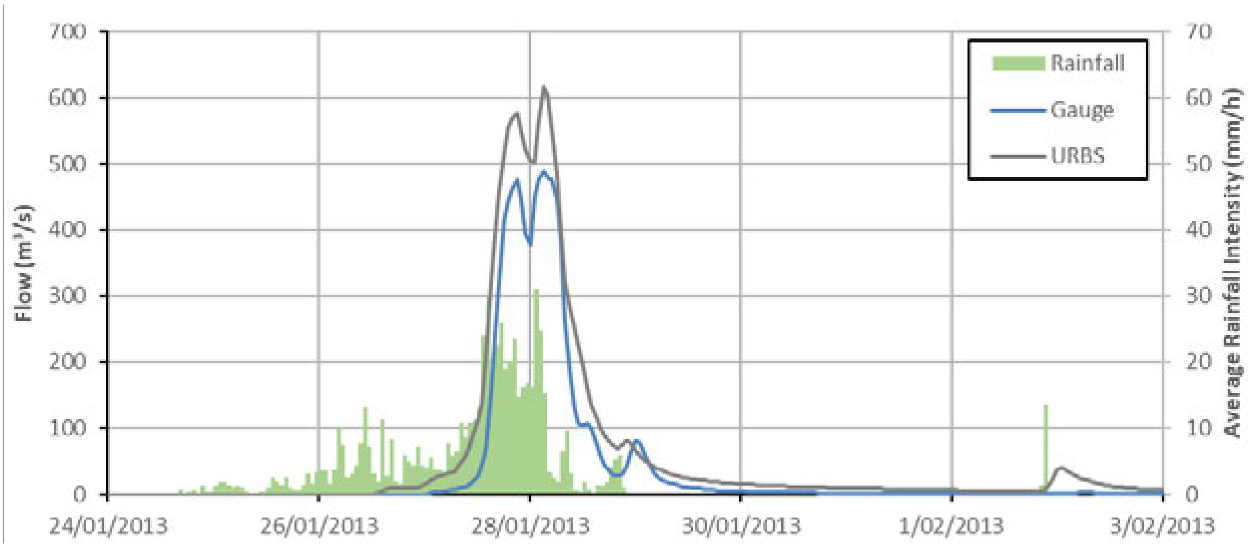


Figure 7.13 Comparison of URBS and stream gauge hydrographs at Adam's Bridge for the 2013 flood

Flood levels at Kuss Road on Western Creek were recorded by the new DNRME gauge. Rated flows using the current DNRME rating are compared with the URBS and TUFLOW hydrographs in Figure 7.14. The rated hydrograph shows a good match of the timing, but predicts significantly lower flows for the flood peak, suggesting either a poor extrapolation of the rating, or that the rating curve only estimates in-channel flows. The TUFLOW model does not include the Kuss Road bridge, hence the model underestimates peak levels by approximately 0.5 m (refer Figure 7.5).

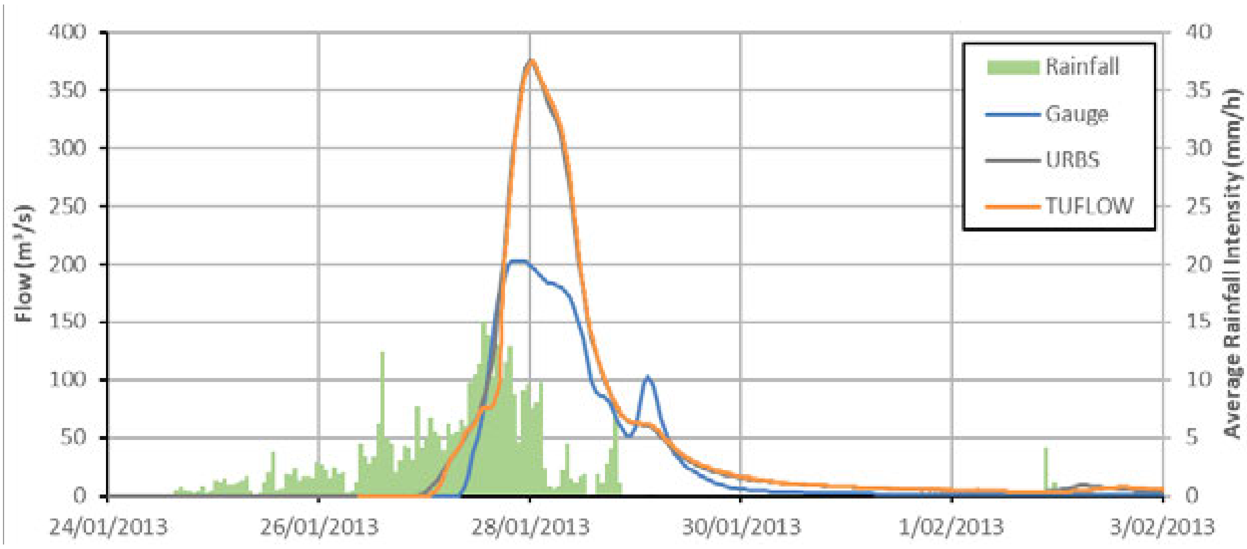


Figure 7.14 **Comparison of URBS, TUFLOW and stream gauge hydrographs at Kuss Road for the 2013 flood**

URBS and TUFLOW hydrographs for the 2013 event at Walloon are compared in Figure 7.15. As with other mid-sized floods (<1,400 m³/s) there is a slight offset between the modelled hydrographs. Although the models do not exactly match the recorded 'spike' at the peak of the flood, the overall shape of the hydrograph is well represented.

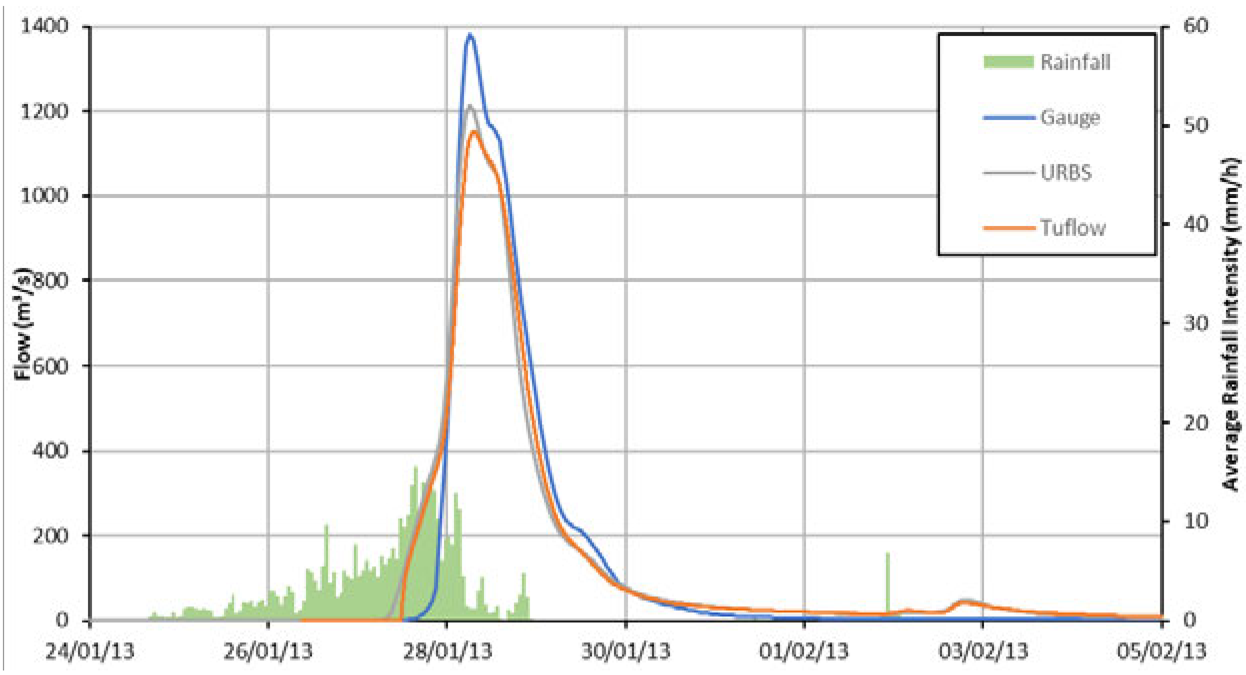


Figure 7.15 **Comparison of URBS, TUFLOW and stream gauge hydrographs at Walloon for the 2013 flood**

7.9 Warrill Creek joint calibration results

The Warrill Creek TUFLOW model set up is presented Appendix B Figure B1-C. Initial roughness parameters for the TUFLOW model were based on the BMT (current) Bremer River Flood Study and confirmed using aerial imagery. Parameter values were confirmed by comparing the model's hydraulic performance at the Amberley gauge. Amberley has a reliable rating based on flow measurements in excess of 900 m³/s (at the gauge site), although this is complicated by breakout of high flows around the gauge site. The TUFLOW model results show minor differences for low flows (<100 m³/s). Two likely factors that may contribute to this difference are the 10 m grid resolution of the model and the adoption of a single composite roughness factor for the main channel (Warrill Creek appears to have a relatively clear channel invert with heavier vegetation on the banks). The Project hydraulic assessment is focussed on larger flows, so these differences are not considered to be significant. A good match of the BRCFS rating, as shown in Figure 7.16, is achieved for moderate to high flows, including those that pass around the gauge site (reported flow is the total including breakout). Adopted hydraulic roughness parameters are listed Table 7.6. It should be noted that, as with the ratings, these values are understood to be indicative of typical creek/catchment conditions and may be different during any individual flood event.

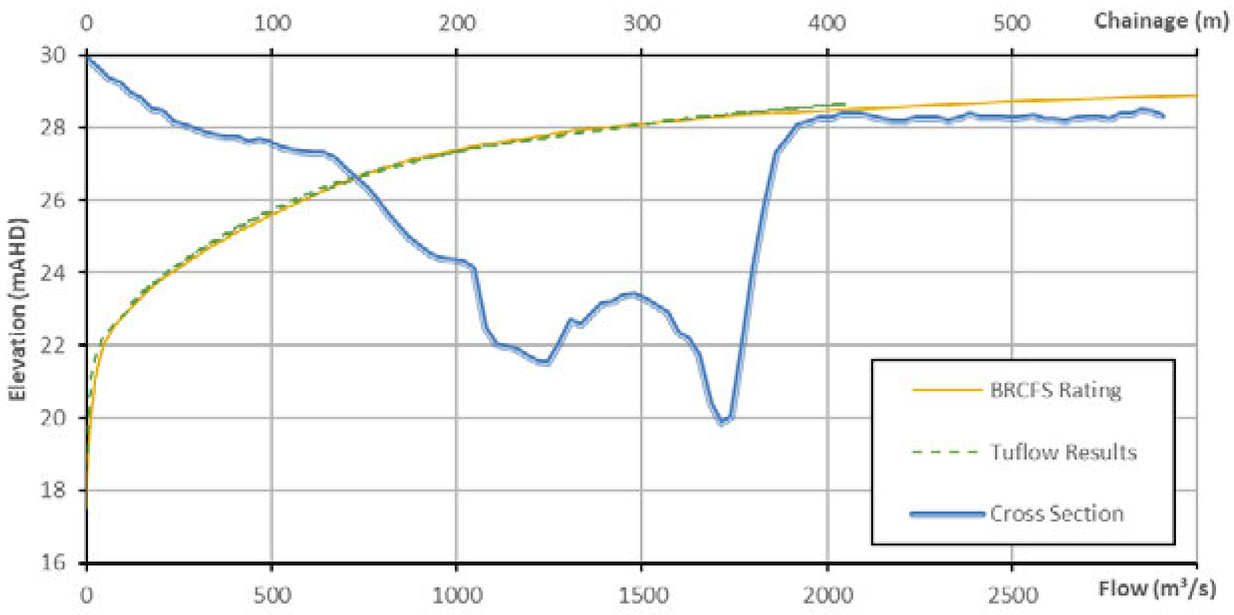


Figure 7.16 Comparison of TUFLOW flow-depth relationship with Amberley rating

Table 7.6 Warrill Creek Manning's roughness parameters

Land use	Manning's n
Non-Tidal Waterway	0.030
Grassland (Long)	0.040
Light Vegetation	0.040
Agricultural Fields/Parks	0.035
Dense Vegetation	0.100
Very Dense Vegetation	0.150
Rough Pasture/Light Brush	0.060
Roads/Car Parks	0.025
Medium Density Urban Block	0.100
Mining	0.070

7.9.1 January 1974

The 1974 flood is the largest flood known to have occurred in the Warrill Creek catchment. Rainfall data for the 1974 flood is relatively limited. When compared against the gauged flows at Amberley in Figure 7.17, although the duration of the flood is overestimated, the URBS and TUFLOW models nevertheless represent the shape of rising and falling limbs relatively well. Little other reliable data is available to further validate the hydraulic model for this event. The gauge at Harrisville is upstream of Amberley, and does not have a reliable rating, but serves to confirm that the model matches the timing of the front of the flood but persists for too long, as shown in Figure 7.18.

Comparing the flood routing performance of the URBS hydrologic and TUFLOW hydraulic models, the routing is virtually identical for flows below 300 m³/s. For higher flows, the TUFLOW model tends to lag the URBS flows by approximately 2 hours. This lag appears to become slightly more pronounced above 1,500 m³/s. However, it must be noted that flows above ~600 m³/s begin to break out of Warrill Creek approximately 5 km upstream from the Amberley gauge site and overflow into Purga Creek. This lag accounts for some of the difference between the TUFLOW and URBS hydrographs for higher flows. Although the rating includes an allowance for breakout flow, this issue also affects the estimate of a rated flow based on a level at Amberley, as travel time in the main channel is likely to be significantly shorter than shallow overbank flow.

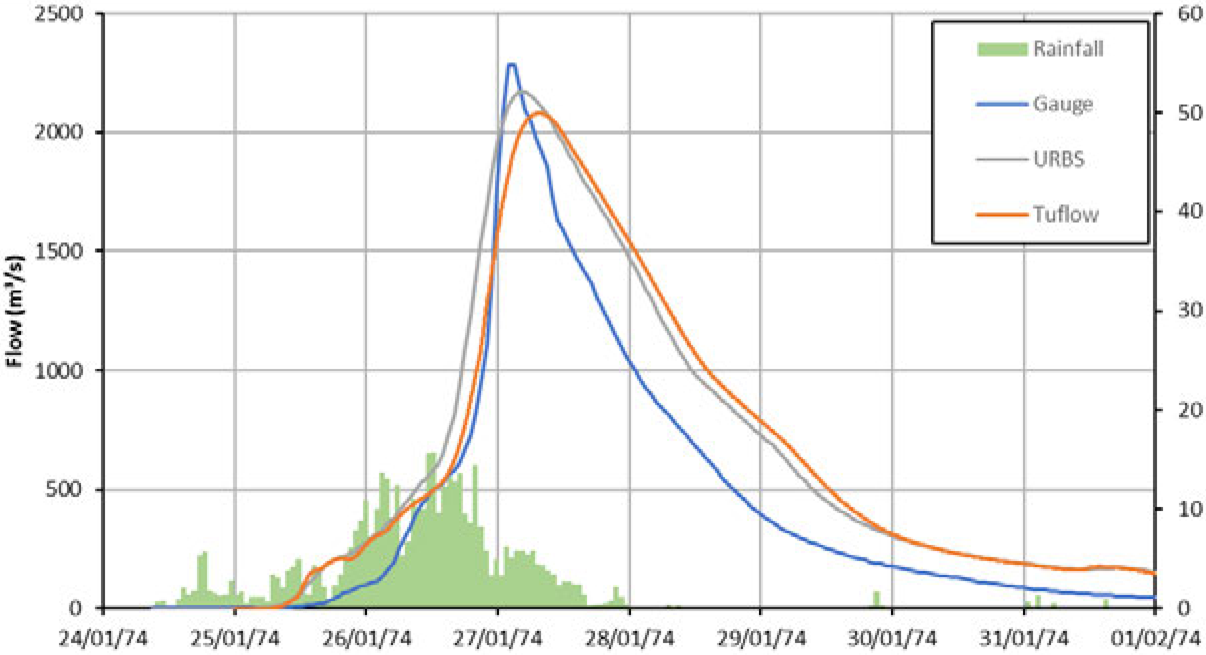


Figure 7.17 Comparison of URBS, TUFLOW and stream gauge hydrographs at Amberley for the 1974 event

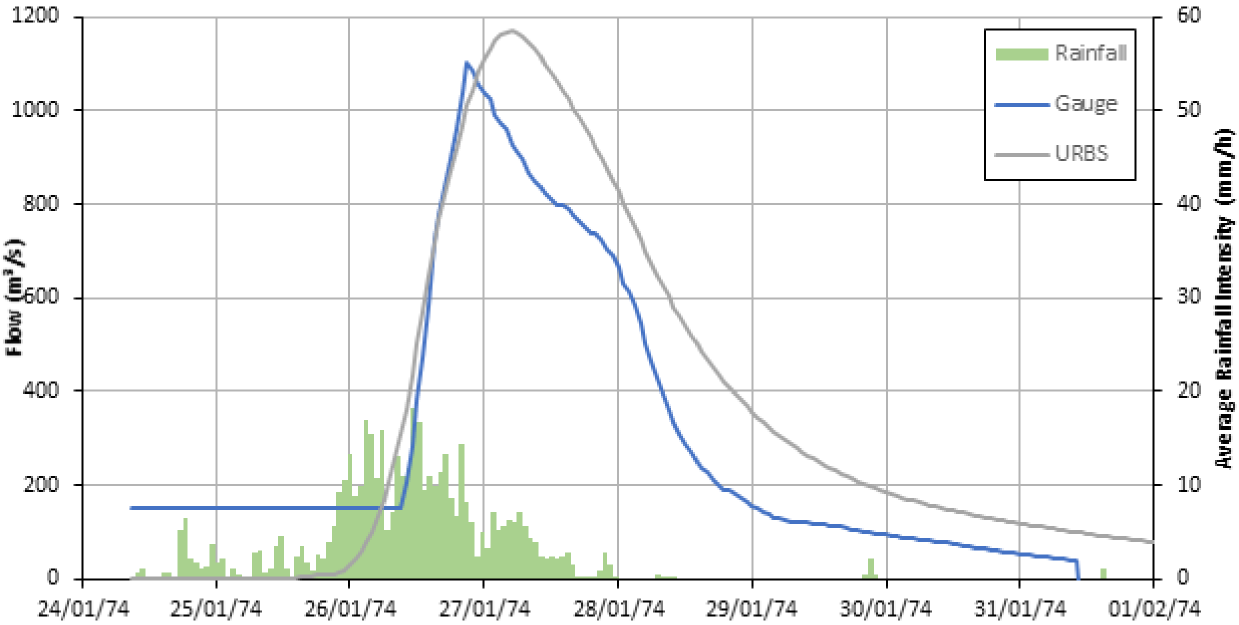


Figure 7.18 **Comparison of URBS and stream gauge hydrographs at Harrisville for the 1974 event**

7.9.2 January 2011

Although a noted flood in the Brisbane River, in Warrill Creek the 2011 flood was significantly smaller than 1974 and smaller than 2013. The 2011 event consisted of several relatively short-duration rainfall bursts. Significantly more rainfall data was available than in 1974 and the URBS model replicates the magnitude, shape and timing of the recorded peak very well, as shown in Figure 7.19. The TUFLOW and URBS hydrographs also match very closely except at the flood peak where the TUFLOW flows are more attenuated. This is potentially related to flows just beginning to break out from the channel upstream of the gauge site.

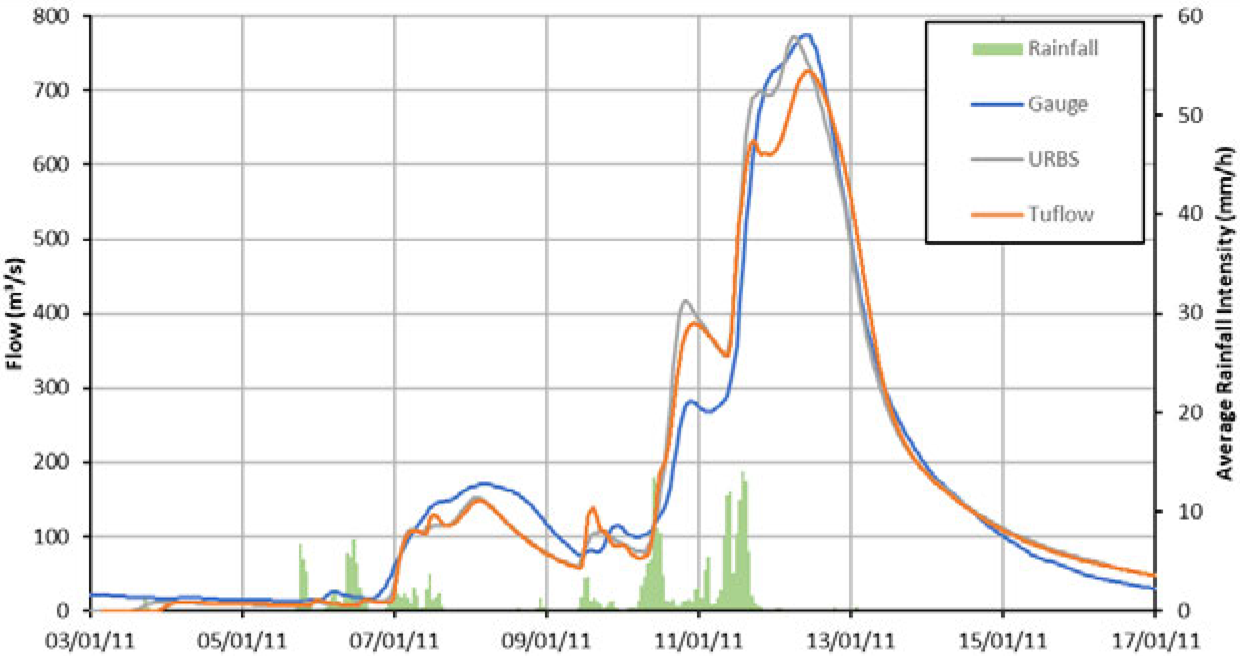


Figure 7.19 **Comparison of URBS, TUFLOW and stream gauge hydrographs at Amberley for the 2011 event**

There is also more data available to confirm the calibration of the hydrologic model. Modelled and rated flows at Junction Weir, which has a relatively reliable rating, are provided in Figure 7.20 as an example.

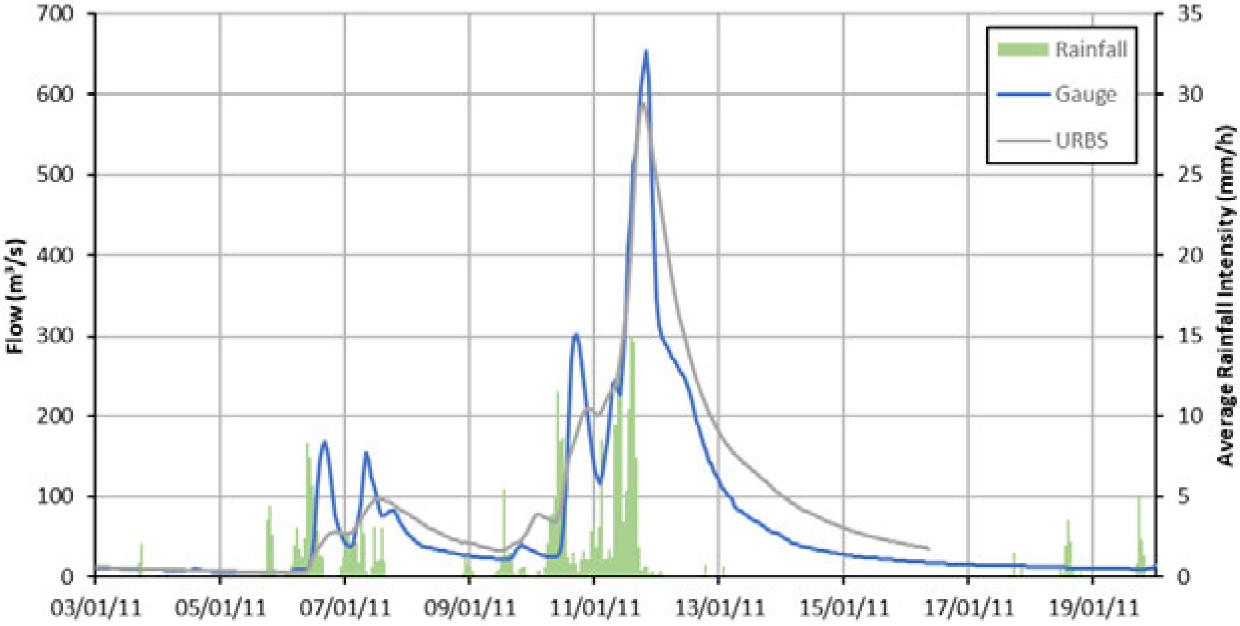


Figure 7.20 **Comparison of URBS and stream gauge hydrographs at Junction Weir for the 2011 event**

7.9.3 January 2013

The 2013 flood is the third largest flood recorded at Amberley, exceeded only by 1974 and a much earlier flood in 1887 (before the construction of Moogerah Dam). The 2013 flood was caused by prolonged, wide-spread rainfall. Although storage levels in Moogerah Dam were high due to 2011 flood and subsequent rainfall, the catchment was nevertheless very dry at the time of the 2013 flood. High initial losses were required to match rainfall and runoff volume. The significant influence of these losses, which may not be uniform across the catchment but are applied as a constant value in URBS, potentially complicates exact matching of the rainfall and runoff. Nevertheless, the models provide a reasonable match of the hydrograph magnitude, shape and timing at Amberley and Junction Weir, as shown in Figure 7.21 and Figure 7.22 respectively.

As with the 1974 event, the TUFLOW flows at Amberley above 300 m³/s tend to lag the URBS flows, becoming more pronounced above 600 m³/s, with the latter likely affected by the breakout of flows upstream of the gauge.

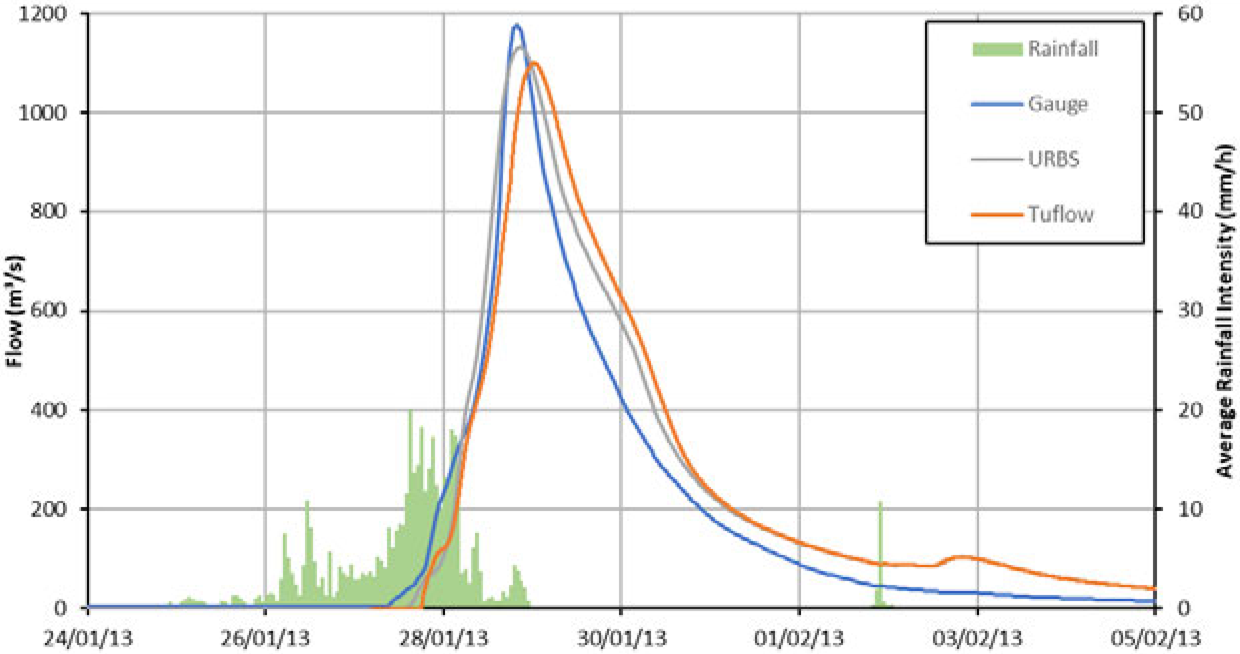


Figure 7.21 **Comparison of URBS, TUFLOW and stream gauge hydrographs at Amberley for the 2013 event**

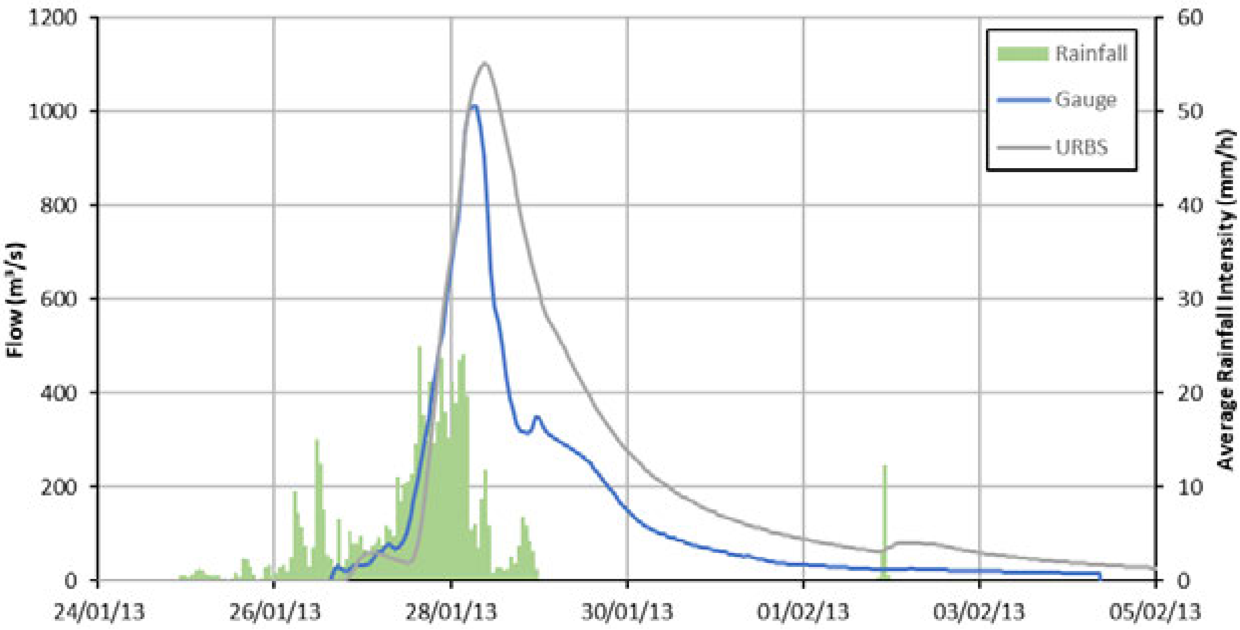


Figure 7.22 **Comparison of URBS and stream gauge hydrographs at Junction Weir for the 2013 event**

7.10 Purga Creek joint calibration results

Initial estimates for roughness were based on the BMT (current) Bremer River Flood Study and confirmed using aerial imagery. The TUFLOW model set up is presented in Appendix C Figure C1-C. Typical hydraulic roughness parameters adopted for Purga Creek are summarised in Table 7.7. It should be noted that, as with the ratings, these values are understood to be indicative of typical creek/catchment conditions and may be different during any individual flood event.

Table 7.7 **Purga Creek Manning's roughness parameters**

Land use	Manning's n
Non-tidal waterway	0.030
Grassland (long)	0.040
Light vegetation	0.060
Agricultural fields/parks	0.035
Dense vegetation	0.120
Very dense vegetation	0.150
Rough pasture/light brush	0.060
Roads/car parks	0.025
Medium density urban block	0.100
Mining	0.070

Suitability of the roughness parameters for the Purga Creek TUFLOW model was confirmed by comparing the hydraulic performance of the model at the Loamside stream gauge. Figure 7.23 shows the relationship between level and flow for the 1974 flood hydrograph. Loamside has the least reliable rating of the three Bremer River tributary catchments, with flows verifiable by in stream flow measurement only up to ~50 m³/s, approximately the main channel capacity. Additionally, the rating becomes increasingly sensitive once flows break out of the main channel. The TUFLOW model shows reasonable agreement with the BRCFS rating curve. The TUFLOW model tends to overestimate levels at low flows (the most reliable part of the BRCFS rating), which may be attributable to the coarse grid size relative to the narrow channel of Purga Creek. However, it shows excellent agreement for larger flows. Model and calibration are therefore considered to be adequate for assessing flows that are of the magnitude of interest to the current study.

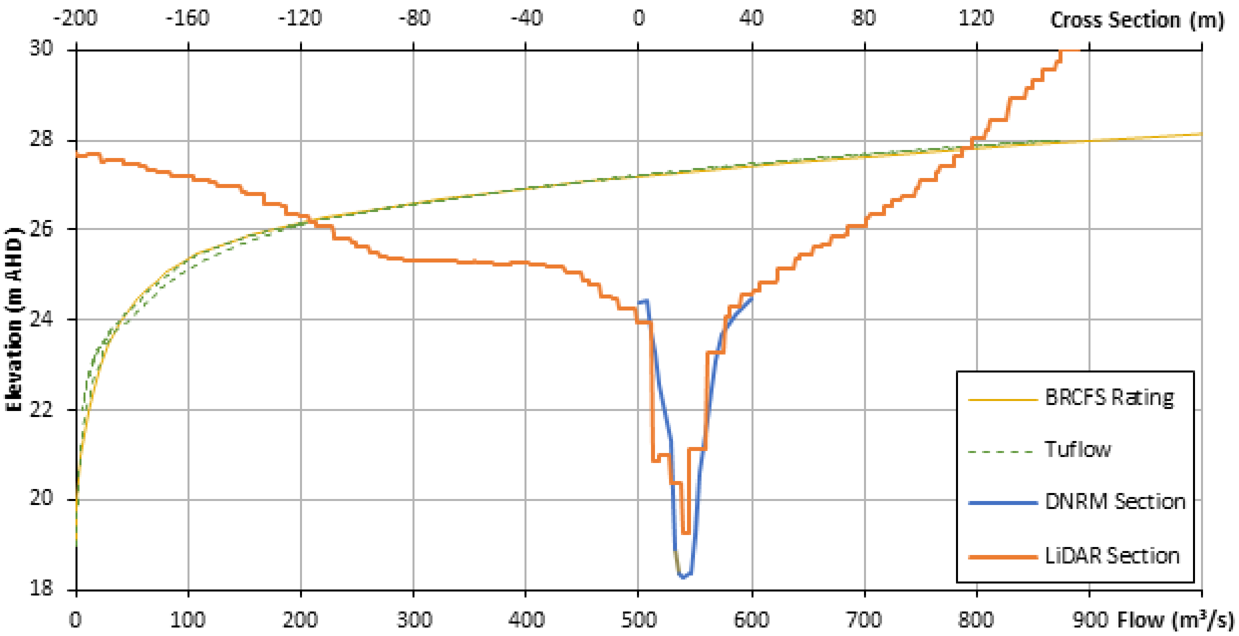


Figure 7.23 Comparison of TUFLOW flow-depth relationship with Loamside rating

A similar comparison was also performed at the Peak Crossing gauge site, shown in Figure 7.24. As discussed in Section 5.5.3, the Peak Crossing site has no official rating. The BRCFS rating was developed based on a simple Manning's equation assessment and is considered highly unreliable. The TUFLOW level-flow relationship deviates significantly from this rating for flows above 100 m³/s but shows good agreement with a power-law fit through the hydrologic model results (URBS model peak flow versus recorded level). This agreement provides positive confirmation of consistency and ability to replicate historical flood flows and levels in both the URBS flow estimates and the TUFLOW roughness parameters.

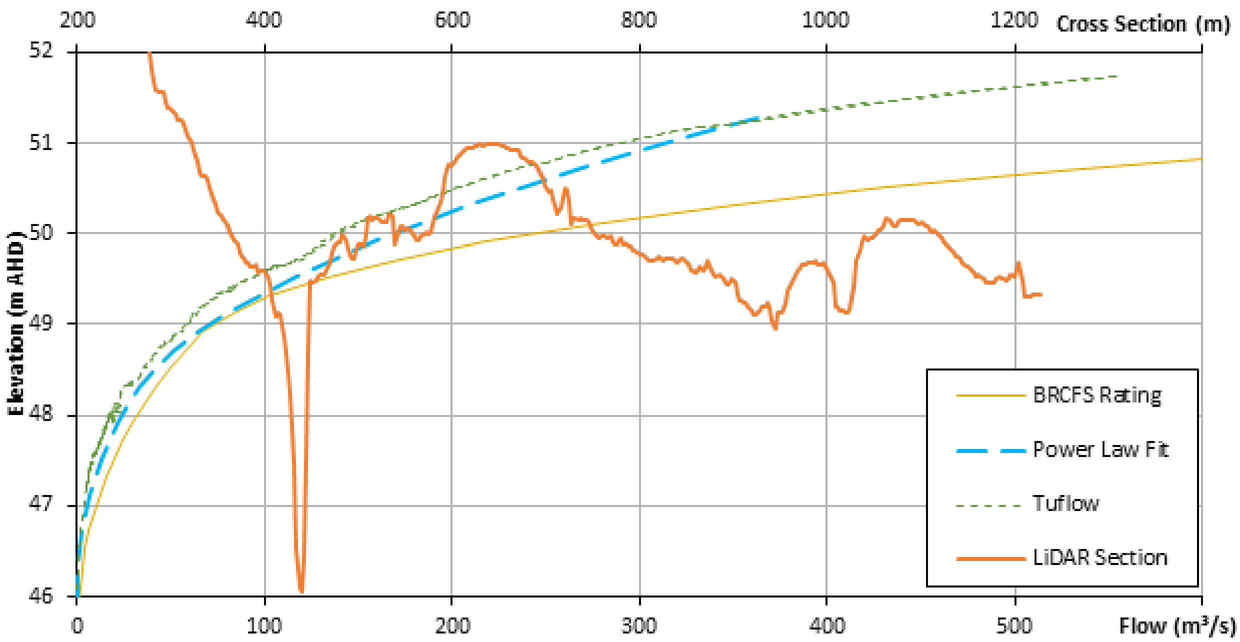


Figure 7.24 Comparison of TUFLOW flow-depth relationship with Loamside rating

7.10.1 January 1974

As discussed in Section 7.2, the 1974 flood is the largest flood known to have occurred in the Bremer River catchment, with a peak flow at Loamside around four times larger than 2011. Purga Creek flows from the URBS and TUFLOW models at Loamside are compared with rated historical flows in Figure 7.25. The ability of the hydrologic model to replicate historical flows at the gauge site is dependent on how well the rainfall data recorded at specific sites within the catchment represents the rainfall that fell across the catchment. Rainfall data within the Purga Creek catchment is relatively sparse, particularly for older flood events. The modelled flows nevertheless show reasonable agreement with the magnitude and timing of the major flood peak.

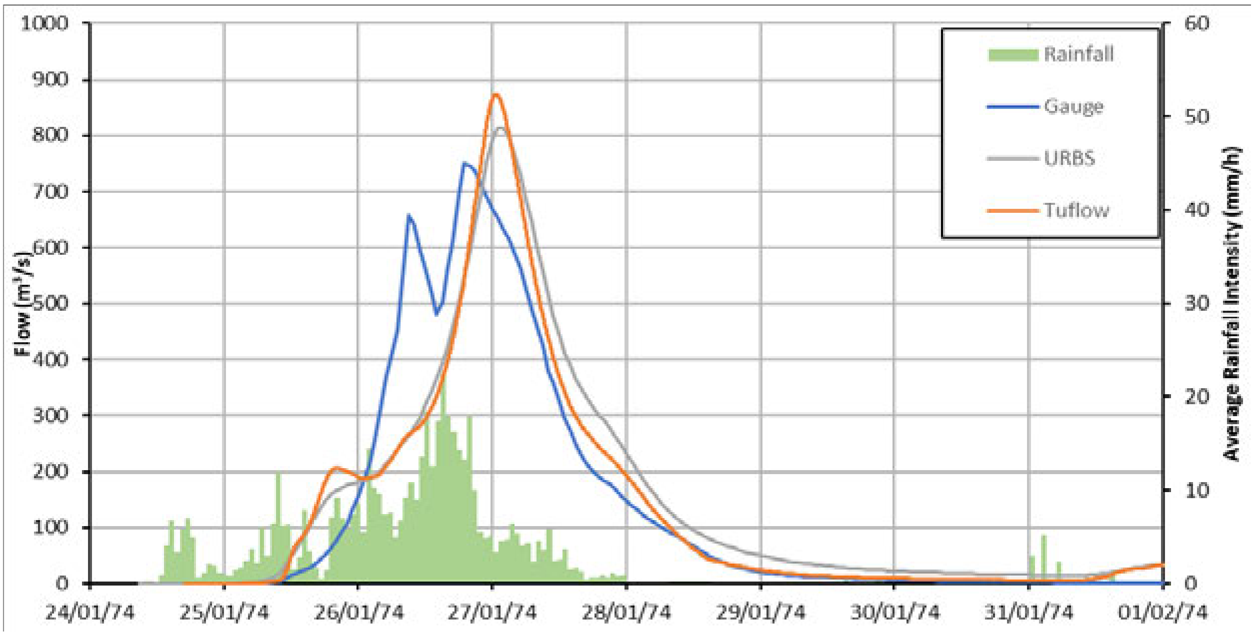


Figure 7.25 Comparison of URBS, TUFLOW and stream gauge hydrographs at Loamside for the 1974 event

The Peak Crossing gauge was not operational in 1974. URBS and TUFLOW hydrographs are compared in Figure 7.26, and show a reasonable match of the magnitude, timing and shape.

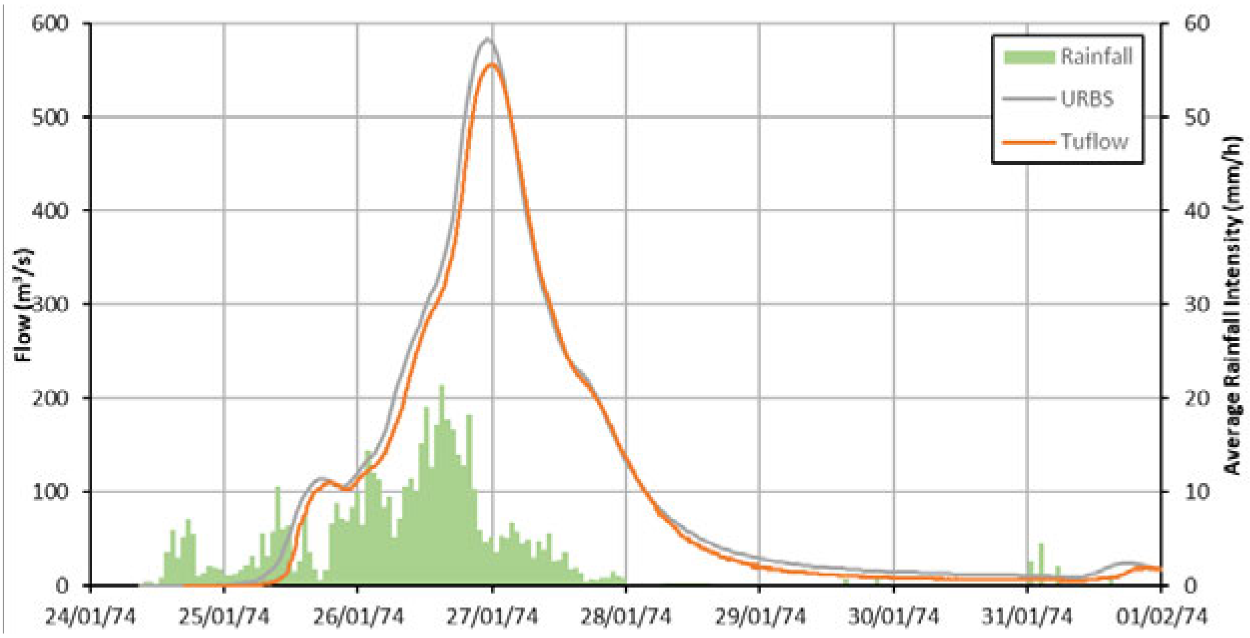


Figure 7.26 Comparison of URBS and TUFLOW hydrographs at Peak Crossing for the 1974 event

Initial comparisons between the TUFLOW and URBS hydrographs identified that the TUFLOW hydrographs tended to lag slightly behind URBS with slight attenuation of the flood peak, and similar trends have been observed with other model's sub-catchment hydrographs that are input into TUFLOW include attenuation and lag due to local catchment storage routing from URBS. Because a 2D hydraulic model does not have a distinct interface between sub-catchment and main-stream routing, this carries the risk of double-counting storage in the lower sub-catchment tributaries. Reducing the sub-catchment lag parameter, β, used to produce TUFLOW local catchment inflows brought forward the TUFLOW hydrograph and reduced the peak attenuation. The TUFLOW model results shown in Figure 7.25 and Figure 7.26 use $\beta = 1.5$ compared to $\beta = 3.8$ for the calibrated URBS model. TUFLOW flows at Loamside are slightly ahead of the URBS hydrograph with less attenuation of the peak, while flows at Peak Crossing lag slightly behind with more attenuation of the peak. While the adopted values therefore do not match exactly either location, they are considered to give a reasonable balance.

7.10.2 January 2011

Although still a relatively large flood, several larger events have been recorded in Purga Creek (1976, 1996, 2009) as well as several of similar size to 2011. The 2011 flood event was the combination of several distinct, scattered rainfall bursts across 10 and 11 January. The localised nature of the rainfall makes it difficult to obtain a reliable representation of rainfall across the catchment and this is typified by the 2011 flood producing a higher recorded peak than the 2013 flood at the Loamside gauge, but a lower peak at the Peak Crossing gauge. Nevertheless, the URBS and TUFLOW models show a good ability to replicate the timing and shape of the recorded hydrographs at both Loamside and Peak Crossing, shown in Figure 7.27 and Figure 7.28 respectively.

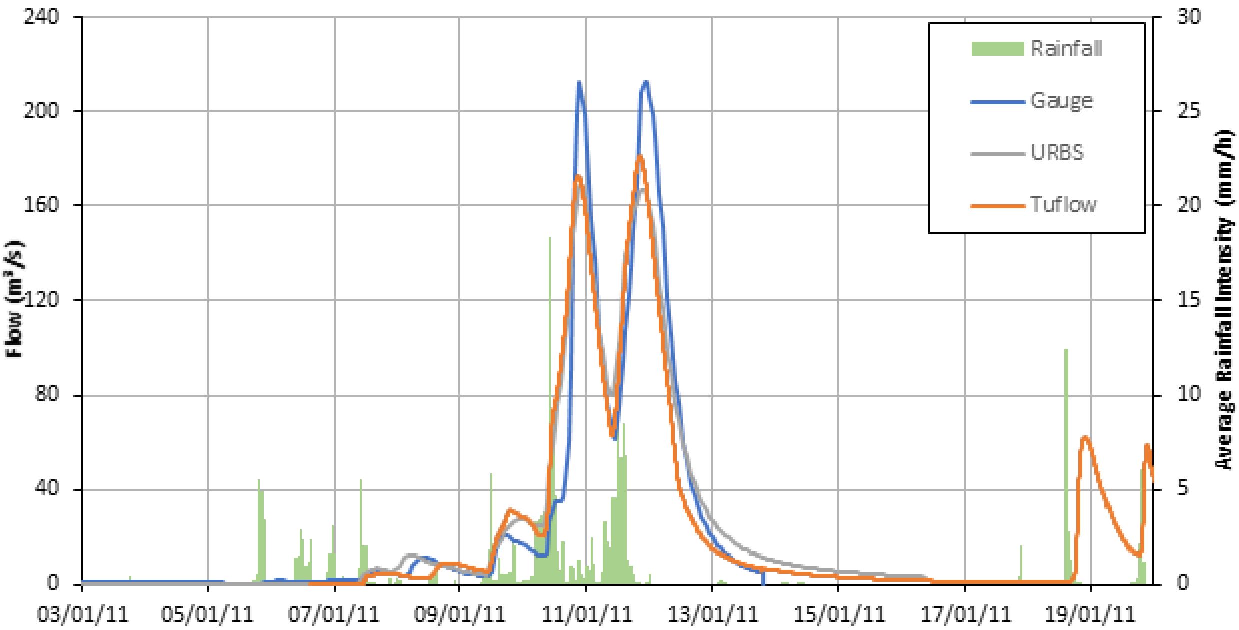


Figure 7.27 Comparison of URBS, TUFLOW and stream gauge hydrographs at Loamside for the 2011 event

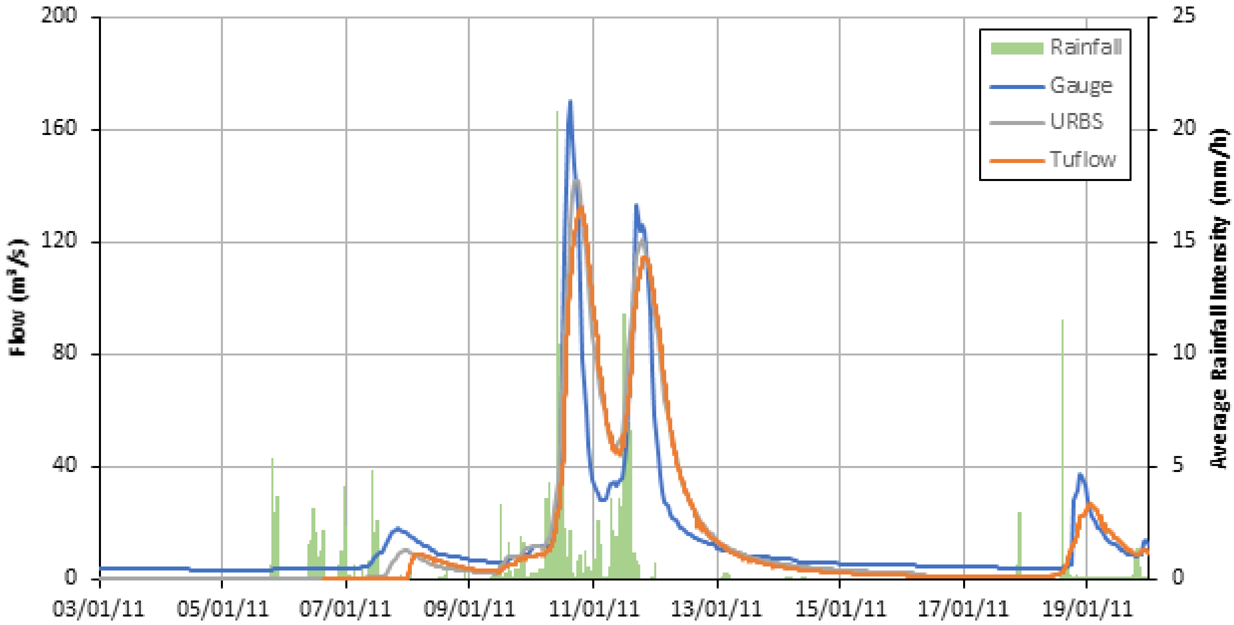


Figure 7.28 Comparison of URBS, TUFLOW and stream gauge hydrographs at Peak Crossing for the 2011 event

7.10.3 January 2013

Unlike the 2011 flood, the 2013 flood was caused by prolonged, widespread rainfall producing a single flood peak in the lower catchment. The 2013 flood occurred on a very dry catchment and significant rainfall (>150 mm) occurred before any runoff was observed. Although the more northerly Bremer River catchment received nearly a day of relatively consistent rainfall following several days of light rainfall (refer Section 7.8.3), rainfall on the Purga Creek catchment appears to have contained a shorter burst lasting a few hours. It is possible that the limited rainfall gauges in the Purga Creek catchment did not record the total rainfall that fell on the catchment, as the modelled URBS hydrograph produces a shorter, sharper peak than was observed at the Loamside gauge, as shown in Figure 7.29.

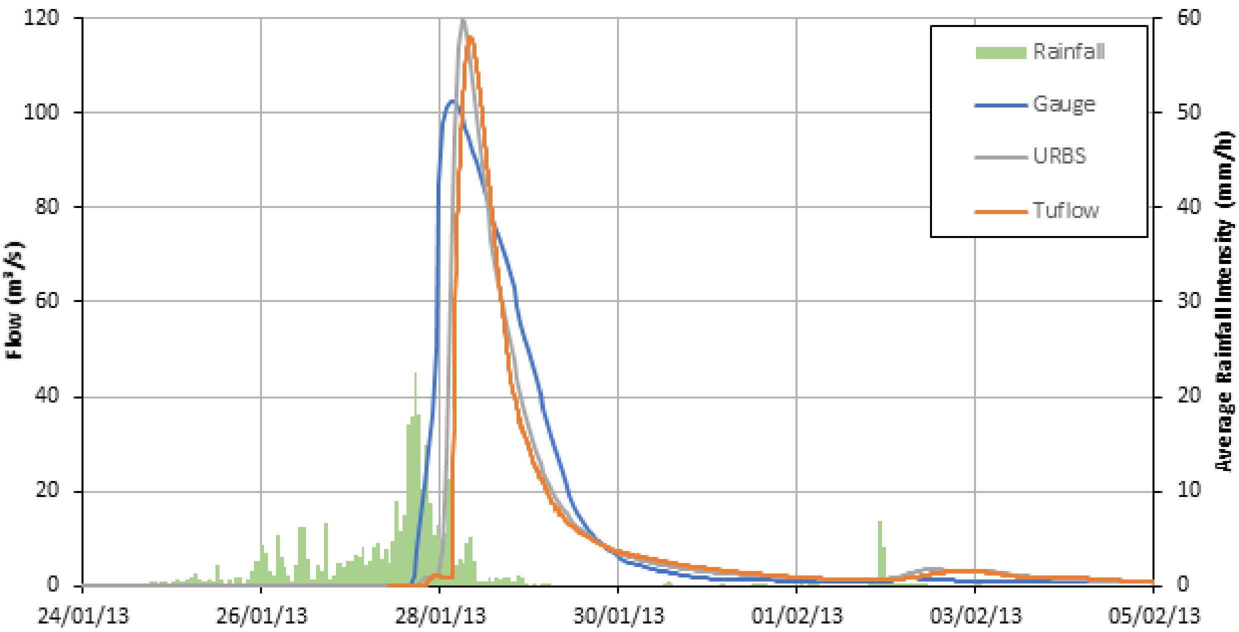


Figure 7.29 Comparison of URBS, TUFLOW and stream gauge hydrographs at Loamside for the 2013 event

The 2013 flood produced a higher and longer flood at Peak Crossing than the 2011 flood. Due to the inaccuracy of the gauge rating at high flows, flood levels from the TUFLOW model are compared with recorded levels in Figure 7.30. The TUFLOW model underestimates the peak flood level, although this is not unreasonable considering the uncertainty in the rainfall data and that model losses were not specifically calibrated to this site. Conversely, water levels are overestimated on the receding limb of the flood. This largely corresponds to relatively low flows (<20 m³/s) when the flow is fully contained within the channel and is likely attributable to the coarseness of the model grid relative to the narrow Purga Creek channel at Peak Crossing.

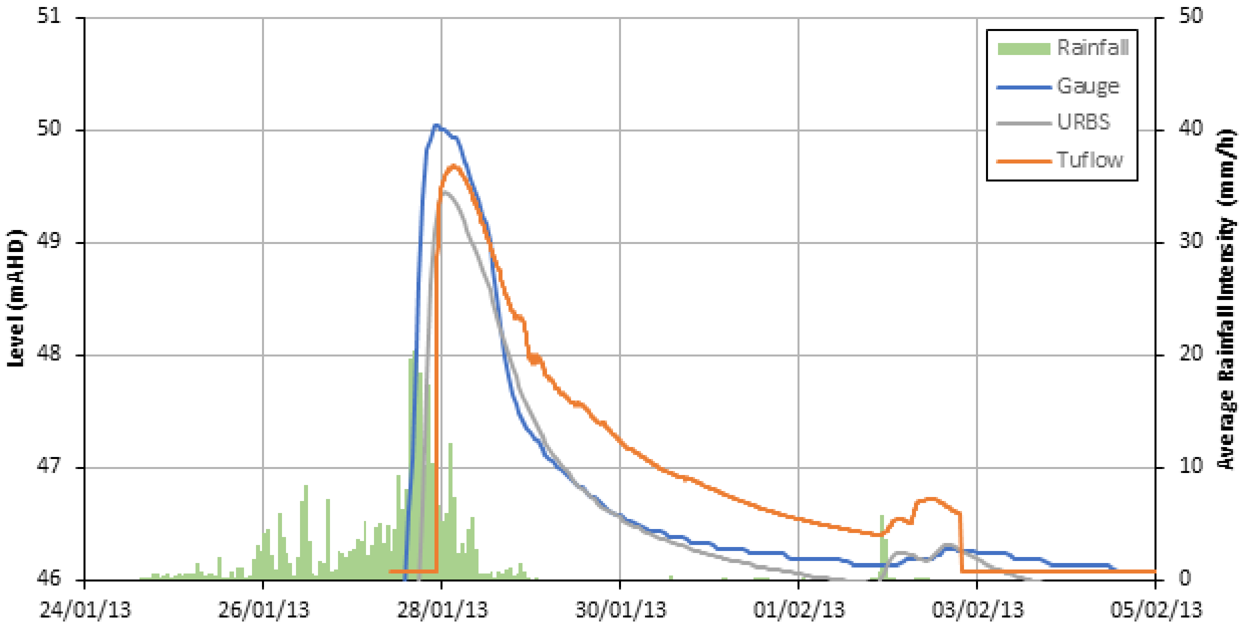


Figure 7.30 **Comparison of URBS, TUFLOW and stream gauge flood levels at Peak Crossing for the 2013 event**

7.11 Teviot Brook joint calibration results

Initial estimates for roughness were based on aerial imagery and the regional Teviot Brook TUFLOW model. These values were refined using parameters in line with Purga and Warrill Creeks. The TUFLOW model set up is presented Appendix D Figure D1-C. Typical roughness parameters adopted for Teviot Brook are summarised in Table 7.8. There was no gauge within the hydraulic model extent to further validate hydraulic roughness parameters.

Table 7.8 **Teviot Brook Manning's roughness parameters**

Land use	Manning's n
Non-tidal waterway	0.030
Waterbodies	0.025
River Bank vegetation – medium density	0.090
Grassland (long)	0.040
Light vegetation	0.040
Roads/car parks	0.025
Mining	0.070

7.11.1 January 1974

For the 1974 event there is a good match in terms of both shape, volume and peak flow at the Overflow gauge, shown in Figure 7.31. RAFTS over-estimates the falling limb of the hydrograph but this will not affect peak flows.

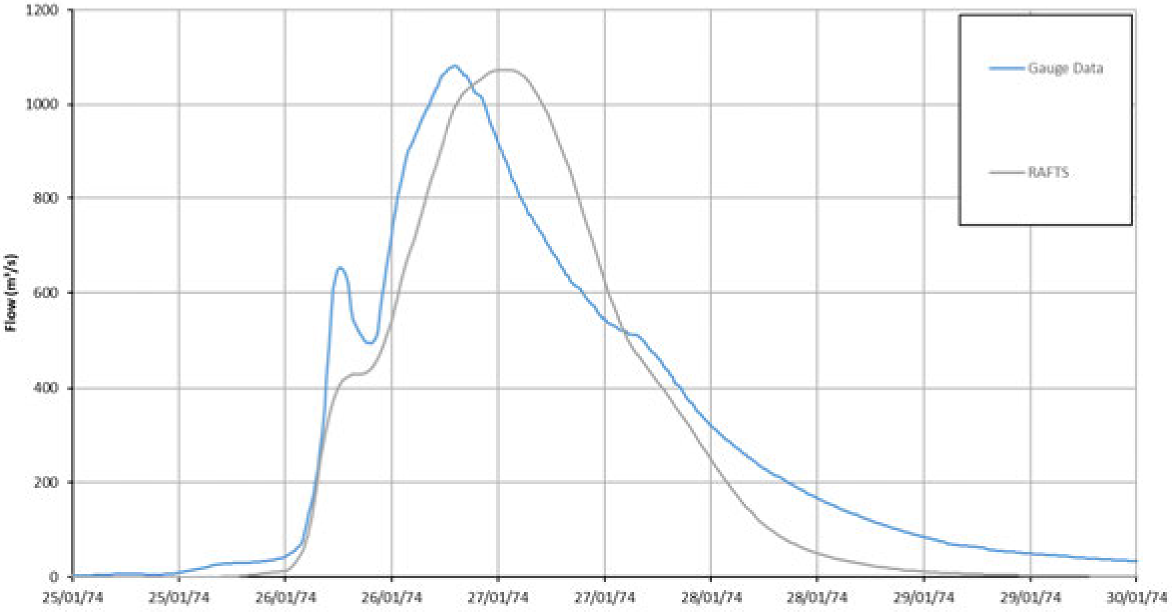


Figure 7.31 **Comparison of RAFTS and Gauge hydrographs at Overflow for the 1974 event**

7.11.2 April 1990

At the Overflow stream gauge was a smaller event being approximately a 20% AEP event. For the 1990 event the peak flow is similar, but the hydraulic model appears to attenuate more water on the rising limb as seen in Figure 7.32.

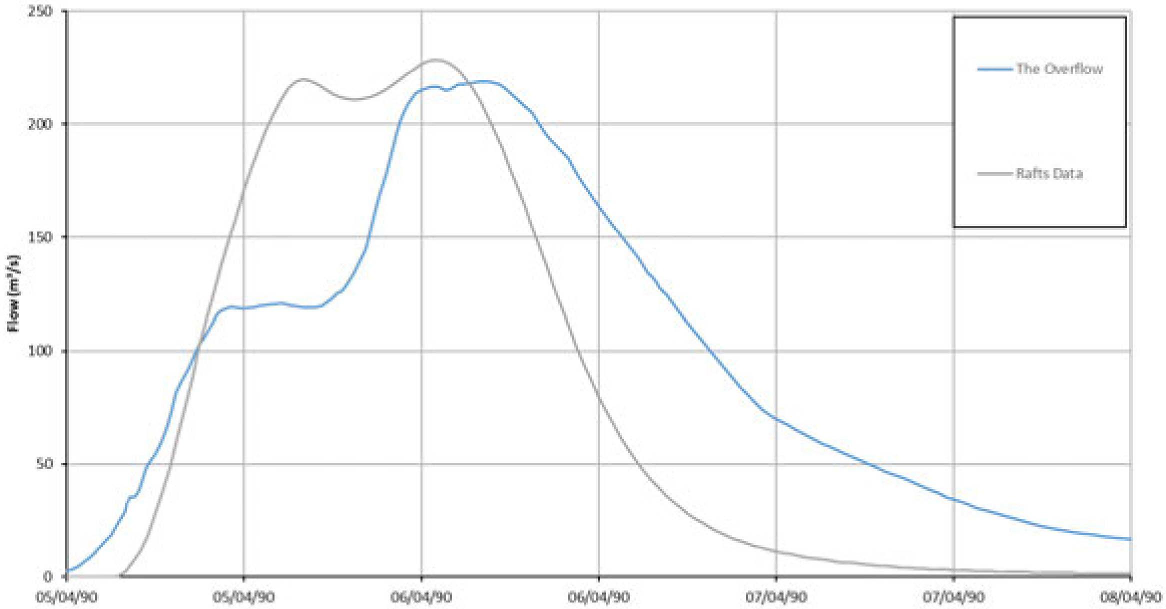


Figure 7.32 **Comparison of RAFTS and Gauge hydrographs at Overflow for the 1990 event**

7.11.3 January 2013

In 2013 the Overflow stream gauge failed. The RAFTS model estimated the peak flow to be over 700 m³/s at the peak of the event as seen in Figure 7.33. SRRC provided a flood marker at Undullah Road at Brookland Bridge for the 2013 event as seen in Appendix D Figure D2-C. This marker is directly upstream of the Project alignment. The flood marker value was 33.21 m AHD at the bridge with the modelling results predicting 33.25 m AHD.

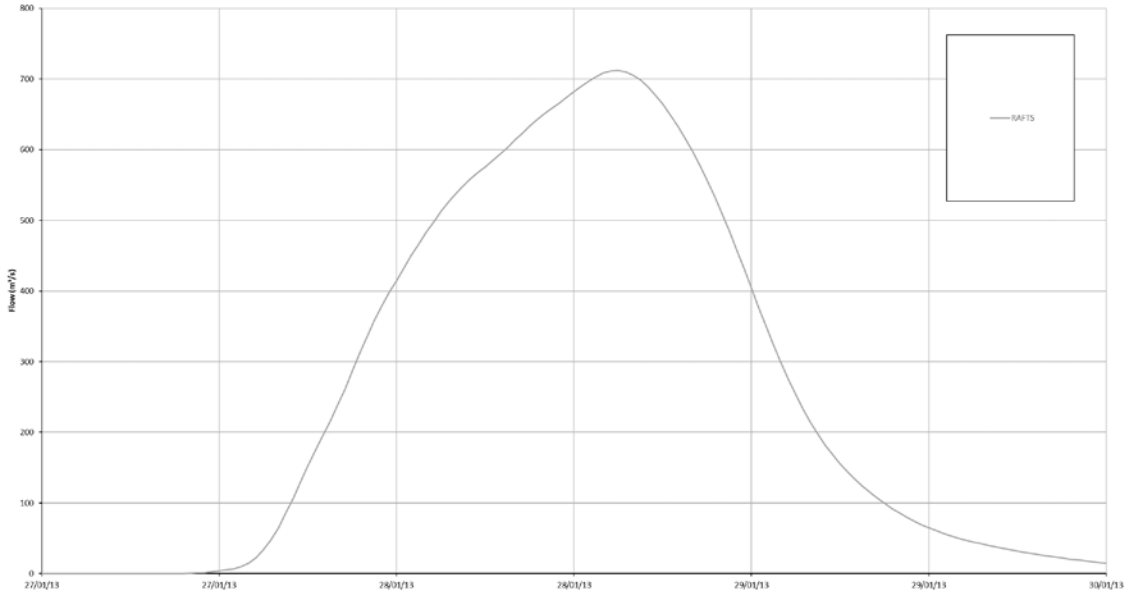


Figure 7.33 RAFTS hydrograph at Overflow for the 2013 event

7.12 Logan River TUFLOW sub-model calibration results

The Logan River sub-model was validated to the regional calibrated Logan River model as outlined in Section 6.7. The results from the sub-model are slightly different due to the TUFLOW HPC solution scheme so the hydraulic roughness parameters were refined to improve the match with the calibration data. The changes to the roughness values in the sub-model are listed in Table 7.9. The TUFLOW model results were compared at the Yarrahapinni stream gauge for the calibration events. The hydraulic sub-model results are slightly more conservative than the results from the regional hydraulic model as seen in Figure 7.34.

Table 7.9 Logan River Manning's roughness parameters

Land use	Regional	Sub-Model
Main channel	0.07	0.08
Floodplain	0.06	0.07

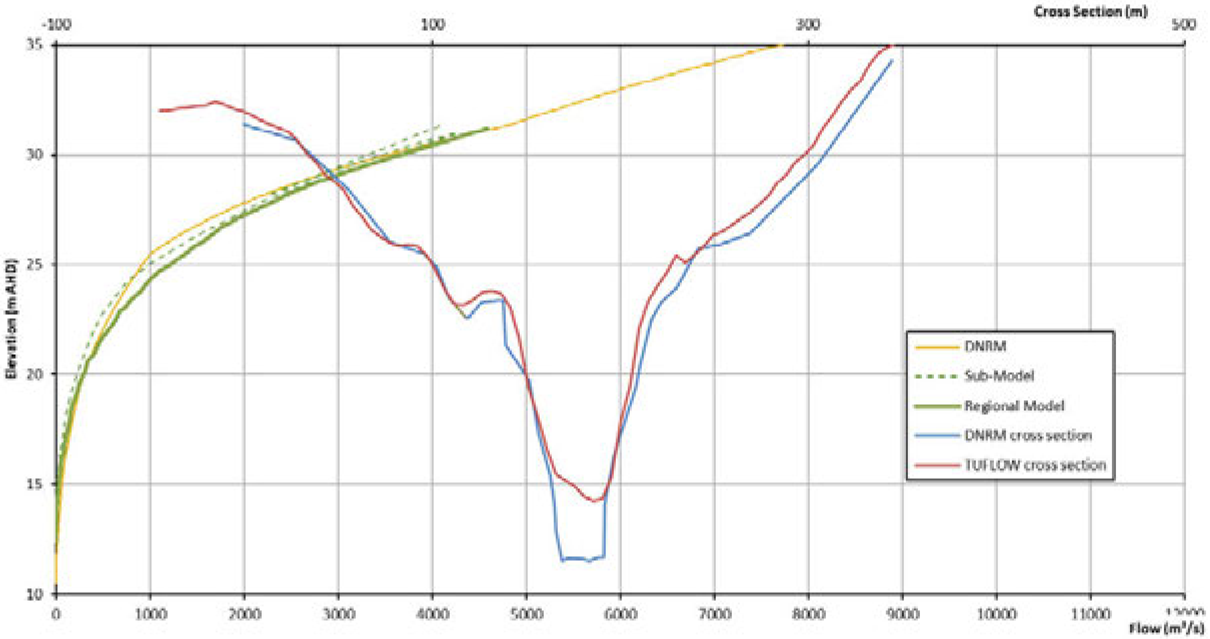


Figure 7.34 Comparison of Rating Curve at Yarrahapinni gauge

The sub-model was validated against the regional model for the 1974, 1990 and 2013 events as seen in Figure 7.35 to Figure 7.37. No changes to the regional hydrology files were undertaken. These figures show that the sub-model in the TUFLOW HPC scheme is appropriately replicating the performance of the calibrated regional model.

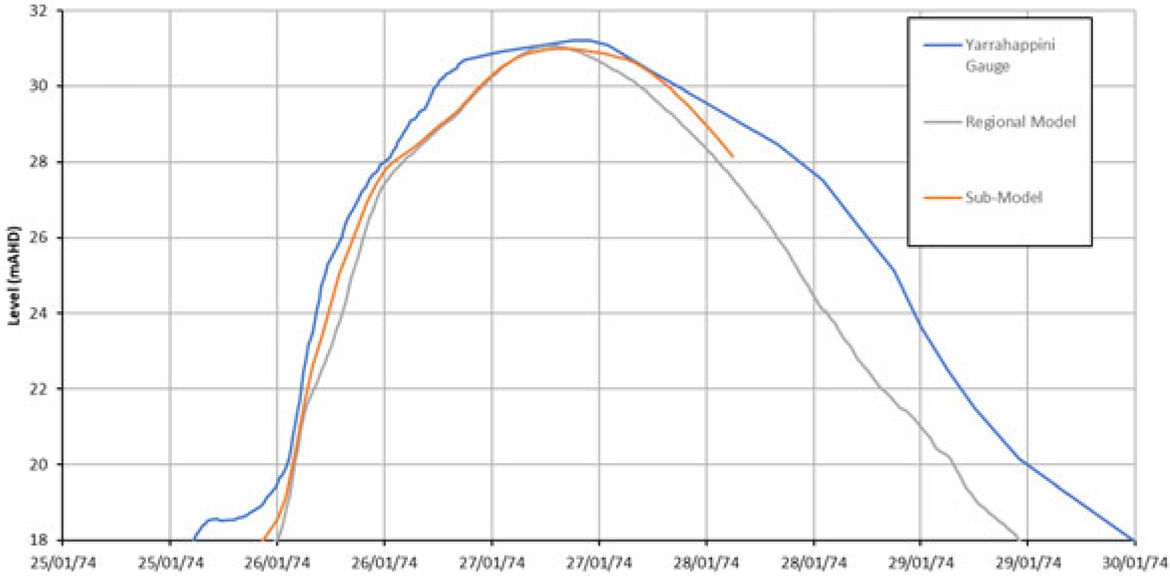


Figure 7.35 **Comparison of Regional, Sub-model TUFLOW and stream gauge flood levels at Yarrahapinni for the 1974 event**

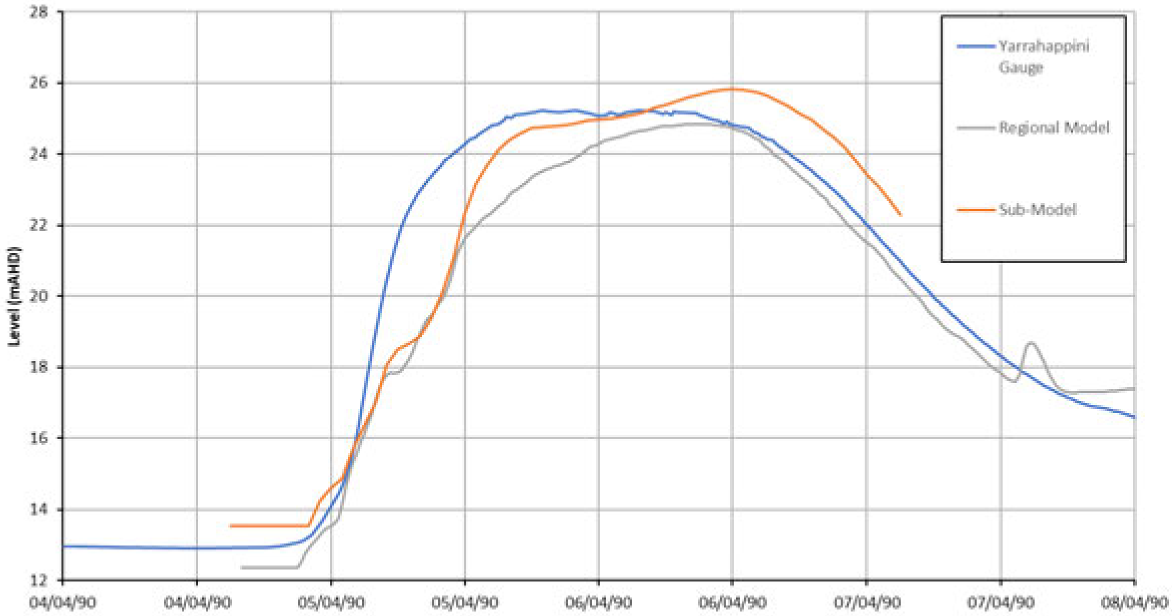


Figure 7.36 **Comparison of Regional, Sub-model TUFLOW and stream gauge flood levels at Yarrahapinni for the 1990 event**

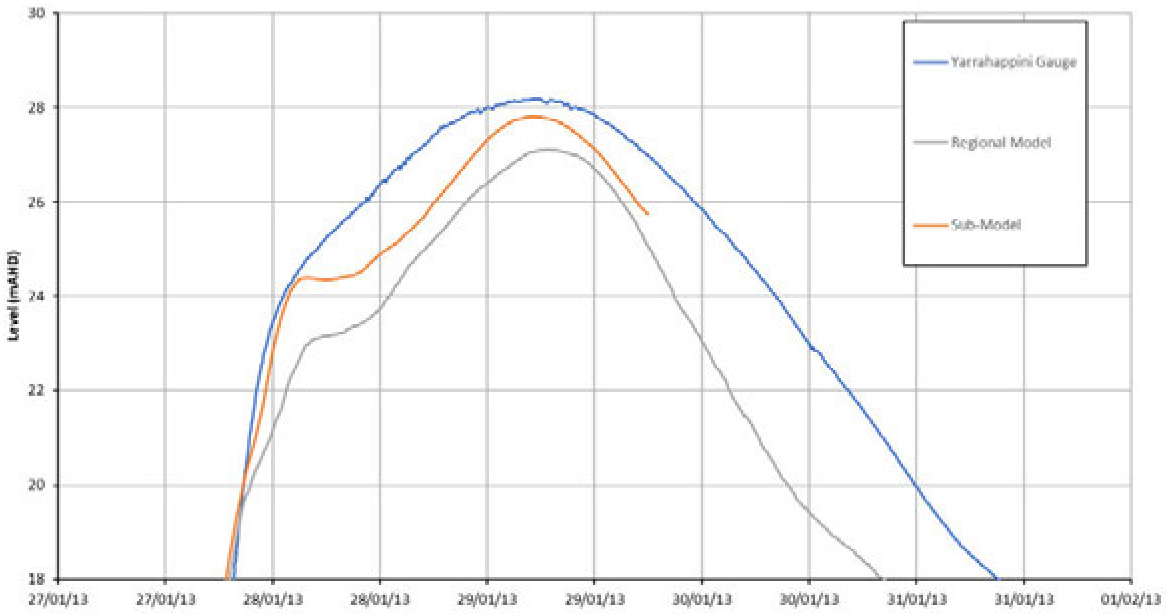


Figure 7.37 **Comparison of Regional, Sub-model TUFLOW and stream gauge flood levels at Yarrahapinni for the 2013 event**

7.13 Estimation of Annual Exceedance Probability

For each of the major stream gauges the AEP of each event has been estimated and is outlined in Table 7.10 and Table 7.11.

Table 7.10 **AEP of historical events – Brisbane River catchments**

Stream gauge	Historical event AEP (Peak discharge (m³/s))		
	Jan 1974	Jan 2011	Jan 2013
Walloon	~0.5% (2,282)	~0.6% (2,084)	~8% (1,163)
Loamside	~0.1% (873)	~23% (181)	~33% (116)
Amberley	~1.4% (2,080)	~11.5% (726)	~5.7% (1,099)

Table 7.11 **AEP of historical events – Teviot Brook catchment**

Stream gauge	Historical event AEP (Peak discharge (m³/s))		
	Jan 1974	Apr 1990	Jan 2013
Overflow	~4% (1,073)	~23% (229)	~6% (712)
Yarrahapinni	~1.4% (4,273)	~16.9% (1,248)	~6.6% (2,230)

To gain an understanding of the potential Project impacts relative to these historical events, the estimated AEP for each historical event can be compared to the results for the design events (e.g. 1% AEP) documented in Section 9.

7.14 Calibration model comparison

A summary of available peak recorded gauge levels for each of the primary gauges is presented in Table 7.12. Modelled levels for the hydrologic (URBS) and hydraulic (TUFLOW) models are also included in the table for reference.

It is noted that the gauge locations for Teviot Brook and Logan River are outside of the Project modelled area and are therefore not included in this table.

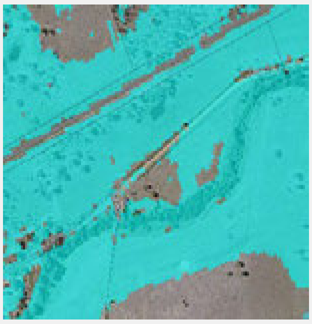
Table 7.12 Historical level comparison

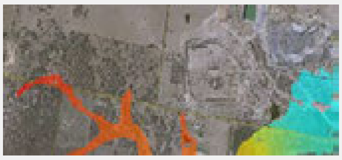
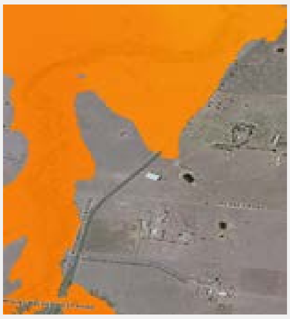
Year of record	Gauge	Recorded gauge level (m AHD)	Modelled URBS gauge level (m AHD)	Modelled TUFLOW level (m AHD)
1974	Amberley	28.62	28.64	28.65
1974	Loamside	27.73	28.06	28.01
2011	Walloon	27.68	27.34	27.20
2011	Amberley	26.81	27.00	26.68
2011	Peak Crossing	49.71	49.88	50.18
2011	Loamside	26.23	26.29	26.02
2013	Walloon	26.25	25.97	25.87
2013	Amberley	27.71	27.78	27.52
2013	Peak Crossing	50.04	49.81	49.80
2013	Loamside	25.42	26.10	25.45

7.15 Community consultation feedback

Community consultation sessions were undertaken to gather historical hydraulic validation information. Table 7.13 presents several photos and statements received from the community which were used to validate the calibration of the hydraulic models.

Table 7.13 Community feedback information

Description	Photo or community feedback	Model results	Modelling results
Purga Creek Flood photo taken on Washpool Road near Peak Crossing in the 2013 flood.			2013 historical calibration flood model results match well with photograph. Point A is the edge of the water and coincides with the 2013 flood extent in the photograph. Point B shows a bank where water does not reach and can be seen in the photograph.
Western Creek Comment taken from community consultation session referring to Bridge at Waters Road and Kuss Road.	*"Bridge at Waters Road goes under first. Water tracks from Kuss Road across the flat, does not follow creek."*		Bridge near Water Road appears to be inundated in the 2011 and 2013 event. Water tracks down Kuss Road for approximately 180 m during both 2011 and 2013 events.
Purga Creek Flood photos taken on Washpool Road near Peak Crossing			Creek crossing on Washpool Road shows inundation in the historical event flood model results.

Description	Photo or community feedback	Model results	Modelling results
Mount Walker Creek Comment taken from community consultation session referring to Paynes Road, Willowbank.	*"This area floods after heavy rain"*		Flood model does not extend this far upstream, however 1% AEP results of the Willowbank local catchment model show that Paynes Road is inundated.
Bremer River Comment taken from community consultation session referring to Rosewood Warrill View Road.	*"Road flooded ex-cyclone Debbie event in 2017"*		2017 historical event not modelled, however both 2011 and 2013 events show inundation of Rosewood-Warrill View Road from the creek side of road.

7.16 Calibration summary

Available calibration data and previous hydrologic and hydraulic models have been collected and reviewed to support the development and calibration of the hydrologic and hydraulic models. The hydrologic models that have been adopted for this assessment are BRCFS URBS models for the Brisbane River catchments and the LCC RAFTS model for Teviot Brook. For each waterway crossing a local TUFLOW hydraulic model was developed. Each hydraulic model was calibrated against three historical events with results matched to recorded data from a number of stream gauges. A summary of the calibration information is outlined in Table 7.14.

Table 7.14 Calibration Summary

Catchment	Hydrologic modelling approach	Hydraulic modelling approach	Calibration events	Stream Gauge data used
Bremer River	URBS (BRCFS)	TUFLOW	1974, 2011, and 2013	Walloon, Rosewood, Kuss Road, Adam's Bridge, and Rosewood WWTP
Warrill Creek	URBS (BRCFS)	TUFLOW	1974, 2011, and 2013	Amberley, Harrisvale, and Junction Weir
Purga Creek including Sandy Creek	URBS (BRCFS)	TUFLOW	1974, 2011, and 2013	Loamside and Peaks Crossing
Teviot Brook	RAFTS (LCC)	TUFLOW	1974, 1990, and 2013	Overflow and Yarrahapinni

Available background information including existing hydrologic and hydraulic models, survey, streamflow data, available calibration information and anecdotal flood data has been gathered. This data was sourced from a wide range of stakeholders and is summarised within Section 5 of the report. This information was used to develop calibrated hydrologic and hydraulic models for each waterway. A good calibration was achieved for all catchments. Based on this performance, the hydrologic and hydraulic models were considered suitably calibrated to assess the potential impacts associated with the Project alignment.

8 Existing case modelling

8.1 Hydrology

8.1.1 Approach

Hydrologic modelling has been undertaken using the ARR 2016 methodology. This methodology adopts a design event type approach (DEA), whereby a spatially uniform temporal pattern is applied across the whole catchment. The major difference from the previous ARR 1987 Design Event approach is that an ensemble of ten different temporal patterns are simulated for each duration and frequency rather than a single pattern. The general procedure for conducting the design event assessment was:

- Obtaining rainfall Intensity-Frequency-Duration (IFD) relationships, temporal patterns, losses and other parameters pertinent to each catchment
- Simulation of the ensemble of design events for a range of durations for each AEP
- Application of Areal Reduction Factors (ARF) to account for catchment size (rainfall IFD is based on point intensities; ARF modifies this to provide areal average values). In each catchment, key stream gauges closest to the alignment were taken as the focal point where ARFs were applied. The selection of location for the ARF (i.e. stream gauge location versus alignment location) has minimal impact on the estimated peak discharges. Therefore, the stream gauge locations were used for consistency with the FFA comparison.
- Determination of the design flows for each AEP. The median peak flow of the critical storm duration (the duration that causes the highest median peak flow) was adopted. Since an ensemble of ten patterns was tested, the median value technically lies between the fifth and sixth ranked values, so current practice is to conservatively take the sixth.
- Comparison of the resulting 2016 design event flow estimates with a Flood Frequency Analysis (FFA), and, where applicable, the results of the BRCFS. Modification of the design parameters where necessary to achieve consistency (refer discussion for each catchment in Section 8.1.6)
- Extraction of design hydrograph(s) for use in the hydraulic models for each catchment.

8.1.2 Rainfall data

Rainfall IFD relationships for each sub-catchment within each hydrologic model were obtained from the BoM online Data Hub. Comparison with the IFD data used for the BRCFS, based on the 2013 IFD data release, indicates that there is typically a slight increase in rainfall intensity across the Bremer River, Warrill Creek and Purga Creek catchments with the 2016 IFD. There is a more notable increase for the 1% AEP event IFD in the Logan River and Teviot Brook. Table 8.1 shows the change in catchment average 24-hour rainfall depth between the 2013 IFD and 2016 IFD tables (note that these trends are not necessarily consistent for different durations or across the entire catchment). Due to the size of the catchments, IFDs were extracted at multiple locations.

Table 8.1 Change in 24-hour Rainfall Depth from 2013 to 2016 IFD Tables (BoM, 2016)

Catchment	50% AEP (mm)	10% AEP (mm)	1% AEP (mm)
Bremer River to Walloon gauge	77.5 → 80.2 (3%)	129.8 → 134.0 (3%)	210.2 → 217.2 (3%)
Warrill Creek to Amberley gauge	78.3 → 81.2 (4%)	130.6 → 134.9 (3%)	213.0 → 218.4 (3%)
Purga Creek to Loamside gauge	82.4 → 84.0 (2%)	139.1 → 140.1 (1%)	227.0 → 227.4 (0%)
Teviot Brook to Overflow	100.3 → 92.3 (-8%)	146.6 → 159.0 (8%)	227.0 → 263.0 (16%)
Logan to Yarrahapinni	104.4 → 96.0 (-8%)	154.6 → 169.0 (9%)	240.0 → 282.0 (18%)

8.1.3 Extreme rainfall

Extreme rainfall events have been assessed. For extreme rainfall estimates (Probable Maximum Precipitation (PMP)), the generalised techniques described by the Generalised Short Duration Method (GSDM) and Generalised Tropical Storm Method Revised (GTSMR, BoM 2003) were adopted. The techniques specified in Book VIII of ARR 2016 have been used to interpolate design rainfall estimates between 1 in 2,000 AEP (i.e. credible limit of extrapolation) and the PMP.

Ten temporal patterns were adopted for 15 durations from 1 to 120 hours for 1 in 10,000 AEP, 1 in 100,000 AEP and the PMP.

8.1.4 Design rainfall losses

Rainfall losses are applied to a hydrologic model to represent rainfall that does not contribute to overland flow (i.e. infiltrates the ground or is lost to evaporation). The loss method adopted was the initial/continuing loss model, where the initial loss (in mm) represents initial catchment wetting where no runoff is produced, followed by a constant continuing loss rate (in mm/h) to account for infiltration/evaporation during the rainfall runoff process.

Design event IFD data and temporal patterns are based on 'bursts' rather than complete storms; that is, they represent the worst part of a rainfall event that may (or may not) be preceded or followed by additional rainfall. The initial losses applied to a design event may therefore be different from those applied to a full storm (e.g. a calibration event). The ARR 2016 design event methodology tries to address this issue by combining a constant initial loss depth with a variable pre-burst depth, a depth of rainfall assumed to occur sometime before the design burst[1]. The pre-burst depth is a function of event duration and frequency. Recommended loss and pre-burst depths are accessed from the online ARR Data Hub. ARR losses for each sub-model are listed in Table 8.2.

Table 8.2 ARR 2016 Rainfall losses

Catchment	ARR Data Hub		Adopted	
	Initial loss (mm)	Continuing loss (mm/hour)	Initial loss (mm)	Continuing loss (mm/hour)
Bremer River	23	1.5	23 (≥20% AEP) 46 (<20% AEP)	1.5
Warrill Creek	27	2.5	27 (≥20% AEP) 32 (<20% AEP)	1.5
Purga Creek	20	1.6	20 (≥10% AEP) 25 to 40 (<10% AEP)	1.6
Teviot Brook	24	1.6	80 (≥50% AEP) 70 (≥10%AEP) 70 (<10%AEP)	2.5 (≥50% AEP) 1.6 (<50% AEP)
Logan River	24	1.6	80 (≥50% AEP) 70 (≥10%AEP) 70 (<10%AEP)	2.5 (≥50% AEP) 1.6 (<50% AEP)

[1] Note that ARR 2016 advises that there is currently little research into the temporal pattern of pre-burst rainfall. The appropriate methodology for applying pre-burst rainfall is open to interpretation. If the pre-burst depth is less than the initial loss, it can be simply considered to reduce the initial loss by that amount. However, if the pre-burst depth exceeds the initial loss then different software packages treat the excess pre-burst rainfall in different ways.

It is noted that ARR Data Hub values (in particular losses), are based on generalised regression of catchment characteristics and are intended to provide typical values for use where local catchment specific data is unavailable. Forty-eight historical rainfall/flood events were simulated during the BRCFS to calibrate/validate the hydrologic models. Median initial and continuing losses and confidence limits for the Brisbane River catchments are presented in Figure 7.1 and Figure 7.2.

Although significant variability of the losses is observed, at least partially due to discrepancies in the recorded rainfall distribution, the median losses should give a reasonable indication of the typical catchment characteristics assuming equal probability that the rainfall is over or under-estimated.

Although the initial and continuing losses can be attributed to physical properties of the catchment (respectively unfilled storages and infiltration for example), losses can serve other less physically based purposes in both calibration and design event modelling. Design event methodology assumes that the process for transforming design rainfall to design flood estimates is AEP neutral; that is, rainfall AEP can be directly correlated to flow AEP and there is no introduced bias that would result in the design flood estimates having a different frequency to that of the original design rainfall. Although there is almost certainly some correlation, other factors such as losses and temporal patterns can influence the relationship. It is therefore implicit in the assumption that the adopted losses are 'AEP neutral'. Modification of the losses provides a mechanism for reconciling the flow produced by rainfall-based design event methods with that determined by alternative independent methods as discussed in Section 8.1.6.

8.1.5 Areal Reduction Factor

ARFs are applied to a hydrologic model to represent the statistical improbability of point design rainfall intensities affecting the whole catchment area simultaneously. As catchment size increases, the chance that the whole catchment experiences the full point design rainfall intensity decreases. It is worth noting that ARFs do not include adjustments for spatial/temporal patterns and are primarily focused on representing rainfall's average depth over a given catchment.

The ARF applied to the Bremer River/Western Creek model is based on the catchment areas upstream of the primary calibration gauge at Walloon.

8.1.6 Comparison of ARR 2016 DEA and BRCFS hydrologic outcomes

For the project design event flows have been estimated using the ARR 2016 design event approach (DEA) validated against flood frequency analyses at key stream gauges.

The BRCFS used two separate methods for estimating design discharges, being:

- Flood Frequency Analysis (FFA) of stream gauge peaks
- Monte Carlo Simulation (MCS) involving stochastic assessment of randomly selected model parameters including rainfall patterns, losses and reservoir levels. Unique to the BRCFS, space-time rainfall patterns for the Brisbane River catchment were produced using a world-leading technique for generating space-time rainfall fields based on stochastic manipulation of radar data obtained from historic rainfall events to represent the complex variability of rainfall both spatially and temporally across the catchment. The MCS flows were adopted for the hydraulic component of the BRCFS.

Flow estimates from the different approaches were reconciled to produce a consistent set of recommended design flows at each location of interest within the catchment.

The first step in this process was to review and select initial and continuing loss parameters in the DEA and MCS models such that DEA and MCS results were as much as possible in accordance with FFA results for frequent events, recognising that loss values need to be consistent with those generally adopted in practice and relatively consistent (within rational explanation) across sub-catchments. Where values could not be reconciled in this manner, reconciliation required use of engineering judgement to determine which method was likely to carry the greatest confidence. In general, this meant:

- At locations where, reliable gauge records (in terms of both rating and record length) were available, FFA results were generally given greater weight
- For rare events where extrapolation of FFA curves have high uncertainty, greater reliance was placed in rainfall-based methods.

8.1.6.1 Bremer River

DEA flow estimates for the Bremer River at Walloon are compared with the BRCFS FFA and MCS results in Figure 8.1 and Table 8.3.

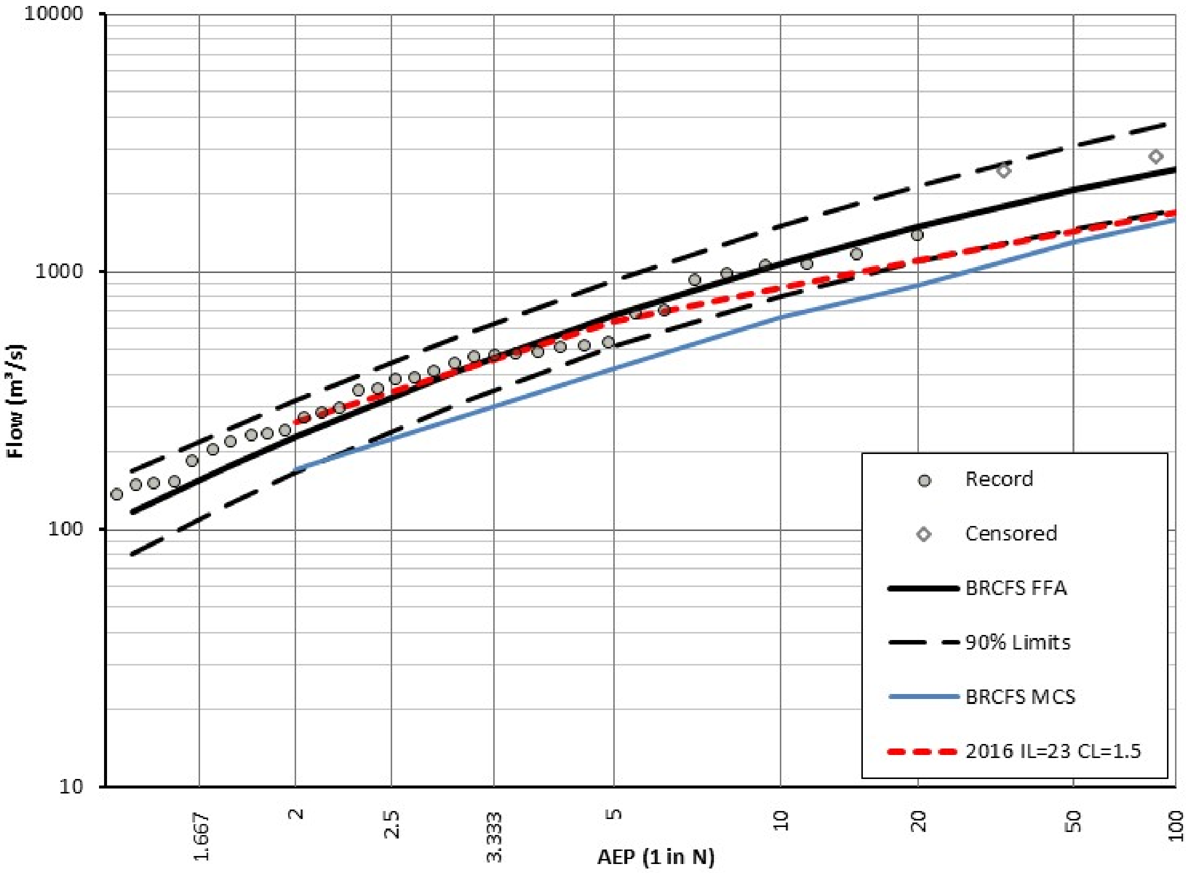


Figure 8.1 Comparison of 2016 FFJV DEA with BRCFS results at Walloon

Table 8.3 Comparison of 2016 FFJV DEA with BRCFS results at Walloon

AEP (%)	BRCFS Lower 90% Confidence Interval (m³/s)	BRCFS FFA (m³/s)	BRCFS Upper 90% Confidence Interval (m³/s)	BRCFS MCS (m³/s)	FFJV DEA (m³/s)
50	170	230	320	170	260
20	510	680	920	420	640
10	800	1,080	1,500	670	870
5	1,100	1,500	2,150	890	1,110
2	1,470	2,070	3,080	1,300	1,440
1	1,730	2,490	3,830	1,600	1,700
1 in 2,000	2,620	4,130	7,160	2,800	3,160

It is noted that the MCS flows were the adopted flows from the BRCFS. The ARR 2016 flows (DEA using ARR 2016 methodology) are typically higher than the MCS results, particularly for frequent events, but generally show good agreement with FFA predictions in this range for floods rarer than 20%, the design flows are consistently lower than the FFA estimates. This trend is similar to Warrill Creek, where the discrepancy is even larger. Possible reasons for the difference are discussed in greater detail below but appear to be at least partially related to a discrepancy between the BoM IFD tables and the rainfall depths of historical floods that have occurred in the Bremer River catchment.

Overall, the results are consistent with the reconciled values adopted for the BRCFS (allowing for a slight increase in design rainfall intensity; see Table 8.1). Initial losses for the 50% AEP event were increased to reconcile flows with the FFA, however no other changes were required. The design ARR 2016 flows were therefore taken forward unmodified.

8.1.6.2 Warrill Creek

Results for BRCFS were prepared for a no-dams situation to allow comparison of rainfall-based methods with FFA estimates at Amberley (FFA requires a consistent gauge record not influenced by changes to the catchment condition and is traditionally applied to a natural catchment without dams or other properties that may distort the relationship between flow magnitude and probability). Design event flows have been estimated using the ARR 2016 methodology using a hydrologic model without the effect of Moogerah Dam to allow comparison with the BRCFS results. This comparison is provided in Figure 8.2 and Table 8.4.

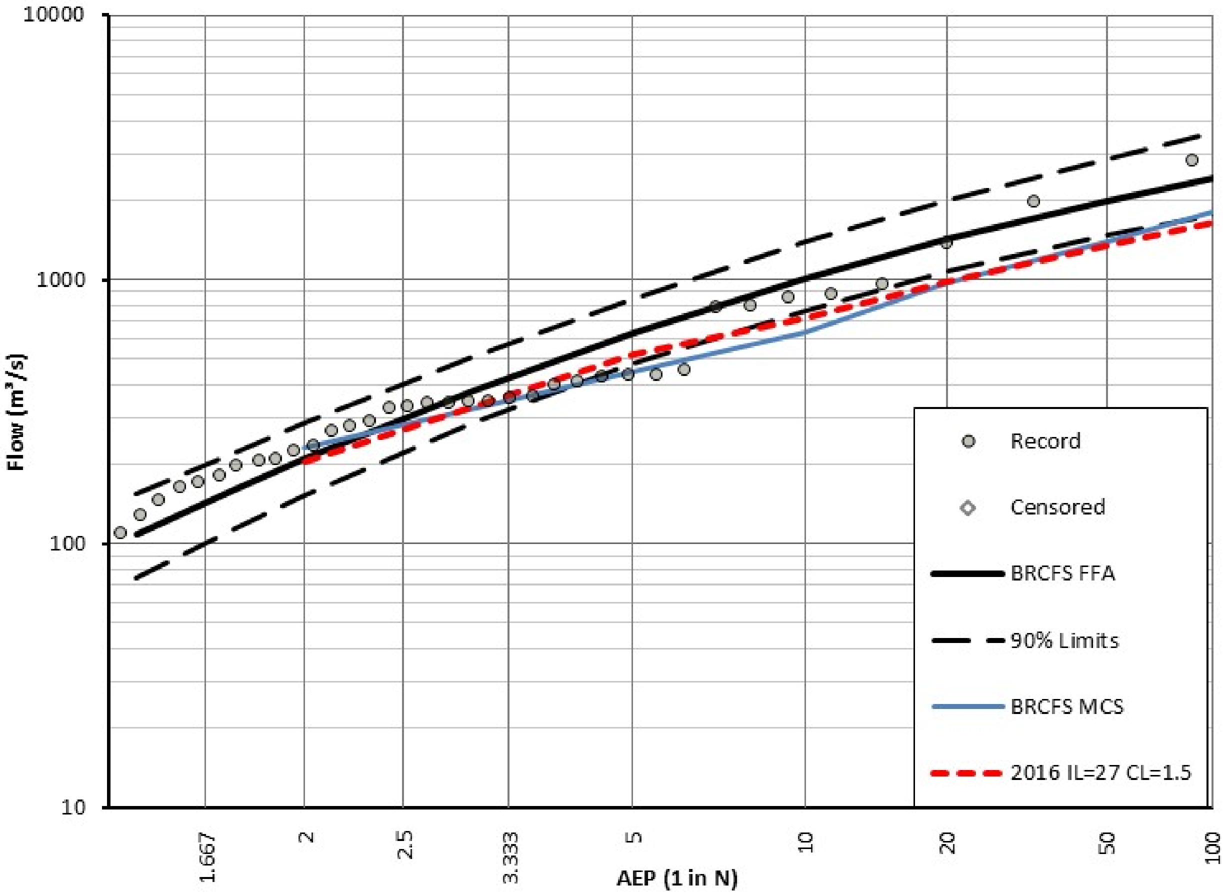


Figure 8.2 **Comparison of 2016 FFJV DEA with BRCFS results at Amberley**

Table 8.4 Comparison of 2016 FFJV DEA with BRCFS results at Amberley

AEP (%)	BRCFS Lower 90% Confidence Interval (m³/s)	BRCFS FFA (m³/s)	BRCFS Upper 90% Confidence Interval (m³/s)	BRCFS MCS (m³/s)	FFJV DEA No Dams (m³/s)
50	150	210	290	230	200
20	480	630	850	450	520
10	760	1,010	1,380	630	720
5	1,070	1,420	1,990	970	970
2	1,470	1,980	2,860	1,400	1,350
1	1,760	2,410	3,580	1,800	1,590

The ARR 2016 design event flows at Amberley tend to be higher than the BRCFS MCS results for frequent events but, unlike the other examined catchments, tend to be lower than the MCS results for rare events. Sensitivity testing suggests that these differences are at least partly due to the different rainfall losses. The MCS simulations used higher initial losses, particularly for frequent events, but lower continuing losses.

As shown in Table 8.2, the continuing losses obtained from the ARR Data Hub are notably higher for Warrill Creek than the surrounding catchments. The recommended losses from the Data Hub are generated from a grid with a side of 0.15º (~15 km to 17 km). The upper half of the catchment falls within grids with continuing loss of 2.8 mm/h to 3.4 mm/h, while in the lower half of the catchment the losses are 0.8 mm/h to 1.8 mm/h. It is not evident why the losses in the upper Warrill Creek catchment should be so much higher than in the lower catchment or the Bremer River and Purga Creek catchments on each side. Nevertheless, it is understood that the ARR Data Hub are generated from generalised regression equations rather than site or catchment specific analysis. It is therefore best-practice to adopt local information if such are available. The BRCFS assessment identified no significant discrepancy between the Warrill Creek, Bremer River and Purga Creek catchments (refer Section 7.4) and adopted consistent losses.

A more significant issue is the discrepancy between the FFA and the rainfall-based methods (design event and MCS). Although the Design Event and MCS results match the historical flow record FFA relatively well for frequent events (< 5% AEP), rarer events are consistently underestimated. This inconsistency was observed and investigated during the BRCFS. The peak flows and discharge ratings used in the FFA were confirmed using the same URBS model used to produce the design event and MCS flows, indicating that the issue is not caused by the hydrologic routing (i.e. the historical rainfall record routed through the model is consistent with the historic flow record). The recorded rainfall of these historical events was analysed. Three of the largest floods (1887, 1974 and 2013) were found to include 24-hour rainfall depths that exceeded the 1 in 500 AEP depth derived from 2013 BoM rainfall IFD tables, with a fourth flood (1976) including a depth of nearly 1% AEP. A discrepancy between the BoM IFD tables and the historical rainfall depths would explain the observed discrepancy between rainfall IFD based methods and the historical flood event based FFA. Possible explanations are that:

- The historical rainfall and flood record are skewed by the occurrence of a disproportionate number of rare flood events in the catchment (statistically unlikely, but nevertheless possible)
- The BoM IFD tables underestimate rainfall depths for the catchment.

Reality most probably lies somewhere between the two. Although the ARR 2016 design flows show good agreement with the reconciled flows adopted for the BRCFS, they appear to significantly underestimate the observed flood record. For the design process it will be necessary to select appropriate design flows for the Project, noting that if standard BoM and ARR methodologies are adopted then the 1% AEP event design flood has already been exceeded twice in the last 45 years. As such, to better match the reconciled FFA a multiplication has been applied to the design flows. This multiplication factor has been applied to the hydraulic model flows. As seen in Table 8.5 and Figure 8.2, this factored design flows better represent the reconciled FFA and have been used in the design Existing and Developed Cases.

Table 8.5 Comparison of 2016 FFJV DEA factored flows to BRCFS results at Amberley

AEP (%)	BRCFS FFA (m^3/s)	FFJV DEA No Dams (m^3/s)	Factor applied to URBS Hydrographs	FFJV DEA No Dams [Factored] (m^3/s)
20	630	520	1.25x	650
10	1,010	720	1.45x	1,040
5	1,420	970	1.5x	1,460
2	1,980	1,350	1.55x	2,090
1	2,410	1,590	1.5x	2,390

Flows for the design of the Project alignment and associated drainage structures, including immunity and impact assessments, have been calculated for current catchment conditions, which includes the influence of Moogerah Dam. Table 8.11 in Section 8.2.3 summarises the factored flows adopted for Existing and Developed Case hydraulic modelling. Moogerah Dam has been assumed to be at Full Supply Level (FSL) at the start of all design events. This assumption is conservative (realistically an assessment should be undertaken to identify levels that achieve AEP neutrality).

8.1.6.3 Purga Creek

Design flow estimates for the Purga Creek at Loamside have been compared with the BRCFS FFA and MCS results in Figure 8.3 with a tabulated version presented in Table 8.6. It is noted that the MCS flows were the adopted flows from the BRCFS. The ARR 2016 flows are typically higher than the MCS results but generally show good agreement with FFA predictions. Initial losses for the 50% AEP and 20% AEP events were increased to reconcile flows with the FFA, however no other changes were required, and the results are relatively consistent with the reconciled values adopted for the BRCFS. As with the Bremer River and Warrill Creek catchments, the rainfall-based methods tend to produce lower flow estimates than the FFA assessment for large events, however the magnitude of the discrepancy is not as significant. The design ARR 2016 flows were therefore taken forward unmodified.

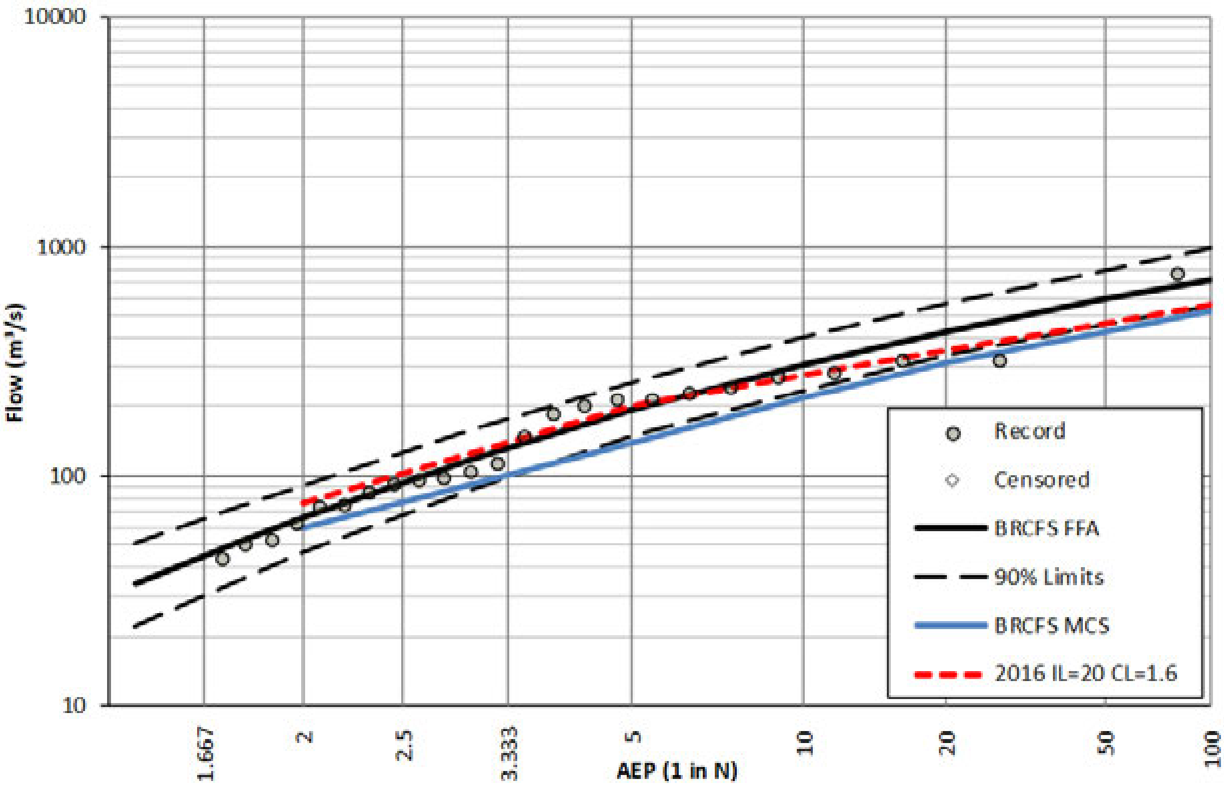


Figure 8.3 Comparison of 2016 FFJV DEA with BRCFS results at Loamside

Table 8.6 **Comparison of 2016 FFJV DEA with BRCFS results at Loamside**

AEP (%)	BRCFS Lower 90% Confidence Interval (m^3/s)	BRCFS FFA (m^3/s)	BRCFS Upper 90% Confidence Interval (m^3/s)	BRCFS MCS (m^3/s)	FFJV DEA (m^3/s)
50	50	70	90	60	80
20	150	190	260	140	200
10	240	310	400	220	280
5	330	430	570	310	350
2	460	590	790	430	470
1	550	720	980	520	560

8.1.6.4 Teviot Brook

The FFA for the Overflow gauge is presented in Figure 8.4. The predicted 1% AEP event flow at the Overflow gauge is 1,060 m^3/s with an ARF and 1,153 m^3/s without an ARF both of which are considerably lower than the FFA 1% AEP event estimate of 2,103 m^3/s. Only 45 years of data was available at the Overflow gauge for preparation of the FFA. The predicted 1% AEP flow is within the 90% confidence limits. It should be note that the predicted 1% AEP flow (no ARF) at the Overflow gauge with ARR 1987 methodology was 1,129 m^3/s. As such no ARF was adopted which is consistent with the Teviot Brook regional flood study.

The differences between the modelled 1% AEP design event flows and the FFA estimates are attributed to:

- Limited historical gauge records available for statically estimating the 1% AEP flows
- Several extreme events occurring in the catchment over the 45 year recording period at the Overflow gauge. The 1991 and 1974 events were the largest recorded at the Overflow gauge. Inspection of the recorded rainfall intensities for these two events against the ARR design rainfall intensity curves suggest these events were greater than the 1% AEP. The 1974 event was of a similar magnitude and is expected to also be around the 1% AEP event. Rainfall data for the 1974 event was not available to confirm this. The relatively short recording period and occurrence of three extreme events during this time results in a statistical skew of the FFA and a larger 1% AEP estimate compared with the modelled results.

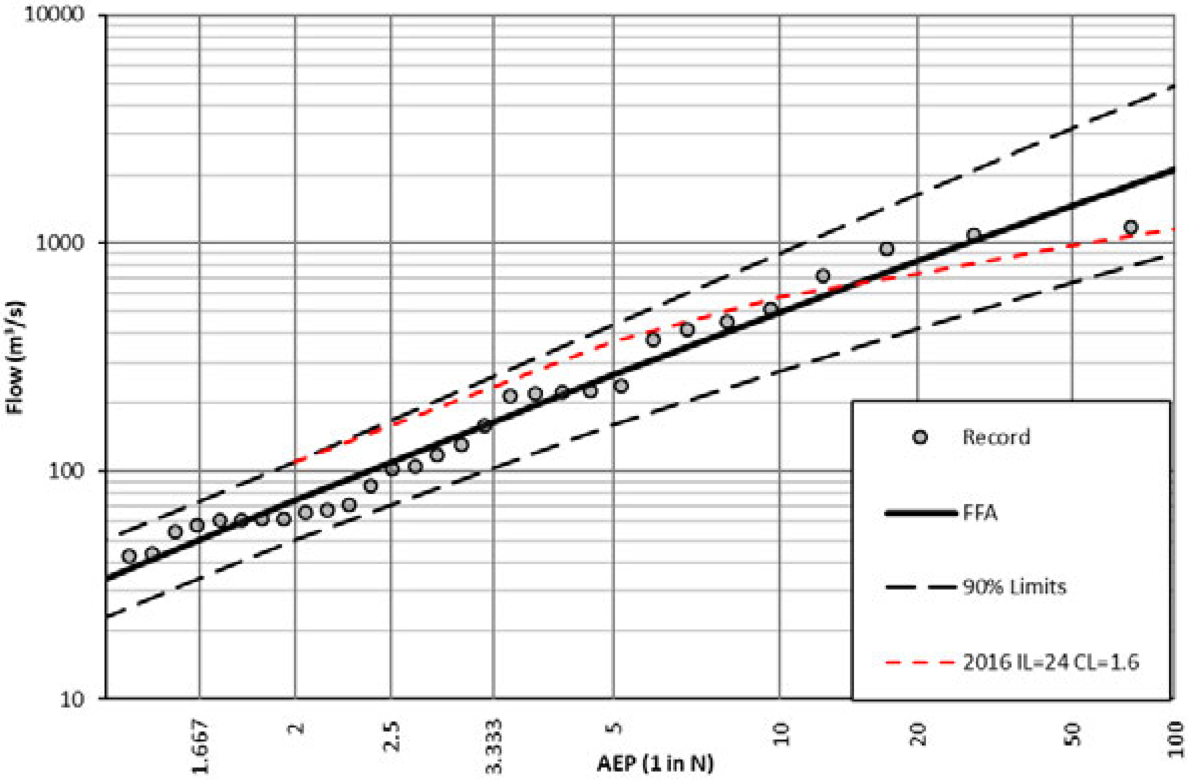


Figure 8.4 **Flood frequency analysis – Overflow gauge**

8.1.6.5 Logan River

The Yarrahapinni stream gauge is well rated to flows up to 2,844 m³/s but relies on extrapolation of the rating curve for higher flows. The predicted 1% AEP event flow at Yarrahapinni is 4,165 m³/s which is lower than the FFA 1% AEP event estimate of 4,836 m³/s at this location. Two key limiting factors of this analysis were that there is only 46 years of records at the gauge and the 1% AEP event is in the extrapolation region of the rating curve. It should be note that the predicted 1% AEP event flow at the Yarrahapinni with ARR 1987 methodology was 3,704 m³/s. The ARR 2016 design flow is well within the 90% confidence limits, as shown in Figure 8.5, and thus was adopted.

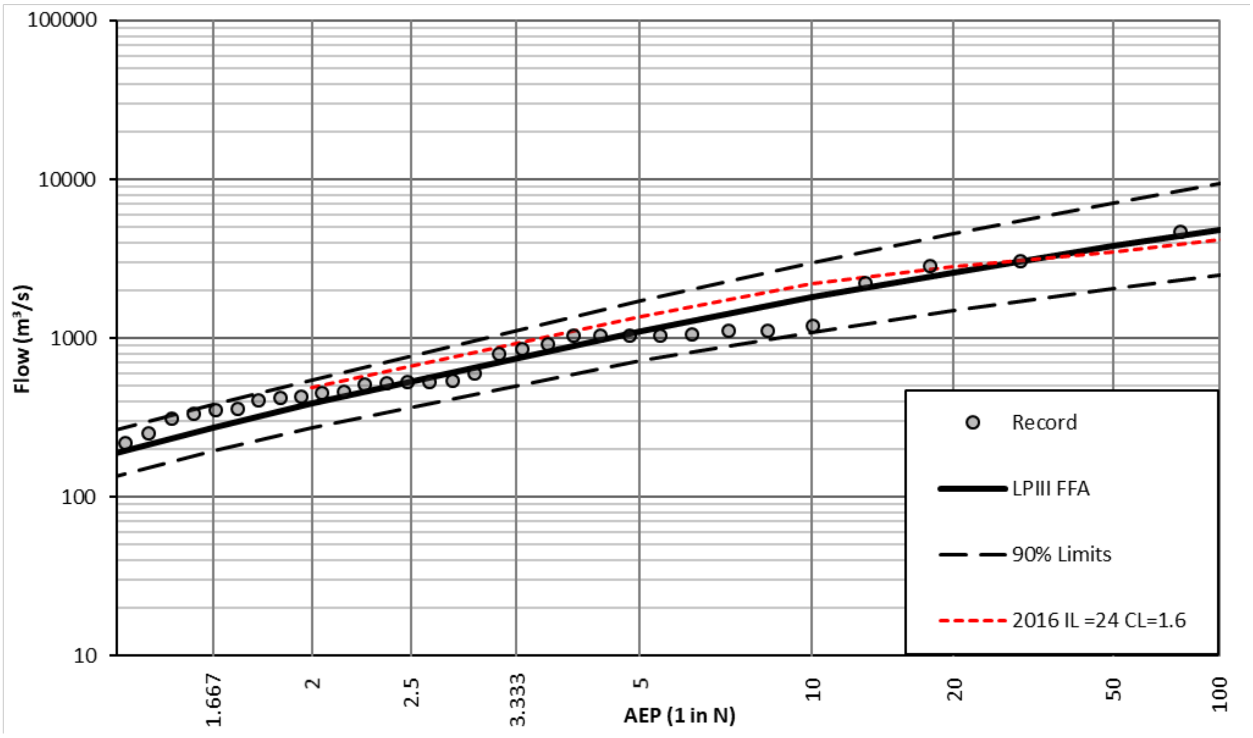


Figure 8.5 Flood frequency analysis – Yarrahapinni gauge

8.1.7 Climate change

The impacts of climate change were assessed for the 1% AEP design event to determine the sensitivity of the Project alignment design to the potential increase in rainfall intensity. The assessment was undertaken in accordance with ARR 2016 guidelines.

The selected representative concentration pathway for the climate change analysis was 8.5 for a 2090 design horizon. The climate change analysis was undertaken by increasing rainfall intensities in the IFDs for the contributing catchments.

8.2 Existing case results

8.2.1 Hydrologic model peak flow assessment

A critical duration assessment was undertaken to determine which storm duration(s) produced peak flood flows at the streamflow gauges locations and where the major waterways are intersected by the Project alignment. To assess the critical storm duration the following methodology was adopted:

- The models were simulated for a range of AEP events: 20%, 10%, 5%, 2%, 1%, 1 in 2,000, 1 in 10,000 AEP and PMF
  - Each AEP was simulated for a range of durations from 30 minutes to 168 hours, and
  - Each duration was simulated for each of the ten associated temporal patterns

- Peak flood levels were mapped for each storm duration
- A critical duration assessment was undertaken at the locations mentioned above to determine which duration produced the highest median flow of the ten temporal patterns for each event.

The critical durations and median temporal patterns selected for this study are outlined in Table 8.7 to Table 8.10. The chainages for each of the catchments represent the locations of the proposed bridge crossings.

Table 8.7 Critical duration assessment for Bremer River hydrologic model

Location	Event	Duration (hrs)	URBS temporal pattern	Peak flow (m^3/s)
Walloon	20% AEP	18h	_E6	644
Ch 65.69 km		18h	_E8	68
Ch 73.21 km		18h	_E3	256
Walloon	10% AEP	18h	_E2	869
Ch 65.69 km		24h	_E5	90
Ch 73.21 km		18h	_E2	342
Walloon	5% AEP	18h	_E5	1,107
Ch 65.69 km		24h	_E5	113
Ch 73.21 km		18h	_E2	433
Walloon	2% AEP	18h	_E2	1,438
Ch 65.69 km		24h	_E4	145
Ch 73.21 km		18h	_E2	558
Walloon	1% AEP	24h	_E0	1,702
Ch 65.69 km		24h	_E4	171
Ch 73.21 km		24h	_E4	820
Walloon	1 in 2,000 AEP	24h	_E5	3,156
Ch 65.69 km		24h	_E4	311
Ch 73.21 km		24h	_E4	1,217
Walloon	1 in 10,000 AEP	12h	_E5	3,764
Ch 65.69 km		9h	_E3	383
Ch 73.21 km		9h	_E3	1,453

Table 8.8 Critical duration assessment for Purga Creek hydrologic model

Location	Event	Duration (hrs)	URBS Temporal Pattern	Peak Flow (m^3/s)
Loamside	20% AEP	24h	_E3	204
Ch 23.40 km		24h	_E3	176
Peak Crossing		18h	_E4	157
Ch 28.73 km		18h	_E3	34
Loamside	10% AEP	24h	_E3	278
Ch 23.40 km		18h	_E4	240
Peak Crossing		18h	_E4	213
Ch 28.73 km		18h	_E3	45

Location	Event	Duration (hrs)	URBS Temporal Pattern	Peak Flow (m³/s)
Loamside	5% AEP	24h	_E3	354
Ch 23.40 km		18h	_E4	303
Peak Crossing		18h	_E4	268
Ch 28.73 km		18h	_E3	56
Loamside	2% AEP	24h	_E3	466
Ch 23.40 km		24h	_E3	394
Peak Crossing		18h	_E4	347
Ch 28.73 km		18h	_E3	72
Loamside	1% AEP	24h	_E3	557
Ch 23.40 km		24h	_E3	469
Peak Crossing		24h	_E3	411
Ch 28.73 km		18h	_E3	85
Loamside	1 in 2,000 AEP	24h	_E3	1,042
Ch 23.40 km		24h	_E3	868
Peak Crossing		18h	_E4	757
Ch 28.73 km		18h	_E6	154
Loamside	1 in 10,000 AEP	36h	_E9	1,263
Ch 23.40 km		36h	_E1	1,022
Peak Crossing		36h	_E1	876
Ch 28.73 km		12h	_E9	202

Table 8.9 Critical duration assessment for Warrill Creek hydrologic model (unfactored flows, Moogerah Dam included)

Location	Event	Duration (hrs)	URBS Temporal Pattern	Peak Flow (m³/s)
Amberley	20% AEP	30h	_E1	518
Ch 17.65 km (Rail Bridge)		30h	_E1	511
Amberley	10% AEP	30h	_E4	715
Ch 17.65 km (Rail Bridge)		30h	_E4	703
Amberley	5% AEP	30h	_E8	972
Ch 17.65 km (Rail Bridge)		30h	_E8	953
Amberley	2% AEP	30h	_E8	1,346
Ch 17.65 km (Rail Bridge)		30h	_E8	1,315
Amberley	1% AEP	30h	_E1	1,654
Ch 17.65 km (Rail Bridge)		30h	_E1	1,611
Amberley	1 in 2,000 AEP	30h	_E1	3,249
Ch 17.65 km (Rail Bridge)		30h	_E1	3,133
Amberley	1 in 10,000 AEP	36h	_E4	4,499
Ch 17.65 km (Rail Bridge)		36h	_E4	4,312

Table 8.10 Critical duration assessment for Teviot Brook hydrologic model

Location	Event	Duration (hrs)	RAFTS Temporal Pattern	Peak flow (m^3/s)
The Overflow	20% AEP	72h	Storm 4	281
Ch 43.06 km (Rail Bridge)		24h	Storm 8	106
Ch 52.80 km (Rail Bridge)		72h	Storm 4	280
The Overflow	10% AEP	24h	Storm 6	460
Ch 43.06 km (Rail Bridge)		6h	Storm 4	159
Ch 52.80 km (Rail Bridge)		24h	Storm 6	459
The Overflow	5% AEP	24h	Storm 7	607
Ch 43.06 km (Rail Bridge)		4.5h	Storm 1	212
Ch 52.80 km (Rail Bridge)		24h	Storm 7	607
The Overflow	2% AEP	24h	Storm 2	828
Ch 43.06 km (Rail Bridge)		3h	Storm 7	297
Ch 52.80 km (Rail Bridge)		24h	Storm 2	827
The Overflow	1% AEP	24h	Storm 9	1003
Ch 43.06 km (Rail Bridge)		3h	Storm 7	373
Ch 52.80 km (Rail Bridge)		24h	Storm 9	1002
The Overflow	1 in 2,000 AEP	48h	Storm 7	1916
Ch 43.06 km (Rail Bridge)		2h	Storm 6	818
Ch 52.80 km (Rail Bridge)		48h	Storm 7	1929
The Overflow	1 in 10,000 AEP	36h	Storm 8	2625
Ch 43.06 km (Rail Bridge)		2h	Storm 1	1109
Ch 52.80 km (Rail Bridge)		36h	Storm 8	2647

8.2.2 Bremer River design events

The hydraulic model was run for all durations and temporal patterns and the R6 critical duration storm was selected at the gauge and alignment crossings. The hydrologic and hydraulic modelling results at these locations for critical durations and temporal patterns are presented in Figure 8.6. Peak water levels for the 1% AEP event Existing Case are presented in Appendix A Figure A7-A.

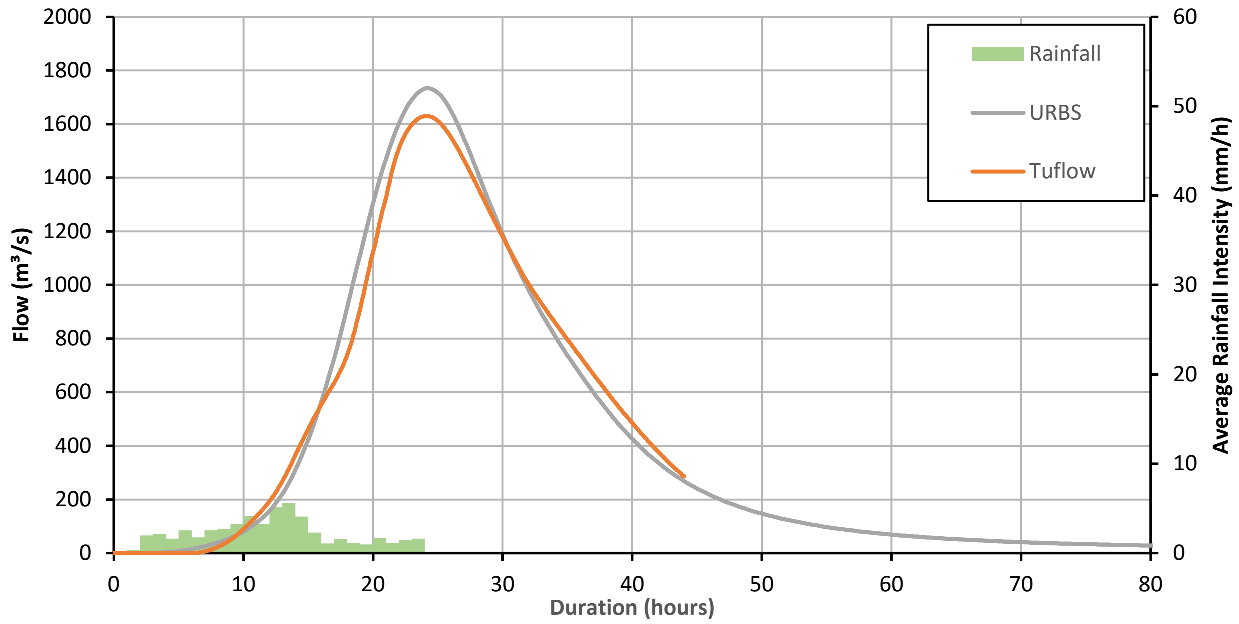


Figure 8.6 **Comparison of URBS and TUFLOW hydrographs at Walloon for 1% AEP flood event**

8.2.3 Warrill Creek design events

The hydraulic model was run for all durations and temporal patterns, and the R6 critical duration storm was selected at the gauge and alignment crossings. The difference in URBS and TUFLOW flows is due to the factoring that has been applied to better match the reconciled FFA as outlined in Section 8.1.6. The factoring was varied for each AEP to achieve flows similar to those predicted for the BRCFS FFA. A summary of the factors is presented in Table 8.11. Peak water levels for the 1% AEP event Existing Case are presented in Appendix B Figure B7-A.

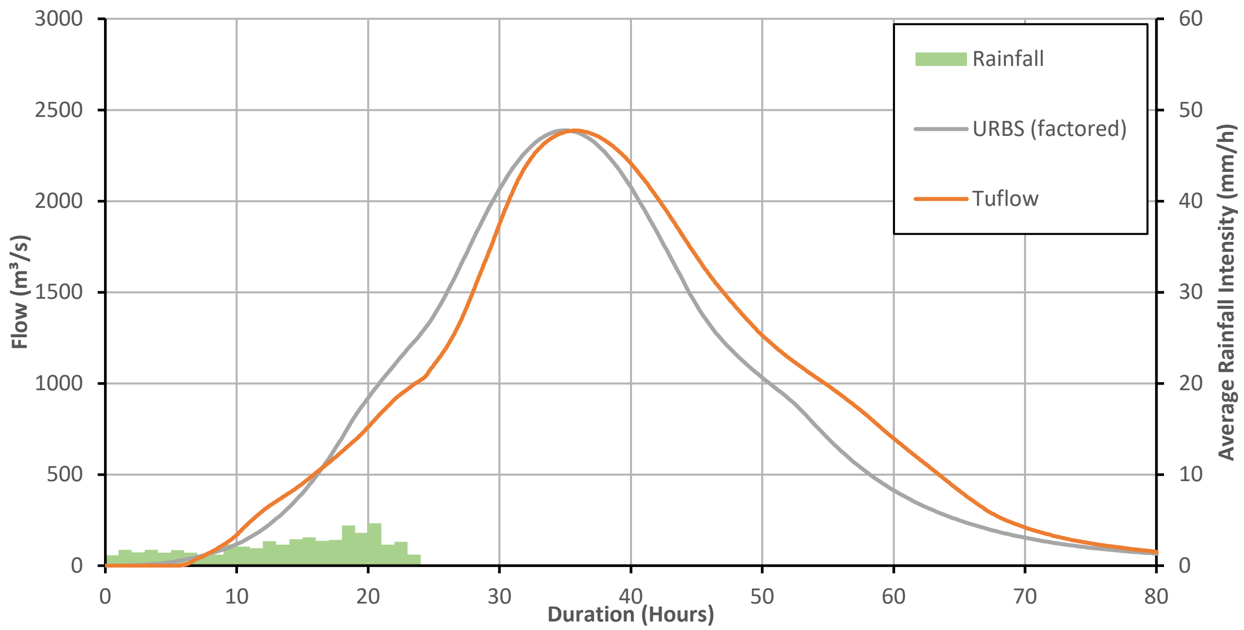


Figure 8.7 **Comparison of URBS and TUFLOW hydrographs at Amberley for 1 % AEP flood event (factored flow, no dams)**

Table 8.11 Applied factors for DEA TUFLOW modelling

AEP (%)	BRCFS FFA (m^3/s)	FFJV DEA No Dams (m^3/s)	FFJV DEA With Dams (m^3/s)	TUFLOW Factor applied to URBS Hydrographs	TUFLOW inflow With Dams [Factored] (m^3/s)
5	630	520	410	1.25x	510
10	1,010	720	540	1.45x	780
20	1,420	970	700	1.50x	1,050
50	1,980	1,350	1,020	1.55x	1,580
100	2,410	1,590	1,270	1.50x	1,910

8.2.4 Purga Creek design events

The hydraulic model was run for all durations and temporal patterns and the R6 critical duration storm was selected at the gauge and alignment crossings. The hydrologic and hydraulic modelling results at these locations for critical durations and temporal patterns are presented in Figure 8.8. Peak water levels for the 1% AEP event Existing Case are presented in Appendix C Figure C7-A.

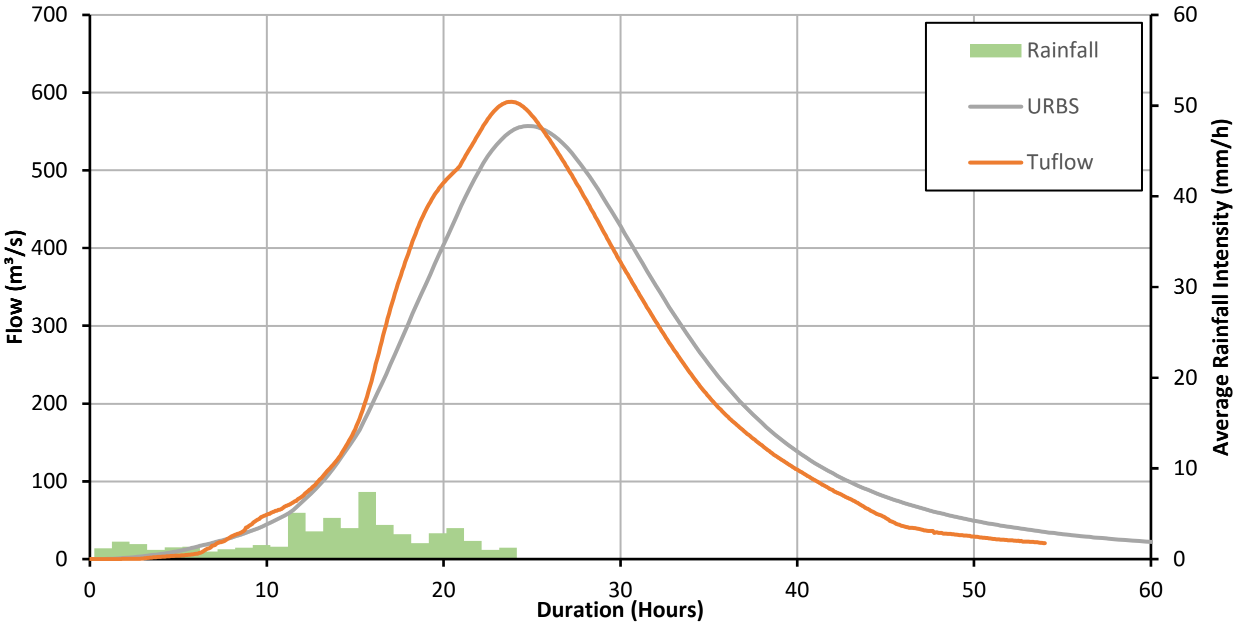


Figure 8.8 Comparison of URBS and TUFLOW hydrographs at Loamside for 1% AEP flood event

8.2.5 Teviot Brook design events

The hydraulic model was run for all durations and temporal patterns and the R6 critical duration storm was selected at alignment crossings. No gauges are located within the Teviot Brook hydraulic model to compare results. Refer to Section 7.11 for hydrologic validations with recorded gauge levels. Peak water levels for the 1% AEP event Existing Case are presented in Appendix D Figure D7-A.

9 Developed Case modelling

The Developed Case incorporates the Project design into the Existing Case hydraulic models. The Developed Case models have been run for the nominated design events and assessed against the hydraulic design criteria and flood impact objectives. Mitigation measures that have been incorporated into the Project design include:

- The Project has been designed to achieve the hydraulic design criteria (refer Section 4.1), and key design criteria including:
  - 50-year design life for formation and embankment performance
  - Track drainage ensures that the performance of the formation and track is not affected by water
  - Earthworks designed to ensure that the rail formation is not overtopped during a 1% AEP flood event
  - Embankment cross section can sustain flood levels up to the 1% AEP
- Bridges are designed to withstand flood events up to and including the 1 in 2,000 AEP event
- Where possible, the Project utilises existing rail corridors as much to avoid introducing a new linear infrastructure corridor across floodplains. For the Project this is limited to the section near Calvert, with the remainder of the alignment in greenfield areas.
- The Project incorporates bridge and culvert structures to maintain existing flow paths and flood flow distributions
- Bridge and culvert structures have been located and sized to avoid increases in peak water levels, velocities and/or duration of inundation, and changes flow distribution in accordance with the flood impact objectives
- Progressive refinement of bridge extents and culvert banks (number of barrels and dimensions) has been undertaken as the Project design has evolved. This refinement process has considered engineering requirements as well as progressive feedback from stakeholders to achieve acceptable outcomes that address the flood impact objectives.
- Scour and erosion protection measures have been incorporated into the design in areas determined to be at risk, such as around culvert headwalls, drainage discharge pathways and bridge abutments
- A climate change assessment has been incorporated into the design of cross drainage structures for the Project in accordance with the Australian Rainfall and Runoff Guidelines (2016) for the 1% AEP design event to determine the sensitivity of the design, and associated impacts, to the potential increase in rainfall intensity
- Identification of flood sensitive receptors and engagement with stakeholders to determine acceptable design outcomes.

The following sections outline how the Project design addresses the hydraulic design criteria and flood impact objectives on each floodplain. For the hydraulic modelling the adjacent H2C Project alignment has been included in the Developed Case to quantify cumulative impacts.

Details of drainage structures for local drainage catchments that cross the alignment are provided in Section 9.5.

9.1 Bremer River/Western Creek

Western Creek, a tributary of the Bremer River, runs parallel to the QR rail line and the proposed Project alignment. The creek channel crosses the Project alignment at Ch 2.95 km and Ch 1.30 km as seen as Appendix A Figure A1-D. The existing QR West Moreton rail line does not have 1% AEP immunity and has several existing cross drainage structures. The Project interfaces with the existing QR West Moreton rail line approximately at Ch 2.2 km.

The main channel of the Bremer River crosses the alignment at Ch 6.20 km. To the east and west of this location there are a number of crossings where tributaries of the Bremer River cross the Project alignment. Under the 1% AEP event the flood waters are between 3 m to 7 m deep and are mostly conveyed through the channel and confined overbanks as seen in Appendix A Figure A7-A.

9.1.1 Drainage structures

The hydraulic design of the flood drainage structures was undertaken using the TUFLOW model (1d and 2d approach). On the Bremer River floodplain, the Project design includes:

- Three rail bridges
- Five rail reinforced concrete pipe culvert (RCP) locations (multiple cells in places).

Details of these structures are listed in Table 9.1 and shown in Appendix A Figure A1-D. In addition, the adjacent H2C project alignment has been included in the Developed Case to quantify cumulative impacts.

Bridges have been represented within the TUFLOW model through use of layered flow constrictions. Each bridge within the model has had a flow constriction coefficient applied to represent obstruction of waterway area due to the piers.

Table 9.1 Bremer River and Western Creek – flood structure locations and details

Waterway	Chainage (km)	Structure name	Structure type	No of cells	Diameter (m)	Soffit level (m AHD)	Bridge length (m)
Western Creek	2.95	340-BR01	Bridge	-	-	54.20	966.0
	1.30*	340-BR02	Bridge	-	-	53.40	782.0
Bremer River	5.34	C5.34	RCP	4	1.20	-	-
	6.20	340-BR03	Bridge	-	-	48.20	684.0
	7.38	C7.38	RCP	20	1.20	-	-
	7.46	C7.46	RCP	40	1.20	-	-
	7.76	C7.76	RCP	10	1.20	-	-
	7.90	C7.90	RCP	15	1.20	-	-

Table note:

* The main Project alignment introduces a deviation near this location to connect with the QR West Moreton Line. Chainage referenced is for the deviation that forks from the main Project alignment.

9.1.2 Hydraulic design criteria outcomes

The hydraulic model was run for the Developed Case with the drainage structures and embankment areas included. Modelling of a range of events was undertaken (20%, 10%, 5%, 2%, 1% AEP events and 1 in 2,000 AEP, 1 in 10,000 AEP and PMF events). The Project design outcomes relative to the hydraulic design criteria (refer Table 4.1) are presented in the following sections.

9.1.2.1 Flood immunity and overtopping risk

The Project alignment has a 1% AEP immunity to formation level. The formation level of the Project alignment is driven by several factors including achieving flood immunity and meeting geometric requirements (e.g. allowing for grade separations). Therefore, the freeboard achieved varies along the alignment with the 1% AEP event flood immunity achieved with a minimum freeboard of over 1 m.

The risk of overtopping of the rail alignment has been assessed for a range of extreme events (1 in 2,000 AEP, 1 in 10,000 AEP and PMF Events). Table 9.2 presents the depth over formation and over top of rail during the 1 in 2,000 AEP, 1 in 10,000 AEP, and PMF events at Ch 0.30 km (QR West Moreton Junction).

Table 9.2 Bremer River – Overtopping of rail formation and top of rail in extreme events

Location	Depth of water above formation level (m)			Depth of water above top of rail (m)		
	1 in 2,000 AEP	1 in 10,000 AEP	PMF	1 in 2,000 AEP	1 in 10,000 AEP	PMF
Ch 0.30 km QR West Moreton Junction	1.2	1.3	1.8	0.4	0.5	1.0

9.1.2.2 Structures results

Table 9.3 presents hydraulic model results at each structure for the 1% AEP event. The hydraulic results at structures for flows, velocities and water surface levels for all events are presented in Appendix E.

Table 9.3 Bremer River – 1% AEP event structure results

Chainage (km)	Structure type	Upstream peak water level (m AHD)	Freeboard to top of formation level (m)	Outlet velocity (m/s)	Peak discharge (m^3/s)
2.95	Bridge (BR01)	51.50	3.9	2.1	628
1.30*	Bridge (BR02)	53.20	1.4	2.3	647
5.38	RCP	44.60	3.0	1.0	3
6.20	Bridge (BR03)	44.10	5.3	2.0	808
7.38	RCP	42.90	14.4	1.3	8
7.45	RCP	43.00	14.7	1.5	28
7.70	RCP	43.70	15.4	2.0	11
7.83	RCP	43.70	16.1	1.9	22

Table note:

* The main Project alignment introduces a deviation near this location to connect with the QR West Moreton Line. Chainage referenced is for the deviation that forks from the main Project alignment.

Scour protection requirements for culverts have been calculated based on the velocities predicted from the hydraulic modelling. The scour protection has been designed in accordance with Austroads Guide to Road Design Part 5B: Drainage (AGRD). Scour protection was specified where the culvert outlet velocities for the 1% AEP event exceeded the allowable soil velocities shown in Table 3.1 of AGRD as follows:

- Stable rock – 4.5 m/s
- Stones 150 mm diameter or larger – 3.5 m/s
- Gravel 100 mm or grass cover – 2.5 m/s
- Firm loam or stiff clay – 1.2 to 2 m/s
- Sandy or silty clay – 1.0 to 1.5 m/s.

The scour protection length and minimum rock size (d50) were determined from Figure 3.15 and Figure 3.17 in AGRD. The resulting lengths of scour protection required were determined through the drainage assessment. All required scour lengths were predicted to fit within the proposed rail footprint.

A conservative scour estimation has been undertaken at each bridge site based on available information and will be refined during detailed design.

9.1.3 Flood impact objectives outcomes

The Project design outcomes relative to the flood impact objectives (refer Table 4.2) are presented in the following sections.

9.1.3.1 Change in peak water levels

The impact of the Developed Case has been assessed through inclusion of the drainage structures and comparison of model results against the Existing Case results. Resulting changes in peak water levels have been mapped (refer Appendix A).

In the 1% AEP event there are a few isolated occurrences of afflux predicted to be greater than 200 mm. These are:

- On the east abutment of the Western Creek Bridge (BR01) there is up to 460 mm afflux. The afflux is localised and in a rural area with no flood sensitive receptors nearby. This afflux decreases to 200 mm within 95 m from the rail alignment.
- Between Ch 7.00 km and Ch 7.90 km there is up to 410 mm afflux. This afflux dissipates to 200 mm within 60 m upstream of the rail and then less than 10 mm at approximately 140 m upstream. This afflux is in a rural area and does not impact flood sensitive infrastructure. As seen in Appendix A Figure A7-B during the 1% AEP the flow is very shallow with the floodplain over 600 m wide.

As seen in Appendix A Figure A7-C there are a number of flood sensitive receptors in the Bremer River catchment. Details of where afflux is greater than 10 mm, under the 1% AEP event, at a flood sensitive receptor are outlined in Table 9.4. Where afflux is 10 mm or greater at a flood sensitive receptor, under the 1% AEP event with climate change, a summary of afflux for all modelled events up to the 1% AEP event with climate change is presented in Appendix H.

Table 9.4 Bremer River/Western Creek – Afflux at flood sensitive receptors

Location	Afflux (mm)	Comment
Along Waters Road, between Kuss Road and Lane Road	+80	Waters Road is inundated by frequent events in existing conditions. In the 1% AEP events it is inundated by over 500 mm of water.

9.1.3.2 Average annual time of submergence and time of submergence

Assessment of the change in the ToS is presented in Appendix A Figure A7-I. Under the 1% AEP event there are a few isolated occurrences of increases in the ToS however no flood sensitive receptors are affected. The affected locations are:

- Western Creek Bridge (BR01). At the eastern embankment (Ch 3.45 km) there is a localised increase of over 10 hours. This localised increase is contained to the creek overbank area and does not impact on any road corridors or sensitive infrastructure. At this location the 1% AEP (24 hour) event is critical and the time of submergence of the floodplain outside of this localised area is not affected.
- Ch 7.00 km and 7.90 km – upstream and downstream of these culverts there is a localised increase of over 10 hours. This localised increase does not inundate transportation corridors and is on an overbank. At this location the 1% AEP (12 hour) event is critical and there is no change in the time of submergence at sensitive infrastructure.

Table 9.5 outlines the AAToS for the 1% AEP Existing and Developed cases for Waters Road.

Table 9.5 AAToS comparison at Waters Road

Location	AAToS Existing Case (hrs/yr)	AAToS Developed Case (hrs/yr)	Difference (hrs/yr)
Along Waters Road, between Kuss Road and Lane Road	31.4	31.6	+0.2

9.1.3.3 Change in velocities

Appendix A Figure A7-H presents the change in peak velocities under the 1% AEP event associated with the Project alignment. In general, the changes are minor, with most changes in velocities experienced immediately adjacent to the Project alignment. Velocity changes within the Western Creek and Bremer River main channels are negligible.

9.1.3.4 Flood flow distribution

Overall, the Project has minimal impacts on flood flows and floodplain conveyance/storage with significant floodplain structures included to maintain the existing flood regime.

9.1.3.5 Extreme event risk management

During extreme events there is widespread floodplain inundation with high flood depths as shown in Appendix A Figure A8 to A10. These impacts have been considered in relation to the Existing Case flood depths at flood sensitive receptors. Under these rare events, the bridge structures and culverts allow adequate passage of flow during the flood events and “damming” effects are therefore not expected to occur.

9.1.4 Sensitivity analysis

9.1.4.1 Blockage

The hydraulic design has included an assessment regarding the blockage of culverts. Blockage potential has been assessed in accordance with the guidelines in ARR 2016. The blockage assessment resulted in no blockage factor being applied to bridges and a blockage factor of 25% being applied to culverts.

ARR 2016 guidelines are focused on blockage of small bridges and culverts. The floodplain bridges proposed for the Project alignment are all multi-span large bridges and ARR 2016 notes that there are limited instances of multiple span bridges being observed with blockages similar to those seen at single span bridges or culverts.

A minimum culvert size of 1,200 mm diameter was adopted to reduce the potential for blockage and for ease of maintenance.

Two blockage sensitivity scenarios were tested; 0 per cent and 50 per cent blockage of all culverts. The results are presented in Appendix A, Figure A7-E and Figure A7-F for the 0% and 50% blockage respectively.

9.1.4.2 Climate change assessment

The impacts of climate change were assessed for the 1% AEP event to determine the sensitivity of the Project design to the potential increase in rainfall intensity. The assessment was undertaken in accordance with ARR 2016 guidelines.

The selected representative concentration pathway for the climate change analysis was 8.5. The climate change analysis was undertaken by increasing rainfall intensities in the IFDs for the contributing catchments. For the Project, 8.5 corresponds to an increase in temperature of 3.7 degrees Celsius in 2090 and an increase in rainfall intensity of 18.7% which was obtained from the ARR 2016 Data Hub.

The only affected flood sensitive receptors are Waters Road and Kuss Road with the change in peak water levels on Waters Road and Kuss Road still less than 100 mm. As noted previously these roadways are already non-trafficable in the Existing Case and this increase in peak water levels does not affect the existing amenity. The downstream extents of these impacts are similar to those under the 1% AEP event.

The resulting peak water levels are presented in Table 9.6. Climate change results in increased peak water levels of up to 300 mm at structure locations for the 1% AEP event. The formation level is significantly higher than the 1% AEP climate change peak water levels at these locations.

Table 9.6 Bremer River – 1% AEP event – Climate Change Assessment

Chainage (km)	Structure type	1% AEP peak water levels (m AHD)	1% AEP + CC peak water levels (m AHD)	Difference in peak water level (m)	Freeboard to rail formation level with CC (m)
2.95	Bridge (BR01)	51.50	51.6	0.1	3.8
1.30*	Bridge (BR02)	53.20	53.4	0.1	1.2
5.38	RCP	44.60	44.8	0.2	2.8
6.20	Bridge (BR03)	44.10	44.7	0.6	4.7
7.38	RCP	42.90	43.0	0.1	14.3
7.45	RCP	43.00	43.1	0.1	14.6
7.70	RCP	43.70	43.8	0.1	15.3
7.83	RCP	43.70	43.9	0.1	15.9

Table note:

* The main Project alignment introduces a deviation near this location to connect with the QR West Moreton Line. Chainage referenced is for the deviation that forks from the main Project alignment.

9.2 Warrill Creek

Warrill Creek crosses the alignment at approximately Ch 17.70 km which is west of Purga Creek as seen in Appendix B Figure B1-D. Under the 1% AEP event it is estimated that approximately 2,140 m³/s of flow passes through this crossing. Warrill Creek continues north of the Project alignment where it merges with Purga Creek, and then into the Bremer River. There are no flood sensitive receptors impacted by the Project alignment under the 1% AEP flood event upstream or downstream of the Warrill Creek crossing.

9.2.1 Drainage structures

The hydraulic design of the major drainage structures was undertaken using the TUFLOW model (1d and 2d approach). There is only a single major crossing in the Warrill Creek TUFLOW model and a 2d bridge was used to represent the structure. Details of this structure are listed in Table 9.7.

Table 9.7 Warrill Creek – Flood structure locations and details

Chainage (km)	Structure name	Structure type	Soffit level (m AHD)	Bridge length (m)
17.65	340-BR07	Bridge	33.70	713.0

9.2.2 Hydraulic design criteria outcomes

The hydraulic model was run for the Developed Case with the drainage structures and embankment areas included. Modelling of a range of events was undertaken (20%, 10%, 5%, 2%, 1% AEP events and 1 in 2,000 AEP, 1 in 10,000 AEP and PMF events). The Project design outcomes relative to the hydraulic design criteria (refer Table 4.1) are presented in the following sections.

9.2.2.1 Flood immunity and overtopping risk

The Project alignment has a 1% AEP immunity to formation level. The formation level of the Project alignment is driven by several factors including achieving flood immunity and meeting geometric requirements (e.g. allowing for grade separations). Therefore, the freeboard achieved varies along the alignment with the 1% AEP event flood immunity achieved with a minimum freeboard of 1 m.

The risk of overtopping of the rail alignment has been assessed for a range of extreme events (1 in 2,000 AEP, 1 in 10,000 AEP and PMF events). The rail formation is not overtopped in any of the assessed events.

9.2.2.2 Structures results

Table 9.8 presents hydraulic model results at the structure for the 1% AEP event. The hydraulic results at structures for flows, velocities and water surface levels for all events are presented in Appendix E.

Table 9.8 Warrill Creek – 1% AEP event structure results

Chainage (km)	Structure type	Upstream Peak Water Level (m AHD)	Freeboard to formation level (m)	Outlet velocity (m/s)	Peak discharge (m^3/s)
17.65	Bridge	32.80	2.1	1.9	1,765

Scour protection requirements for culverts have been calculated based on the velocities predicted from the hydraulic modelling. A conservative scour estimation has been undertaken at the bridge site based on available information and will be refined during detailed design.

9.2.3 Flood impact objectives outcomes

The Project design outcomes relative to the flood impact objectives (refer Table 4.2) are presented in the following sections.

9.2.3.1 Change in peak water levels

The impact of the Developed Case has been assessed through inclusion of the drainage structures and comparison of model results against the Existing Case results. Resulting changes in peak have been mapped (refer Appendix B).

At the eastern and western embankments, the afflux is greater than 200 mm (up to 300 mm). This afflux is on rural land and is localised. It reduces to less than 200 mm within the Project disturbance footprint, approximately 30 m from the rail alignment. As seen in Appendix B Figure B7-C no identified flood sensitive receptors in the Warrill Creek catchment have greater than 10 mm of afflux for events up to the 1% AEP event.

Where afflux is 10 mm or greater at a flood sensitive receptor, under the 1% AEP event with climate change, a summary of afflux for all modelled events up to the 1% AEP event with climate change is presented in Appendix H.

9.2.3.2 Average annual time of submergence and time of submergence

Assessment of the difference in the ToS is presented in Appendix B Figure B7-G. There are only localised changes to the time of submergence and there appears to be no changes on any flood sensitive infrastructure. No flood sensitive receptors have an increased ToS. Therefore, AAToS calculations were not performed.

9.2.3.3 Change in velocities

Appendix B Figure B7-F presents the changes in peak velocities under the 1% AEP event associated with the Project alignment. In general, the changes are minor, with most changes in velocities experienced immediately adjacent to the Project alignment.

9.2.3.4 Flood flow distribution

Overall, the Project has minimal impacts on flood flows and floodplain conveyance/storage with significant floodplain structures included to maintain the existing flood regime.

9.2.3.5 Extreme event risk management

During extreme events there is widespread floodplain inundation with high flood depths as shown in Appendix B Figure B8 to B10. These impacts have been considered in relation to the Existing Case flood depths at flood sensitive receptors. Under these rare events, the bridge structures and culverts allow adequate passage of flow during the flood events and “damming” effects are therefore not expected to occur.

9.2.4 Sensitivity analysis

9.2.4.1 Blockage

The hydraulic design has included an assessment regarding the blockage of culverts. Blockage potential has been assessed in accordance with the guidelines in ARR 2016. The blockage assessment resulted in no blockage factor being applied to bridges and a blockage factor of 25% being applied to culverts.

ARR 2016 guidelines are focused on blockage of small bridges and culverts. The floodplain bridges proposed for the Project alignment are all multi-span large bridges and ARR 2016 notes that there are limited instances of multiple span bridges being observed with blockages similar to those seen at single span bridges or culverts.

As no culverts are proposed within this model no blockage sensitivity was undertaken.

9.2.4.2 Climate change assessment

The impacts of climate change were assessed for the 1% AEP event to determine the sensitivity of the Project design to the potential increase in rainfall intensity. The assessment was undertaken in accordance with ARR 2016 guidelines.

The selected representative concentration pathway for the climate change analysis was 8.5. The climate change analysis was undertaken by increasing rainfall intensities in the IFDs for the contributing catchments. For the Project, 8.5 corresponds to an increase in temperature of 3.7 degrees Celsius in 2090 and an increase in rainfall intensity of 18.7% which was obtained from the ARR 2016 Data Hub.

The overall extents of the changes in peak water levels under the 1% AEP event with climate change around Warrill Creek is generally similar to those seen in the 1% AEP event.

The climate change analysis was undertaken by increasing rainfall intensities within the IFDs for the local catchments and the resultant peak water levels are shown in Table 9.9. Climate change results increase water levels 370 mm at the bridge for the 1% AEP. The formation level is higher than the 1% AEP climate change water peak water levels at this location.

Table 9.9 Warrill Creek – 1% AEP event – Climate Change Assessment

Chainage (km)	Structure type	1% AEP Peak water levels (m AHD)	1% AEP + CC Peak water levels (m AHD)	Difference in peak water level (m)	Freeboard to rail formation with CC (m)
17.65	Bridge	32.80	33.10	0.3	1.8

9.3 Purga Creek

During a 1% AEP event approximately 2,140 m^3/s of flow passes through the Purga Creek bridge. The floodplain width at this location is approximately 1,700 m wide and there is no well-defined channel at the proposed crossing location. The average depth across the floodplain under the 1% AEP event in existing conditions is approximately 750 mm.

There are a number of flood sensitive receptors near the Project alignment including Washpool Road which runs adjacent to the Project alignment. As part of the Project, Washpool Road is realigned and raised.

9.3.1 Drainage structures

The hydraulic design of the major drainage structures was undertaken using the TUFLOW model (1d and 2d approach). On the Purga Creek system, the Project design includes:

- Seven rail bridges
- One rail reinforced concrete box culverts (RCBC) locations (multiple cells in places)
- Two rail reinforced concrete pipe culvert (RCP) locations (multiple cells in places)
- Five road reinforced concrete pipe culvert (RCP) locations (multiple cells in places).

Details of these structures are listed in Table 9.10 and Table 9.11.

Table 9.10 Purga Creek – Flood structure locations and details

Chainage (km)	Structure name	Structure type	No of cells	Diameter/ width (m)	Height (m) or Soffit level (m AHD)	Bridge length (m)
23.60	340-BR08	Bridge	-	-	46.60	621.0
24.71	340-BR09	Bridge	-	-	48.00	759.0
28.73	340-BR12	Bridge	-	-	66.80	115.0
33.81	C33.81	RCBC	9	2.40	2.10	-
34.21	C34.21	RCP	50	1.20	-	-
35.70	340-BR13	Bridge	-	-	73.80	115.0
36.08	C36.08	RCP	2	2.40	-	-
36.66	340-BR14	Bridge	-	-	77.60	138.0
37.53	340-BR16	Bridge	-	-	83.60	98.0
37.78	340-BR17	Bridge	-	-	85.70	299.0

Table 9.11 Purga Creek – Road structure locations and details

Approximate Project chainage (km)	Road name	Structure type	No cells	Diameter (m)
35.70	Washpool Road	RCP	4	2.40
36.70	Washpool Road	RCP	20	1.80
37.10	Washpool Road	RCP	20	1.20
37.30	Washpool Road	RCP	4	2.40
37.50	Washpool Road	RCP	25	0.60

9.3.2 Hydraulic design criteria outcomes

The hydraulic model was run for the Developed Case with the drainage structures and embankment areas included. Modelling of a range of events was undertaken (20%, 10%, 5%, 2%, 1% AEP events and 1 in 2,000 AEP, 1 in 10,000 AEP and PMF events). The Project design outcomes relative to the hydraulic design criteria (refer Table 4.1) are presented in the following sections.

9.3.2.1 Flood immunity and overtopping risk

The Project alignment has a 1% AEP immunity to formation level. The formation level of the Project alignment is driven by several factors including achieving flood immunity and meeting geometric requirements (e.g. allowing for grade separations). Therefore, the freeboard achieved varies along the alignment with the 1% AEP event flood immunity achieved with a minimum freeboard of over 2 m.

There is one tunnel on the Project alignment to the east of the Purga Creek catchment. The tunnel portals are not affected by flood inundation from Purga Creek and therefore achieve the required 1 in 10,000 AEP event flood immunity. The Project alignment has a crest at the eastern portal of the tunnel and the vertical grade falls away from the tunnel at both portals.

The risk of overtopping of the rail alignment has been assessed for a range of extreme events (1 in 2,000 AEP, 1 in 10,000 AEP and PMF events). The rail is not overtopped in the 1 in 2,000 AEP and 10,000 AEP events. There are two sections of the rail overtopped in the PMF event, this occurs at Ch 34.70 km and Ch 35.10 km. Table 9.12 outlines this overtopping. As shown in the table, the formation level is overtopped by 1.2 m and 0.5 m at Ch 34.70 km and Ch 35.10 km respectively during a PMF event.

Table 9.12 Purga Creek – Overtopping of rail formation and top of rail in extreme events

Chainage (km)	Depth of water above formation level (m)			Depth of water above top of rail (m)		
	1 in 2,000 AEP	1 in 10,000 AEP	PMF	1 in 2,000 AEP	1 in 10,000 AEP	PMF
34.70	N/A	N/A	1.2	N/A	N/A	0.4
35.10	N/A	N/A	0.5	N/A	N/A	N/A

9.3.2.2 Structures results

Table 9.13 presents hydraulic model results at each structure for the 1% AEP event. The hydraulic results at structures for flows, velocities and water surface levels for all events are presented in Appendix E.

Table 9.13 Purga Creek – 1% AEP event structure results

Chainage (km)	Structure type	Upstream peak water level (m AHD)	Freeboard to rail formation level (m)	Outlet velocity (m/s)	Peak discharge (m^3/s)
23.55	Bridge	40.00	7.8	1.3	248
24.75	Bridge	41.00	8.2	1.6	260
28.72	Bridge	60.40	7.6	3.4	170
33.83	RCBC	62.30	5.8	0.7	19
34.20	RCP	62.30	7.5	0.2	1
35.70	Bridge	70.20	4.8	2.3	91
35.70	RCP (road)	71.4	N/A	3.0	91
36.10	RCP	68.90	8.8	0.7	1
36.65	Bridge	71.30	7.5	2.6	64
36.70	RCP (road)	71.70	N/A	1.8	64
37.10	RCP (road)	76.90	N/A	2.0	22
37.30	RCP (road)	78.60	N/A	2.3	35
37.50	RCP (road)	79.90	N/A	1.4	7
37.55	Bridge	80.70	4.1	2.7	56
37.80	Bridge	82.90	4.0	2.0	64

Table note:
N/A – Structure does not convey flow in the 1% AEP Event, structure assessed in local drainage models

Scour protection requirements for culverts have been calculated based on the velocities predicted from the hydraulic modelling. The scour protection has been designed in accordance with Austroads Guide to Road Design Part 5B: Drainage (AGRD). Scour protection was specified where the culvert outlet velocities for the 1% AEP event exceeded the allowable soil velocities shown in Table 3.1 of AGRD as follows:

- Stable rock – 4.5 m/s
- Stones 150 mm diameter or larger – 3.5 m/s

- Gravel 100 mm or grass cover – 2.5 m/s
- Firm loam or stiff clay – 1.2 to 2 m/s
- Sandy or silty clay – 1.0 to 1.5 m/s.

The scour protection length and minimum rock size (d50) were determined from Figure 3.15 and Figure 3.17 in AGRD. Resulting length of scour protection required were determined through the drainage assessment. All required scour lengths were predicted to fit within the proposed rail footprint.

A conservative scour estimation has been undertaken at each bridge site based on available information and will be refined during detailed design.

9.3.3 Flood impact objectives outcomes

The Project design outcomes relative to the flood impact objectives (refer Table 4.2) are presented in the following sections.

9.3.3.1 Change in peak water levels

The impact of the Developed Case has been assessed through inclusion of the drainage structures and comparison of model results against the Existing Case results. Resulting changes in peak water levels have been mapped (refer Appendix C).

Under the 1% AEP event there are a few isolated occurrences of afflux predicted to be 200 mm or greater. These are:

- On the upstream embankment between (Ch 23.60 km to Ch 24.71 km) there is up to 465 mm afflux. At this crossing the natural channel is very shallow (less than 1.5 m deep in the 1% AEP event as compared to over 3 m deep upstream and downstream). At the bridge crossing the average 1% AEP event flood depth in the floodplain for the Existing Case is approximately 750 mm. Developed Case peak water levels reduce to within 10 mm of the Existing Case approximately 500 m upstream and 1.7 km downstream of the Project alignment. Within 170 m south of the Project alignment the difference between water levels decreases to less than 200 mm. Where the afflux is greater than 10 mm there are no identified flood sensitive receptors.
- Between Ch 33.81 km and Ch 34.21 km there is up to 400 mm afflux localised south-west of the Project alignment. This afflux is due to the rail alignment crossing a natural overbank flow area. These levels decrease by 200 mm in afflux within 200 m of the Project alignment. There are no flood sensitive receptors in this area. On the upstream end (Ch 34.21 km) the flow is shallow and 50/1.20 m RCPs have been modelled under the Project alignment and on the downstream end (Ch 33.81 km) 9/2.40 m x 1.20 m RCBCs are required.
- At Washpool Road between Ch 33.81 km and Ch 34.21 km there is up to 200 mm afflux predicted. This afflux is due to Washpool Road being raised (by greater than 200 mm) and realigned for the level crossing. As the road is inundated by the 1% AEP event (in Existing and Developed Cases) there is an increase in peak water levels. However, the increase in road level also increases the road flood immunity in this location. The overall flood immunity of Washpool Road is not governed by this location and as is demonstrated by the AAToS calculations.
- On Washpool Road at Ch 35.70 km there is 400 mm afflux in the channel directly upstream of the Project alignment. This afflux is due to the increase in road height at this location (the existing Washpool Road is a low-level crossing). At this location 8/2.40 m RCPs are proposed to be added under Washpool Road and all impacts are contained within the channel. The afflux dissipates to less than 200 mm within 30 m of the road.
- Between Ch 36.95 km and Ch 37.80 km there is afflux up to 400 mm afflux on rural land. This afflux is due to the realignment and upgrade of Washpool Road. All afflux from the Project alignment is contained within the Project disturbance footprint. There is no afflux on flood sensitive receptors in this area.

As seen in Appendix C Figure C7-C-2 Washpool Road is the only flood sensitive receptor with more than 10 mm afflux in the Purga Creek catchment. Details of this receptor are outlined in Table 9.14.

Table 9.14 Purga Creek – 1% AEP Event – Afflux at flood sensitive receptors

Location	Afflux (mm)	Comment
Washpool Road (near crossing of Purga Creek, east of Ipswich Boonah Road)	+200	Washpool Road is being raised at this location (greater than 200mm) for the level crossing to the south. As it is inundated during the 1% AEP event in existing conditions there is afflux due to the impediment of flow. It is also noted the overall flood immunity of Washpool Road is not governed by this location.

Where afflux is 10 mm or greater at a flood sensitive receptor, under the 1% AEP event with climate change, a summary of afflux for all modelled events up to the 1% AEP event with climate change is presented in Appendix H.

9.3.3.2 Average annual time of submergence and time of submergence

Assessment of the difference in the ToS is presented in Appendix C Figure C7-I.

Under the 1% AEP event there are a few isolated occurrences of an increase in ToS. These are:

- Purga Creek Bridge (Ch 23.55 km). There is an increase of the time of submergence of 2.5 hours. This increase does not inundate roadways or flood sensitive receptors. At this location the 1% AEP (24 hour) event is critical.
- Between Ch 33.83 km and Ch 34.20 km north-east of the alignment there is a localised increase in ToS of 31.7 hours. This localised increase does not inundate transportation corridors or sensitive infrastructure. At this location the 1% AEP (12 hour) event is critical.
- At Washpool Road between Ch 33.81 km and Ch 34.21 km there is a localised increase of ToS. The increase is predominantly in the long drain running adjacent to the road and not on the road itself. The level of Washpool Road in this area has been increased and the ToS has been reduced.

Table 9.15 outlines the AAToS for the Existing and Developed Cases at Washpool Road.

Table 9.15 AAToS Comparison for Washpool Road

Location	AAToS Existing Case (hrs/yr)	AAToS Developed Case (hrs/yr)	Difference (hrs/yr)
Washpool Road (near crossing of Purga Creek, east of Ipswich Boonah Road)	47.8	47.4	-0.4

9.3.3.3 Change in velocities

Appendix C Figure C7-H presents the changes in peak velocities under the 1% AEP event associated with the Project alignment. In general, the changes are generally minor, with the greatest changes in velocities experienced between Ch 33.6 km and Ch 34.5 km. These changes do not exceed 0.7 m/s and therefore there is a limited risk of increased scour to the adjacent Washpool Road and in Purga Creek overbanks areas.

9.3.3.4 Flood flow distribution

Overall, the Project has minimal impacts on flood flows and floodplain conveyance/storage with significant floodplain structures included to maintain the existing flood regime.

9.3.3.5 Extreme event risk management

During extreme events there is widespread floodplain inundation with high flood depths as shown in Appendix C Figure C8 to C10. These impacts have been considered in relation to the Existing Case flood depth at flood sensitive receptors. Under these rare events, the bridge structures and culverts allowing adequate passage of flow during the flood events and “damming” effects are therefore not expected to occur.

9.3.4 Sensitivity analysis

9.3.4.1 Blockage

The hydraulic design has included an assessment regarding the blockage of culverts. Blockage potential has been assessed in accordance with the guidelines in ARR 2016. The blockage assessment resulted in no blockage factor being applied to bridges and a blockage factor of 25% being applied to culverts.

ARR 2016 guidelines are focused on blockage of small bridges and culverts. The floodplain bridges proposed for the Project alignment are all multi-span large bridges and ARR 2016 notes that there are limited instances of multiple span bridges being observed with blockages similar to those seen at single span bridges or culverts.

A minimum culvert size of 1,200 mm diameter was adopted to reduce the potential for blockage and for ease of maintenance.

Two blockage sensitivity scenarios were tested; 0% and 50% blockage of all culverts. The results are presented in Appendix C, Figure C7-E and C7-F for the 0% and 50% blockage respectively. The afflux at Washpool Road increased to 250 mm in the 50% blockage scenario as seen in Appendix C Figure C7-F. No other flood sensitive receptors were impacted by the blockage scenarios.

9.3.4.2 Climate change assessment

The impacts of climate change were assessed for the 1% AEP event to determine the sensitivity of the Project design to the potential increase in rainfall intensity. The assessment was undertaken in accordance with ARR 2016 guidelines.

The selected representative concentration pathway for the climate change analysis was 8.5. The climate change analysis was undertaken by increasing rainfall intensities in the IFDs for the contributing catchments. For the Project, 8.5 corresponds to an increase in temperature of 3.7 degrees Celsius in 2090 and an increase in rainfall intensity of 18.7% which was obtained from the ARR 2016 Data Hub.

The overall extents of the changes in peak water levels under the 1% AEP event with climate change around Purga Creek are generally similar to those seen in the 1% AEP event.

The climate change analysis was undertaken by increasing rainfall intensities within the IFDs for the local catchments and the resulting peak water levels are shown in Table 9.16.

Table 9.16 Purga Creek – 1% AEP event – Climate Change Assessment

Chainage (km)	Structure type	1% AEP Peak water levels (m AHD)	1% AEP + CC Peak water levels (m AHD)	Difference in peak water level (m)	Freeboard to rail formation with CC (m)
23.55	Bridge	40.00	40.1	0.1	7.7
24.75	Bridge	41.00	41.2	0.2	8.0
28.72	Bridge	60.40	60.9	0.5	7.1
33.83	RCBC	62.30	62.6	0.3	5.6
34.20	RCP	62.30	62.6	0.3	7.2
35.70	Bridge	70.20	70.7	0.5	4.3
35.70	RCP (road)	71.40	72.0	0.6	N/A

Chainage (km)	Structure type	1% AEP Peak water levels (m AHD)	1% AEP + CC Peak water levels (m AHD)	Difference in peak water level (m)	Freeboard to rail formation with CC (m)
36.10	RCP	68.90	69.1	0.2	8.6
36.65	Bridge	71.30	71.4	0.1	7.4
36.70	RCP (road)	71.70	72.0	0.3	N/A
37.10	RCP (road)	76.90	77.2	0.3	N/A
37.30	RCP (road)	78.60	78.6	0.0	N/A
37.50	RCP (road)	79.90	80.0	0.1	N/A
37.55	Bridge	80.70	80.8	0.1	4.0
37.80	Bridge	82.90	83.1	0.2	3.8

Table note:

N/A – Structure does not convey flow in the 1% AEP Event, structure assessed in local models

9.4 Teviot Brook

Teviot Brook crosses the Project alignment at a single location around Ch 52.80 km. This crossing is approximately 5 km upstream of the confluence between Teviot Brook and the Logan River as seen in Appendix D Figure D1-A. At the Teviot Brook Project alignment crossing the peak water levels are governed by backwater from Logan River flooding.

Woollaman Creek, a tributary of Teviot Brook, runs parallel to the Project alignment. At the confluence of Woollaman Creek and Teviot Brook peak water levels are influenced by Logan River flooding. Woollaman Creek and its tributaries cross the alignment at multiple locations.

As presented in Appendix D Figure D7-A-2, under the 1% AEP event flood waters in Teviot Brook are over 10 m deep at the Project alignment crossing location. No habitable structures are in the vicinity of the rail corridor. Upstream of the rail alignment there are two flood sensitive receptors which are a quarry and Undullah Road. Along Woollaman Creek there are no flood sensitive receptors that are close to the alignment or within the 1% AEP event inundation extents. In the Teviot Brook catchment, the Project alignment vertical grade is governed by factors other than flooding.

9.4.1 Drainage structures

The hydraulic design of the major drainage structures was undertaken using the TUFLOW model (1d and 2d approach). Within the Teviot Brook TUFLOW Model the design includes:

- Nine rail bridges
- One rail reinforced concrete pipe (RCP) location (multiple cells)
- One road reinforced concrete pipe (RCP) location (multiple cells).

Details of these structures are listed in Table 9.17 and Table 9.18.

Table 9.17 Teviot Brook – flood structure locations and details

Chainage (km)	Structure name	Structure type	No of cells	Diameter (m)	Soffit level (m AHD)	Bridge length (m)
41.87	340-BR18	Bridge	-	-	105.70	184.0
42.76	340-BR19	Bridge	-	-	97.30	138.0
43.06	340-BR20	Bridge	-	-	92.10	161.0
43.40	340-BR21	Bridge	-	-	87.90	230.0
46.20	340-BR22	Bridge	-	-	63.20	115.0
47.00	340-BR23	Bridge	-	-	59.20	161.0

Chainage (km)	Structure name	Structure type	No of cells	Diameter (m)	Soffit level (m AHD)	Bridge length (m)
48.33	C48.33	RCP	12	1.50	-	-
50.60	340-BR24	Bridge	-	-	46.20	207.0
51.35	340-BR25	Bridge	-	-	44.00	230.0
52.80	340-BR26	Bridge	-	-	41.60	722.0

Table 9.18 Teviot Brook – road structure locations and details

Approximate Project chainage (km)	Road name	Structure type	No cells	Diameter (m)
43.00	Wild Pig Creek Road	RCP	9	2.40

9.4.2 Hydraulic design criteria outcomes

The hydraulic model was run for the Developed Case with the drainage structures and embankment areas included. Modelling of a range of events was undertaken (20%, 10%, 5%, 2%, 1% AEP events and 1 in 2,000 AEP, 1 in 10,000 AEP and PMF events). The Project design outcomes relative to the hydraulic design criteria (refer Table 4.1) are presented in the following sections.

9.4.2.1 Flood immunity and overtopping risk

The Project alignment has a 1% AEP immunity to formation level. The formation level of the Project alignment is driven by several factors including achieving flood immunity and meeting geometric requirements (e.g. allowing for grade separations). Therefore, the freeboard achieved varies along the alignment with the 1% AEP event flood immunity achieved with a minimum freeboard of 5 m.

The risk of overtopping of the rail alignment has been assessed for a range of extreme events (1 in 2,000 AEP, 1 in 10,000 AEP and PMF Events). The rail is not overtopped in the 1 in 2,000 AEP and 10,000 AEP events. There is a section of the rail overtopped in the PMF event around Ch 53.90 km, where the rail ties in to the existing line. Table 9.19 outlines this overtopping. As shown in Table 9.19, the formation level is overtopped by 50 mm and the top of rail is not overtopped.

Table 9.19 Teviot Brook – Overtopping of rail formation and top of rail in extreme events

Chainage (km)	Depth of water above formation level (m)			Depth of water above top of rail (m)		
	1 in 2,000 AEP	1 in 10,000 AEP	PMF	1 in 2,000 AEP	1 in 10,000 AEP	PMF
53.90	N/A	N/A	0.05	N/A	N/A	N/A

9.4.2.2 Structures results

Table 9.20 presents hydraulic model results at each structure for the 1% AEP event. The hydraulic results at structures for flows, velocities and water surface levels for all events are presented in Appendix E.

Table 9.20 Teviot Brook – 1% AEP event structure results

Chainage (km)	Structure type	Upstream Peak Water Level (m AHD)	Freeboard to rail formation level (m)	Outlet velocity (m/s)	Peak discharge (m^3/s)
42.80	Bridge	74.20	24.3	1.9	131
43.00	RCP (road)	73.60	N/A	2.5	77
43.10	Bridge	72.20	21.1	3.0	203
43.45	Bridge	N/A	N/A	N/A	N/A
46.20	Bridge	53.20	11.2	2.3	126

Chainage (km)	Structure type	Upstream Peak Water Level (m AHD)	Freeboard to rail formation level (m)	Outlet velocity (m/s)	Peak discharge (m^3/s)
47.00	Bridge	50.20	10.2	2.9	38
48.37	RCP	46.90	8.5	1.3	13
50.60	Bridge	34.80	12.6	1.9	2
51.40	Bridge	34.70	10.5	1.1	36
51.81	RCP	N/A	N/A	N/A	N/A
52.90	Bridge	34.80	8.0	1.8	917
53.90	RCP	N/A	N/A	N/A	N/A

Table note:

N/A – Structure does not convey flow in the 1% AEP Event, structure assessed in local models

Scour protection requirements for culverts have been calculated based on the velocities predicted from the hydraulic modelling. The scour protection has been designed in accordance with Austroads Guide to Road Design Part 5B: Drainage (AGRD). Scour protection was specified where the culvert outlet velocities for the 1% AEP event exceeded the allowable soil velocities shown in Table 3.1 of AGRD as follows:

- Stable rock – 4.5 m/s
- Stones 150 mm diameter or larger – 3.5 m/s
- Gravel 100 mm or grass cover – 2.5 m/s
- Firm loam or stiff clay – 1.2 to 2 m/s
- Sandy or silty clay – 1.0 to 1.5 m/s.

The scour protection length and minimum rock size (d50) were determined from Figure 3.15 and Figure 3.17 in AGRD. Resulting length of scour protection required were determined through the drainage assessment. All required scour lengths were predicted to fit within the proposed rail footprint.

A conservative scour estimation has been undertaken at each bridge site based on available information and will be refined during detailed design.

9.4.3 Flood impact objectives outcomes

The Project design outcomes relative to the flood impact objectives (refer Table 4.2) are presented in the following sections.

9.4.3.1 Change in peak water levels

The impact of the Developed Case has been assessed through inclusion of the drainage structures and comparison of model results against the Existing Case results. Resulting changes in peak have been mapped (refer Appendix D).

Under the 1% AEP event there are a few isolated occurrences of afflux predicted to be greater than 200 mm. These are:

- Upstream of Wild Pig Creek Road afflux is up to 400 mm for approximately 170 m upstream of structure. Afflux reduces to 200 mm approximately 350 m from the Project alignment. This area is highly vegetated with no nearby flood sensitive receptors.
- Ch 48.37 km culvert crossing there is approximately 250 mm of afflux. This decreases to 200 mm within the Project disturbance footprint. This area is highly vegetated with no nearby flood sensitive receptors.

As seen in Appendix D Figure D7-C-2 no flood sensitive receptors in the Teviot Brook catchment have greater than 10 mm of afflux.

9.4.3.2 Average annual time of submergence and time of submergence

Assessment of the difference in the ToS is presented in Appendix D Figure D7-I-2. Under the 1% AEP event there are a few isolated occurrences of increases in the ToS however no flood sensitive receptors are affected. As no flood sensitive receptors have an increased ToS, AAToS calculations were not undertaken. The affected locations are:

- Upstream of Wild Pig Creek Road – Upstream of these road culverts there is a localised increase of over 22 hours. This localised increase does not inundate roads and is contained with the channel. There is no change in the ToS for flood sensitive infrastructure at this location.
- Ch 48.37 km culvert crossing – Upstream of these rail culverts there is a localised increase of over 36 hours. This localised increase does not inundate roads and is contained with the channel. There is no change in the ToS at flood sensitive infrastructure at this location.

9.4.3.3 Change in velocities

Appendix D Figure D7-H presents the changes in peak velocities under the 1% AEP event associated with the Project alignment. In general, the changes are minor, with most changes in velocities experienced immediately adjacent to the Project alignment.

9.4.3.4 Flood flow distribution

Overall, the Project has minimal impacts on flood flows and floodplain conveyance/storage with significant floodplain structures included to maintain the existing flood regime.

9.4.3.5 Extreme event risk management

During extreme events there is widespread floodplain inundation with high flood depths as shown in Appendix D Figure D8 to D10. These impacts have been considered in relation to the Existing Case flood depth at flood sensitive receptors. Under these rare events, the bridge structures and culverts allowing adequate passage of flow during the flood events and “damming” effects are therefore not expected to occur.

9.4.4 Sensitivity analysis

9.4.4.1 Blockage

The hydraulic design has included an assessment regarding the blockage of culverts. Blockage potential has been assessed in accordance with the guidelines in ARR 2016. The blockage assessment resulted in no blockage factor being applied to bridges and a blockage factor of 25 per cent being applied to culverts.

ARR 2016 guidelines are focused on blockage of small bridges and culverts. The floodplain bridges proposed for the Project alignment are all multi-span large bridges and ARR 2016 notes that there are limited instances of multiple span bridges being observed with blockages similar to those seen at single span bridges or culverts.

A minimum culvert size of 1,200 mm diameter was adopted to reduce the potential for blockage and for ease of maintenance.

Two blockage sensitivity scenarios were tested; 0 per cent and 50 per cent blockage of all culverts. The results are presented in Appendix D, Figure D7-E and Figure D7-F for the 0 per cent and 50 per cent blockage respectively. Although water levels increased with the 50 per cent blockage as seen in Appendix D Figure D7-F there was no change of water levels at any flood sensitive receptors.

9.4.4.2 Climate change assessment

The impacts of climate change were assessed for the 1% AEP design event to determine the sensitivity of the Project alignment design to the potential increase in rainfall intensity. The assessment was undertaken in accordance with ARR 2016 guidelines.

The selected representative concentration pathway for the climate change analysis was 8.5. The climate change analysis was undertaken by increasing rainfall intensities in the IFDs for the contributing catchments. For the Project, 8.5 corresponds to an increase in temperature of 3.7 degrees Celsius in 2090 and an increase in rainfall intensity of 18.7% which was obtained from the ARR 2016 Data Hub.

The inclusion of climate change has no impact on the change in peak water levels associated with the Project alignment.

The climate change analysis was undertaken by increasing rainfall intensities within the IFDs for the local catchments and the resultant water levels are shown in Table 9.21. Climate change results increase water levels up to 420 mm along the alignment for the 1% AEP event. The formation level is considerably higher than the 1% AEP climate change water levels at this location. Appendix D Figure D7-D presents the 1% AEP climate change results for the Teviot Brook catchment.

Table 9.21 Teviot Brook – 1% AEP event – Climate Change Assessment

Chainage (km)	Structure type	1% AEP Peak water levels (m AHD)	1% AEP + CC Peak water levels (m AHD)	Difference in peak water levels (m)	Freeboard to rail formation level with CC (m)
42.80	Bridge	74.20	74.70	0.5	22.6
43.00	RCP (road)	73.60	74.50	0.9	N/A
43.10	Bridge	72.20	72.80	0.6	19.3
43.45	Bridge	N/A	N/A	N/A	N/A
46.20	Bridge	53.20	53.90	0.7	9.3
47.00	Bridge	50.20	50.50	0.3	8.7
48.37	RCP	46.90	47.20	0.3	8.2
50.60	Bridge	34.80	35.60	0.8	10.6
51.40	Bridge	34.70	44.20	9.5	3.5
51.81	RCP	N/A	35.40	N/A	8.6
52.90	Bridge	34.80	41.30	6.5	3.8
53.90	RCP	N/A	35.50	N/A	6.1

Table note:

N/A – Structure does not convey flow in the 1% AEP Event, structure assessed in local models

9.5 Local catchment drainage

The following section details the hydraulic assessment that has been undertaken for cross drainage for the local catchments along the rail alignment which are outside the regional floodplain extents.

9.5.1 Hydrology

9.5.1.1 Drainage catchment classification

The proposed rail alignment crosses a number of existing flowpaths in the different catchment areas that contribute flows to the cross drainage structures. To determine the appropriate hydrologic methods for the local drainage design, the existing catchments were categorised based on the contributing catchment areas. Table 9.22 presents the drainage catchment classification criteria and number of catchments relating to each classification.

Table 9.22 Drainage catchment classification

Catchment size	Drainage catchment classification	Number of catchments
Less than or equal to 10 km^2	Minor	60
Greater than 10 km^2 and less than or equal to 100 km^2	Moderate	1
Greater than 100 km^2	Major	4

The major floodplains are addressed in Sections 9.1 to 9.4.

9.5.1.2 Minor catchments

The 1% AEP and 1 in 2,000 AEP catchment flows for the minor catchments were generated in accordance with ARR 2016 using the ILSAX hydrologic model within the 12D Drainage Network Editor.

Ten temporal patterns were run for each storm duration and the median temporal pattern from each duration were compared to determine the peak runoff for each catchment.

The losses adopted within ILSAX were taken from the calibrated hydrologic models for the regional catchments along the alignment.

As no calibration data was available to compare against the local catchment flows, the 1% AEP flows generated from ILSAX was compared against the traditional Rational Method. The flows generated using ILSAX compare closely with the flows generated from the traditional Rational Method and are within a tolerance of -3 to 4%.

The Rational Method is no longer compliant with ARR 2016; however, it is still considered to give a reasonable approximation of local catchment flows and therefore the parameters and resultant ILSAX flows were adopted for the design.

9.5.1.3 Moderate catchments

The catchments situated on the Willowbank floodplain are categorised as moderate catchments and are located within the Warrill Creek catchment. The design flows for the Willowbank floodplain were generated from a URBS hydrologic model which used the same parameters as the calibrated Warrill Creek URBS model.

The models were run for 10 temporal patterns for all durations from 10 minutes to 168 hours and the median temporal pattern from each duration were compared to determine the critical design storm for each catchment.

9.5.2 Hydraulic design

Cross drainage structures are provided where the rail intercepts existing flowpaths. The type of structures adopted depends on a range of factors including as the natural topography, rail formation levels, design flows and soil type.

The cross drainage design was undertaken in accordance with the Project hydraulic design criteria set out in Table 4.1. Cross drainage structures outside the regional floodplains were sized based on the flows generated from the local drainage catchments. Cross drainage structures that have a well-defined local catchment boundary and are located within or near the regional floodplains were assessed for both the local catchment flows and regional floodplain conditions to determine the governing design conditions.

9.5.2.1 Minor catchments

Cross drainage structures located within minor catchments where the upstream flow path is primarily 1-Dimensional (1D) were assessed as per the following methodology:

- Culverts were initially sized and optimised using 12D Dynamic Culvert
- The resultant afflux was assessed in TUFLOW and the culvert designs were adjusted as required to meet the afflux criteria. Further details of the impact assessment are detailed in Section 9.5.2.3
- Final culvert designs were analysed back in 12D Dynamic Culvert to determine final design water levels and velocities at the culverts which are detailed in Appendix I.

9.5.2.2 Moderate catchments

A 10 m grid 2-Dimensional (2D) hydraulic analysis was undertaken in TUFLOW for the Willowbank floodplain to design the cross drainage culverts and bridge structures within the Willowbank catchment. The model attributes were adopted from the calibrated Warrill Creek TUFLOW model. The extent and details of the TUFLOW model are presented in Figure 9.1.

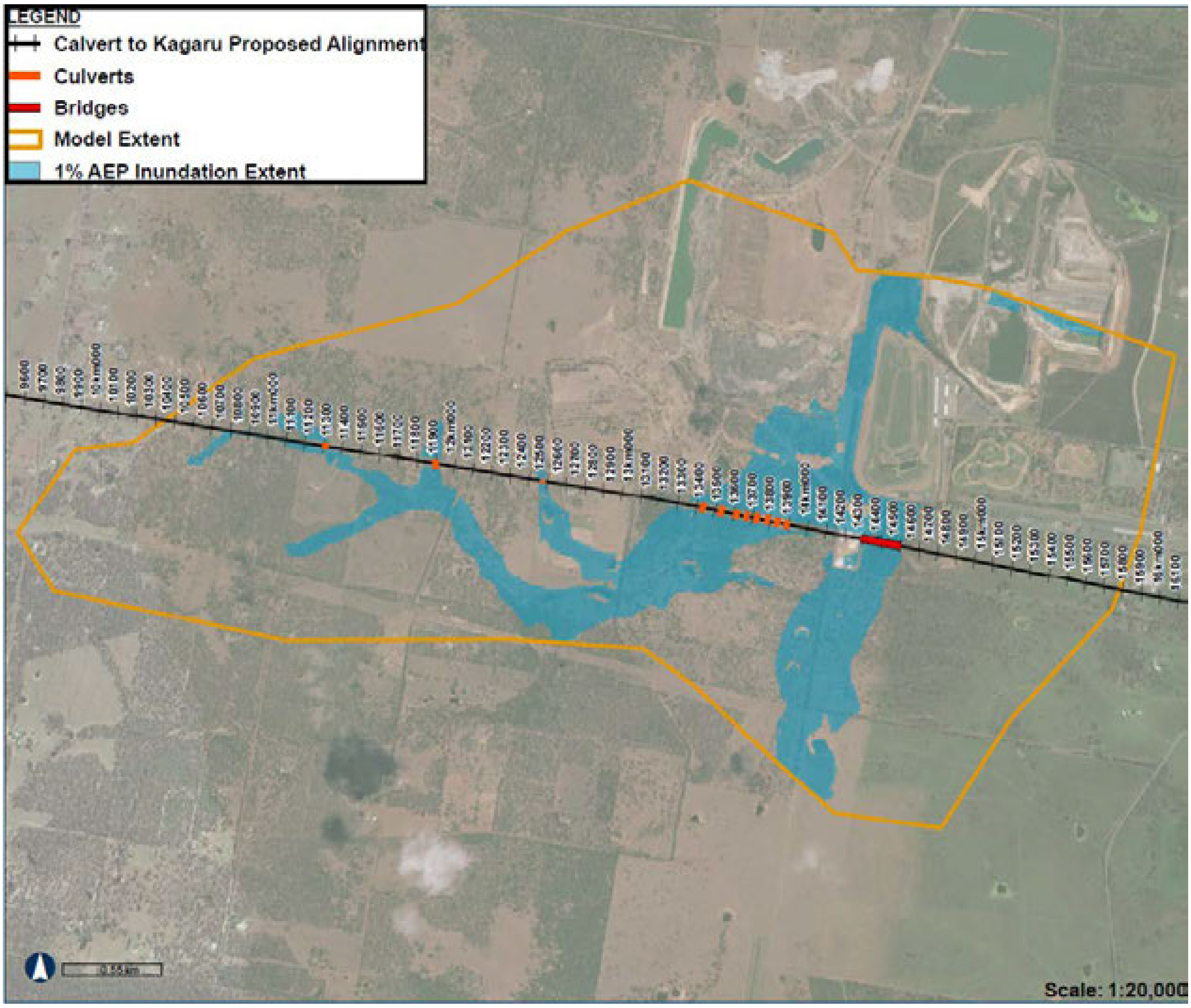


Figure 9.1 Willowbank TUFLOW model

The resulting flows through the structures, upstream water levels and crossing velocities were extracted from the TUFLOW model for the cross drainage structures in the Willowbank catchment and are documented in the Appendix I.

9.5.2.3 Impact assessment

For each of the local catchment crossings the impact of the Project upon the existing flood regime was quantified and compared against flood impact objectives as detailed in Table 4.2. These objectives have been used to guide the Project design. Acceptable impacts will ultimately be determined on a case by case basis with interaction with stakeholders/landholders through the community engagement process using these objectives as guidance. This takes into account flood sensitive receptors and land use.

The land use across the Project area has been classified as agricultural grazing/pasture land or forest areas based on aerial imagery. Sensitive agricultural land may be identified during further consultation with landowners which will need to be considered in Detailed Design. The hydraulic impacts in the local catchments are considered 'localised' in comparison to regional flood impacts due to the shorter time of flood inundation and smaller flood extents. The afflux and change in time of inundation at each structure is tabulated in Appendix I. The predicted impacts all comply with the flood impact objectives.

There are two local roads which are impacted by the 1% AEP Willowbank flooding, being Paynes Road and M Hines Road. The M Hines Road is being realigned and raised as part of the proposed design. The existing and proposed Time of Inundation (TOI) for the 1% AEP event has been assessed (refer Table 9.23) to ensure the serviceability of these roads has not been impacted by the rail alignment. The results show that the 1% AEP TOI decreases between the existing and proposed cases and therefore the serviceability of the roads is not adversely impacted by the design.

Table 9.23 Time of Inundation assessment at local roads in the Willowbank floodplain

Sensitive Receptor ID	Road name	Existing Time of Inundation (hrs)	Design Time of Inundation (hrs)	Change in Time of Inundation (hrs)
18	M Hines Road (Proposed road)	16.8	1	-15.8
19	Paynes Road	21.5	21.4	-0.1

9.5.3 Sensitivity analysis

9.5.3.1 Blockage

A blockage assessment for the 1% AEP event was undertaken in accordance with ARR16 Book 6 Chapter 6 Blockage of Hydraulic Structures.

Within C2K there are a number of steep catchments throughout the Teviot Range (Ch 35000–53000) which were assessed as having a high debris blockage potential due to the dense scrub and high stream velocities within the catchments. This corresponds to a design blockage factor of 50% to 100% for the 1% AEP as per ARR 2016 Book 6 Chapter 6 which results in high numbers of culvert to achieve the required afflux criteria and design immunity. To mitigate the blockage potential at these culvert cells, debris deflector walls can be incorporated at the inlets of the culverts which decreases the blockage factor to 25% to account for sediment blockage.

A 25% blockage was adopted during feasibility design for all structures along the alignment and debris deflector walls have been indicated in the register where required.

The blockage factor was applied by reducing the culvert opening by 25% within the 12D Dynamic Culvert Editor and was applied in TUFLOW within the culvert network layer.

9.5.3.2 Climate change assessment

The impacts of climate change were assessed in accordance with ARR 2016 Book 1 Chapter 6 for the local drainage catchments for the 1% AEP design event to determine the sensitivity of the design to the potential increase in rainfall intensity. The selected representative concentration pathway for the climate change analysis was 8.5 which represents a high emissions scenario. For C2K, a representative concentration pathway of 8.5 corresponds to an increase in temperature of 3.7°C in 2090 and an increase in rainfall intensity of 19.7% which was obtained from the ARR 2016 Datahub.

The climate change analysis was undertaken by increasing rainfall intensities within the IFDs for the local catchments. The climate change factor increases the 1% AEP local drainage water levels by a maximum of 1.03 m along the alignment. However, the flood immunity of the rail formation is not adversely affected by climate change within the local catchments with the minimum freeboard along the alignment being 0.39 m and the majority of crossing having a freeboard in excess of 1 m to rail formation.

10 Limitations

FFJV has prepared this report in accordance with the usual diligence and thoroughness of the consulting profession with reference to current standards, procedures and practices.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by FFJV for use of any part of this report in any other context.

This report was prepared for the exclusive use of the Project. FFJV accepts no liability or responsibility whatsoever for, any use of, or reliance upon, this report by any third party.

This report was prepared based on information available at the time of writing. The models detailed in this report are based on LiDAR survey taken generally in 2015 (or as detailed in each catchment section). Therefore, any development or topographical change occurring within the catchment after the surveys taken is not included in this investigation, unless directly specified.

There are a number of limitations that apply to the modelling to date, some of which include:

- Stakeholder engagement will continue during detailed design, construction and operation. As such proposed impacts and structural solutions still need to be confirmed with relevant stakeholders. Modelling may need to be updated as a result of any ongoing stakeholder engagement.
- Future proofing for future 3,600 m train lengths has not been included in the flood modelling.

The approval for the construction of future 3,600 m crossing loops will be subject to separate approval applications in the future.

ARR 2016 outlines several fundamental themes which are also particularly relevant to this investigation:

- All models are coarse simplifications of very complex processes. No model can therefore be perfect, and no model can represent all of the important processes accurately.
- Model accuracy and reliability will always be limited by the accuracy of the terrain and other input data.
- Model accuracy and reliability will always be limited by the reliability/uncertainty of the inflow data.
- No model is 'correct' therefore the results require interpretation.
- A model developed for a specific purpose is probably unsuitable for another purpose without modification, adjustment, and recalibration. The responsibility must always remain with the modeller to determine whether the model is suitable for a given problem.
- Recognition that no two flood events behave in exactly the same manner.
- Design floods are a best estimate of an "average" flood for their probability of occurrence.

It is noted that ARR 2019 has recently been released as an update to the ARR 2016 guidelines. Although there is limited difference in methodology between these versions it is recommended that in the next phase ARR 2019 guidelines are adopted.

The interpretation of results and other presentations in this report should be done with an appreciation of any limitations in their accuracy, as noted above.

Unless otherwise stated, presentations in this report are based on peak values of water surface level, flow, depth and velocity. Therefore, using water levels as an example, the peak level does not occur everywhere at the same time and, therefore, the values presented are based on taking the maximum value which occurred at each computational point in the model during the entire flood event. Hence, a presentation of peak water levels does not represent an instantaneous point in time, but rather an envelope of the maximum values that occurred at each computational point over the duration of the flood event.

11 Conclusions

The key objectives of this report are to provide information on the data investigation, hydrology and hydraulic calibration, impact assessment and mitigation and to provide comment on the performance on the Project design. This report outlines the methodology followed, the outcomes of this investigation and the assessment of the Project design.

There are four major waterway catchments that the Project alignment crosses being the Bremer River, Warrill Creek, Purga Creek and Teviot Brook. Detailed hydrologic and hydraulic assessments have been undertaken due to the catchment size and substantial floodplain flows associated with each of these watercourses. Bremer River, Warrill Creek and Purga Creek all form part of the larger Brisbane River system. Teviot Brook is a tributary of the Logan River.

Hydrologic and hydraulic modelling was undertaken for each of these catchments with the models calibrated to multiple historical events using stream gauges records and anecdotal data where available. Based on this performance, the hydrologic and hydraulic models were considered validated and appropriate to use to assess the potential impacts associated with the Project.

Design event hydrology was developed using ARR 2016 flood flow estimation techniques. The hydraulic models were run for a suite of design events from the 20% AEP event to the 1 in 10,000 AEP and PMF events. The flows and levels predicted by the hydrologic and hydraulic models were compared to the results of a FFA at stream gauges within each catchment as well as results from previous flood studies.

Modelling of the current state of development (Existing Case) was undertaken and details of the existing flood regime were determined for the modelled design events. The proposed works associated with the Project were incorporated into the hydraulic models to form the Developed Case. Assessment of the potential impacts upon the existing flood regime was undertaken and refinement of the Project design was undertaken to mitigate impacts.

Consultation with stakeholders, including landholders, was undertaken at key stages including validation of the performance of the modelling in replicating experienced historical flood events and presentation of the design outcomes and impacts on properties and infrastructure.

The Project design has been guided and refined using hydraulic design criteria (refer Table 4.1) and flood impact objectives (refer Table 4.2). The resulting design outcomes relative to the hydraulic design criteria are detailed in Table 11.1.

Table 11.1 Project hydraulic design criteria outcomes

Performance criteria	Design outcomes
Flood immunity	Rail line – 1% AEP flood immunity with minimum of 300 mm freeboard to formation level has been achieved. Tunnel portals – 1 in 10,000 AEP event flood immunity has been achieved.
Hydraulic analysis and design	Hydrologic and hydraulic analysis and design has been undertaken using ARR 2016 and state/local government guidelines. The Project design includes significant rail drainage structures under the Project alignment to convey flood flows on floodplains and minimise impacts under the full range of design events, being: ▪ Twenty (20) rail bridges ▪ One (1) rail reinforced concrete box culvert (RCBC) banks ▪ Eight (8) rail reinforced concrete pipe culvert (RCP) banks ▪ Inclusion of road drainage structures under local roads adjacent to the Project alignment, being: – Six (6) road reinforced concrete pipe culvert (RCP) banks. In addition, drainage structures are included for local catchment crossings.

Performance criteria	Design outcomes
Scour protection of structures	Culvert scour protection has been designed in accordance with Austroads Guide to Road Design Part 5B: Drainage (AGRD). Scour protection was specified where the culvert outlet velocities for the 1% AEP event exceeded the allowable soil velocities shown in Table 3.1 of AGRD. Required lengths of scour protection have been determined and are predicted to fit within the proposed rail disturbance footprint. A conservative scour estimation has been undertaken at each bridge site based on available information and will be refined during detailed design.
Structural design	1 in 2,000 AEP event has been modelled with details used for bridge design purposes.
Extreme events	Overtopping of the Project alignment under extreme events occurs at limited locations being: ▪ Bremer River – Above formation level and top of rail level at Ch 0.30 km for 1 in 2,000, 1 in 10,000 AEP and PMF events ▪ Warrill Creek – not overtopped ▪ Purga Creek – Above formation level and top of rail level at Ch 34.70 km and Ch 35.10 km for PMF event ▪ Teviot Brook – Above formation level at Ch 53.90 km for PMF event.
Flood flow distribution	Structures have been located along the Project alignment to maintain existing flood conveyance and spread of floodwaters.
Sensitivity testing	The risk to the Project design from climate change and blockage has been assessed in accordance with ARR 2016. Key outcomes are: ▪ The Project design maintains 1% AEP flood immunity under 2090 climate change conditions ▪ Based on ARR 2016, a blockage factor of 25% has been applied to culverts and no blockage factor has been applied to bridges ▪ Varying the level of blockage to culverts between 0% and 50% does not impact upon the Project design.

Flood impact objectives, as presented in Table 4.2, have been established and used to guide the Project design including mitigation of impacts through refinement of the hydraulic design, including adjustment of the numbers, dimensions and location of major drainage structures. Table 11.2 summarises how the Project design performs against each of the flood impact objectives.

Table 11.2 Flood impact objectives and outcomes

<table>
<tr><th>Parameter</th><th colspan="5">Objectives and outcomes</th></tr>
<tr><td rowspan="3">Change in peak water levels</td><td>Existing habitable and/or commercial and industrial buildings/premises (e.g. dwellings, schools, hospitals, shops)</td><td>Residential or commercial/industrial properties/lots where flooding does not impact dwellings/buildings (e.g. yards, gardens)</td><td>Existing non-habitable structures (e.g. agricultural sheds, pump-houses)</td><td>Roadways</td><td>Agricultural and grazing land/forest areas and other non-agricultural land</td></tr>
<tr><td>≤ 10 mm</td><td>≤ 50 mm</td><td>≤ 100 mm</td><td>≤ 100 mm</td><td>≤ 200 mm with localised areas up to 400 mm</td></tr>
<tr><td colspan="5">Objective: Changes in peak water levels are to be assessed against the above proposed limits.
Outcome: Generally, the Project design meets the above limits with number of localised areas along the Project alignment where these limits are slightly exceeded. These areas are generally agricultural land or along Washpool Road where the road is being raised as part of the Project design. No flood sensitive receptors are impacted by the changes in peak water levels under the 1% AEP event.</td></tr>
<tr><td>Change in duration of inundation</td><td colspan="5">Objective: Identify changes to time of inundation through determination of time of submergence (ToS). For roads, determine AAToS (if applicable) and consider impacts on accessibility during flood events.
Outcome: There are localised increases in duration of inundation (ToS) at the same locations where peak water levels are increased. These changes in inundation duration do not affect flood sensitive receptors except for three local roads being Waters Road, Kuss Road and Washpool Road. Waters Road has a +0.2 hrs/yr increase in AAToS which is a negligible change with Kuss Road experiencing an even lower impact. Washpool Road experiences a reduction in AAToS (-0.4 hrs/yr) near Ch 33.81 km due to the roadway being raised as part of the Project design.</td></tr>
</table>

Parameter	Objectives and outcomes
Flood flow distribution	**Objective:** Aim to minimise changes in natural flow patterns and minimise changes to flood flow distribution across floodplain areas. Identify any changes and justify acceptability of changes through assessment of risk with a focus on land-use and flood sensitive receptors. **Outcome:** The Project has minimal impacts on flood flows and floodplain conveyance/storage with significant floodplain structures included to maintain the existing flood regime.
Velocities	**Objective:** Maintain existing velocities where practical. Identify changes to velocities and impacts on external properties. Determine appropriate scour mitigation measures taking into account existing soil conditions. **Outcome:** In general, changes in velocities are minor, with most changes in velocities experienced immediately adjacent to the Project alignment and no flood sensitive receptors impacted. Scour protection has been specified where the outlet velocities for the 1% AEP event exceed the allowable soil velocities for the particular soil type for each location, which was identified from published soil mapping.
Extreme event risk management	**Objective:** Consider the risks posed to neighbouring properties for events larger than the 1% AEP event to ensure no unexpected or unacceptable impacts. **Outcome:** A review of impacts under the 1 in 2,000 AEP, 1 in 10,000 AEP and PMF events has been undertaken with the existing flood depths and increase in peak water levels at flood sensitive receptors identified on each floodplain. Considering the flood depths that occur, particularly under the PMF event, indicates that the changes in peak water levels would be unlikely to exacerbate flood conditions during extreme events. There is one location on Purga Creek that will require refinement during detailed design to address redirection of flood flows under the PMF event.
Sensitivity testing	**Objective:** Consider risks posed by climate change and blockage in accordance with Australian Rainfall and Runoff 2016. Undertake assessment of impacts associated with Project alignment for both scenarios. **Outcomes:** Climate change – climate change has been assessed in accordance with ARR 2016 requirements with the representative concentration pathway 8.5 (2090 horizon) scenario adopted giving an increase in rainfall intensity of 18.7% across the catchment areas. The impacts resulting from changes in peak water levels under the 1% AEP event with climate change are generally similar to those seen under the 1% AEP event. Blockage – Blockage of drainage structures has been assessed in accordance with ARR 2016 requirements. The blockage assessment resulted in no blockage factor being applied to bridges and a blockage factor of 25% being applied to culverts. Two blockage sensitivity scenarios were tested with both 0% and 50% blockage of all culverts assessed. The resulting changes in peak water levels associated with the Project alignment are still localised and do not impact on any flood sensitive receptors.

A comprehensive consultation exercise has been undertaken to provide the community with detailed information and certainty around the flood modelling and the Project design. In future stages, ARTC will:

- Continue to work with landowners concerned with hydrology and flooding throughout the detailed design, construction and operational phases of the Project
- Continue to work with directly impacted landowners affected by the alignment throughout the detailed design, construction and operational phases of the Project
- Continue to work with local Councils and State government departments throughout the detailed design, construction and operational phases of the Project.

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APPENDIX N

Hydrology and Flooding Technical Report

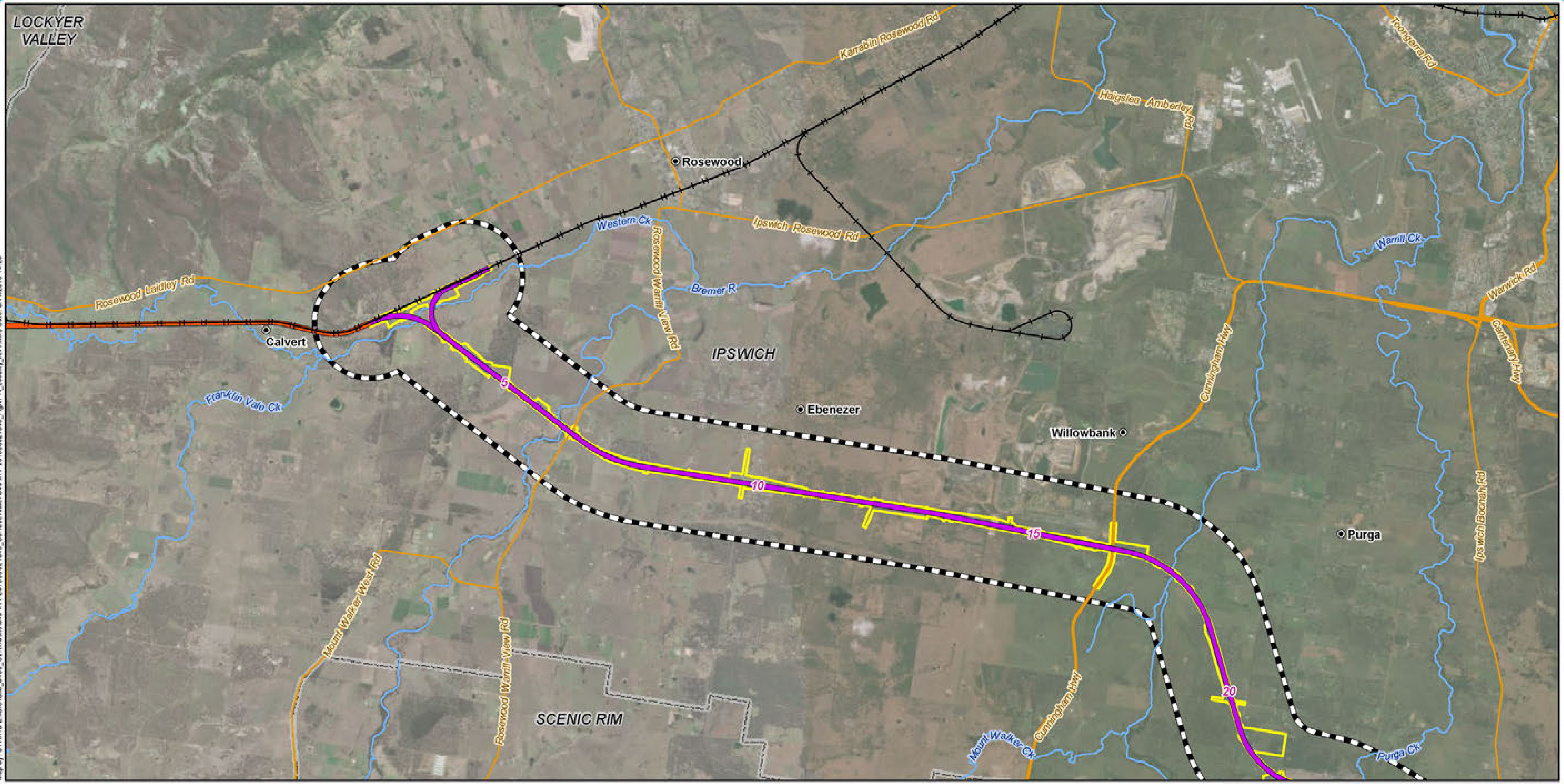
Appendix A Bremer River Figures

CALVERT TO KAGARU ENVIRONMENTAL IMPACT STATEMENT

IR_1381

Appendix A
Bremer River Figures

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- EIS investigation corridor
- Local Government Areas

A3 scale: 1:75,000

0 0.55 1.1 1.65 2.2 2.75km

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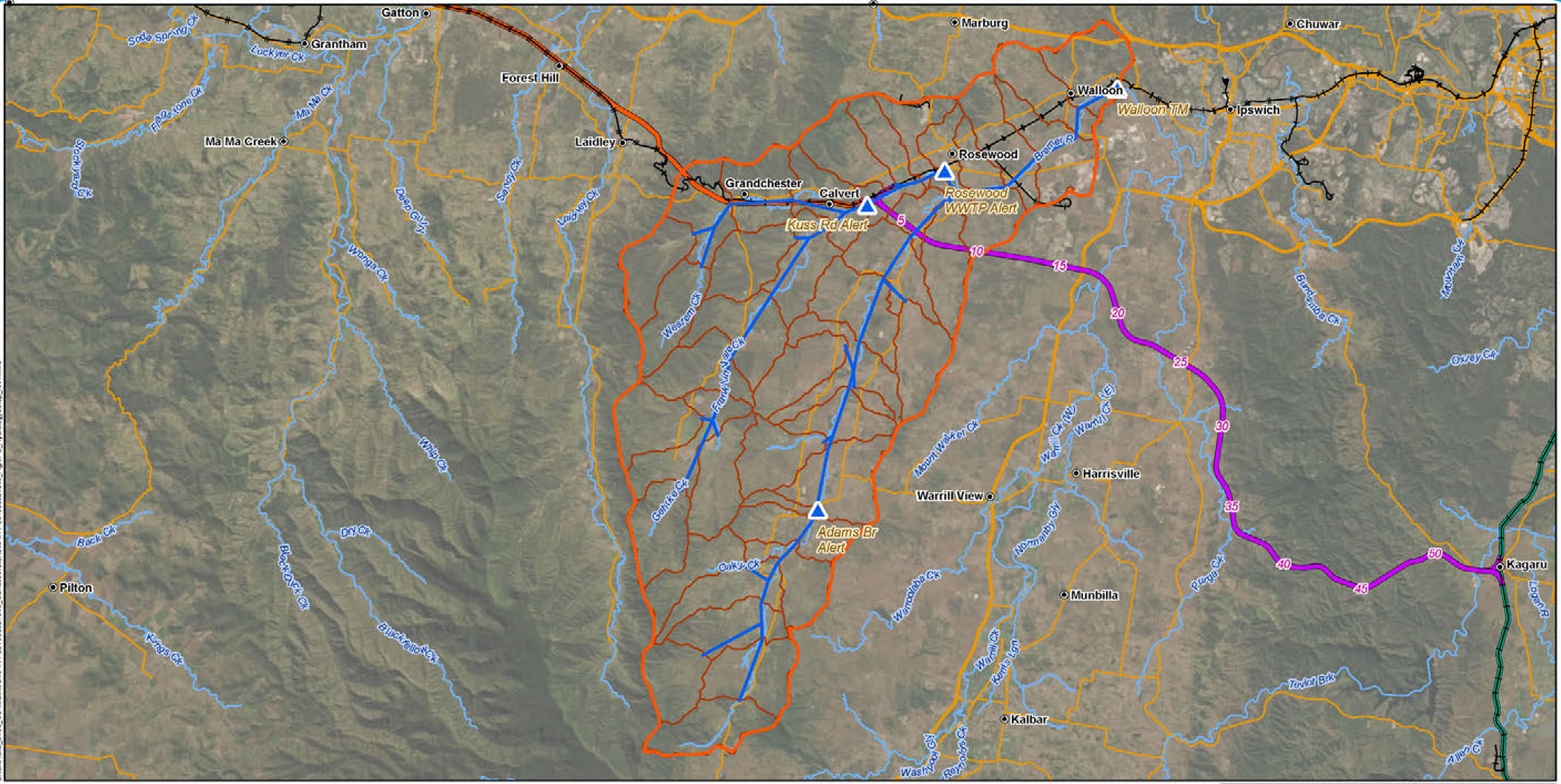
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru
Figure A1-A: Locality: Bremer River

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



Minor roads

A3 scale: 1:250,000

0 1.5 3 4.5 6 7.5km

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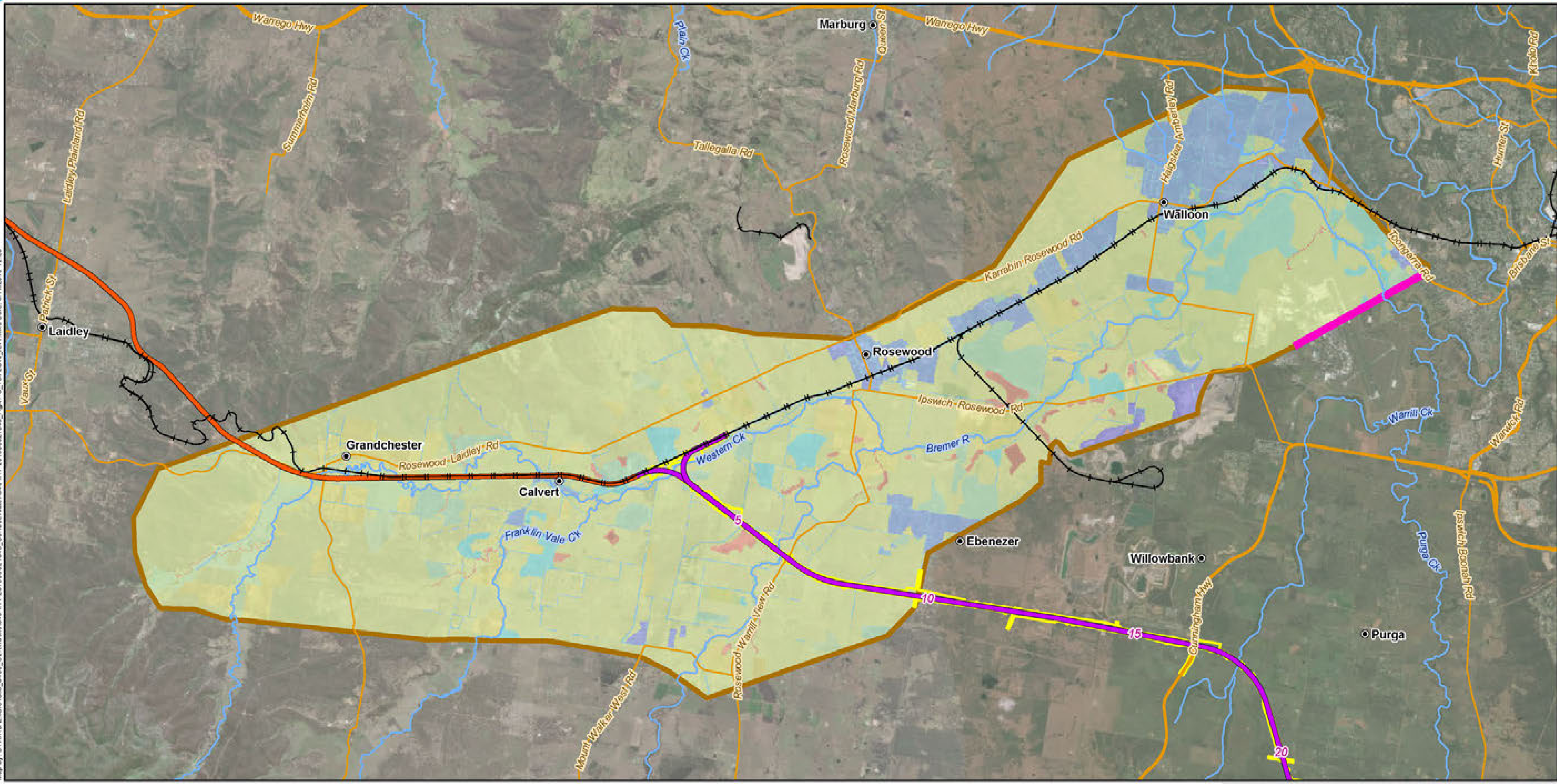
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A1-B: Hydrology setup: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- Downstream boundary
- Code boundary

Materials

- Non Tidal Waterway
- Waterbodies
- Low Density River Bank Vegetation
- Medium Denisty River Bank Vegetation
- High Density River Bank Vegetation
- Grassland
- Light Vegetation
- Fields/ Parks
- Dense Vegetation
- Very Dense Vegetation
- Rough Pasture/ Light Brush
- Roads
- Low Density Urban Block
- Medium Density Urban Block
- Commercial/ Industrial
- Mining

A3 scale: 1:100,000
0 0.75 1.5 2.25 3 3.75km

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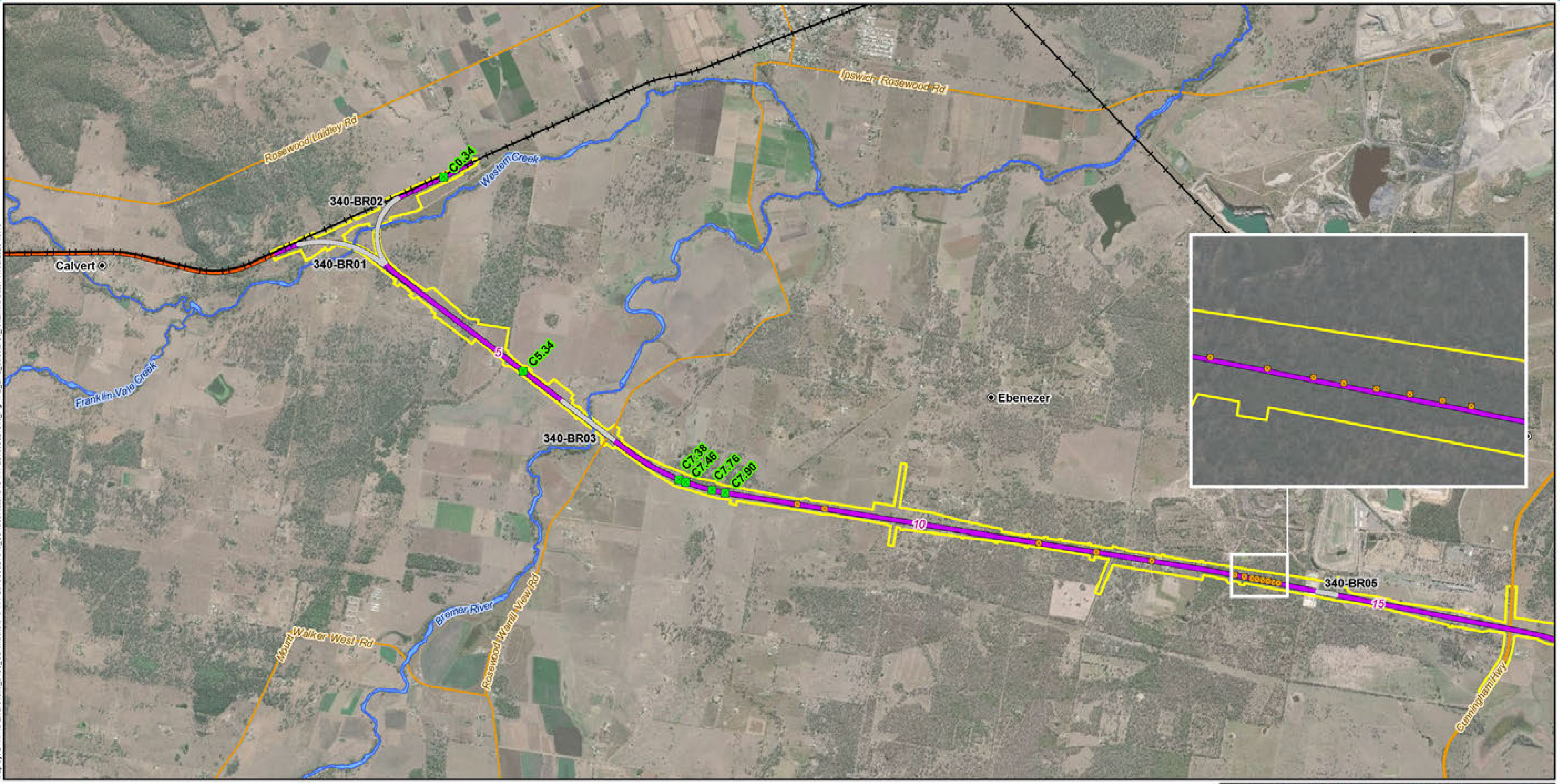
Calvert to Kagaru

Figure A1-C: TUFLOW model setup: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Major roads
- Minor roads
- Defined watercourses
- EIS disturbance footprint

Drainage Structures

- Flood culvert
- Local drainage culvert
- Bridges

A3 scale: 1:45,000

0 0.3 0.6 0.9 1.2 1.5 km

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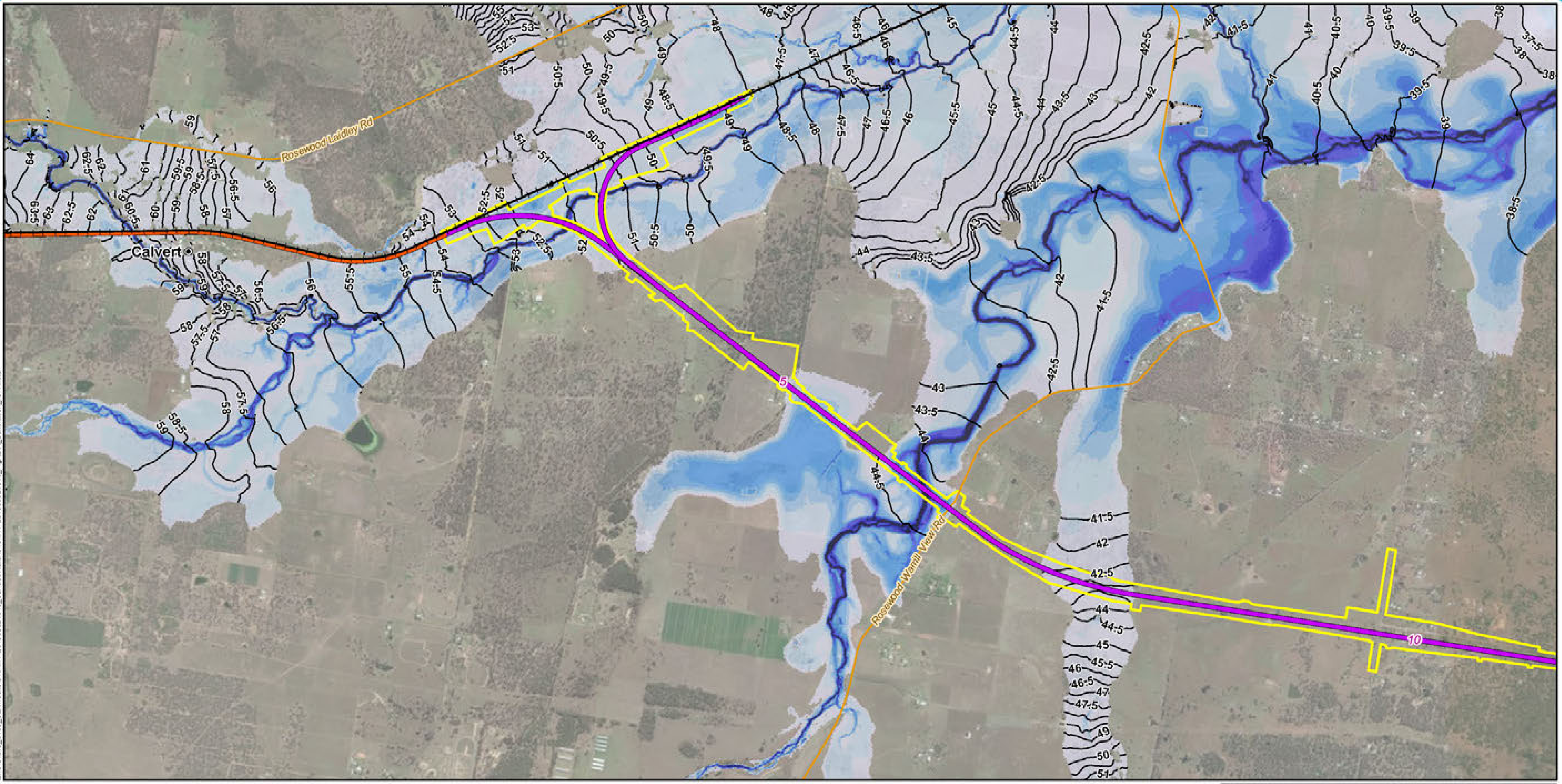
Issue date: 11/03/2020 Version: 2
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A1-D: Design structures: Bremer River



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Minor roads
- EIS disturbance footprint
- 0.5m Contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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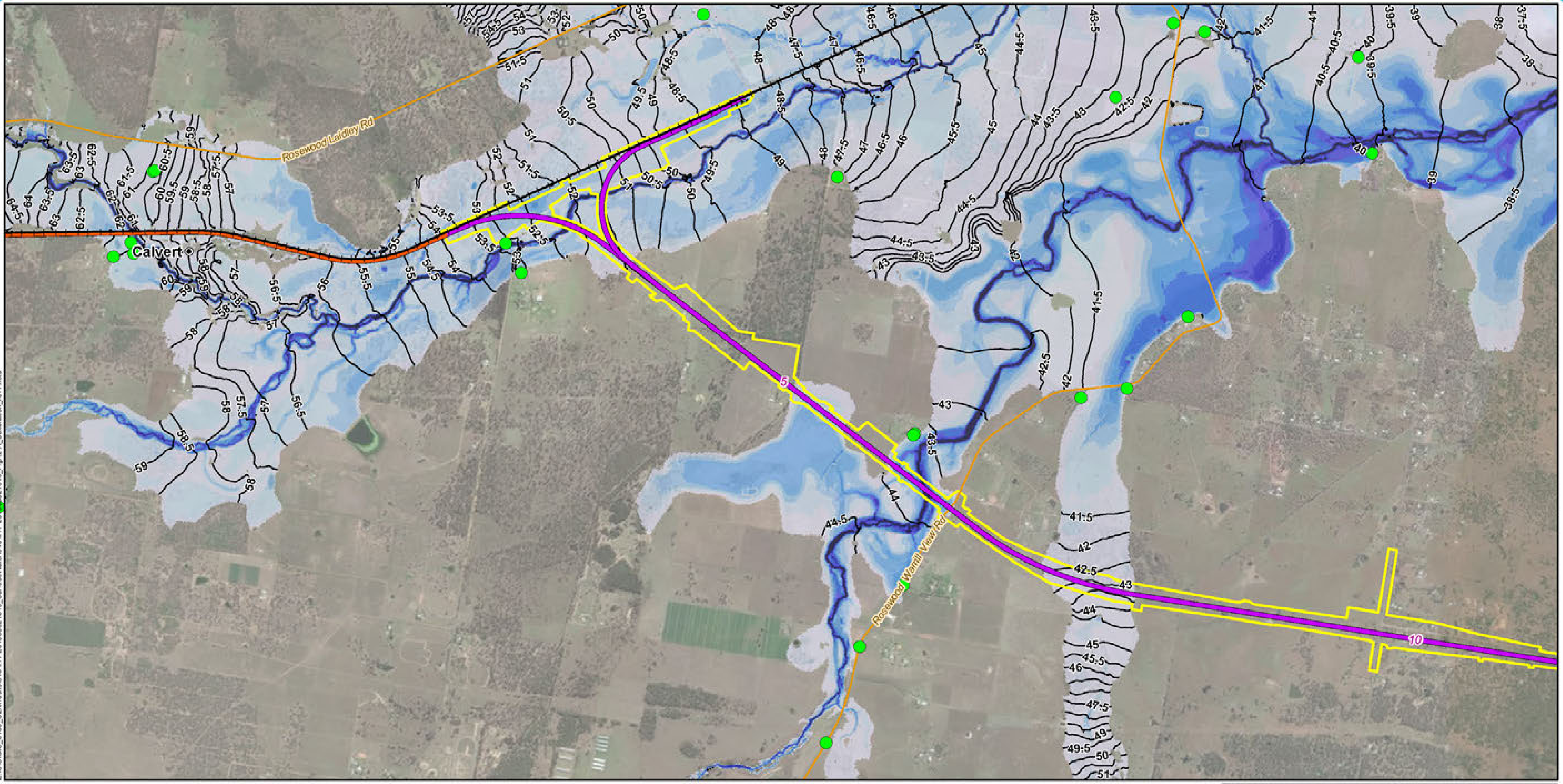
Issue date: 18/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A2-A: 1974 Calibration event: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Minor roads
- EIS disturbance footprint
- 0.5m Contour mAHD
- Flood markers (2011)

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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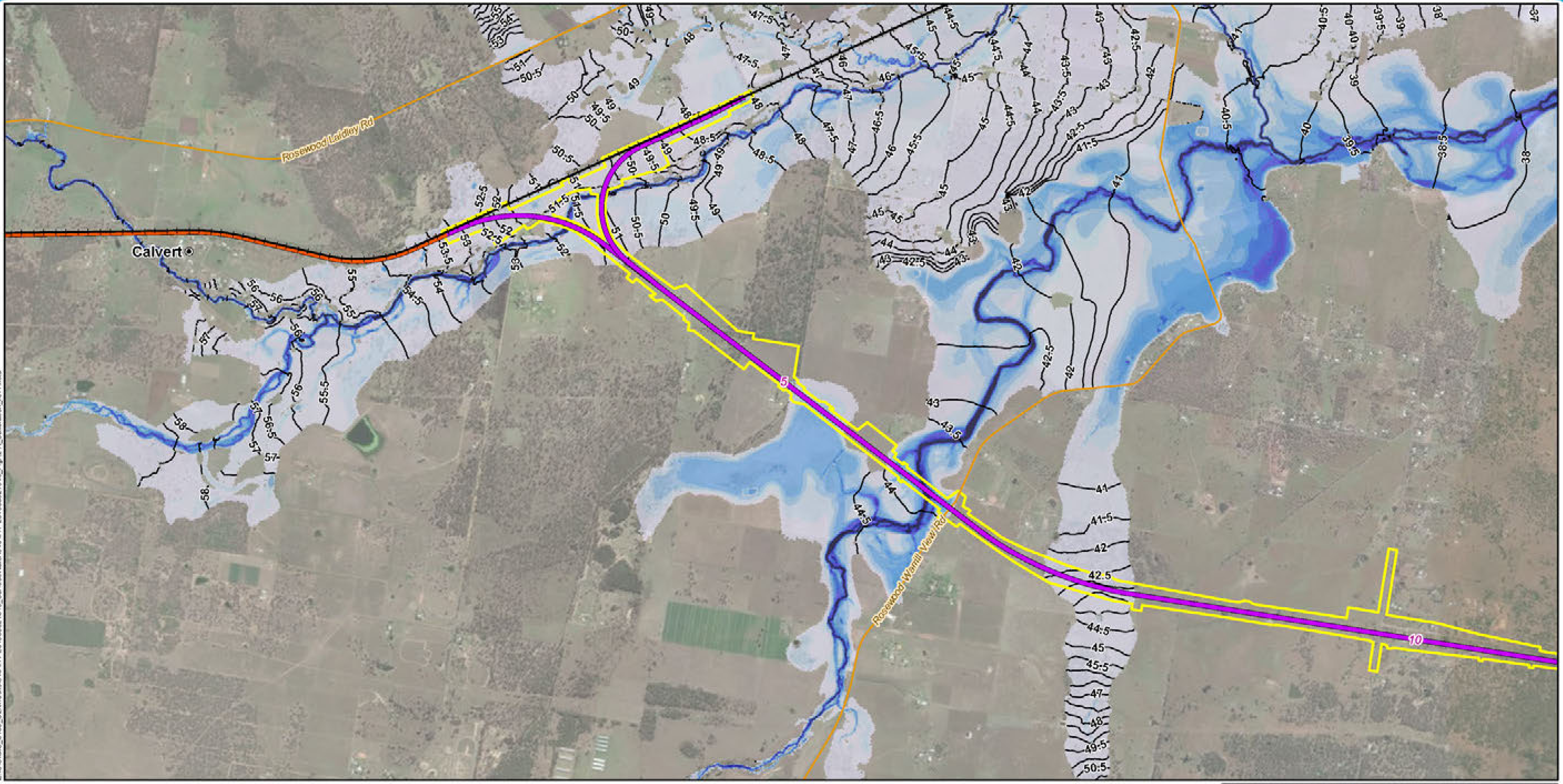
Issue date: 18/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A2-B: 2011 Calibration event: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Minor roads
- EIS disturbance footprint
- 0.5m Contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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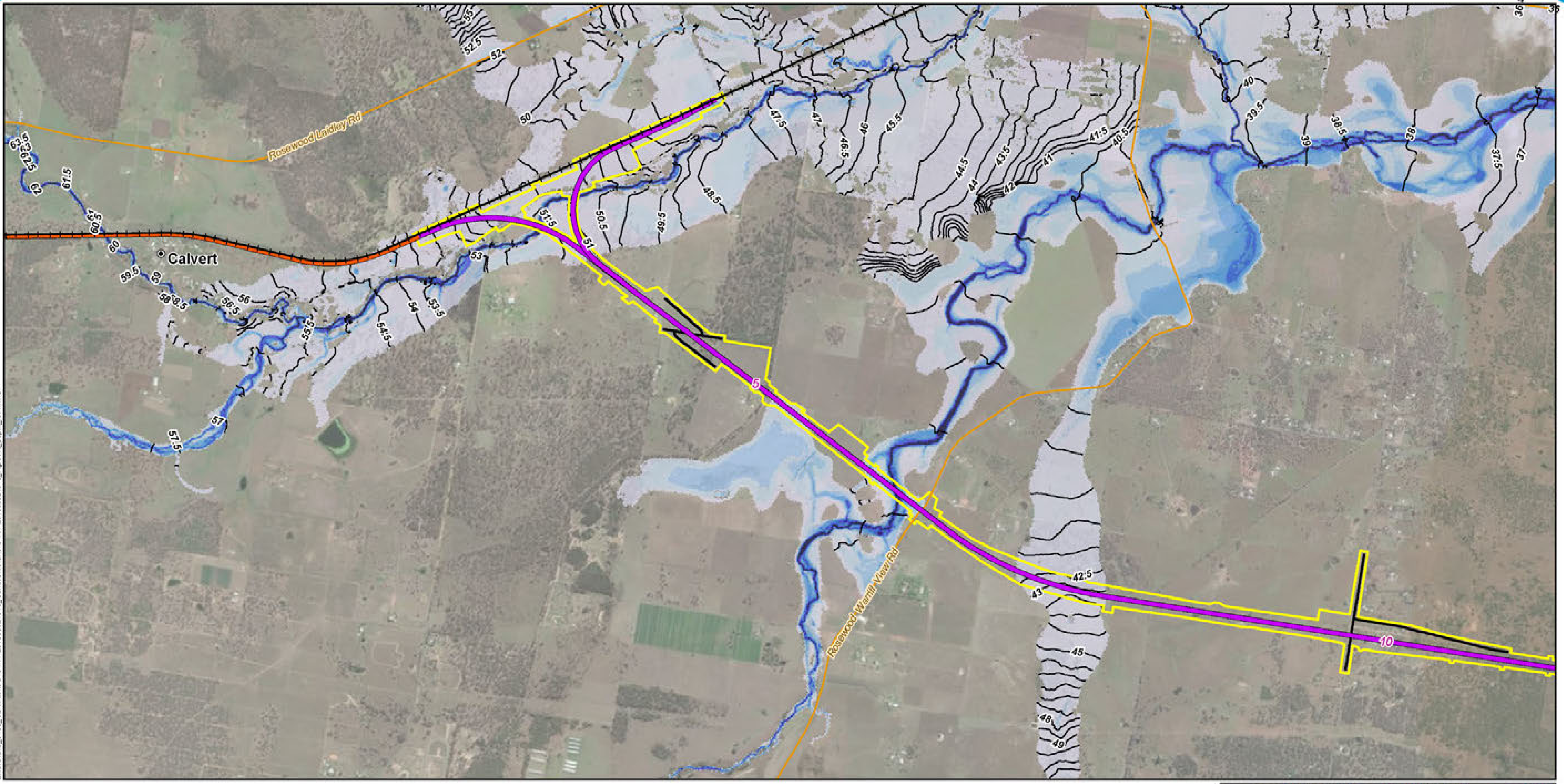
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A2-C: 2013 Calibration event: Bremer River

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



Map by: DTH/RB Date: 7/11/2019 13:56

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

Future Freight
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Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A3-A: 20% AEP event Existing Case inundation extent: Bremer River

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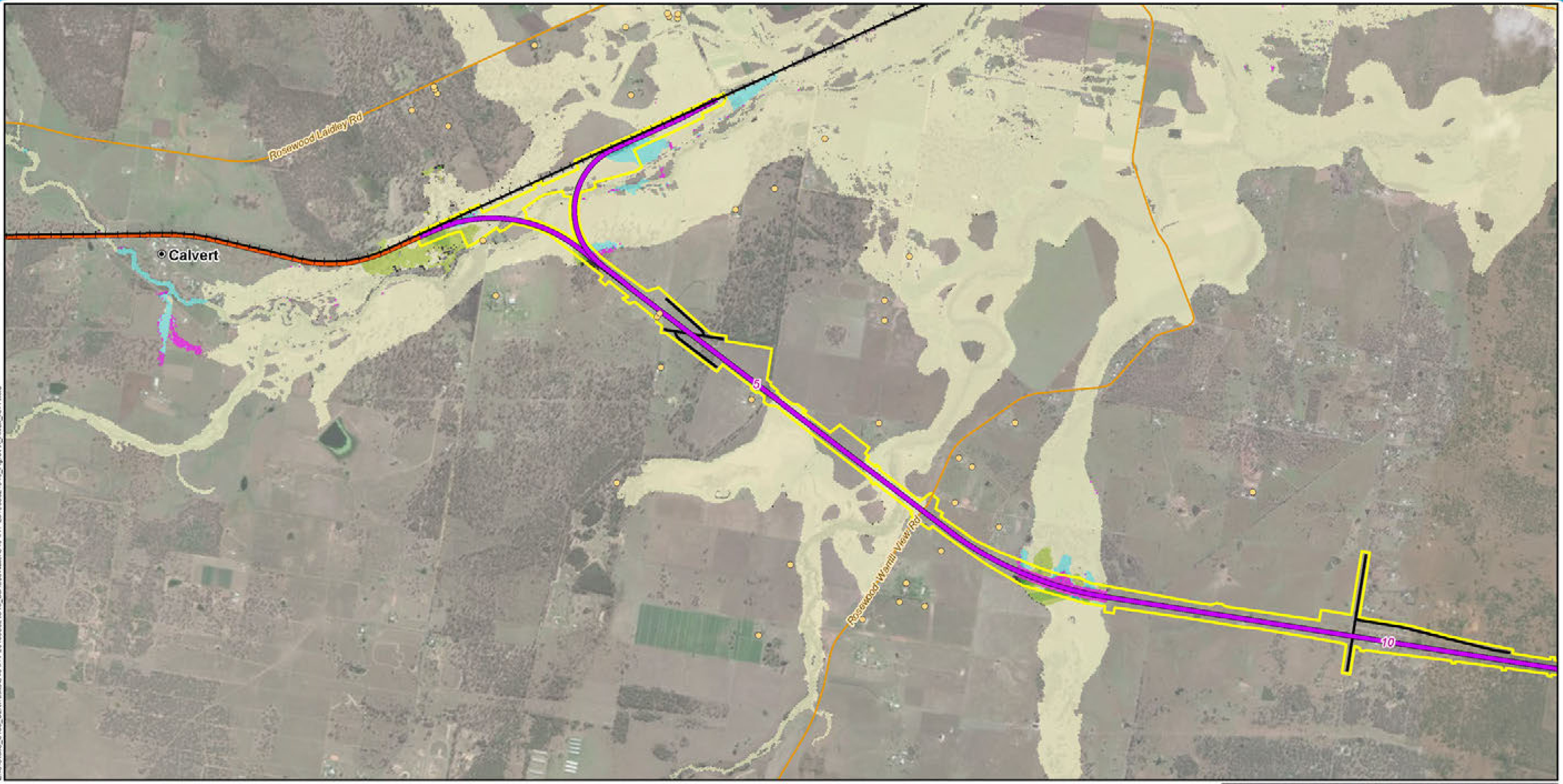

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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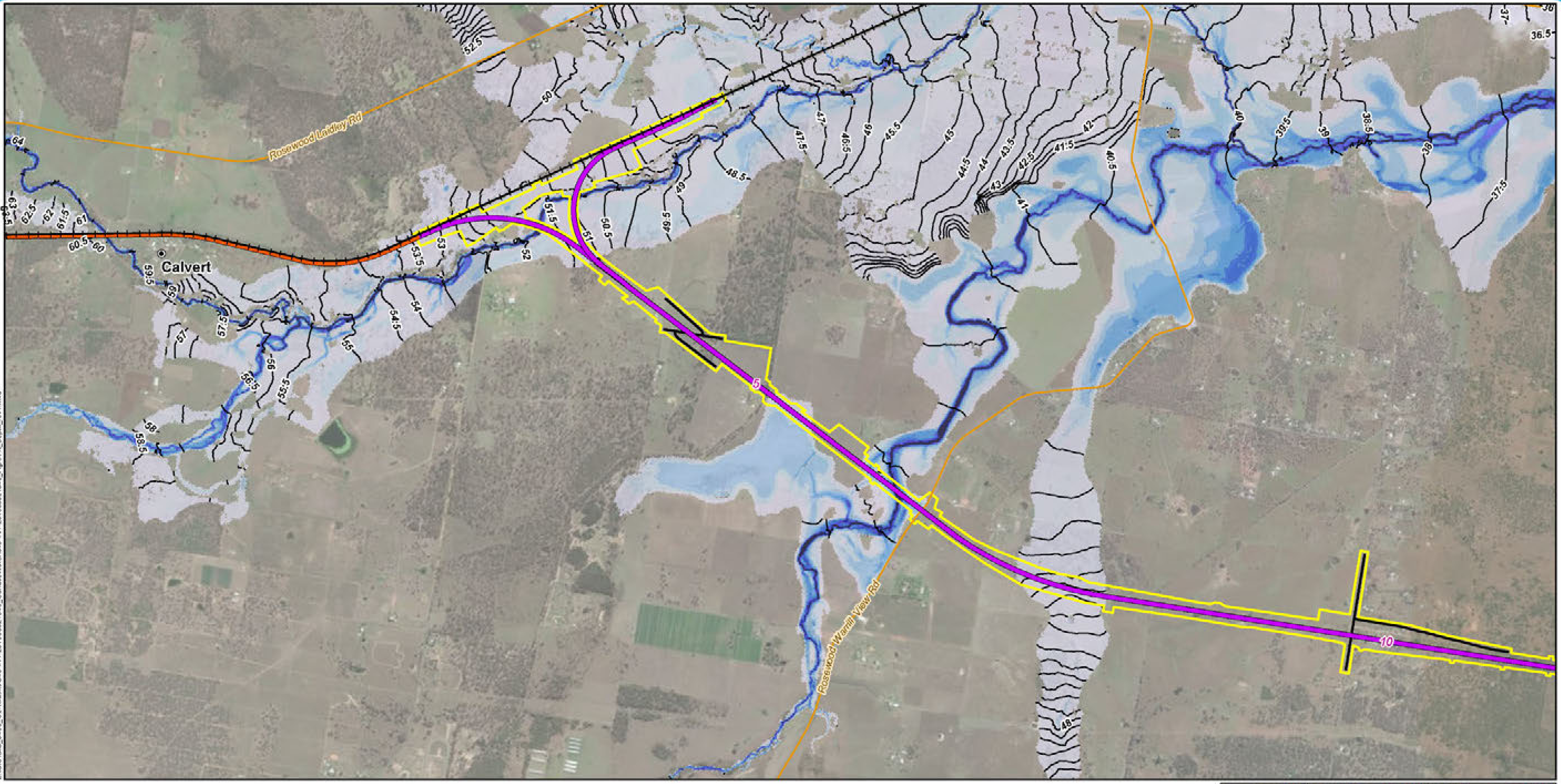
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A3-B: 20% AEP event Developed Case afflux: Bremer River

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



Map by: DTH/RB Date: 7/11/2019 13:56

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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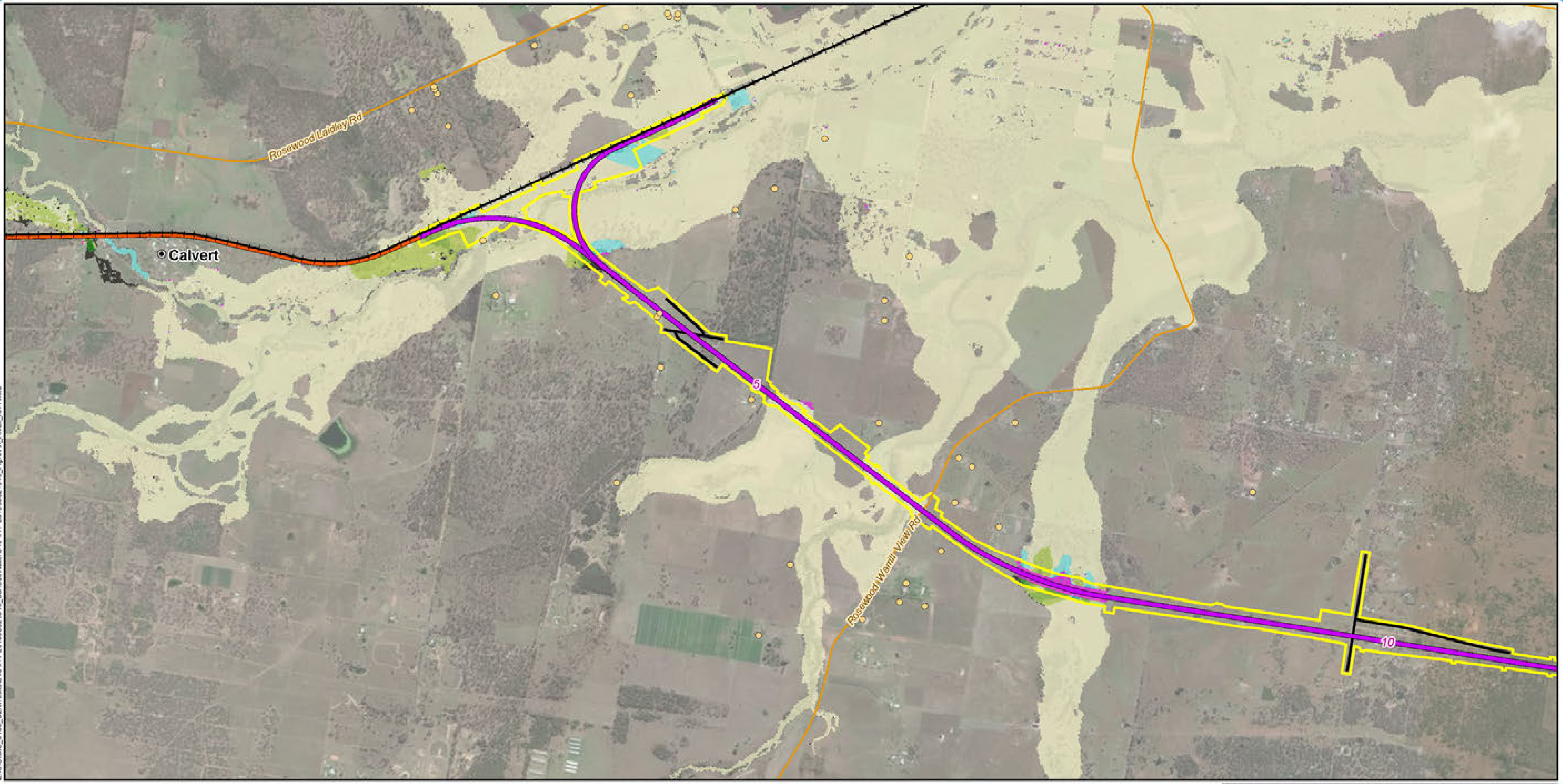
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A4-A: 10% AEP event Existing Case inundation extent: Bremer River

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



Map by: DTH/RB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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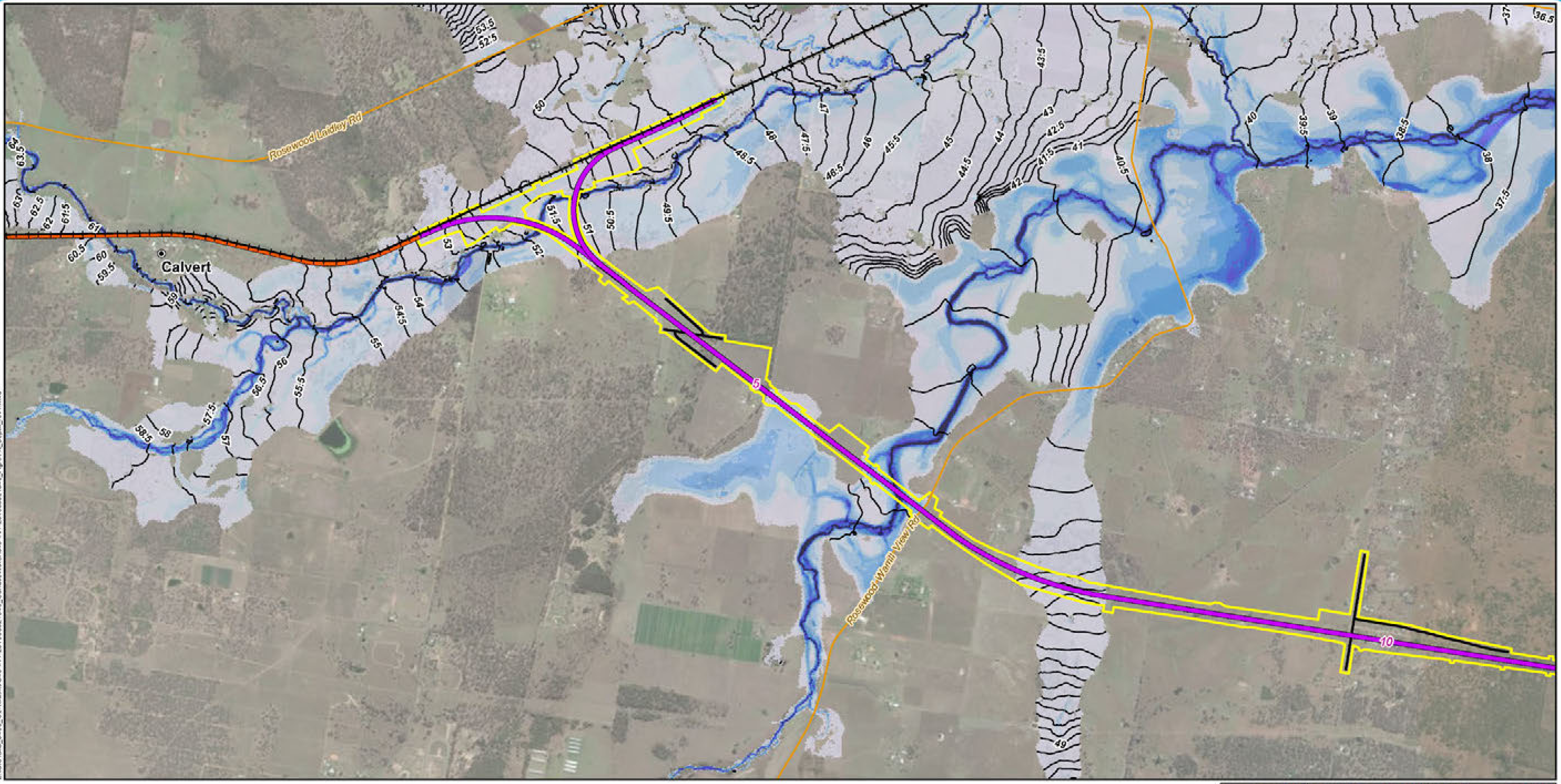
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A4-B: 10% AEP event Developed Case afflux: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

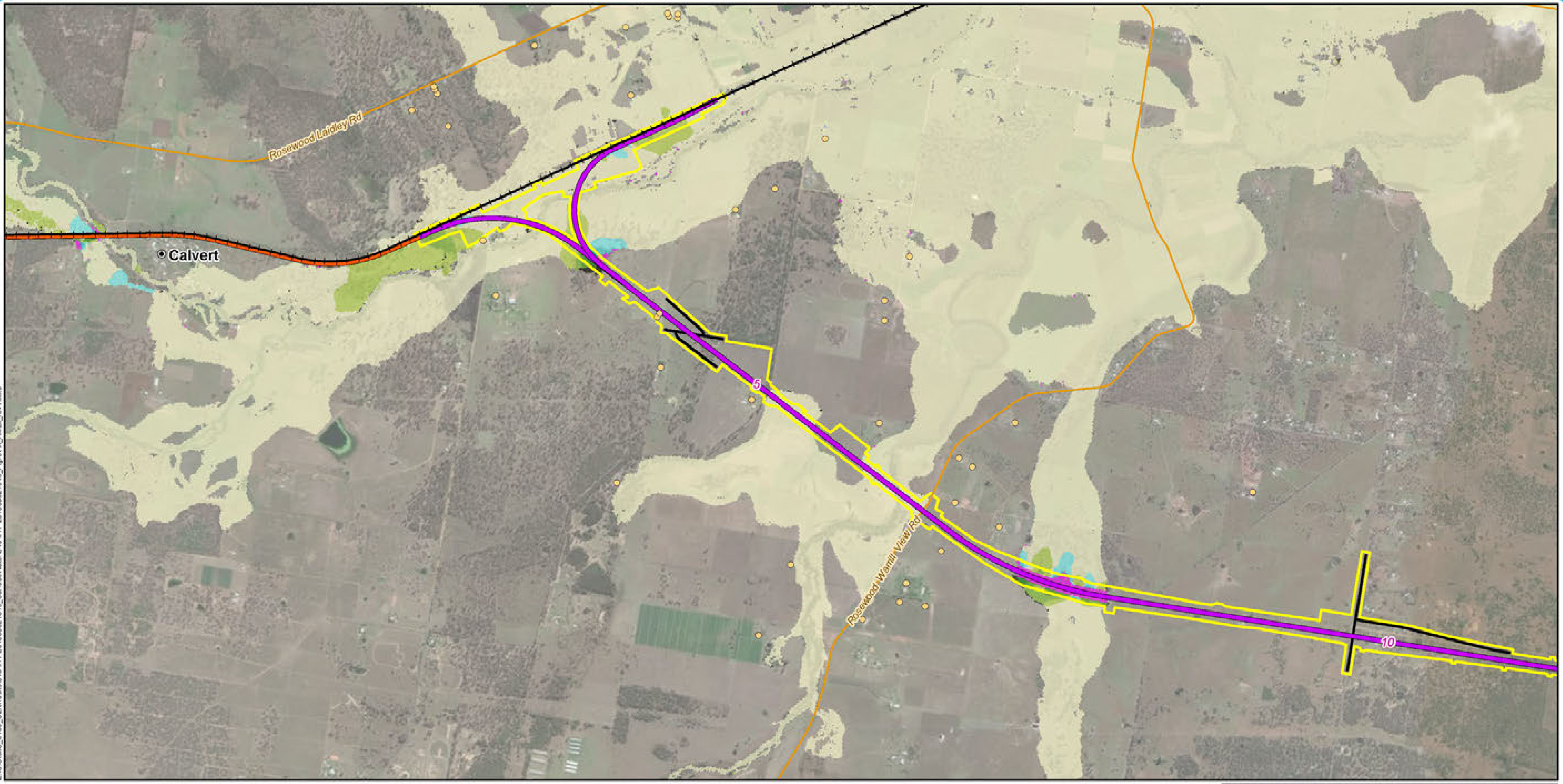
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A5-A: 5% AEP event Existing Case inundation extent: Bremer River

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



Map by: DTH/RB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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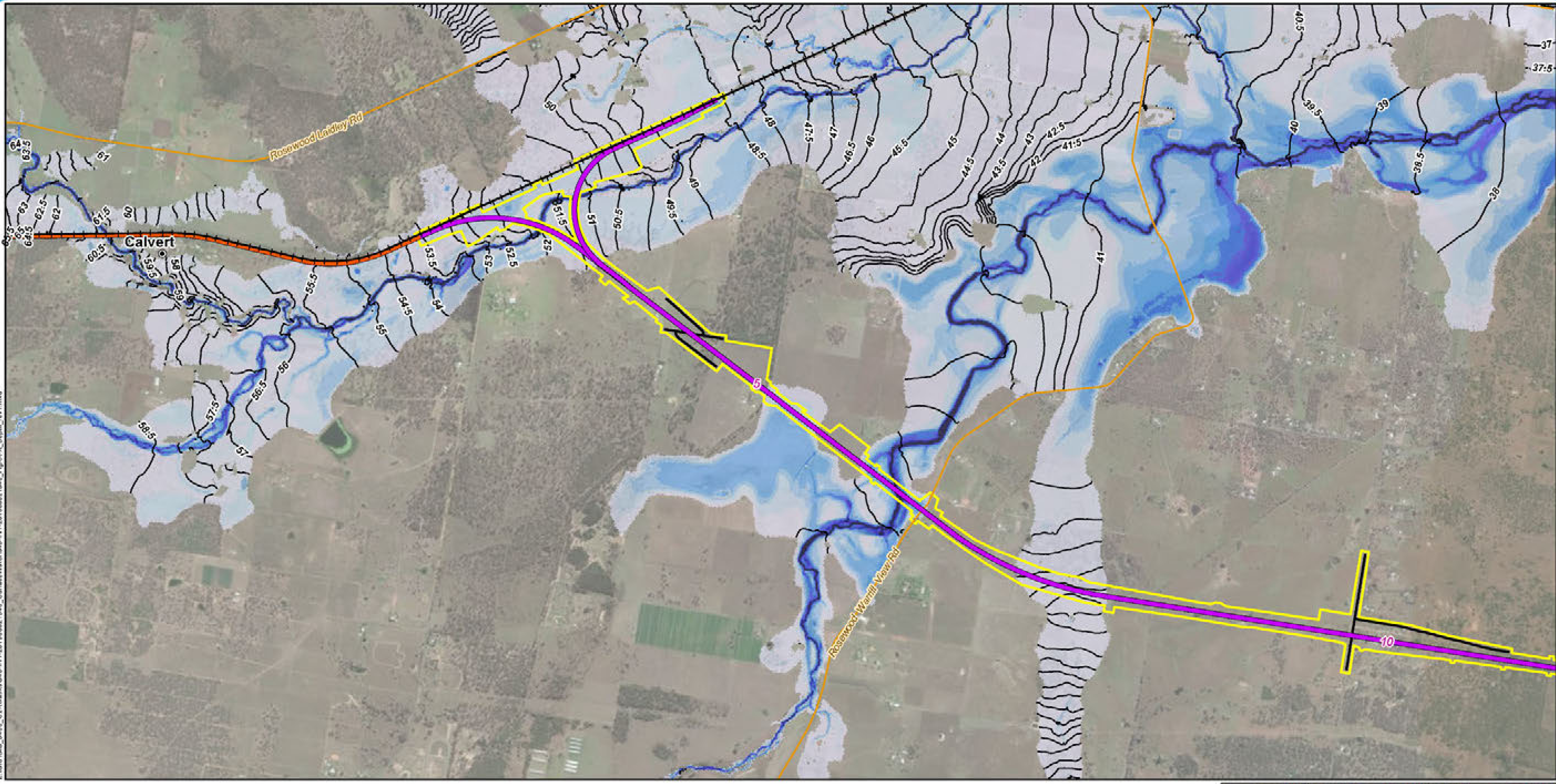
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A5-B: 5% AEP event Developed Case afflux: Bremer River

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



Map by: DTH/RB Date: 7/11/2019 13:56
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Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

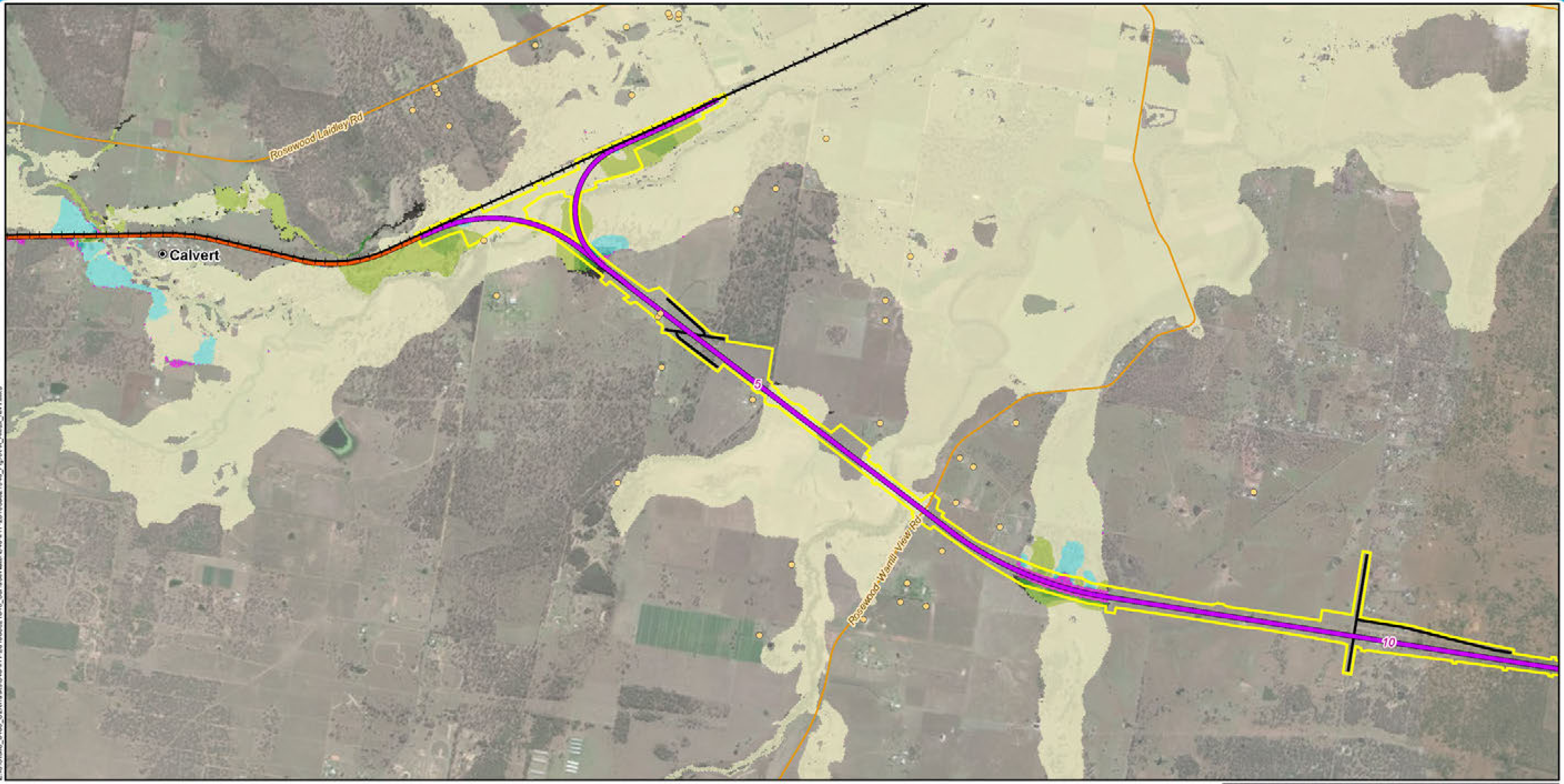
0 0.2 0.4 0.6 0.8 1 km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A6-A: 2% AEP event Existing Case inundation extent: Bremer River



Map by: DTHRB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

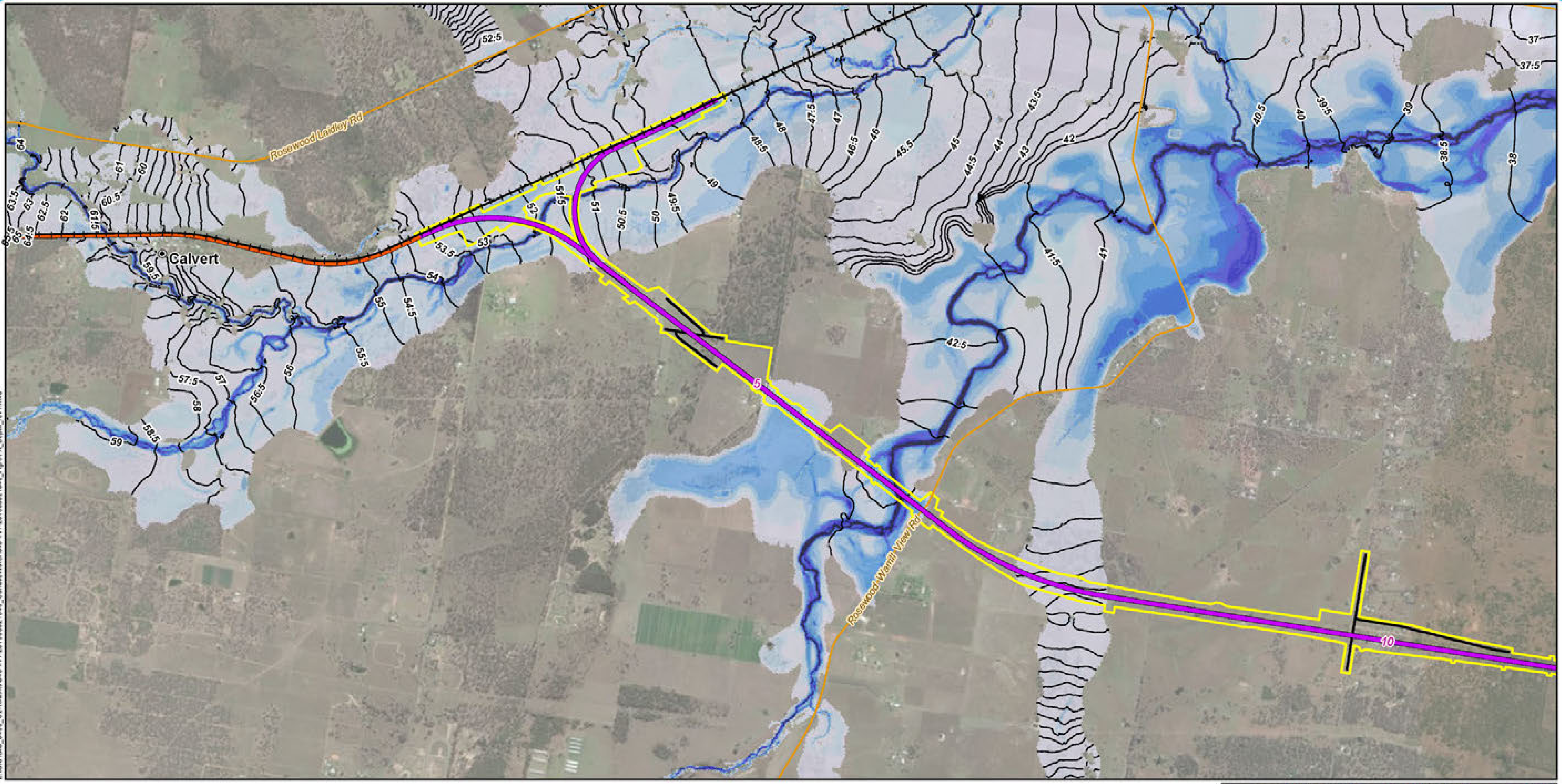
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A6-B: 2% AEP event Developed Case afflux: Bremer River

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



Map by: DTH/RB Date: 7/11/2019 13:56

Legend

5 Chainage (km)
Localities
Existing rail
H2C project alignment
C2K project alignment
Proposed roadworks
Minor roads
EIS disturbance footprint
0.5m contour mAHD

Depth (m)

0 - 0.5
0.5 - 1.0
1.0 - 1.5
1.5 - 2.0
2.0 - 2.5
2.5 - 3.0
3.0 - 3.5
3.5 - 4.0
4.0 - 4.5
4.5 - 5.0
> 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

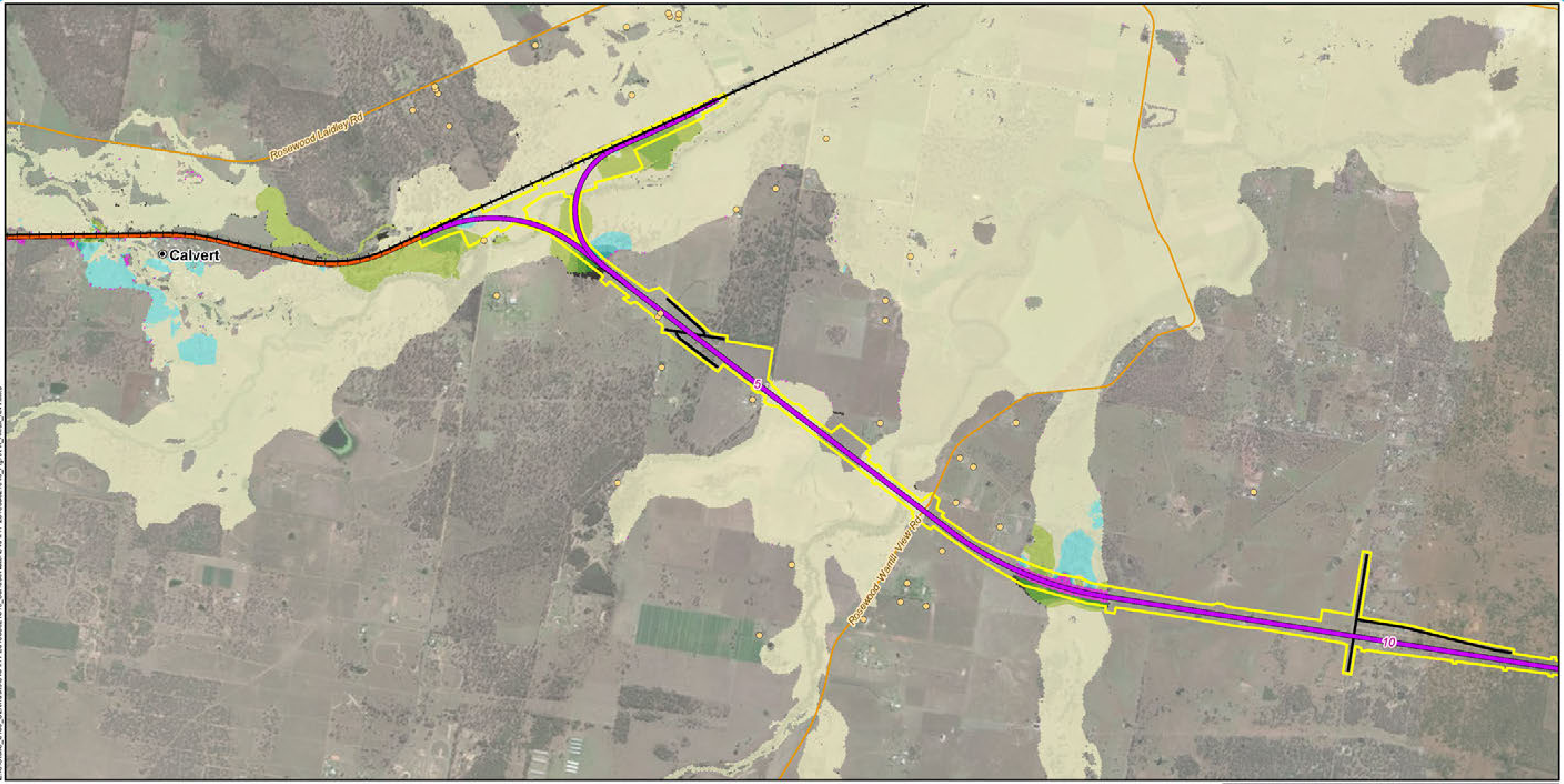
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-A: 1% AEP event Existing Case inundation extent: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

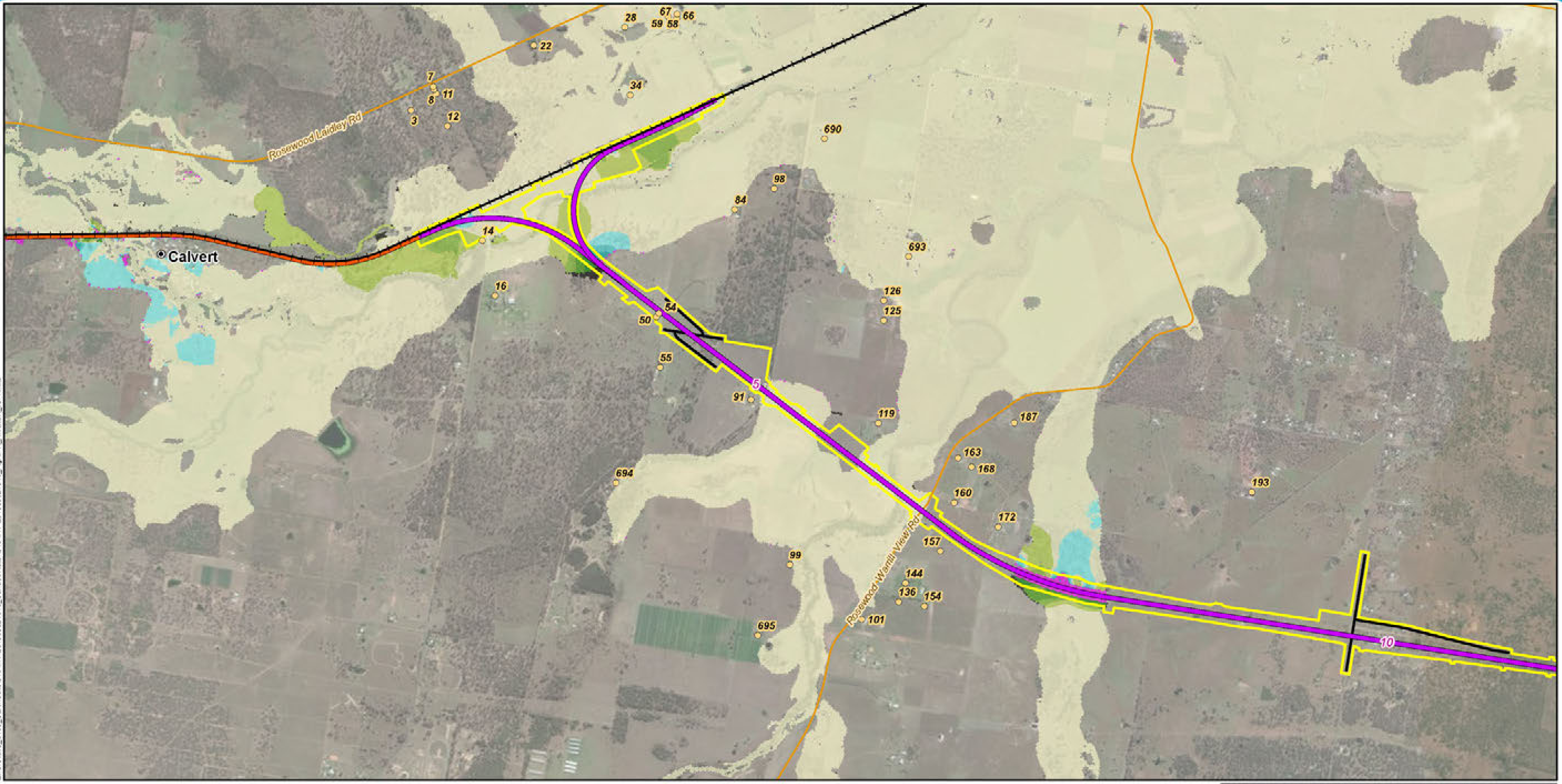
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-B: 1% AEP event Developed Case afflux: Bremer River

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



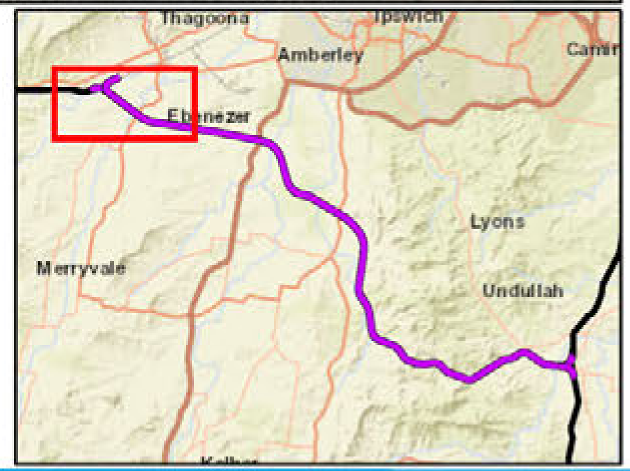
Map by: DTH Date: 8/11/2019 11:20

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5



A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

Future Freight
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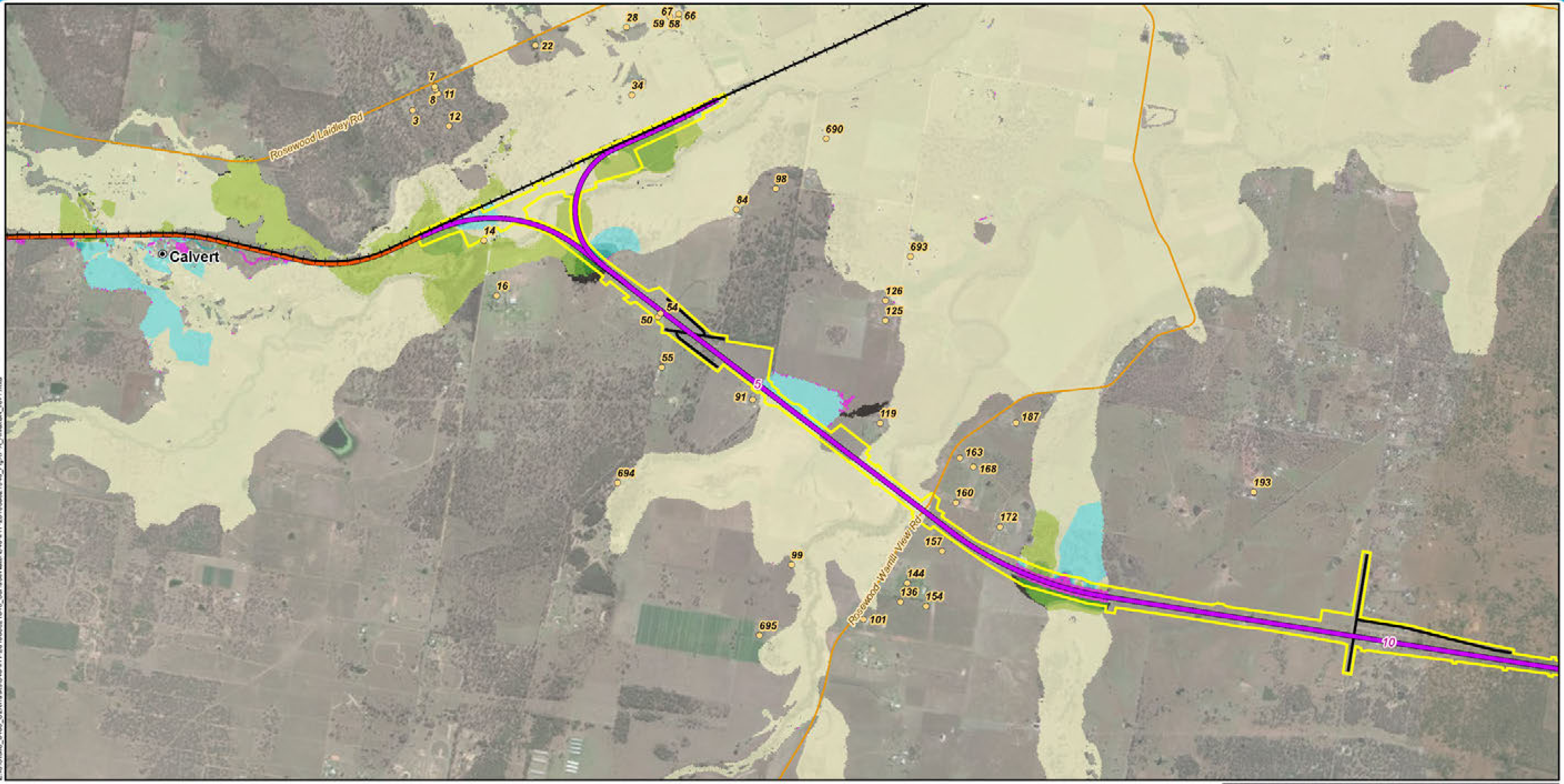
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-C: 1% AEP event Developed Case afflux with flood sensitive receptors: Bremer River

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



Map by: DTH Date: 8/11/2019 11:22
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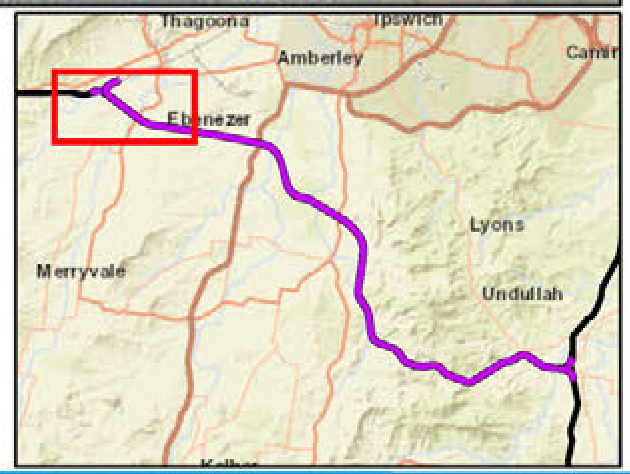


Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

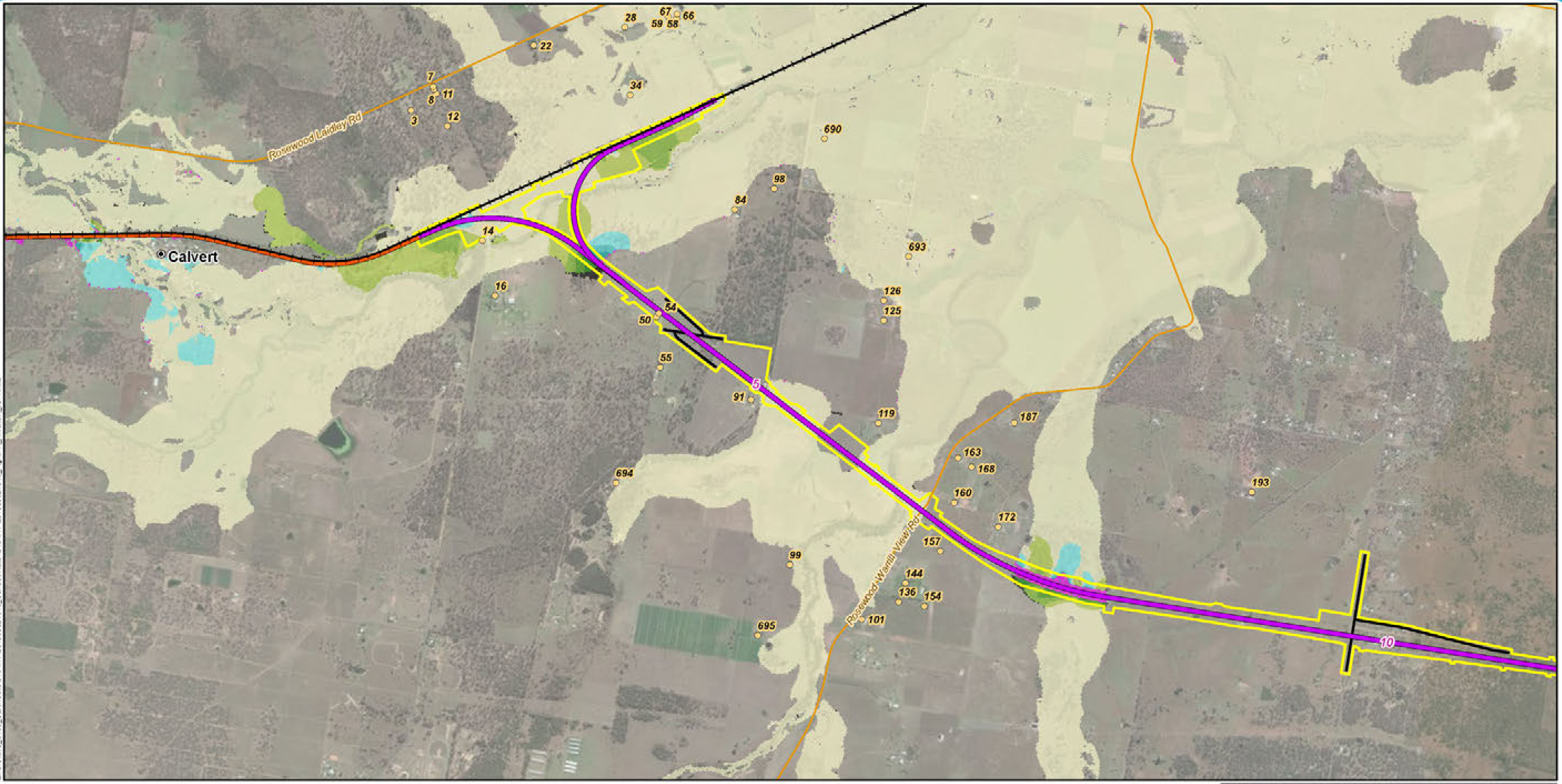
Future Freight
Integrating Community, Environment and Engineering

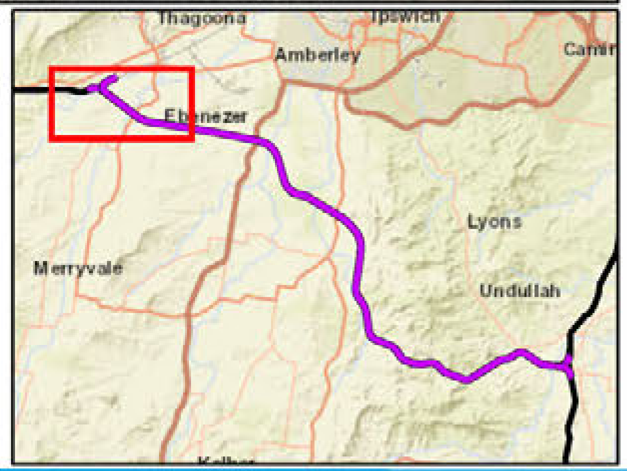
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-D: 1% AEP event with climate change afflux and flood sensitive receptors: Bremer River

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





Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

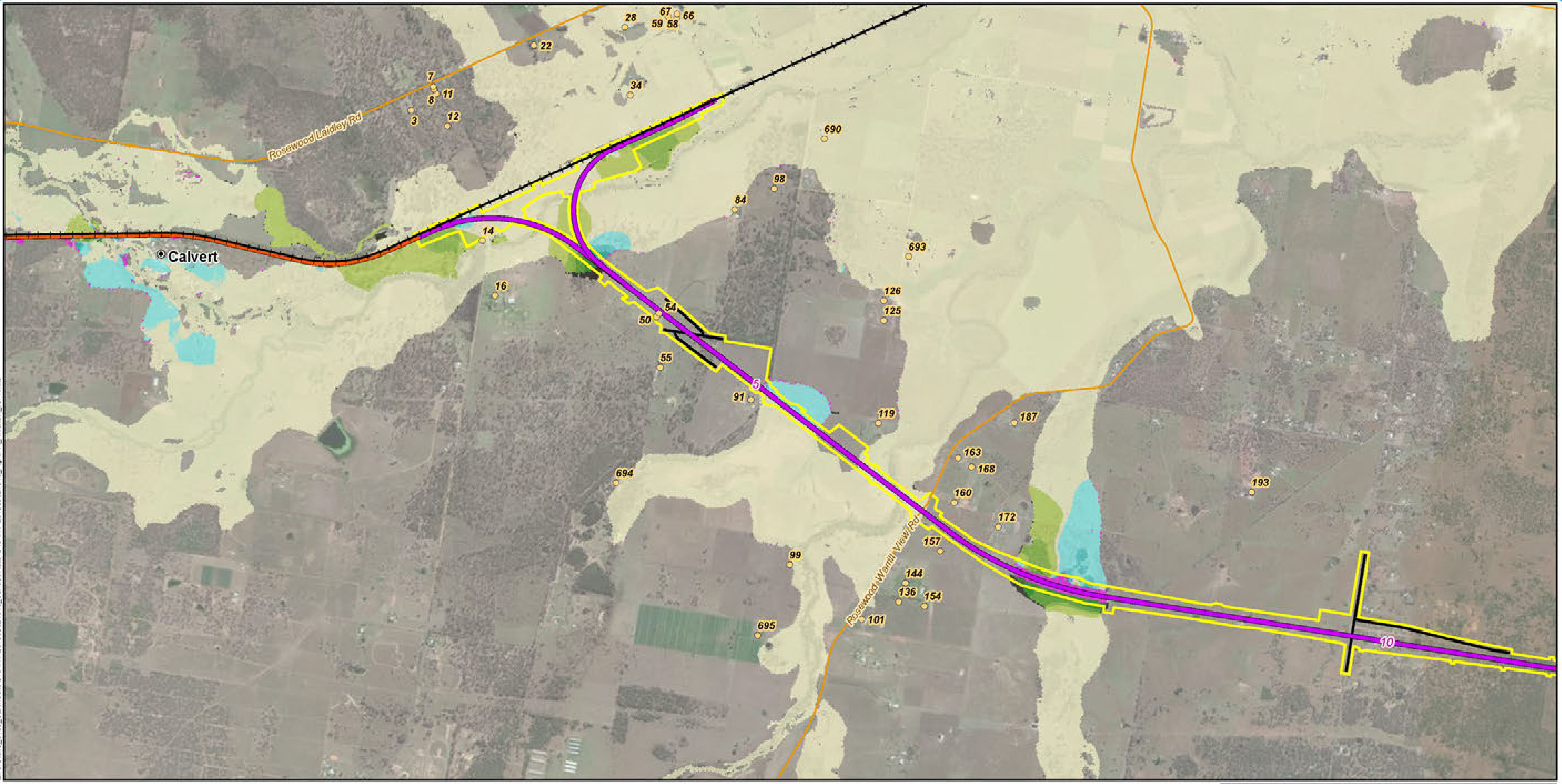
Future Freight
Integrating Community, Environment and Engineering

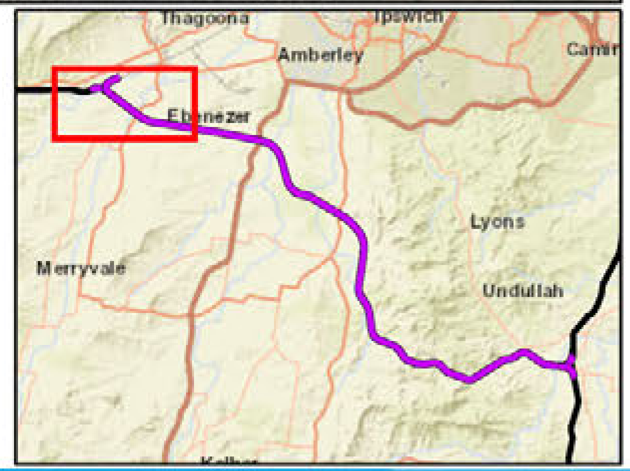
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-E: 1% AEP event with 0% blockage afflux and flood sensitive receptors: Bremer River

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





Legend

5	Chainage (km)
	Localities
	Flood sensitive receptors
	Existing rail
	H2C project alignment
	C2K project alignment
	Proposed roadworks
	Minor roads
	EIS disturbance footprint
	Was Wet Now Dry
	Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

Future Freight
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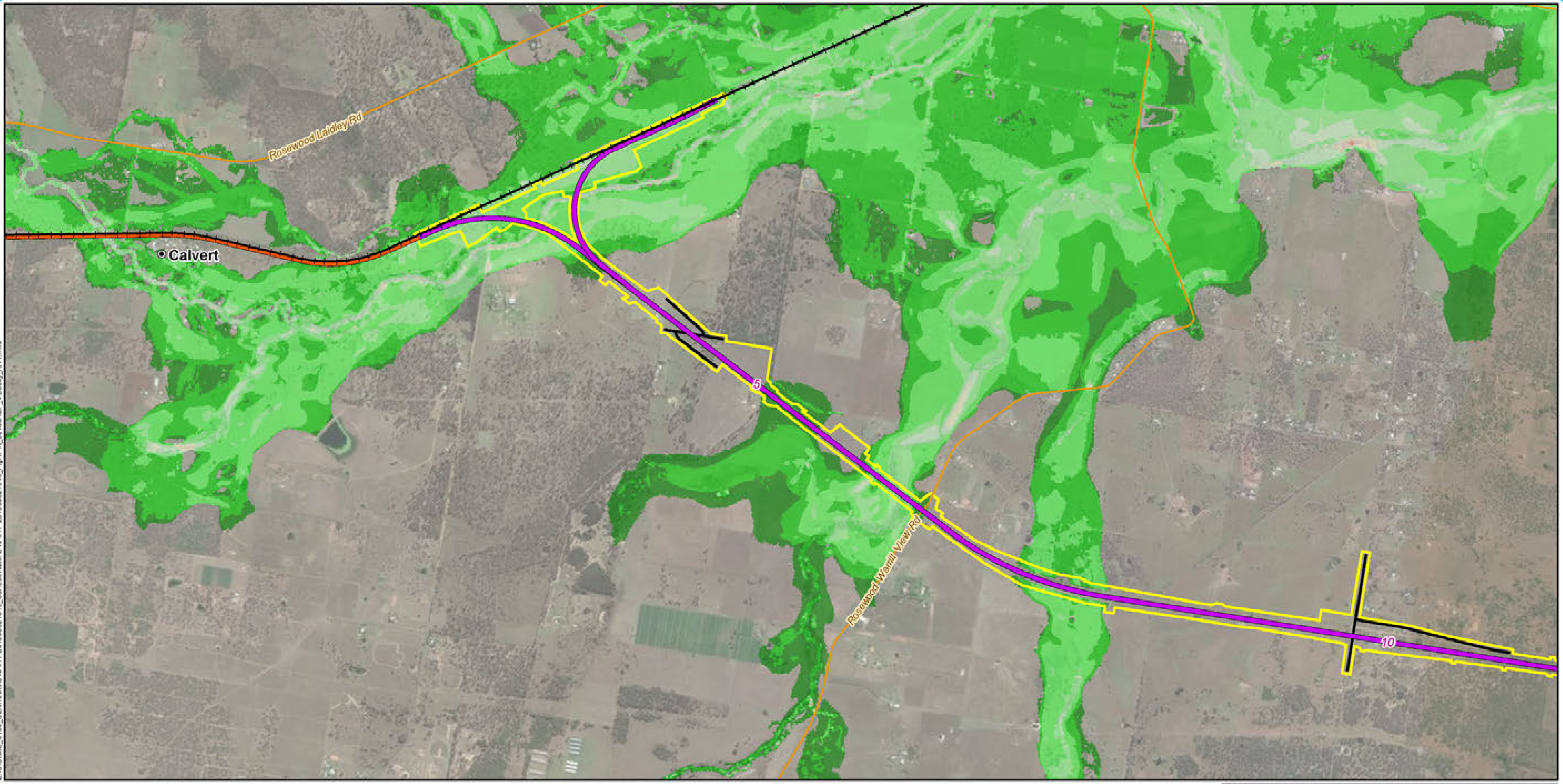
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-F: 1% AEP event with 50% blockage afflux and flood sensitive receptors: Bremer River

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



Map by: DTH/RB Date: 18/11/2019 16:22

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Minor roads
- Proposed roadworks
- EIS disturbance footprint

Peak velocity (m/s)

0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

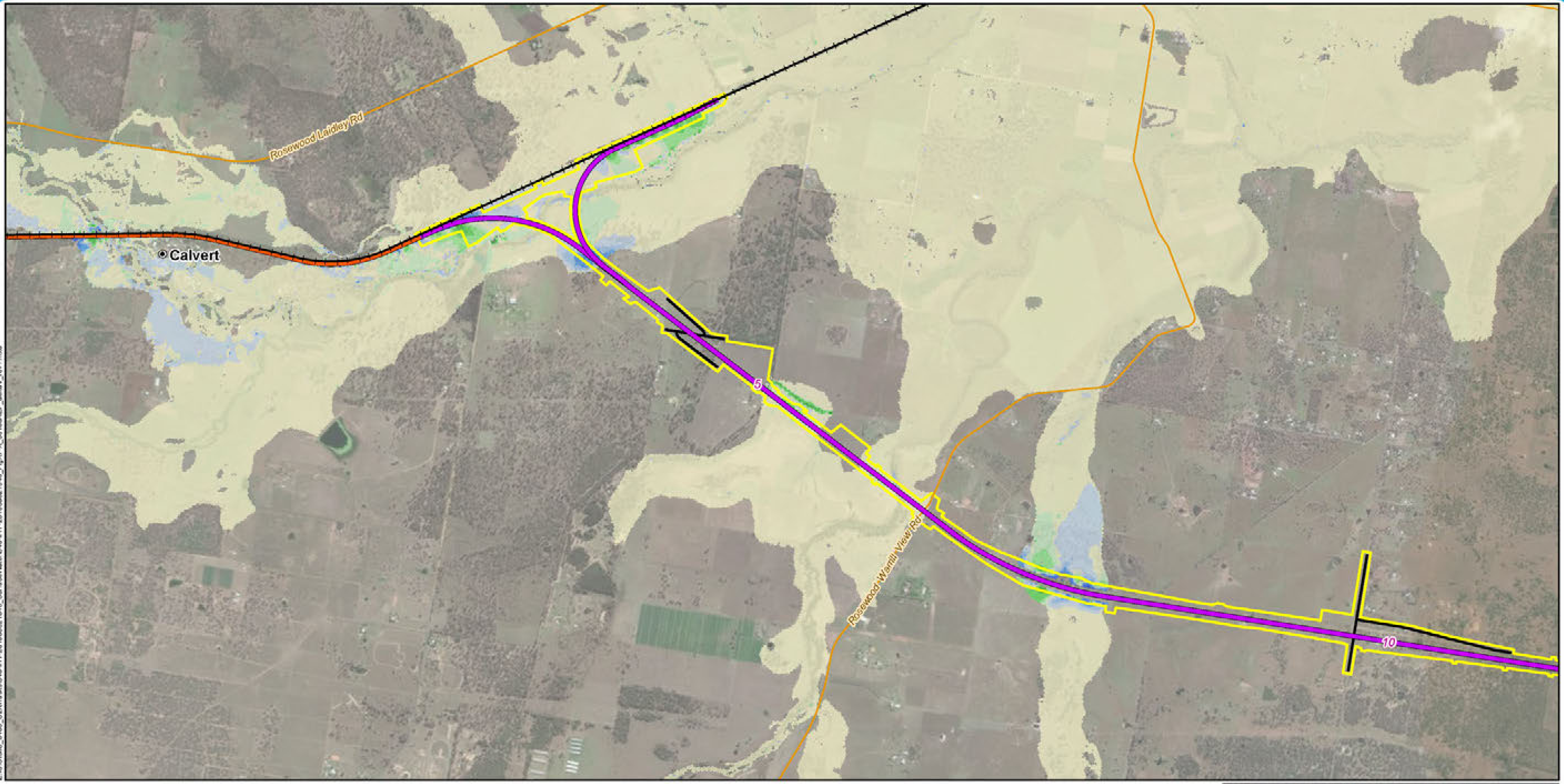
Future Freight
Integrating Community, Environment and Engineering

Issue date: 18/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-G: 1% AEP event Developed Case velocity: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint

Change in peak velocity (m/s)

- < -0.50
- -0.50 to -0.20
- -0.20 to -0.10
- -0.10 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.10
- 0.10 to 0.20
- 0.20 to 0.50
- > 0.50

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

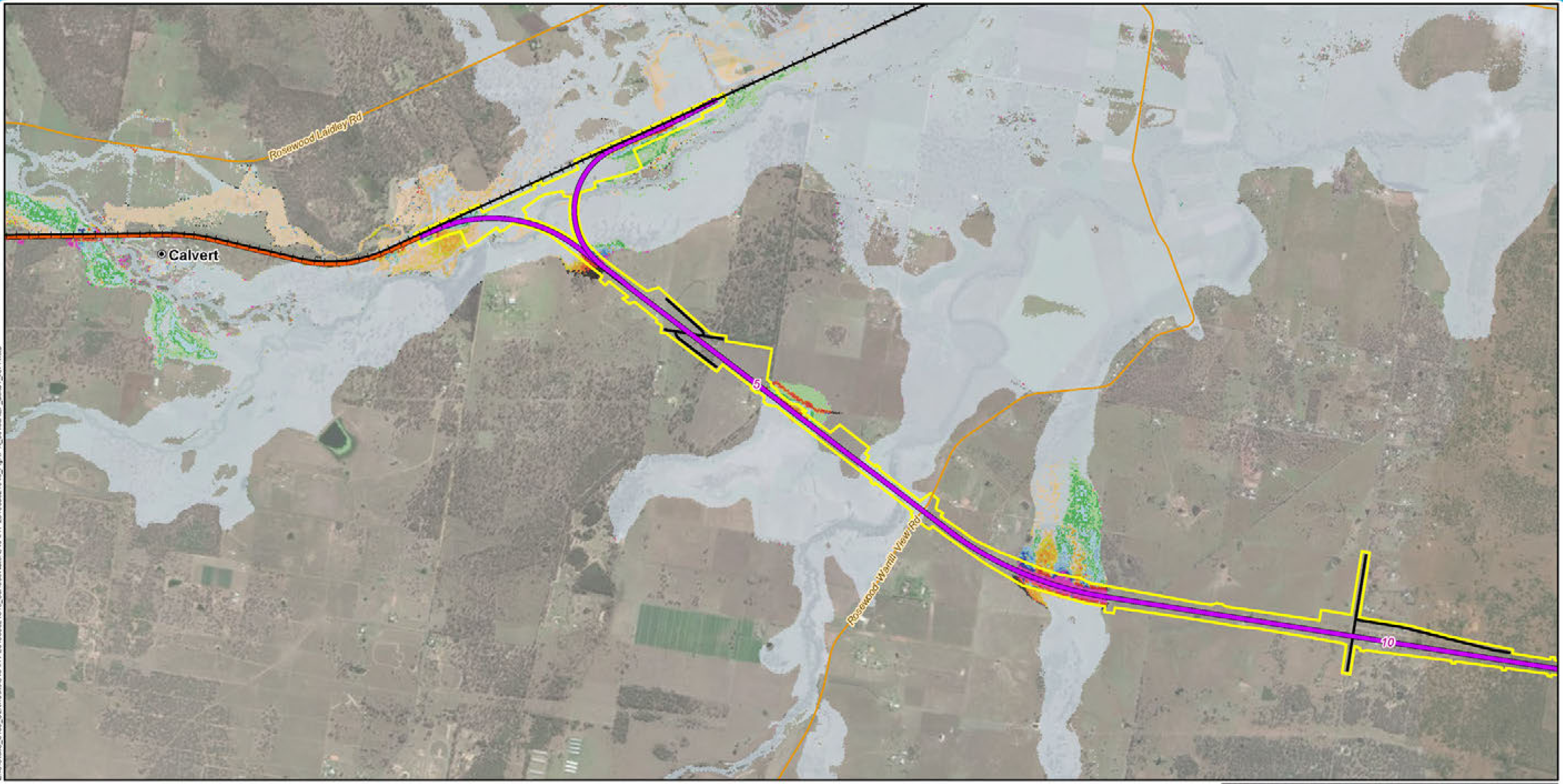
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-H: 1% AEP event Developed Case difference in velocity: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Difference in Time of Submergence

- Over 10 hour decrease
- Up to 10 hour decrease
- Up to 5 hour decrease
- Up to 2 hour decrease
- Up to 1 hour decrease
- Up to 0.5 hour decrease
- Within 15 minutes
- Up to 0.5 hour increase
- Up to 1 hour increase
- Up to 2 hour increase
- Up to 5 hour increase
- Up to 10 hour increase
- Over 10 hour increase

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

Future Freight
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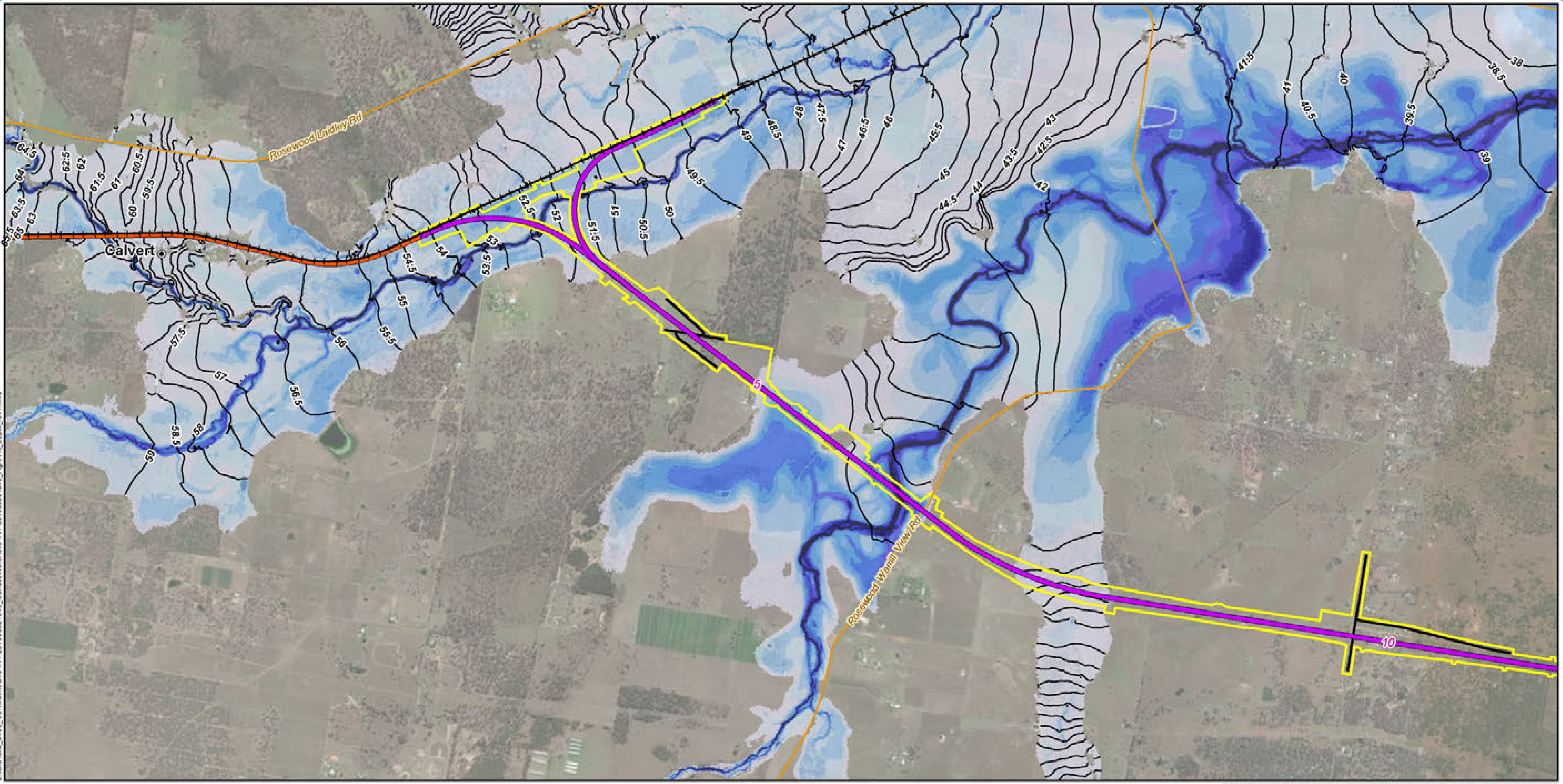
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A7-I: 1% AEP event Developed Case difference in time of submergence: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

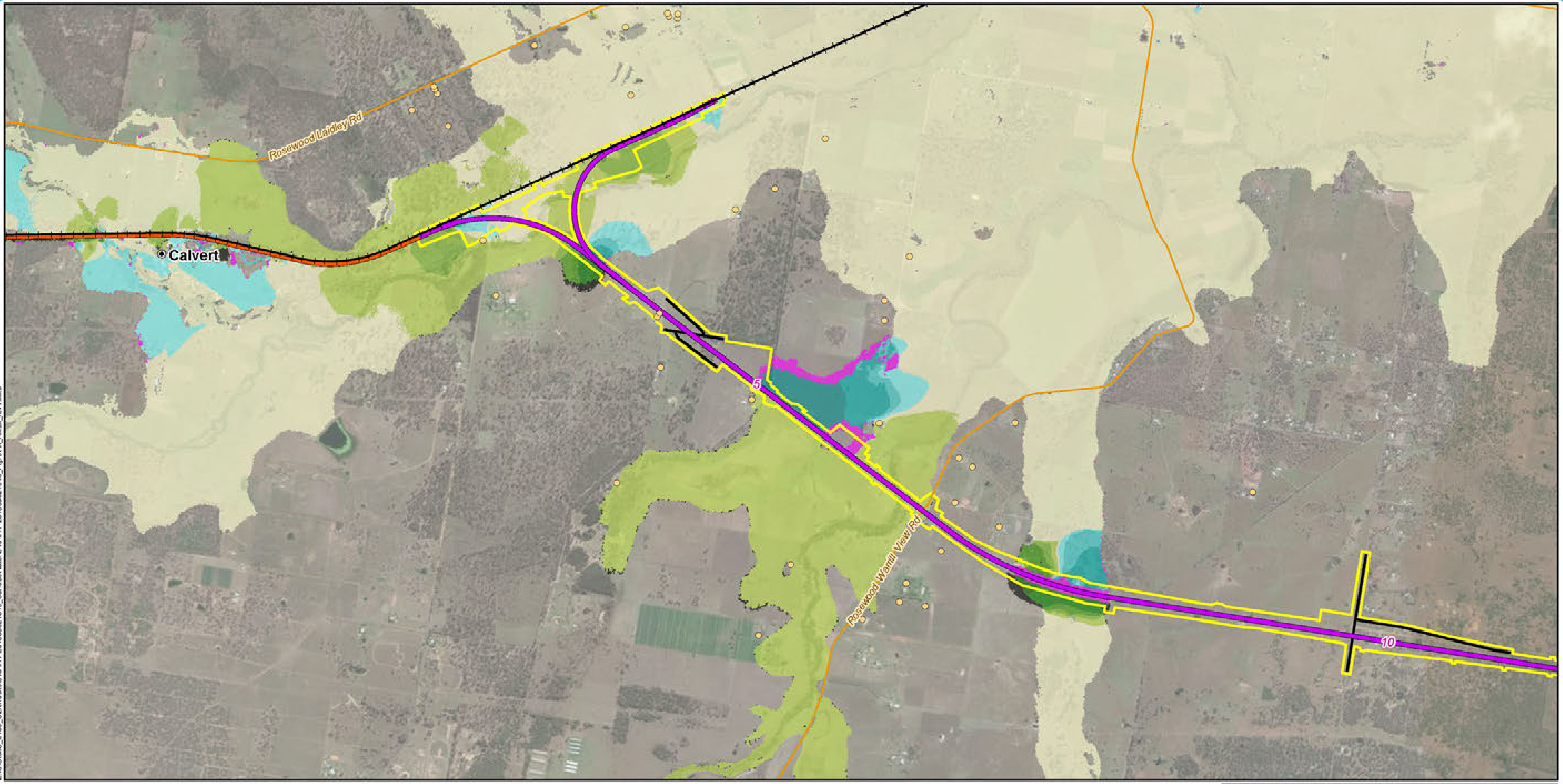
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A8-A: 1 in 2,000 AEP event Existing Case inundation extent: Bremer River

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



Map by: DTH/RB Date: 11/11/2019 21:22
Z:\GIS\GIS_3400_C2K\Tasks\340-IHY-201906021346_SurfaceWater\340-IHY-201906021346_FigXX-X_Afflux_rev1.mxd

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

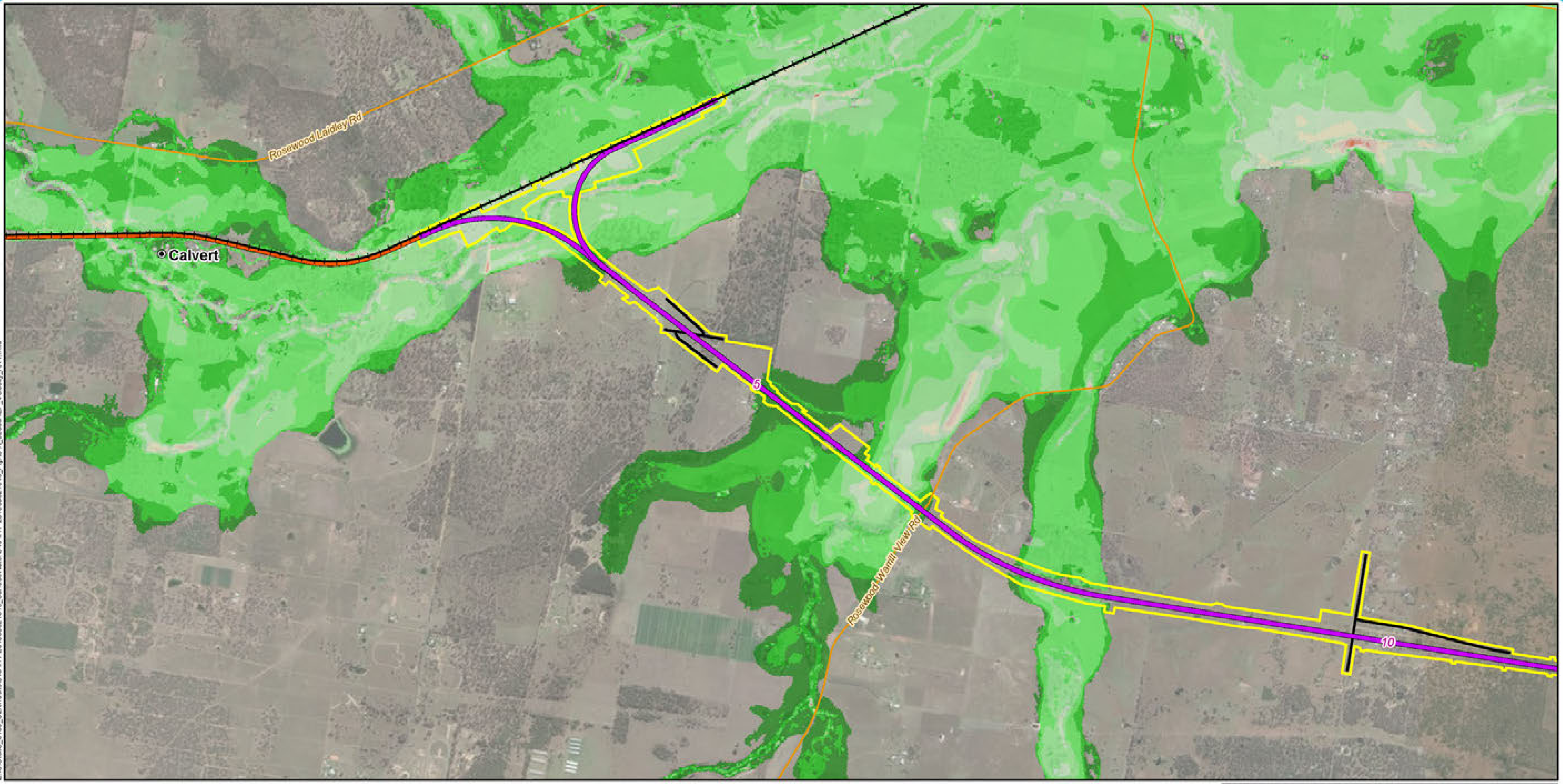
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A8-B: 1 in 2,000 AEP event Developed Case afflux: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint

Peak velocity (m/s)

- 0.0
- 0.5
- 1.0
- 1.5
- 2.0
- 2.5
- 3.0
- 3.5
- 4.0
- 4.5
- 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

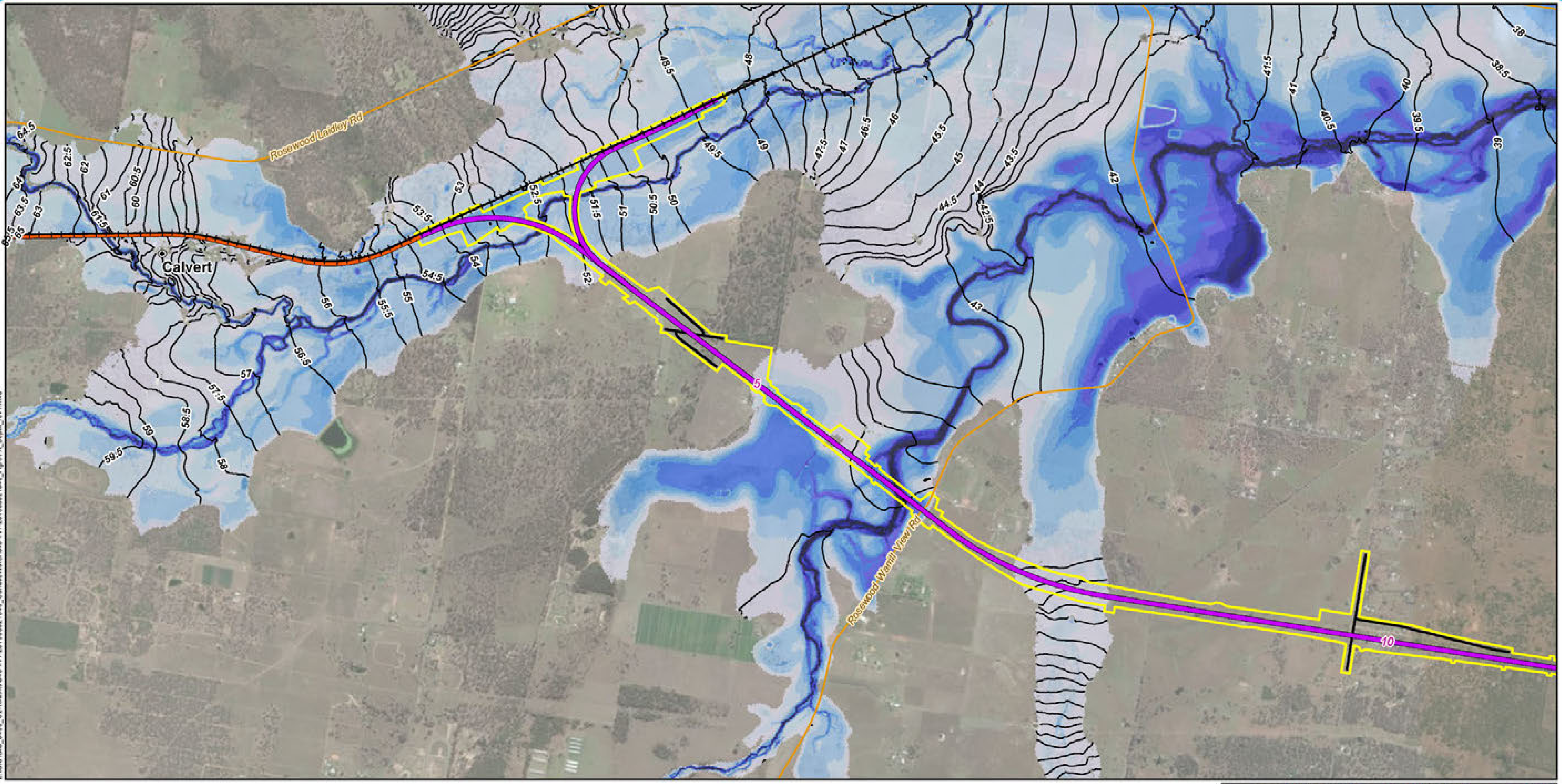
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A8-C: 1 in 2000 AEP event Developed Case velocity: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

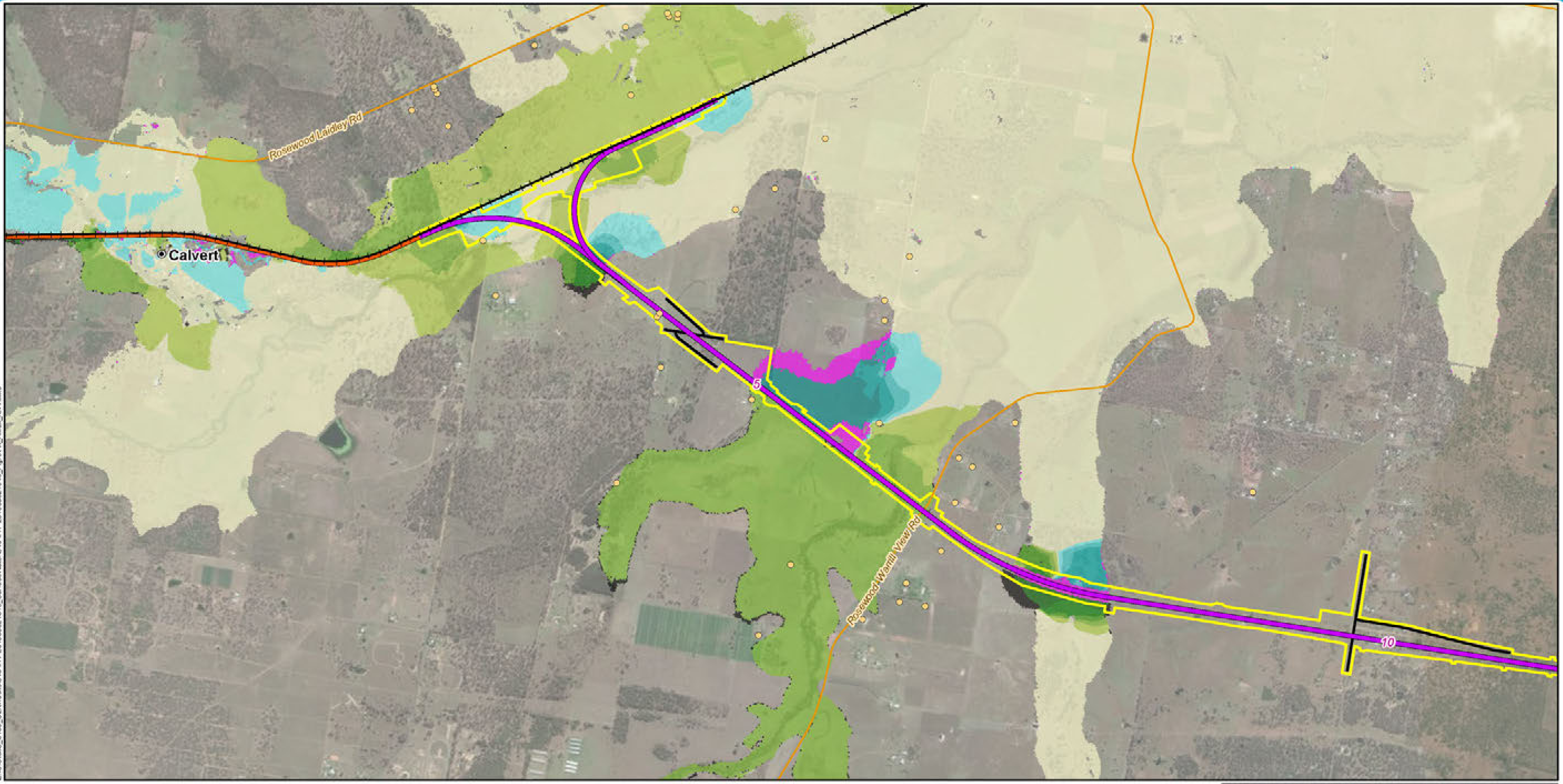
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A9-A: 1 in 10,000 AEP event Existing Case inundation extent: Bremer River

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



Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

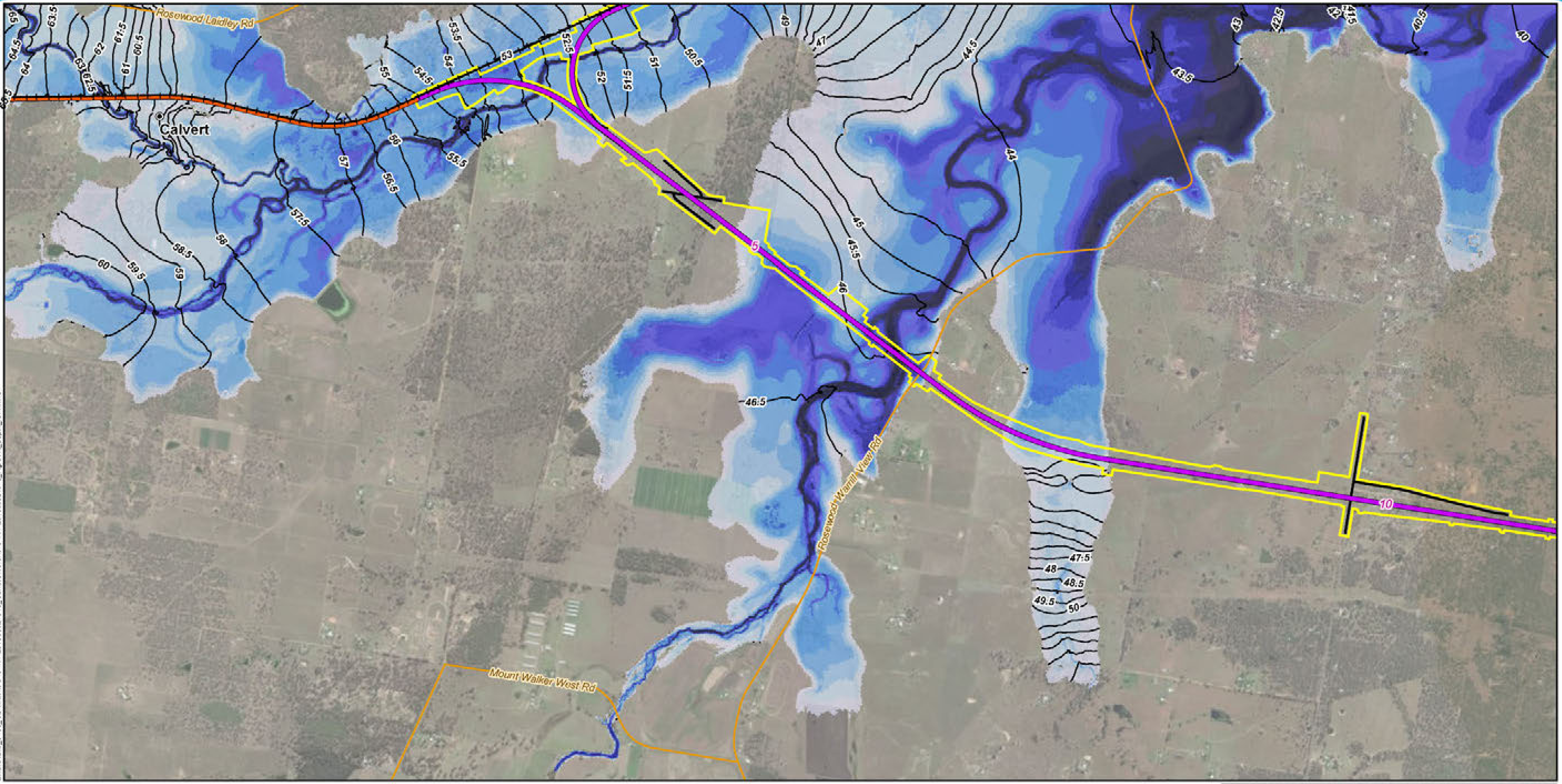
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A9-B: 1 in 10,000 AEP event Developed Case afflux: Bremer River

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



Map by: DTH/RB Date: 7/11/2019 13:56
Z:\GIS\GIS_3400_C2K\Tasks\340-IHY-201908021345_SurfaceWater\340-IHY-201908021345_FigXx-X_Depth_rev1.mxd

Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

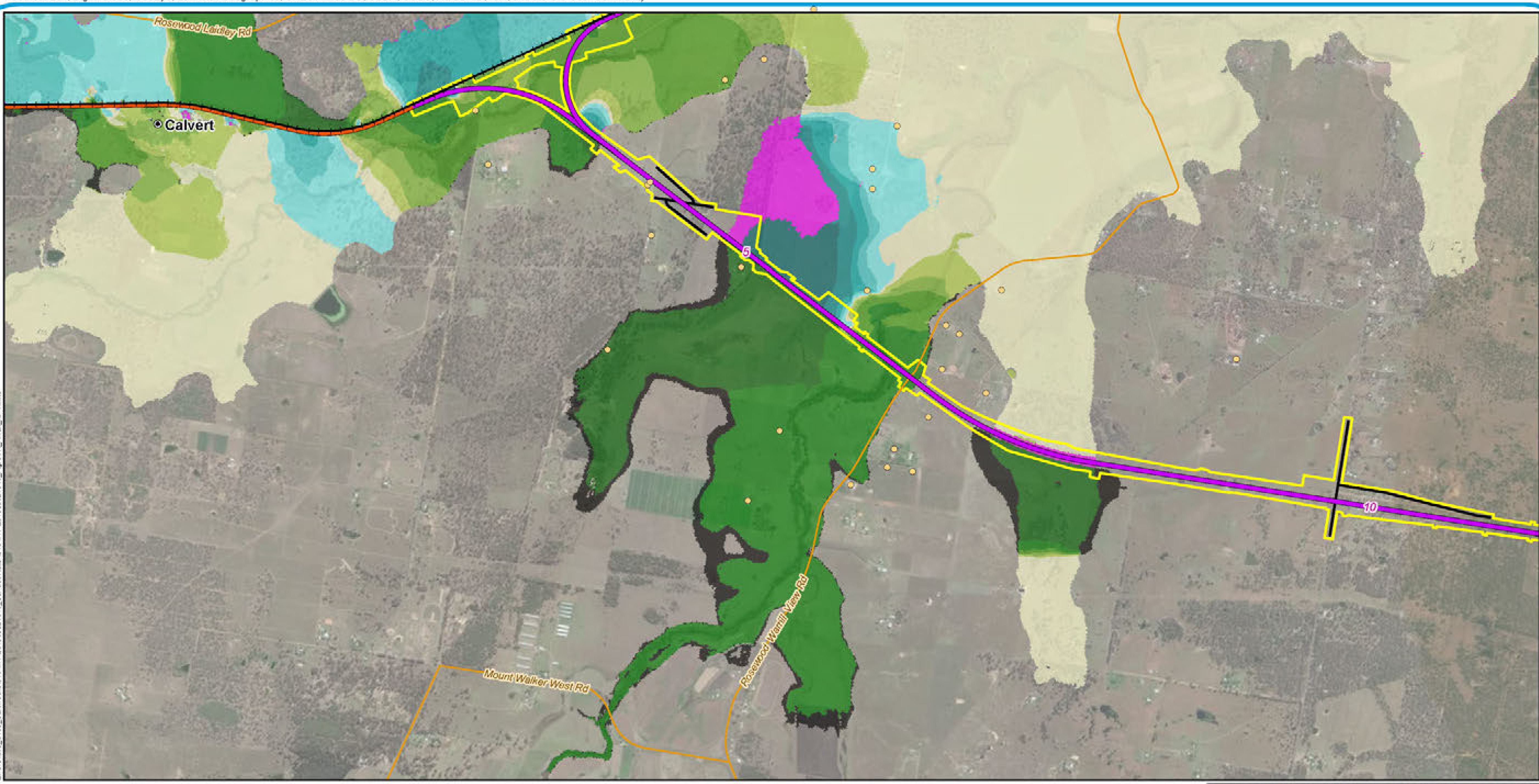
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A10-A: PMF event Existing Case inundation extent: Bremer River

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



Map by: DTH/RB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Localities
- Flood sensitive receptors
- Existing rail
- H2C project alignment
- C2K project alignment
- Proposed roadworks
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure A10-B: PMF event Developed Case afflux: Bremer River

APPENDIX
N

Hydrology and Flooding Technical Report

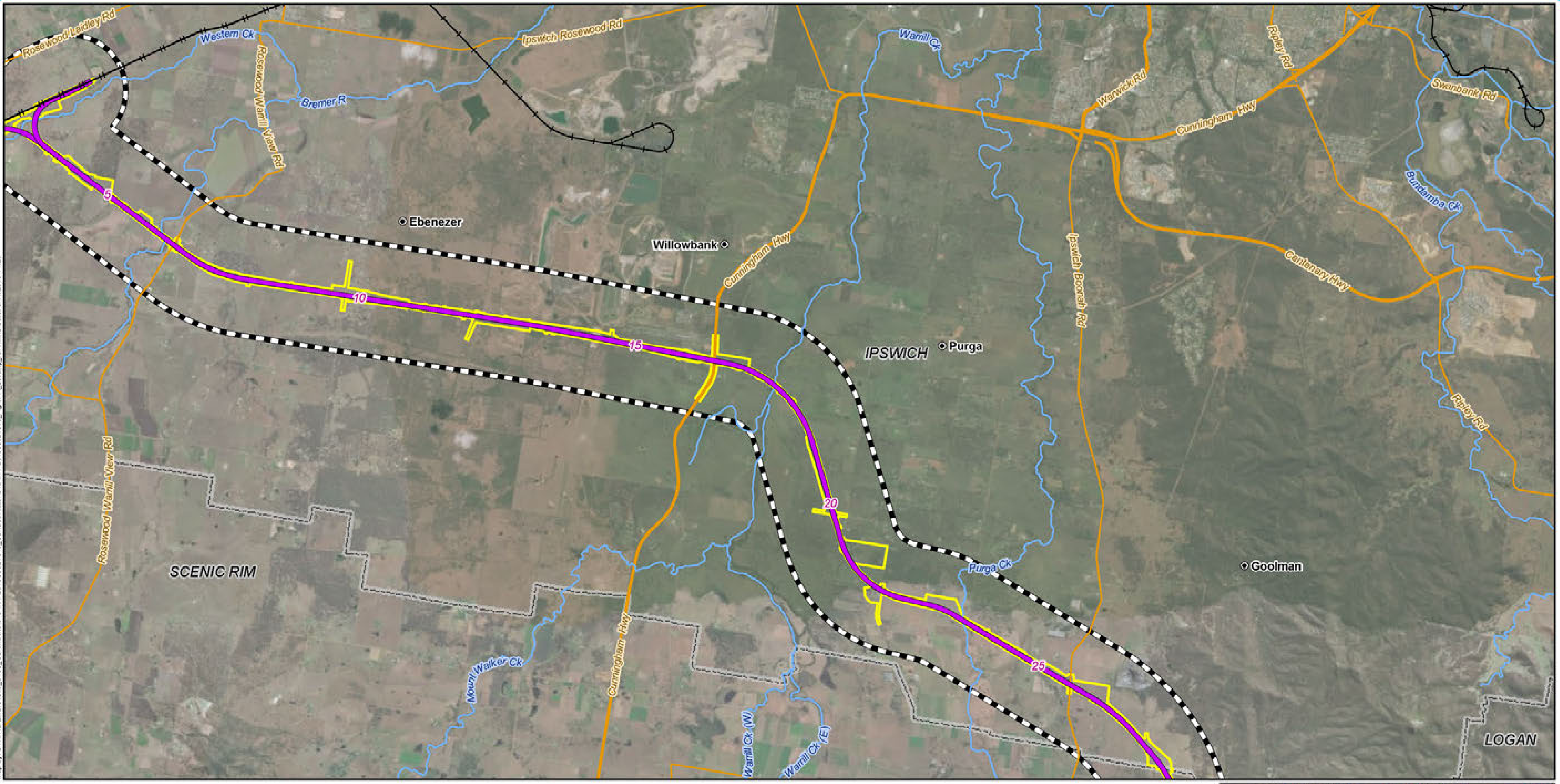
Appendix B Warrill Creek Figures

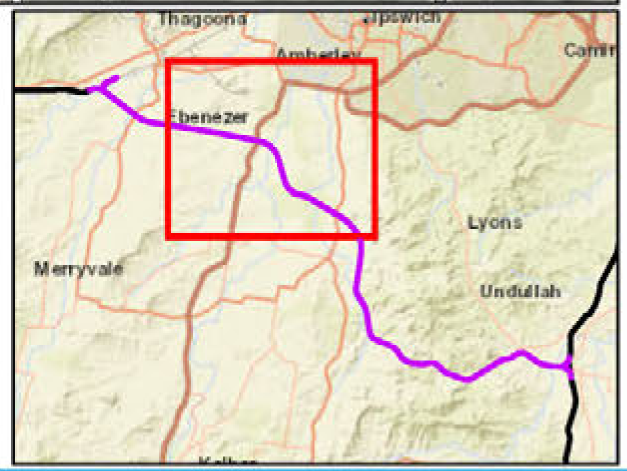
CALVERT TO KAGARU ENVIRONMENTAL IMPACT STATEMENT

IR_1381

Appendix B
Warrill Creek Figures

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





Legend

- 5 Chainage (km)
- Localities
- Existing rail
- C2K project alignment
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- EIS investigation corridor
- Local Government Areas

A3 scale: 1:75,000

0 0.55 1.1 1.65 2.2 2.75km

Future Freight
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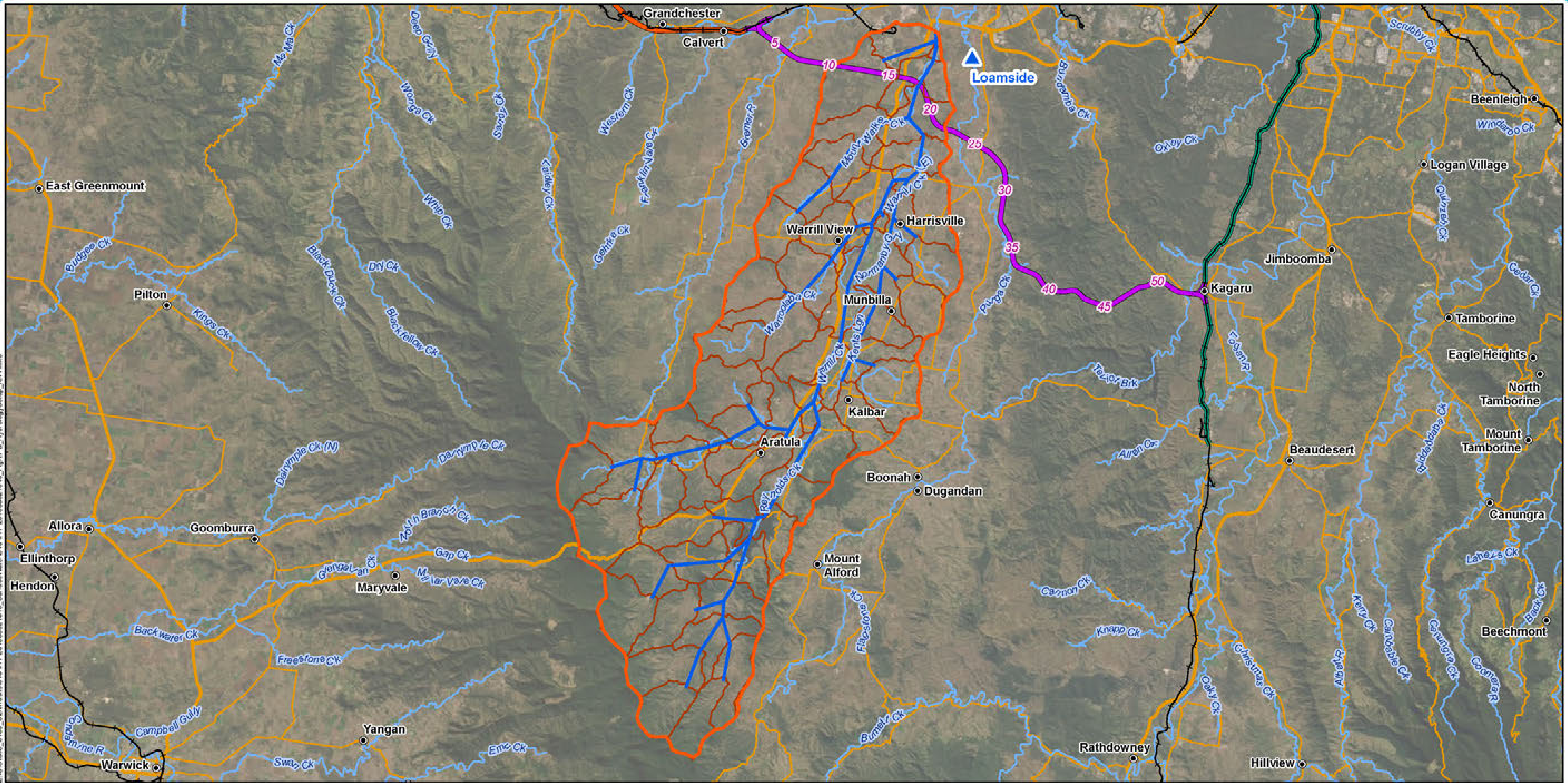
Issue date: 06/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru
Figure B1-A: Locality: Warrill Creek

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



Legend

- 5 Chainage (km)
- Localities
- Existing rail
- H2C project alignment
- C2K project alignment
- K2ARB project alignment
- Watercourses
- Major roads
- Minor roads
- Stream gauge
- Warrill Creek model subcatchments
- Model subcatchments
- Hydrologic model links

A3 scale: 1:350,000

0 2.5 5 7.5 10 12.5km

Future Freight
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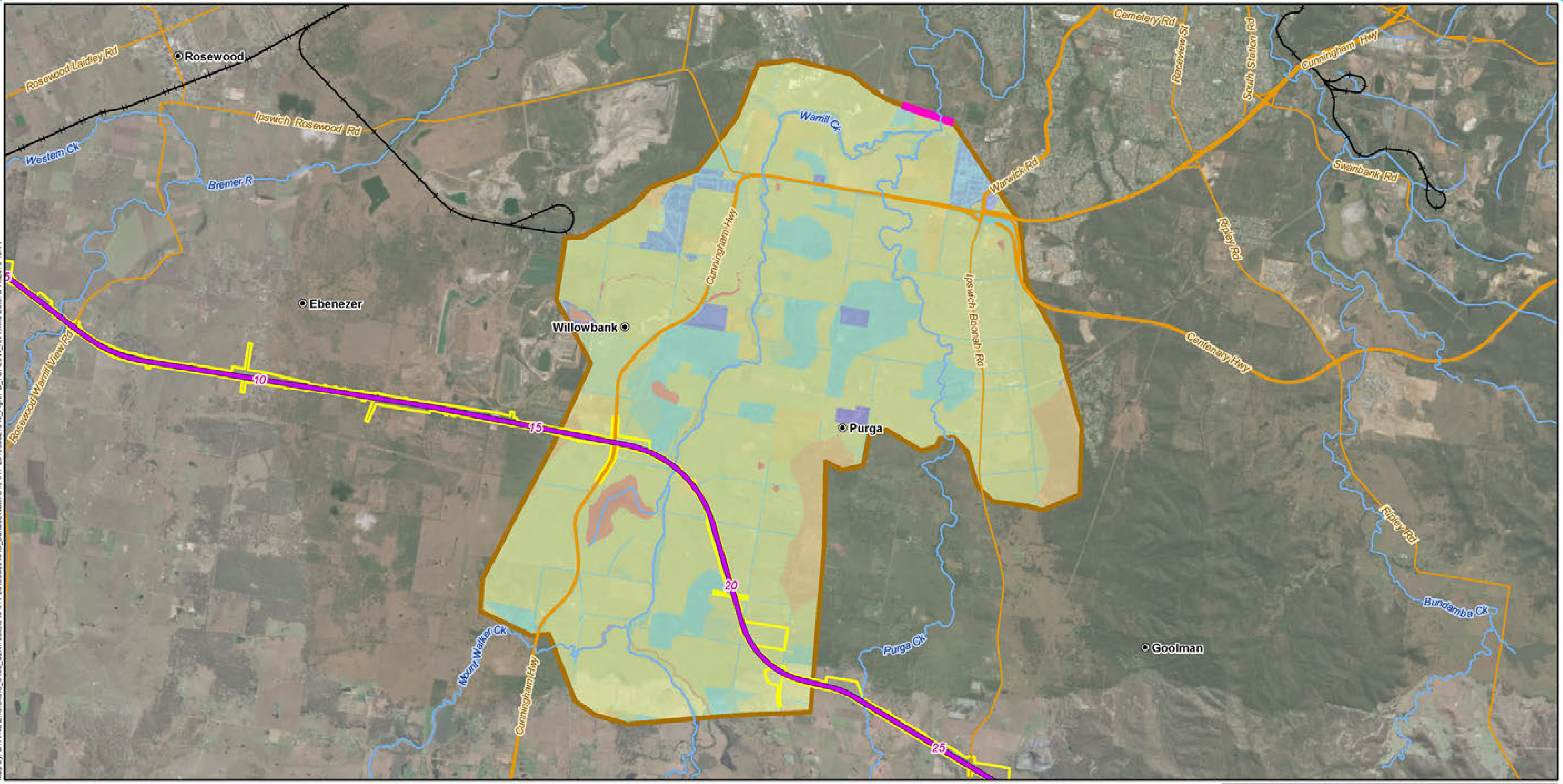
Issue date: 06/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B1-B: Hydrology setup: Warrill Creek

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

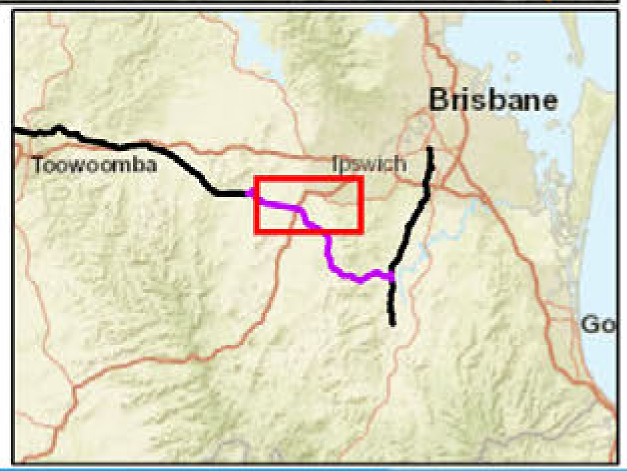


Legend

- 5 Chainage (km)
- Localities
- Existing rail
- C2K project alignment
- Watercourses
- Major roads
- Minor roads
- EIS disturbance footprint
- Downstream boundary
- Code boundary

Materials

- Non Tidal Waterway
- Waterbodies
- Medium Density River Bank Vegetation
- High Density River Bank Vegetation
- Grassland
- Light Vegetation
- Dense Vegetation
- Very Dense Vegetation
- Rough Pasture/ Light Brush
- Roads
- Low Density Urban Block
- Medium Density Urban Block
- Commercial/ Industrial
- Mining



A3 scale: 1:75,000

0 0.55 1.1 1.65 2.2 2.75 km

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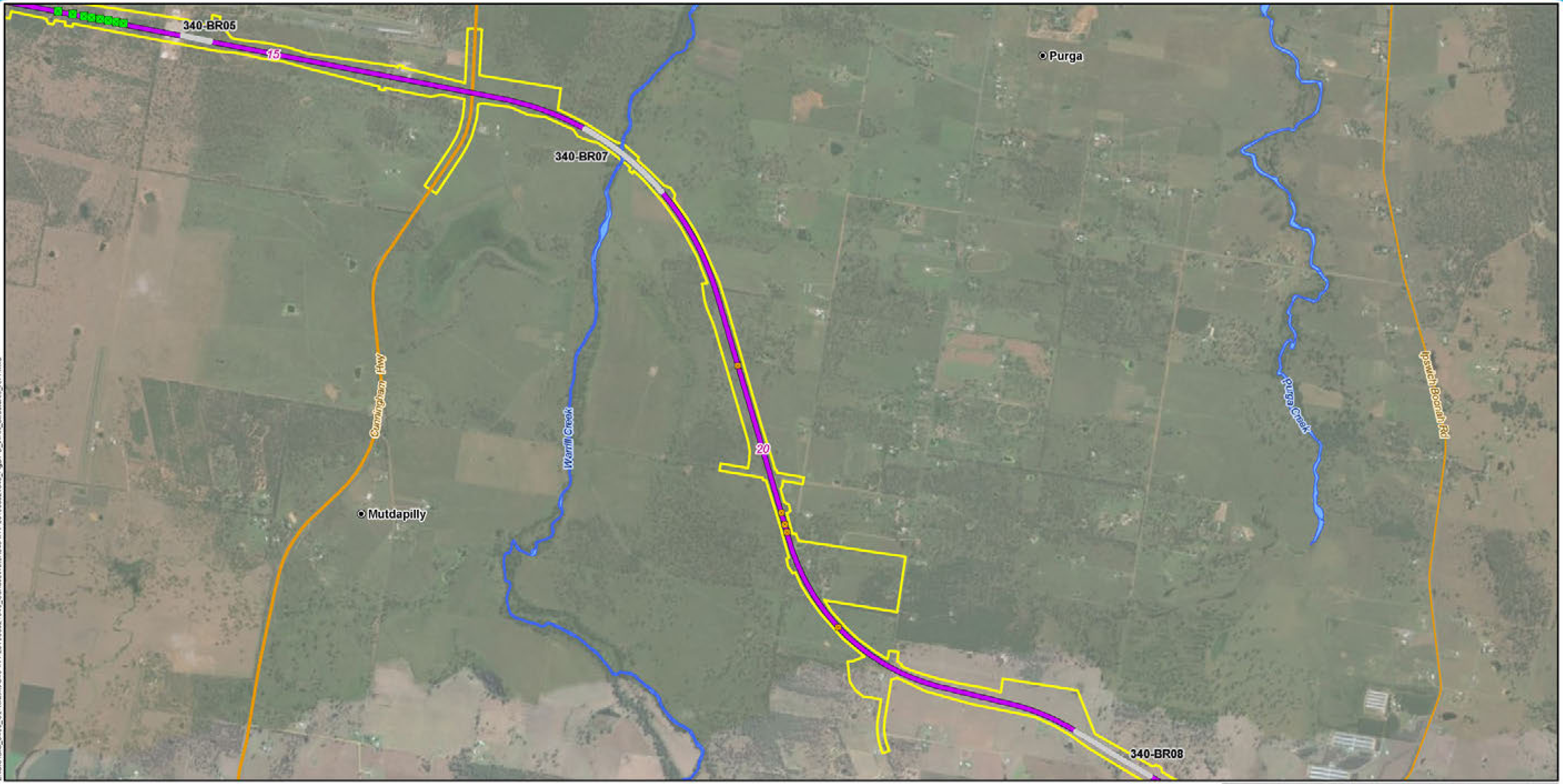
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B1-C: TUFLOW model setup: Warrill Creek



Legend

- 5 Chainage (km)
- Localities
- C2K project alignment
- Defined watercourses
- Major roads
- Minor roads
- EIS disturbance footprint

Drainage Structures

- Flood culvert
- Local drainage culvert
- Bridges

A3 scale: 1:30,000

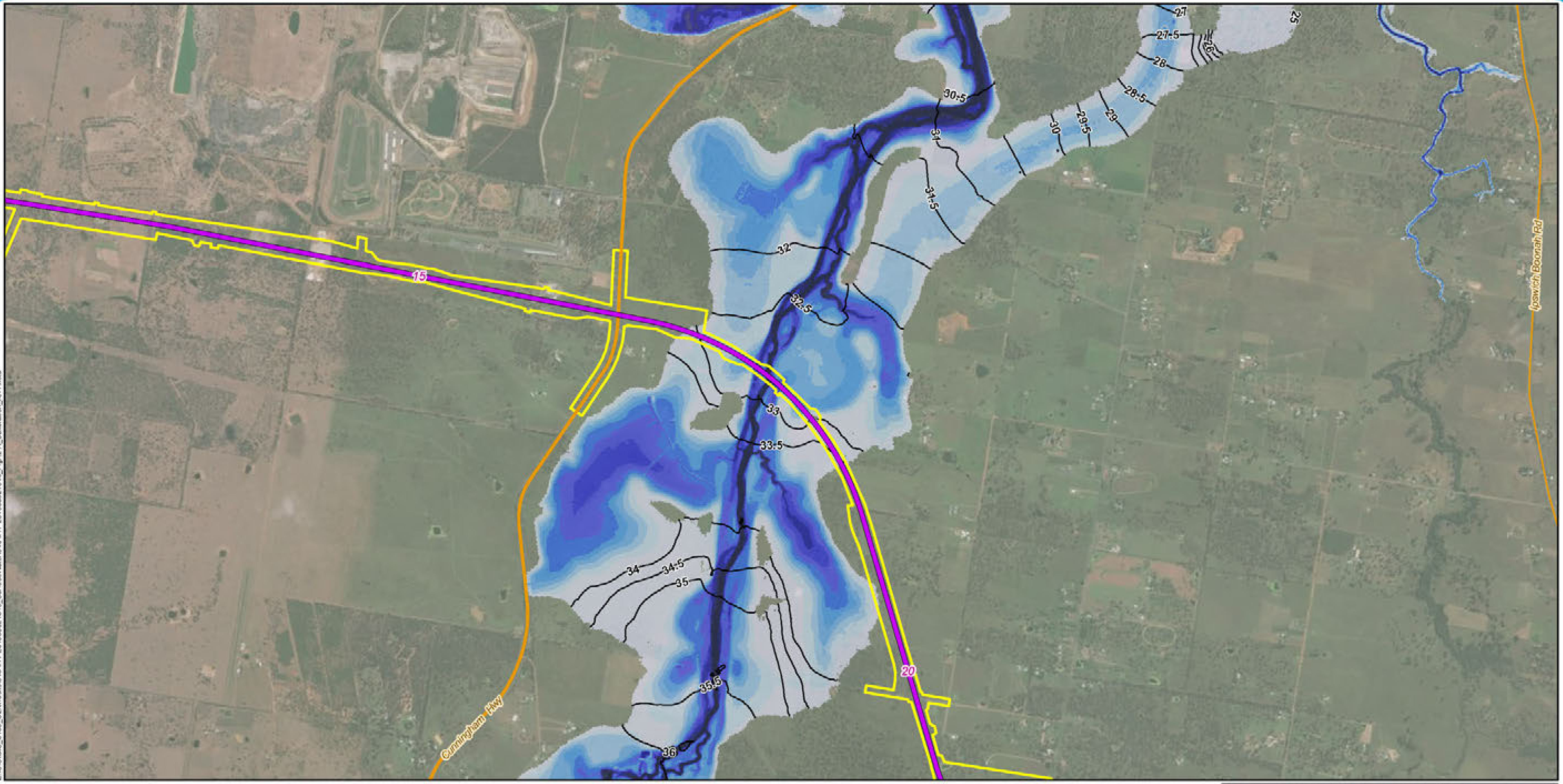
0 0.2 0.4 0.6 0.8 1km

Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru
Figure B1-D: Design structures: Warrill Creek

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



Map by: DTH/RB Date: 18/11/2019 16:12

Legend

5 Chainage (km)	EIS disturbance footprint	**Depth (m)**
Localities	0.5m Contour mAHD	0 - 0.5
C2K project alignment		0.5 - 1.0
Major roads		1.0 - 1.5
Minor roads		1.5 - 2.0
		2.0 - 2.5
		2.5 - 3.0
		3.0 - 3.5
		3.5 - 4.0
		4.0 - 4.5
		4.5 - 5.0
		> 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

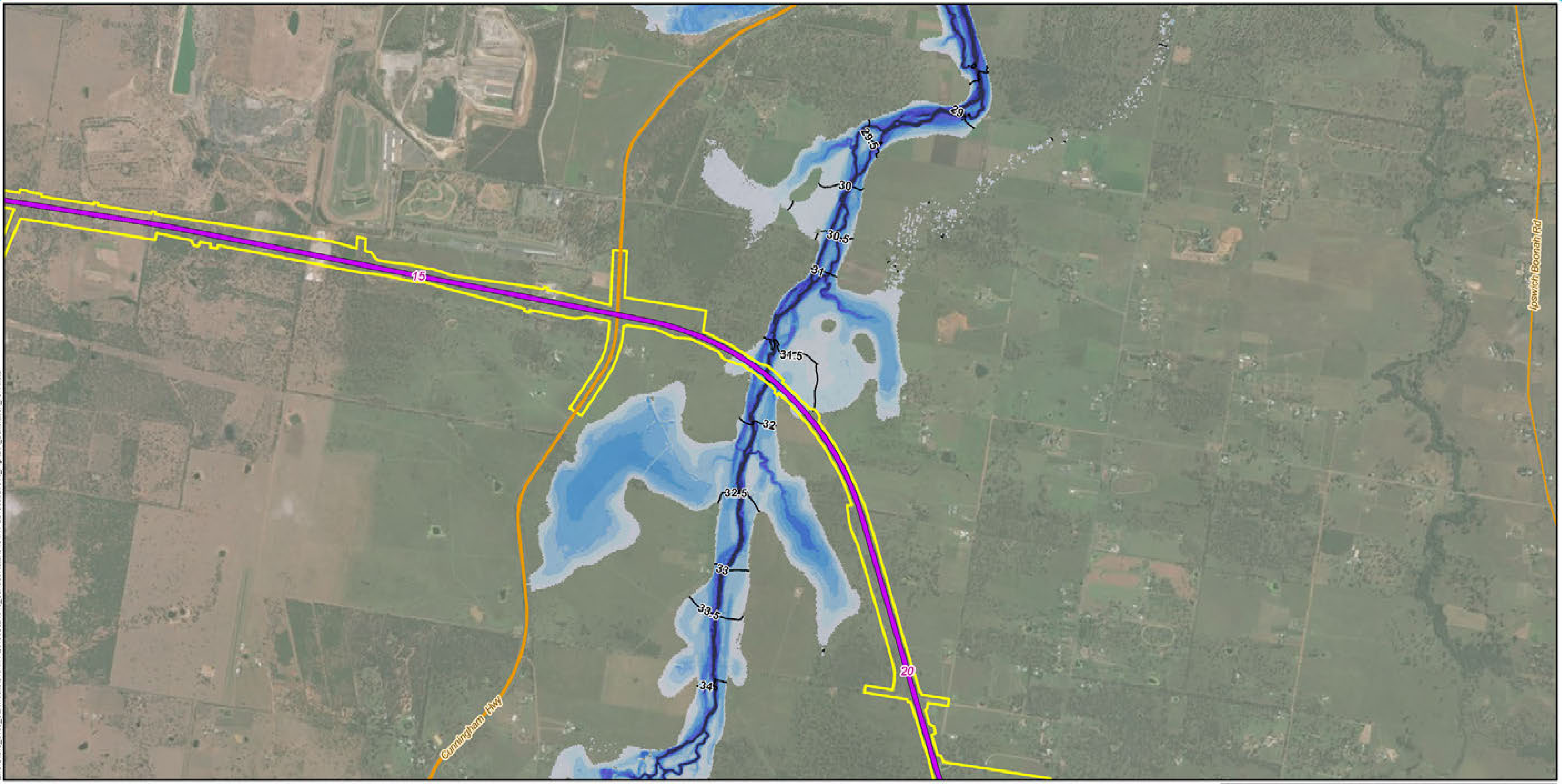
Future Freight
Integrating Community, Environment and Engineering

Issue date: 18/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B2-A: 1974 Calibration event: Warrill Creek

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



Legend

5	Chainage (km)
◉	Localities
	C2K project alignment
	Major roads
	Minor roads
	EIS disturbance footprint
	0.5m Contour mAHD

Depth (m)

0 - 0.5	1.5 - 2.0	3.5 - 4.0
0.5 - 1.0	2.0 - 2.5	4.0 - 4.5
1.0 - 1.5	2.5 - 3.0	4.5 - 5.0
	3.0 - 3.5	> 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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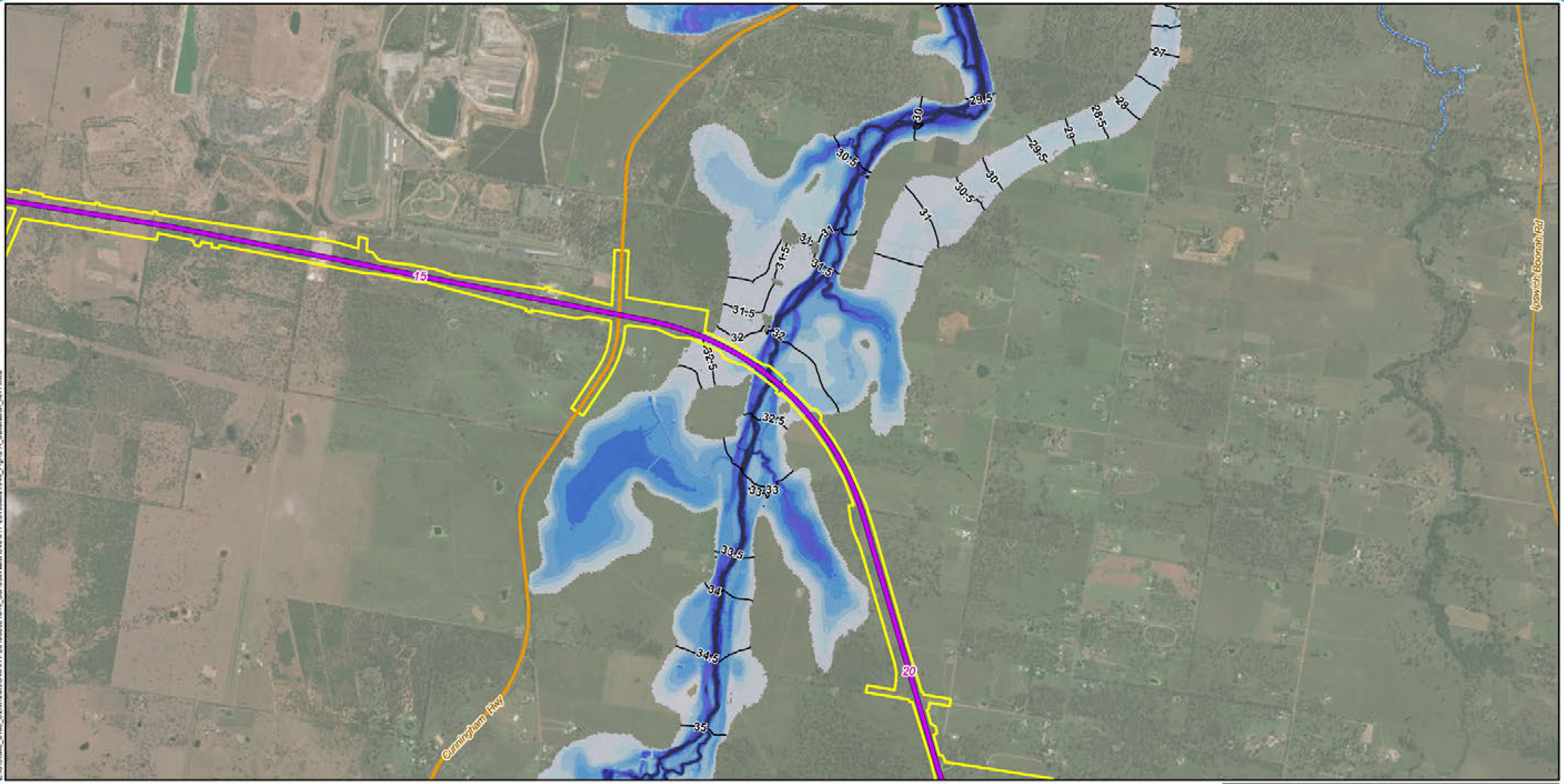
Issue date: 18/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B2-B: 2011 Calibration event: Warrill Creek

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



Map by: DTH/RB Date: 18/11/2019 16:12

Legend

- 5 Chainage (km)
- Localities
- C2K project alignment
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m Contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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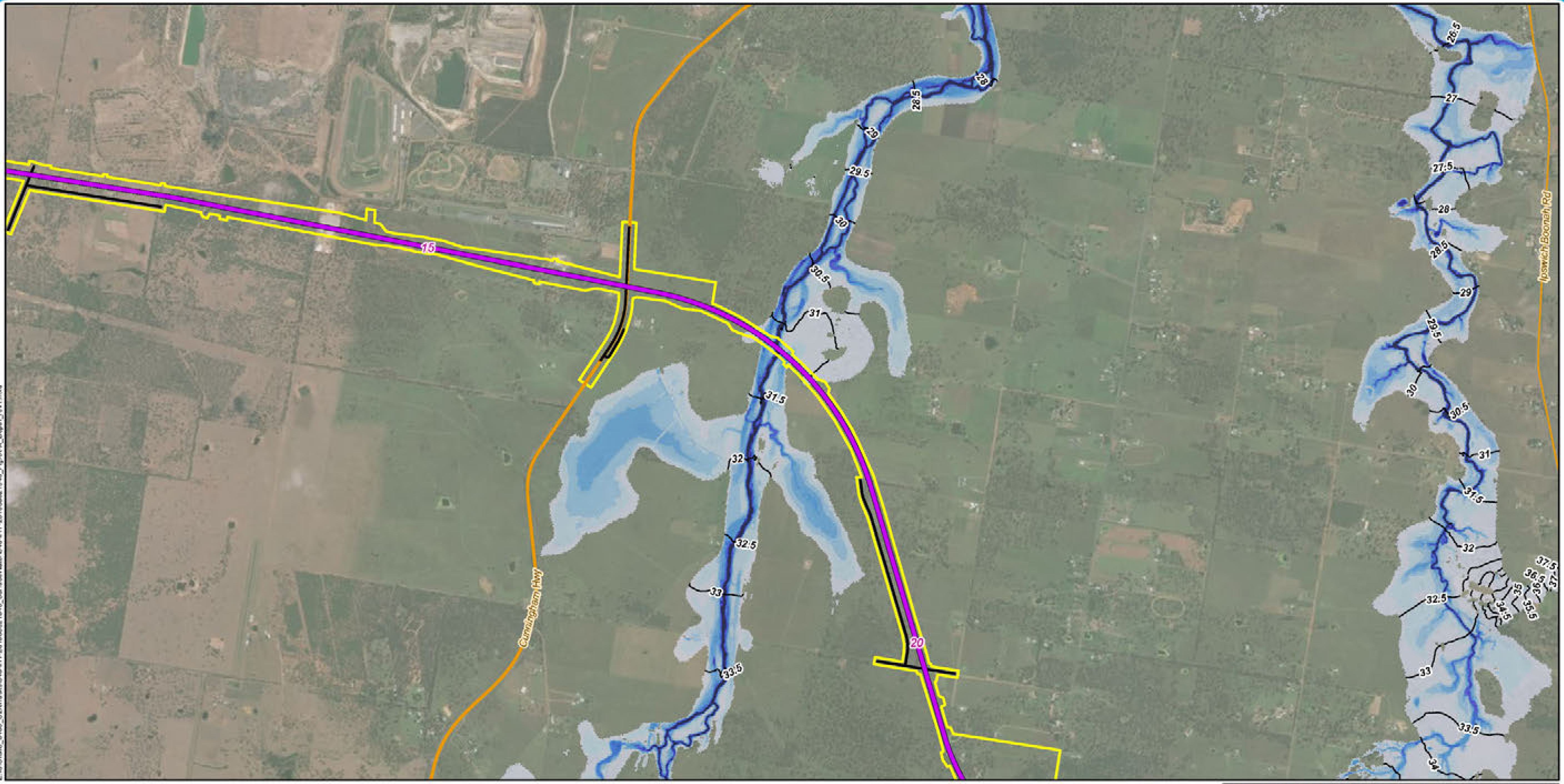
Issue date: 18/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B2-C: 2013 Calibration event: Warrill Creek



Map by: DTH/RB Date: 8/11/2019 10:56

Legend

5 Chainage (km)	EIS disturbance footprint
C2K project alignment	0.5m contour mAHD
Proposed roadworks	
Major roads	
Minor roads	

Depth (m)

0 - 0.5	2.5 - 3.0
0.5 - 1.0	3.0 - 3.5
1.0 - 1.5	3.5 - 4.0
1.5 - 2.0	4.0 - 4.5
2.0 - 2.5	4.5 - 5.0
	> 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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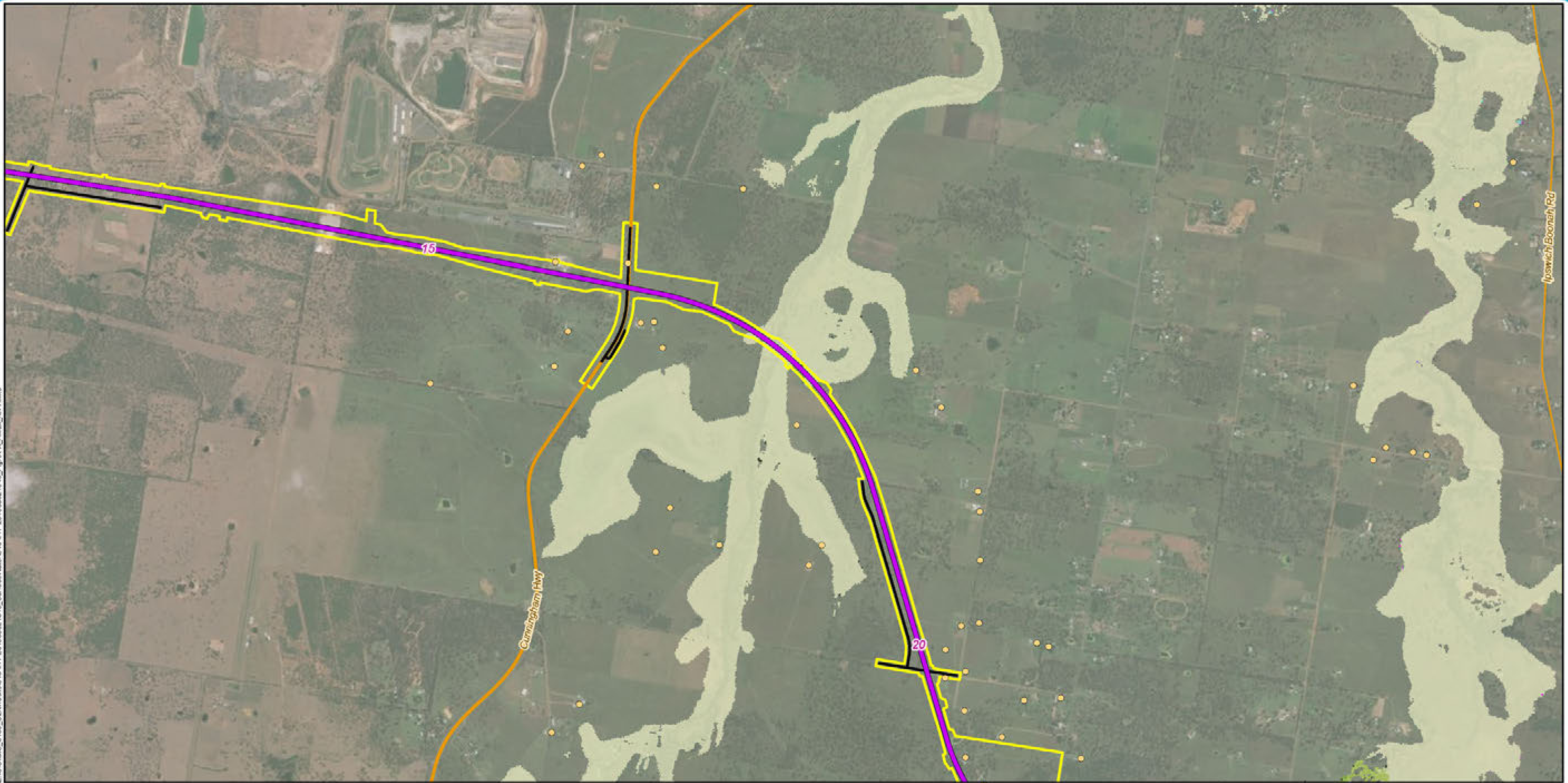
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B3-A: 20% AEP event Existing Case inundation extent: Warrill Creek



Map by: DTH/RB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

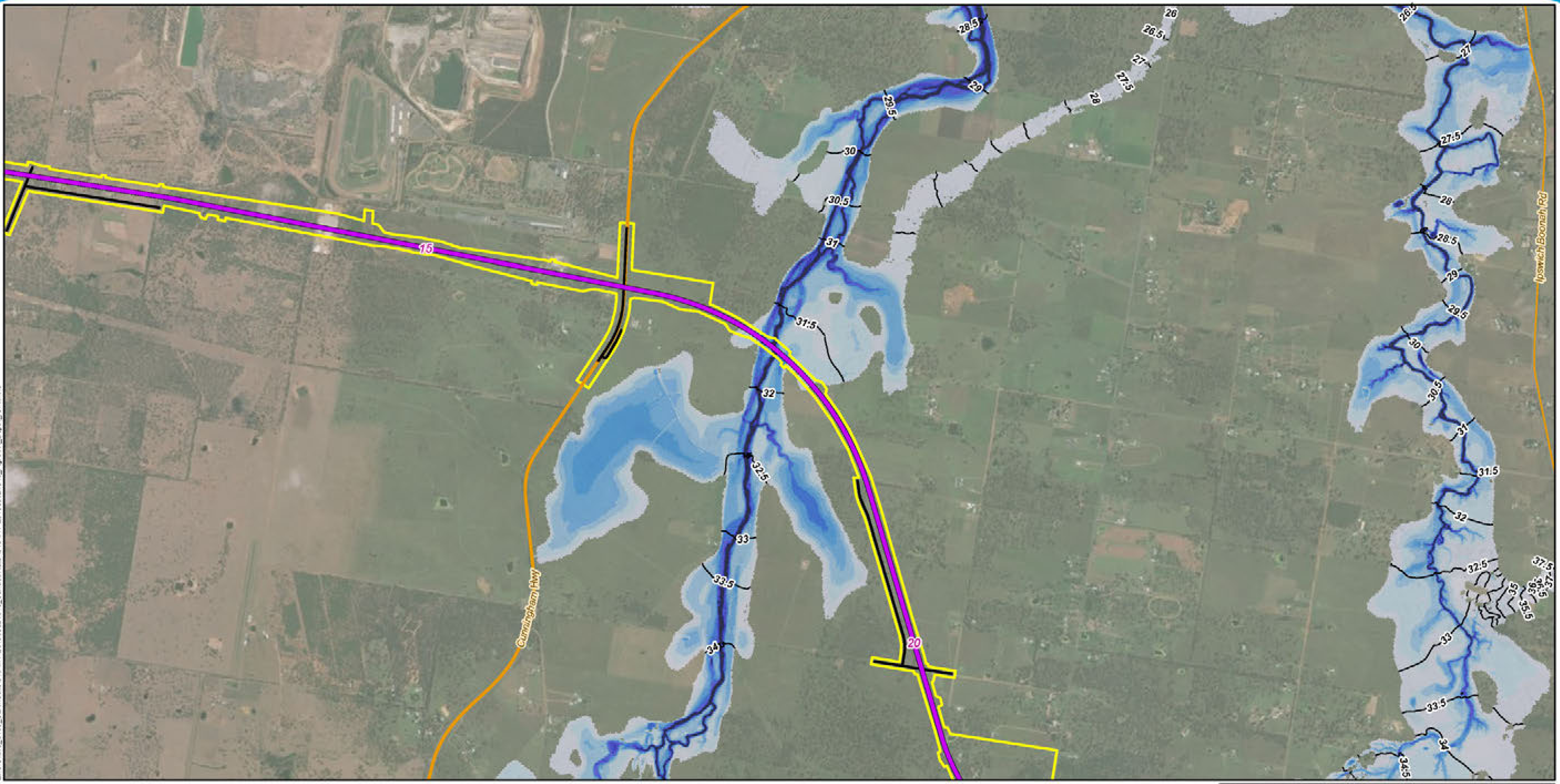
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B3-B: 20% AEP event Developed Case afflux: Warrill Creek

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



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

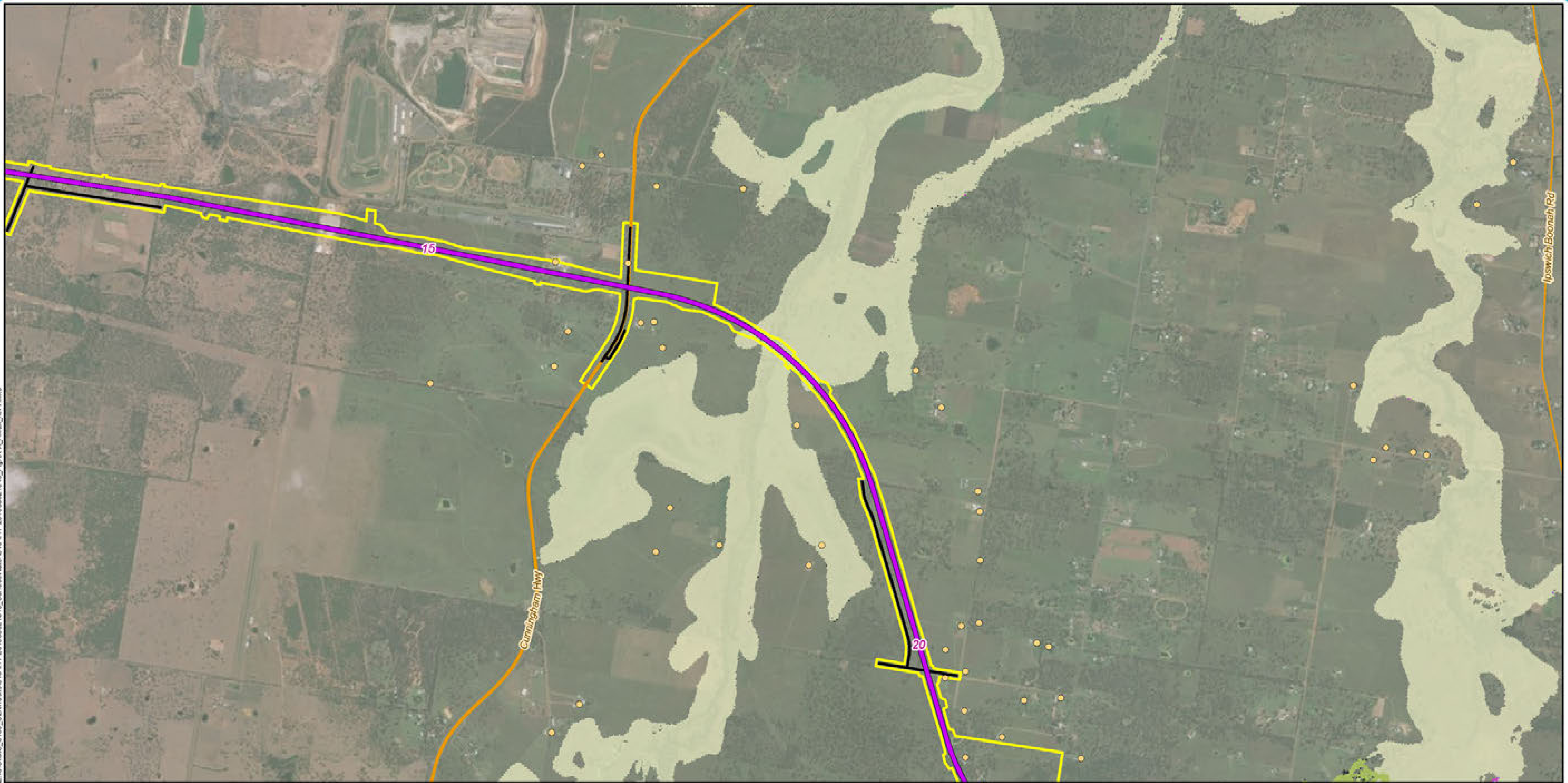
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B4-A: 10% AEP event Existing Case inundation extent: Warrill Creek

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



Legend

5	Chainage (km)
	Flood sensitive receptors
	C2K project alignment
	Proposed roadworks
	Major roads
	Minor roads
	EIS disturbance footprint
	Was Wet Now Dry
	Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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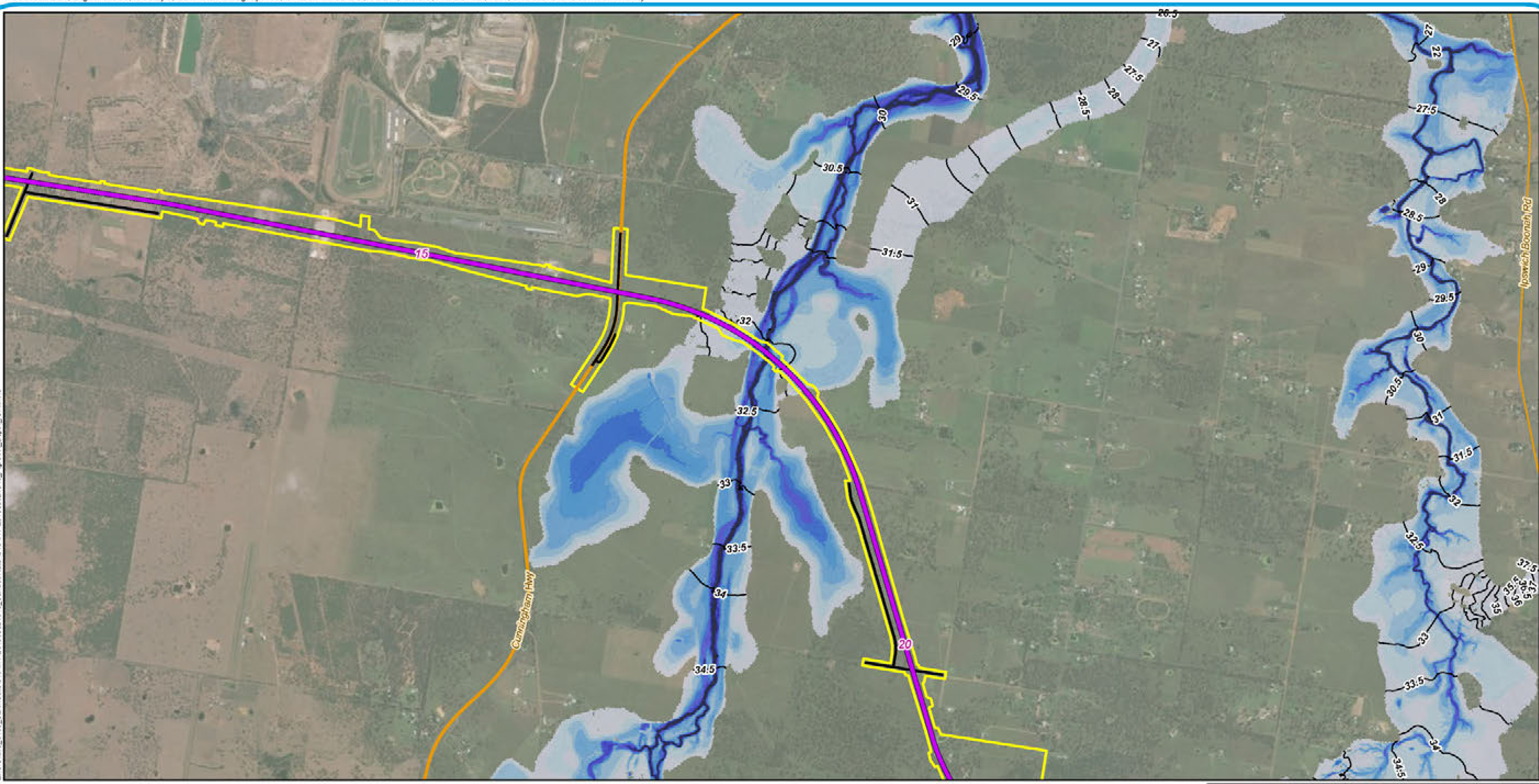
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B4-B: 10% AEP event Developed Case afflux: Warrill Creek

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



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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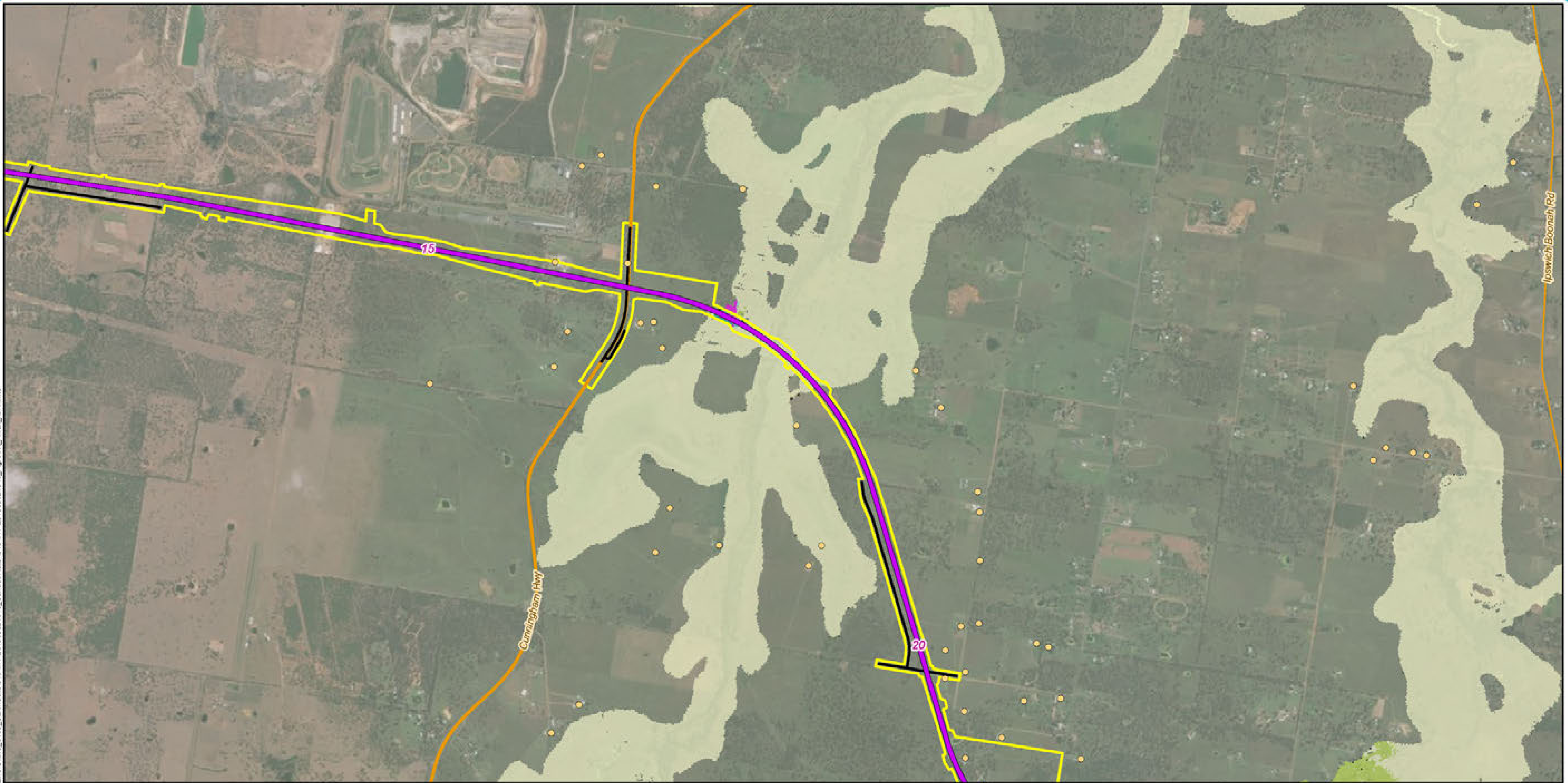
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B5-A: 5% AEP event Existing Case inundation extent: Warrill Creek

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



Map by: DTH/RB Date: 11/11/2019 21:22
Z:\GIS\GIS_3400_C2K\Tasks\340-IHY-201908021346_SurfaceWater\340-IHY-201908021346_FigXX-X_Afflux_rev1.mxd

Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

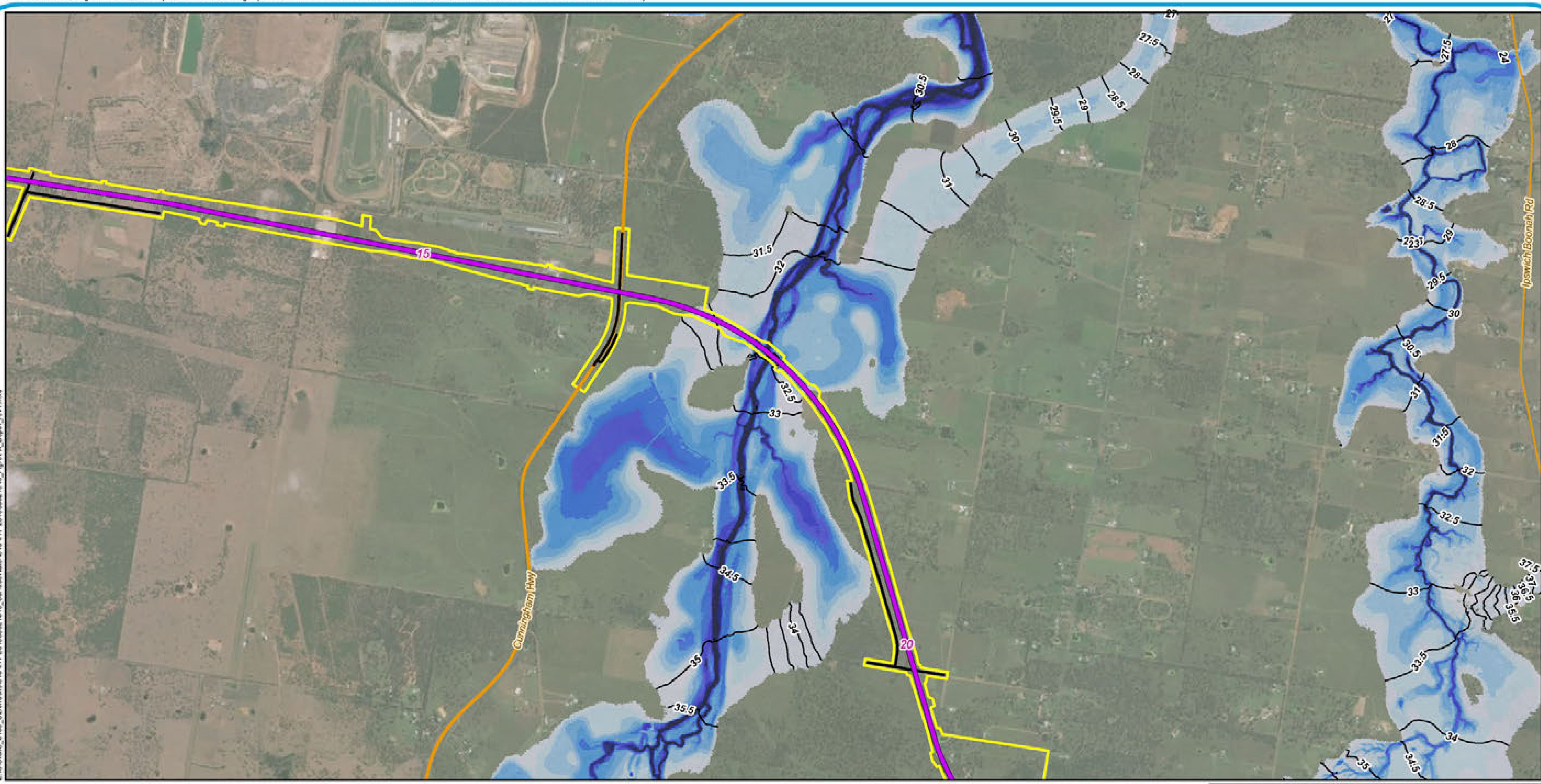
Future Freight
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B5-B: 5% AEP event Developed Case afflux: Warrill Creek

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



Map by: DTH/RB Date: 8/11/2019 10:58
Z:\GIS\GIS_3400_C2K\Tasks\340-IHY-201908021346_SurfaceWater\340-IHY-201908021346_FigXX-X_Depth_rev1.mxd

Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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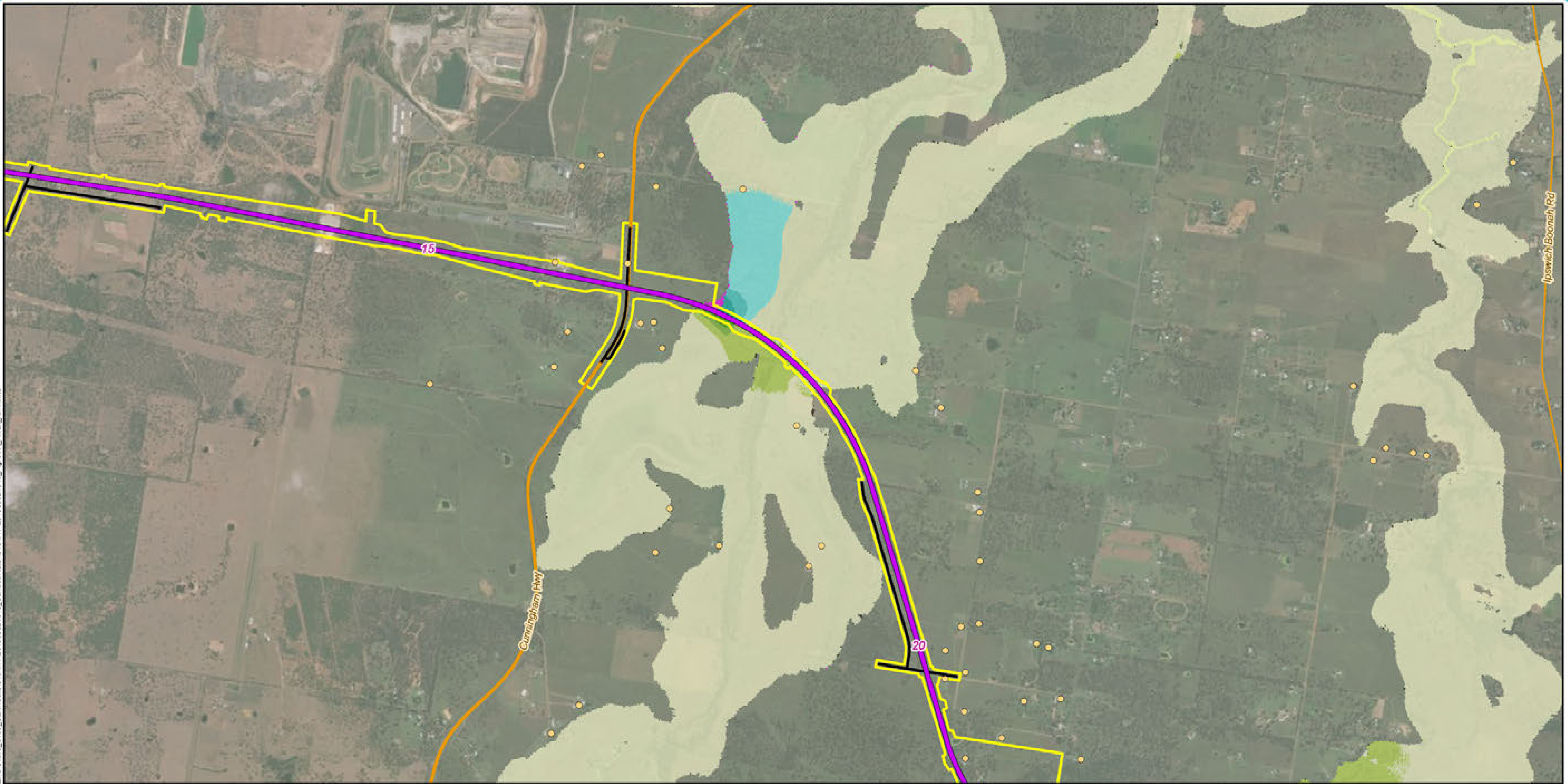
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B6-A: 2% AEP event Existing Case inundation extent: Warrill Creek

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



Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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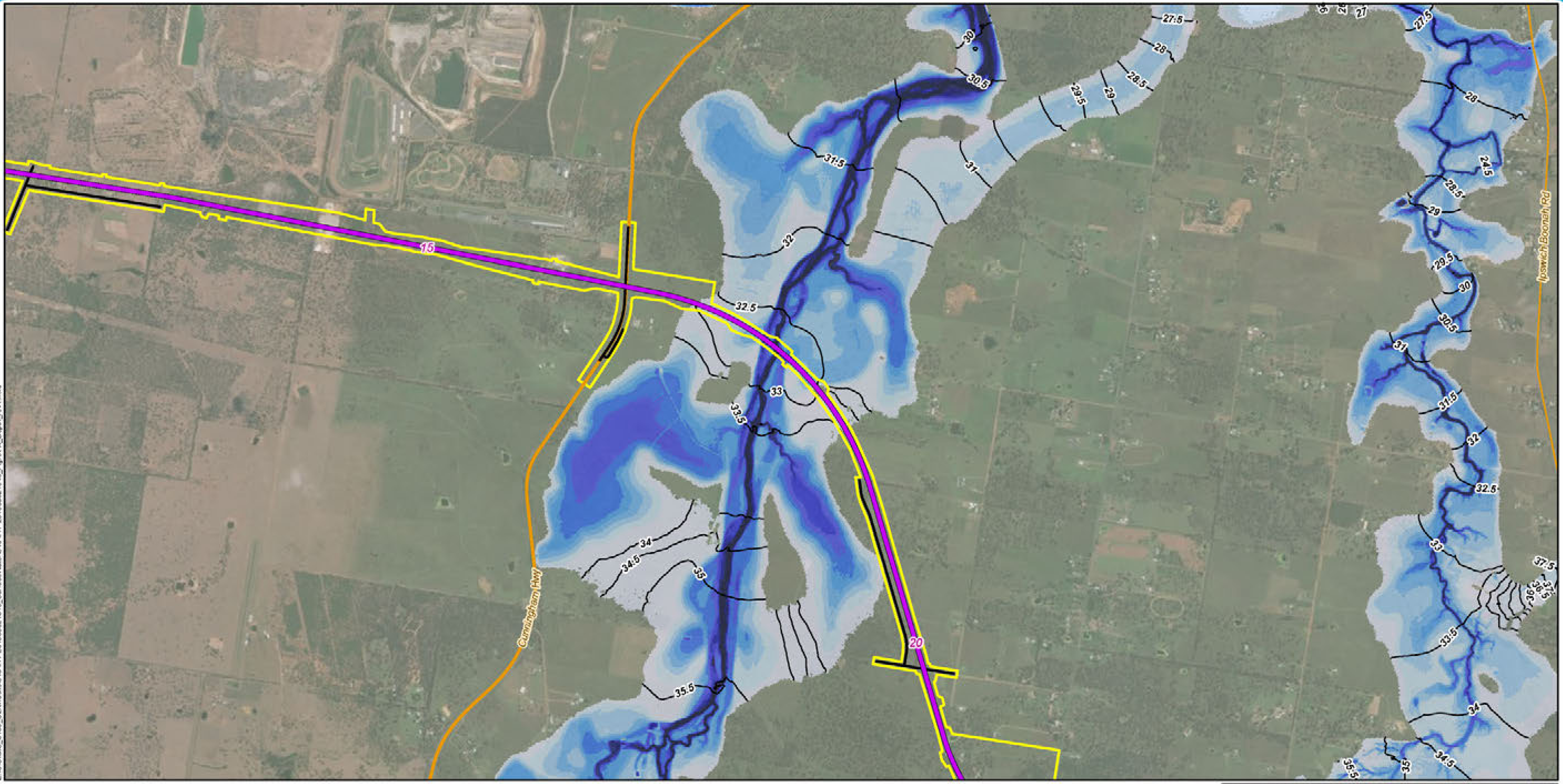
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B6-B: 2% AEP event Developed Case afflux: Warrill Creek



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

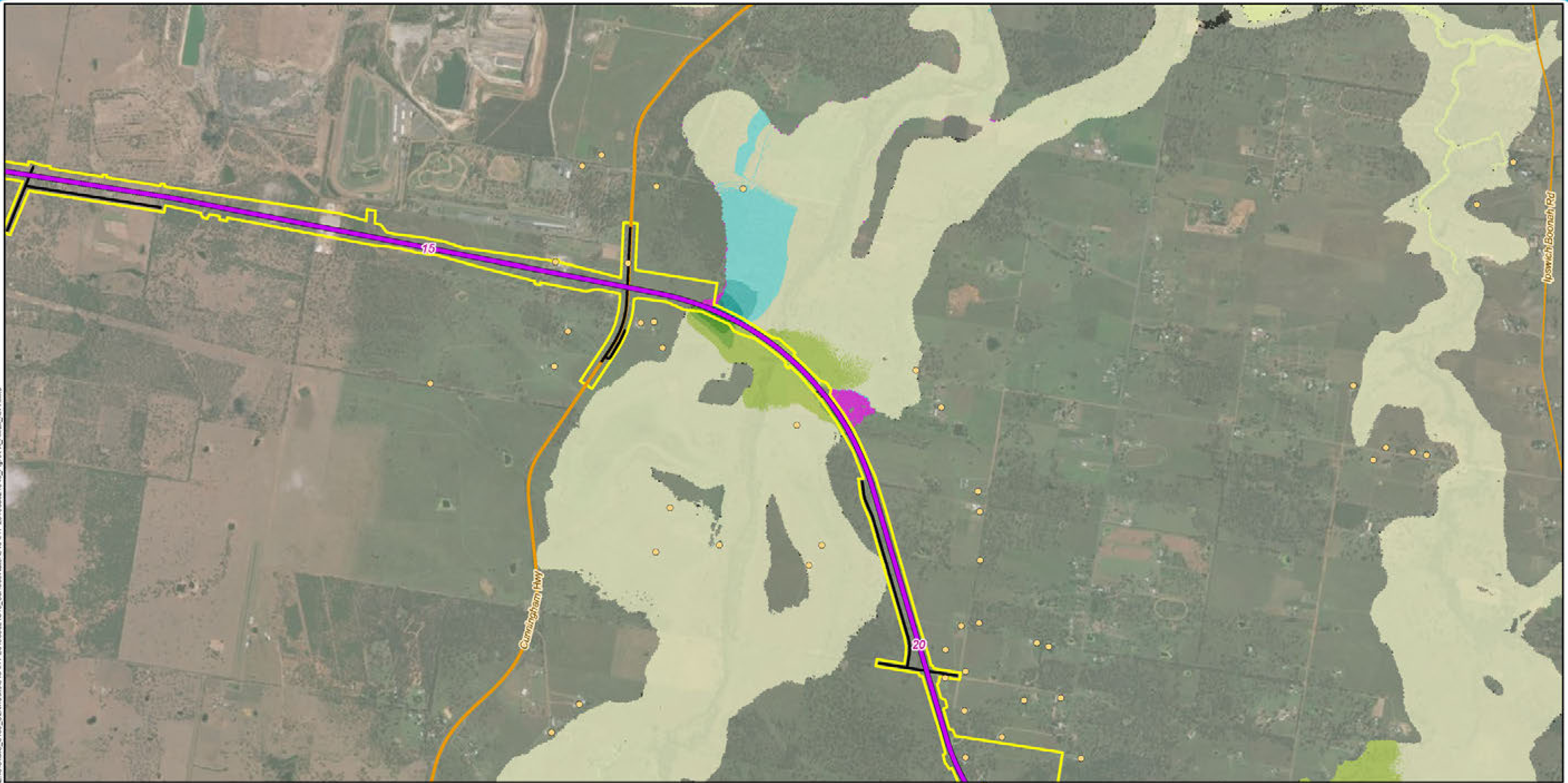
Future Freight
Integrating Community, Environment and Engineering

Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-A: 1% AEP event Existing Case inundation extent: Warrill Creek

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



Map by: DTH/RB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

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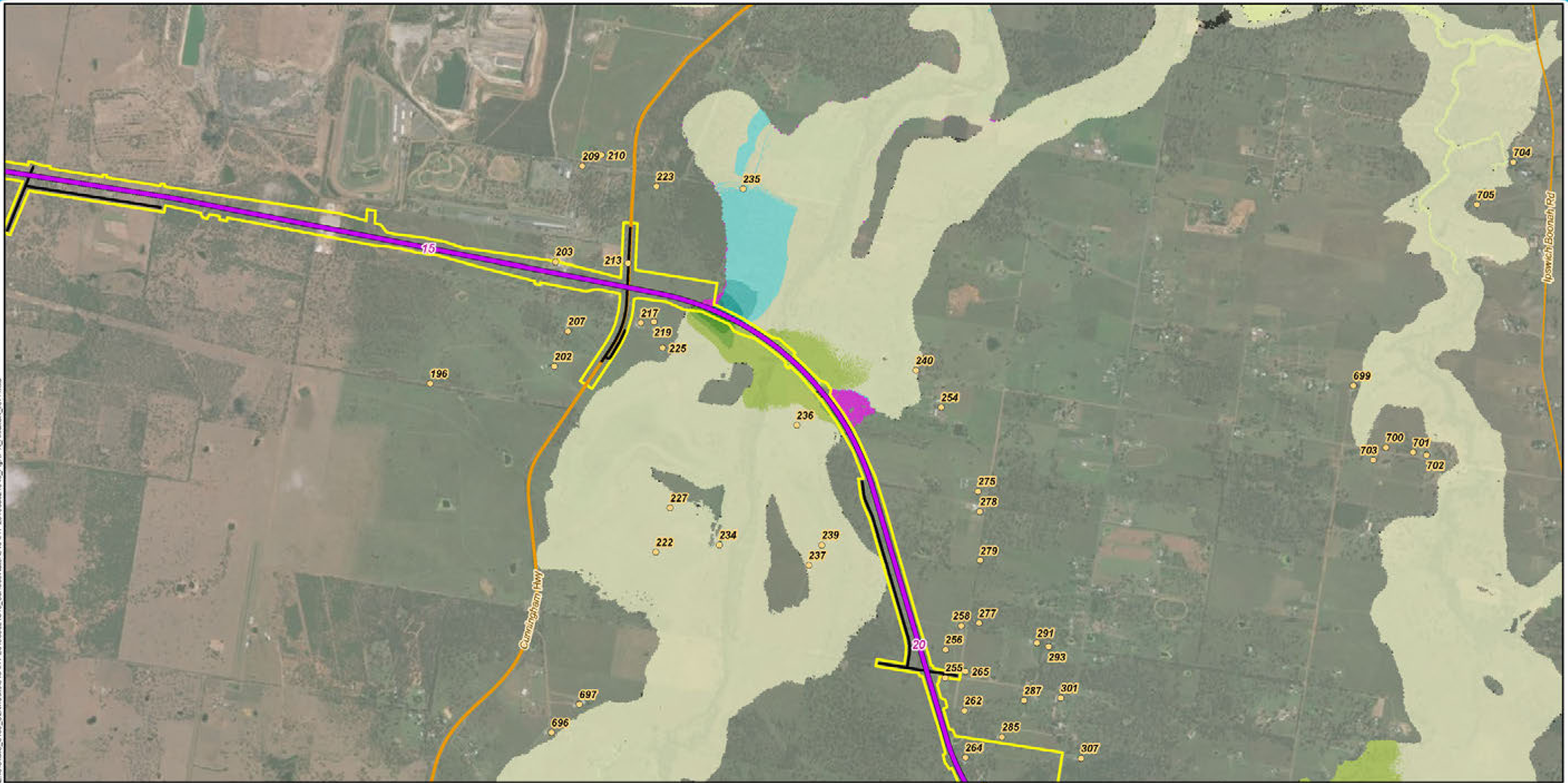
Integrating Community, Environment and Engineering

Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-B: 1% AEP event Developed Case afflux: Warrill Creek

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



Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

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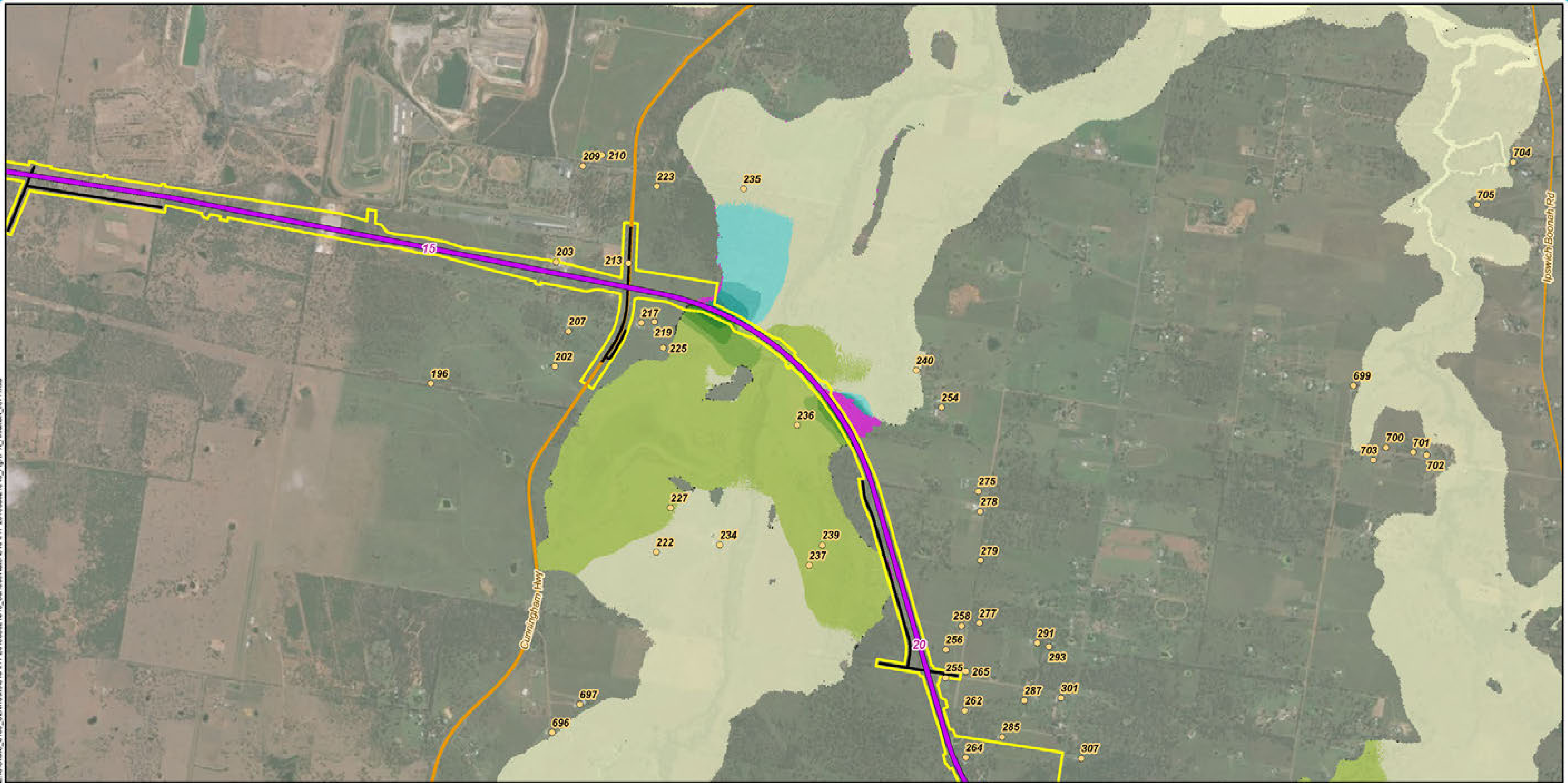
Issue date: 08/11/2019 Version: 1

Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-C: 1% AEP event Developed Case afflux with flood sensitive receptors: Warrill Creek

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



Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

Future Freight
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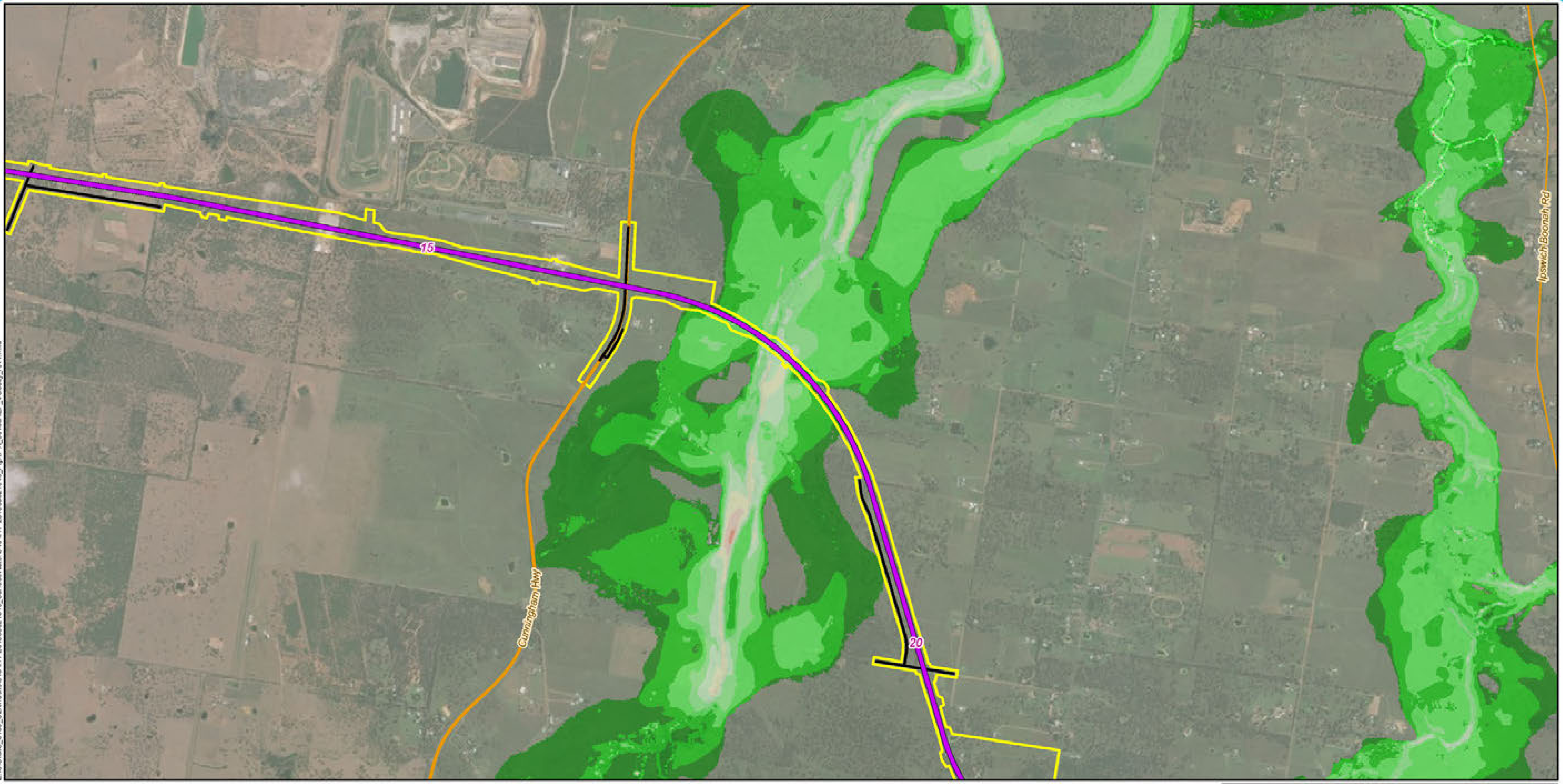
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-D: 1% AEP event with climate change afflux and flood sensitive receptors: Warrill Creek

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



Legend

5	Chainage (km)
	C2K project alignment
	Major roads
	Minor roads
	Proposed roadworks
	EIS disturbance footprint

Peak velocity (m/s)

0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1 km

Future Freight
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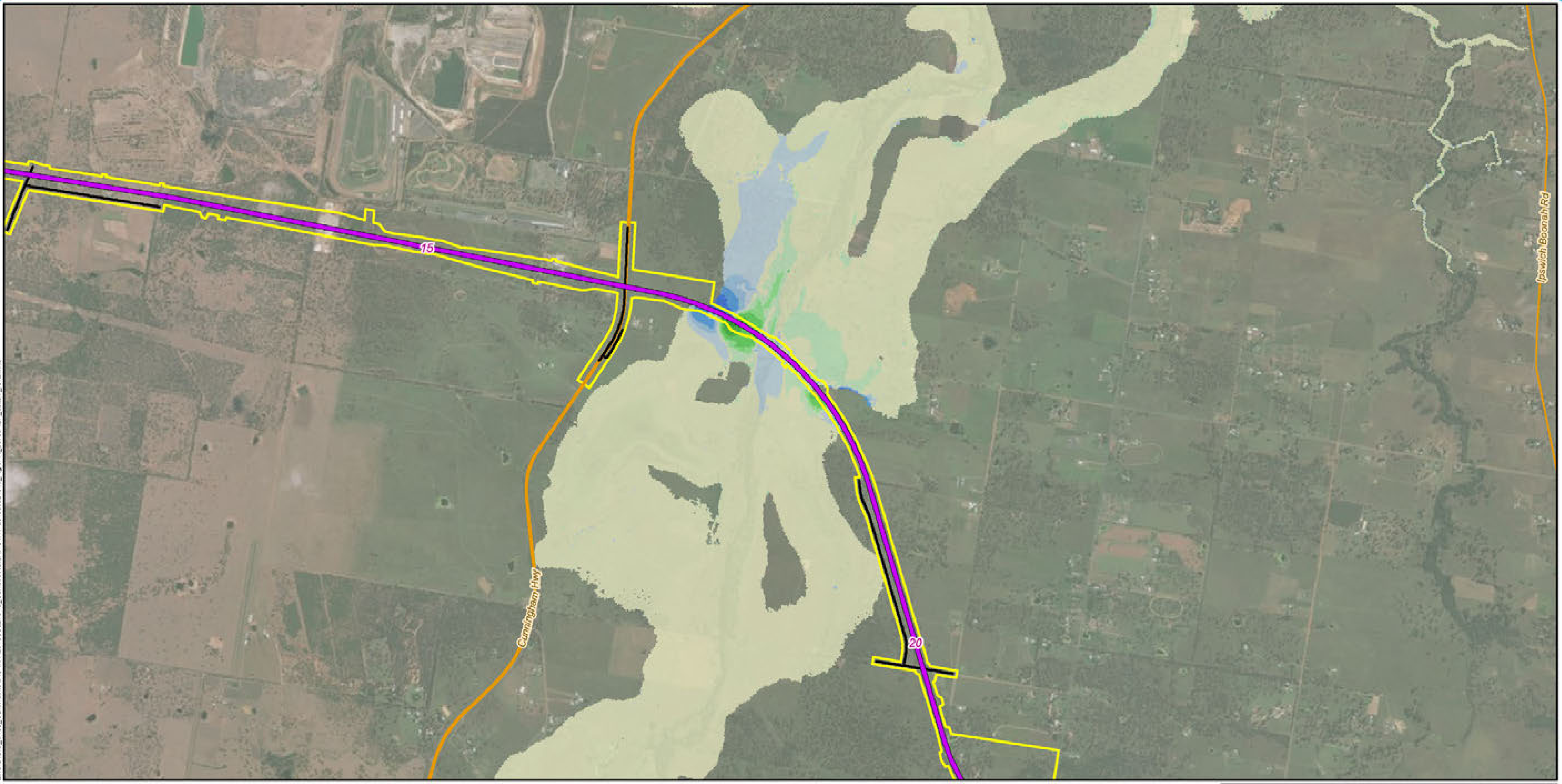
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-E: 1% AEP event Developed Case velocity: Warrill Creek

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



Legend

5	Chainage (km)
	C2K project alignment
	Proposed roadworks
	Major roads
	Minor roads
	EIS disturbance footprint

Change in peak velocity (m/s)

- < -0.50
- -0.50 to -0.20
- -0.20 to -0.10
- -0.10 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.10
- 0.10 to 0.20
- 0.20 to 0.50
- > 0.50

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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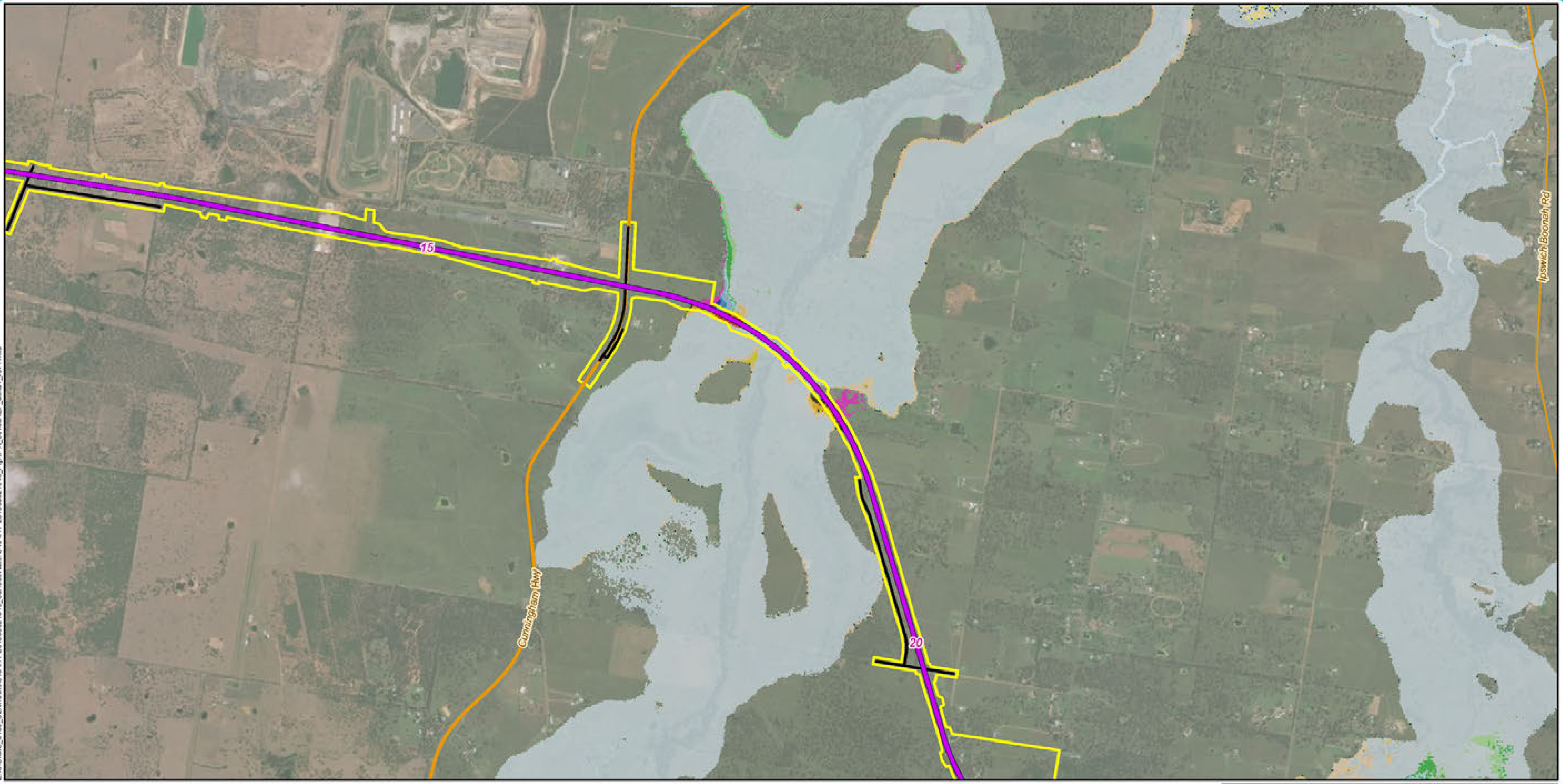
Issue date: 08/11/2019 Version: 1

Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-F: 1% AEP event Developed Case difference in velocity: Warrill Creek

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



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Difference in Time of Submergence

- Over 10 hour decrease
- Up to 10 hour decrease
- Up to 5 hour decrease
- Up to 2 hour decrease
- Up to 1 hour decrease
- Up to 0.5 hour decrease
- Within 15 minutes
- Up to 0.5 hour increase
- Up to 1 hour increase
- Up to 2 hour increase
- Up to 5 hour increase
- Up to 10 hour increase
- Over 10 hour increase

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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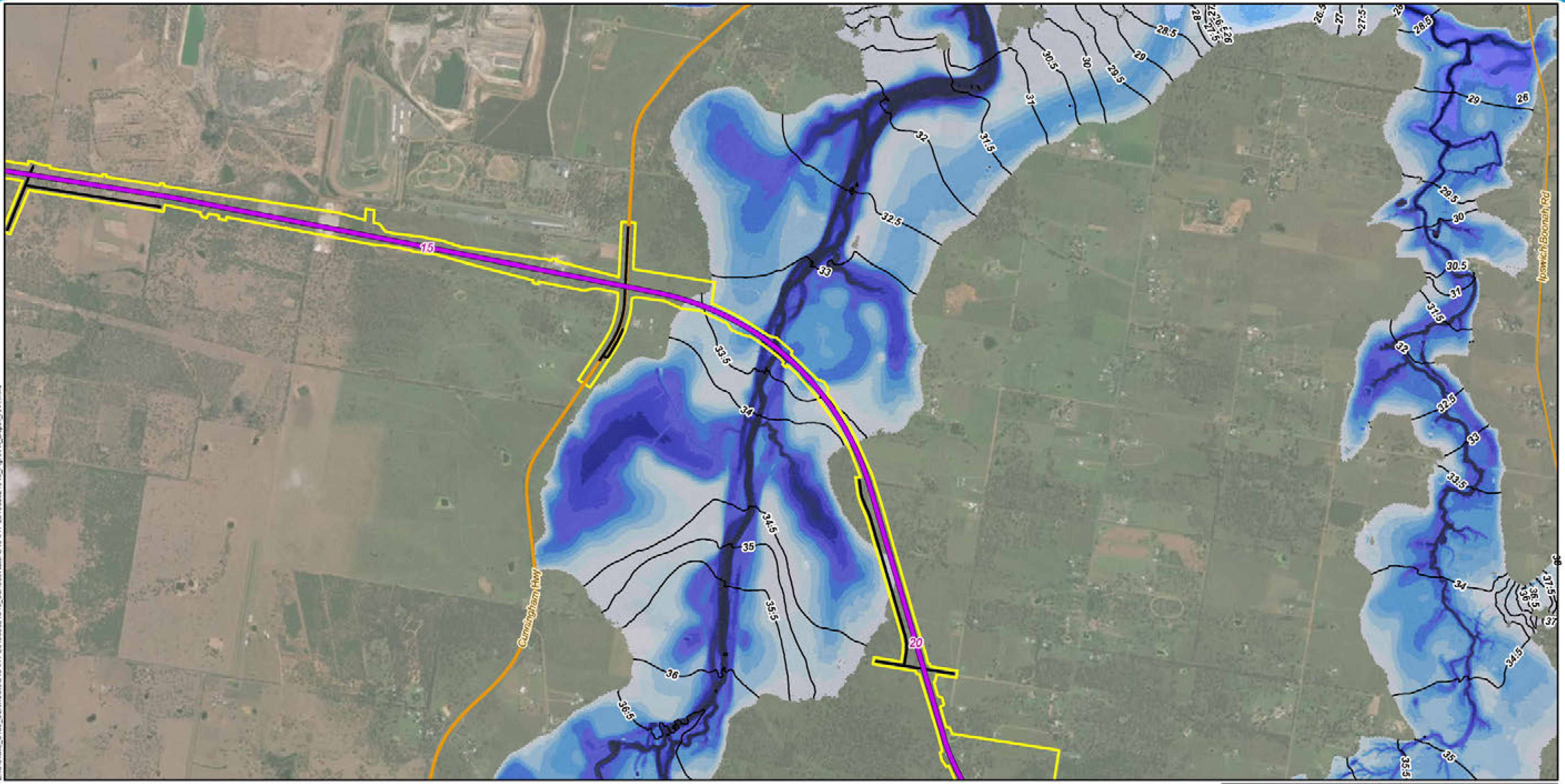
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B7-G: 1% AEP event Developed Case difference in time of submergence: Warrill Creek

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



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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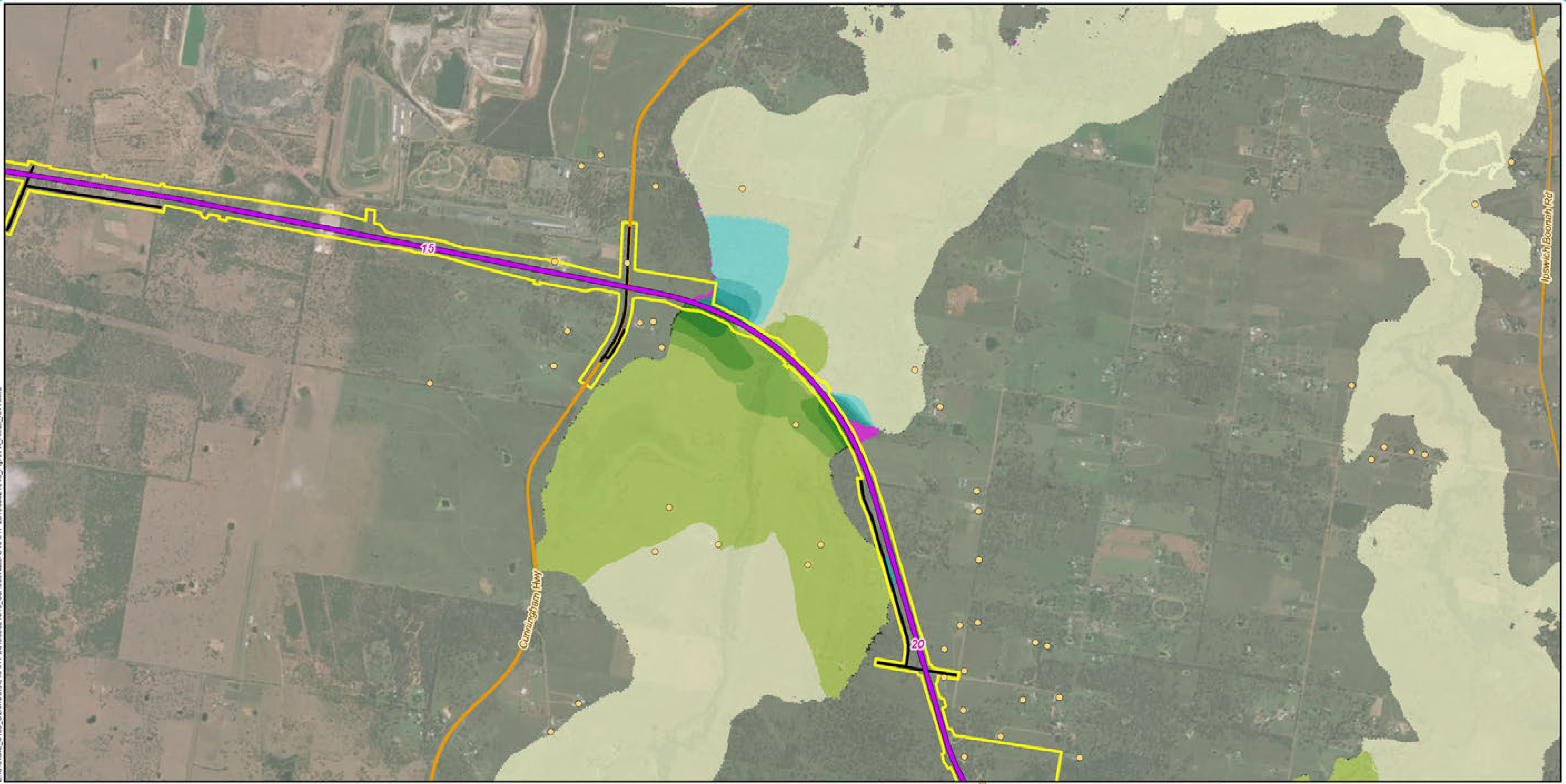
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B8-A: 1 in 2,000 AEP event Existing Case inundation extent: Warrill Creek



Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Map by: DTH/RB Date: 11/11/2019 21:22

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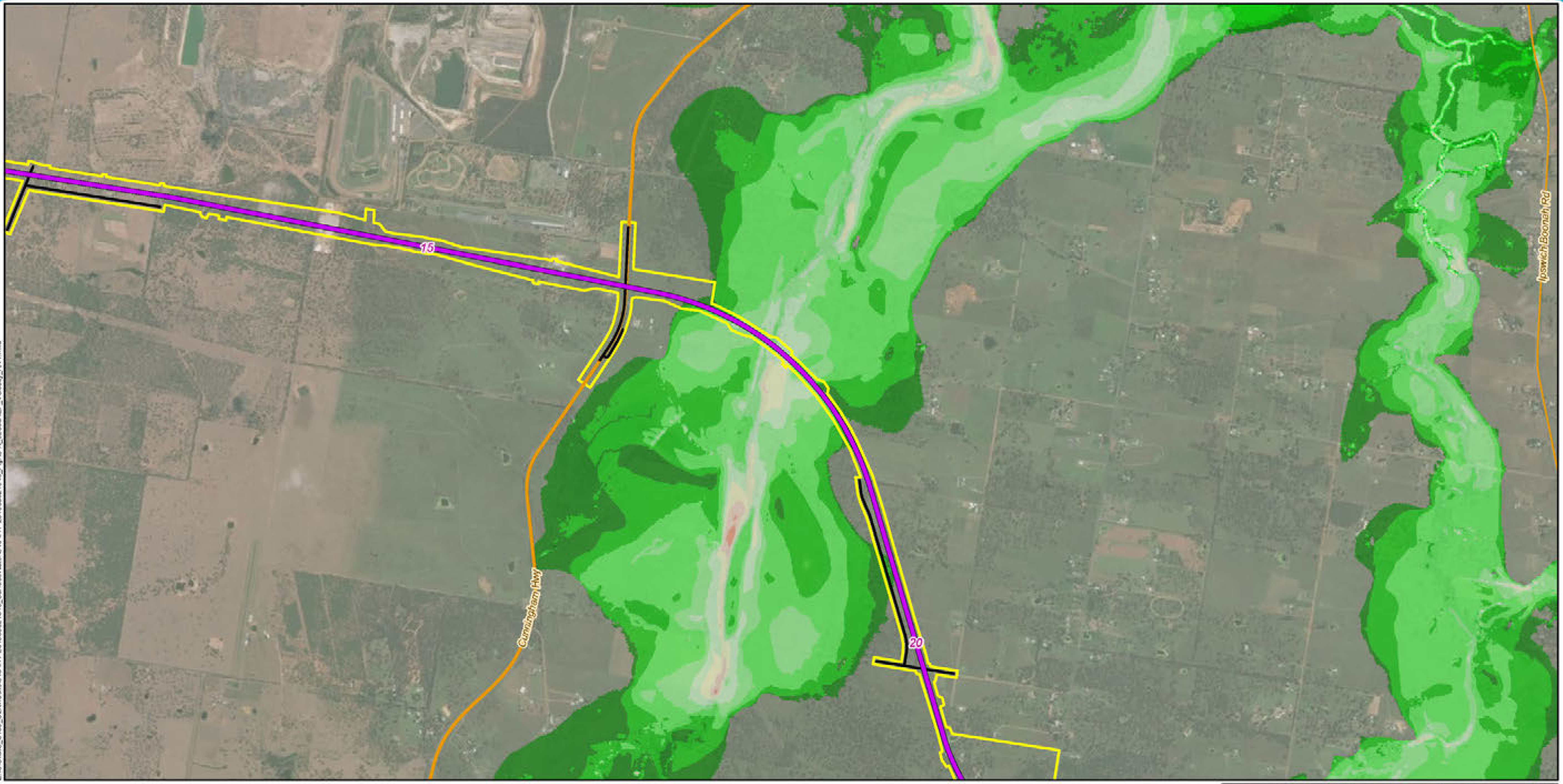
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B8-B: 1 in 2,000 AEP event Developed Case afflux: Warrill Creek

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



Map by: DTH Date: 12/11/2019 11:06
Z:\GIS\GIS_3400_C2K\Tasks\340-IHY-201908021346_SurfaceWater\340-IHY-201908021346_FigX8-X_C2000AEP_Velocity_rev1.mxd

Legend

5	Chainage (km)
	C2K project alignment
	Proposed roadworks
	Major roads
	Minor roads
	EIS disturbance footprint

Peak velocity (m/s)

0.0	2.5
0.5	3.0
1.0	3.5
1.5	4.0
2.0	4.5
	5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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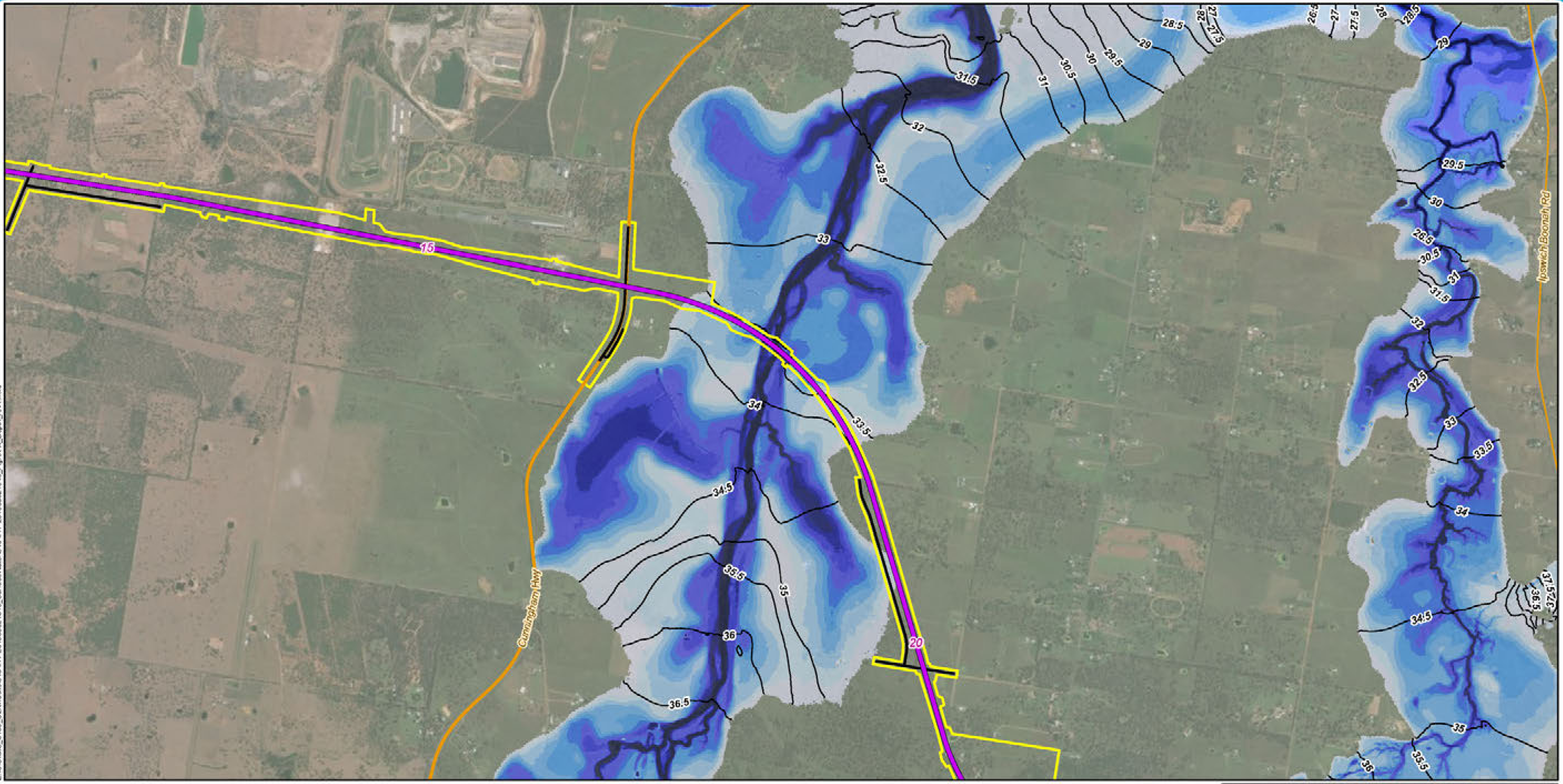
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B8-C: 1 in 2000 AEP event Developed Case velocity: Warrill Creek

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



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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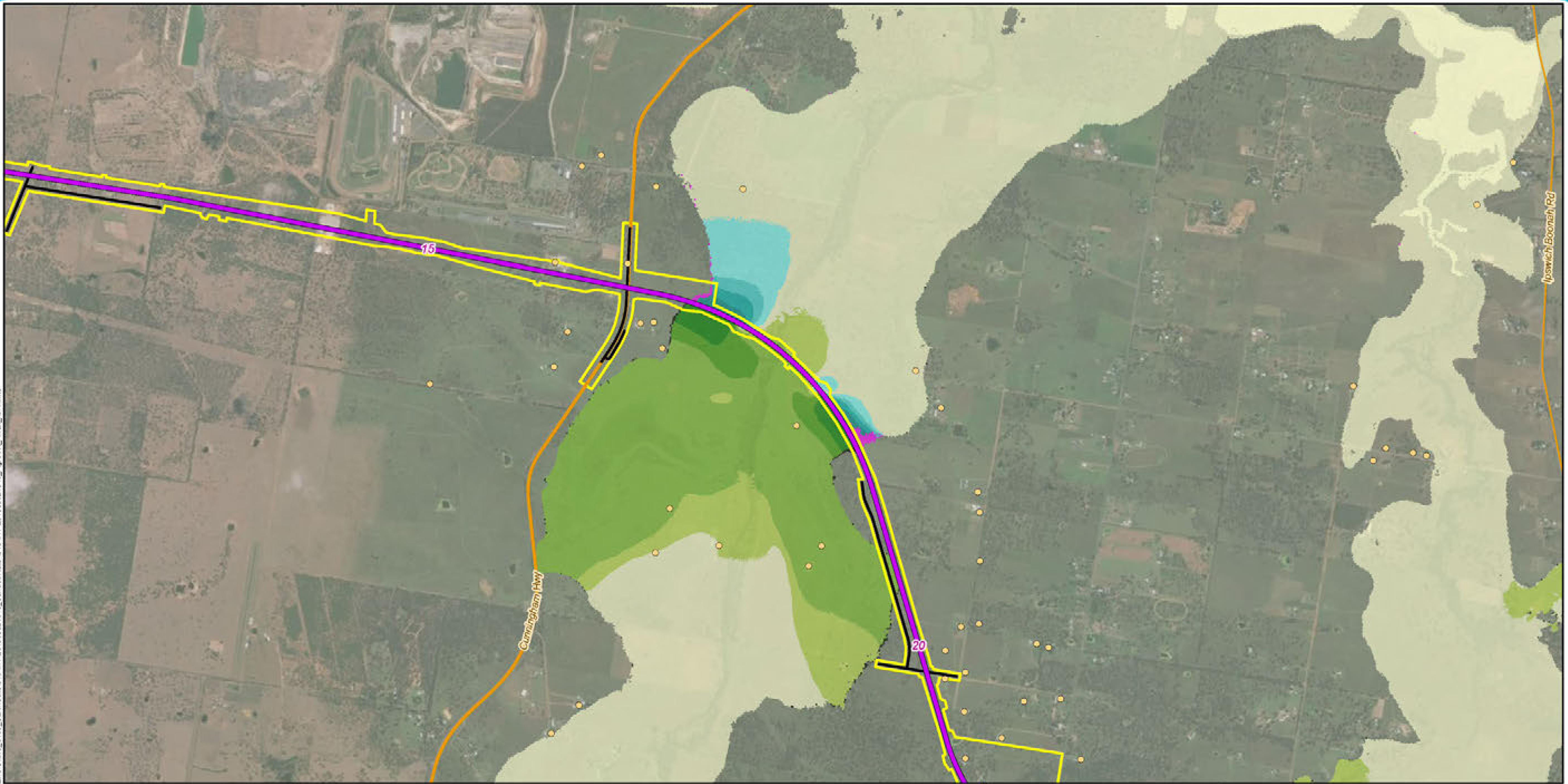
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B9-A: 1 in 10,000 AEP event Existing Case inundation extent: Warrill Creek

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



Map by: DTH/RB Date: 11/11/2019 21:22

Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:30,000

0 0.2 0.4 0.6 0.8 1km

Future Freight
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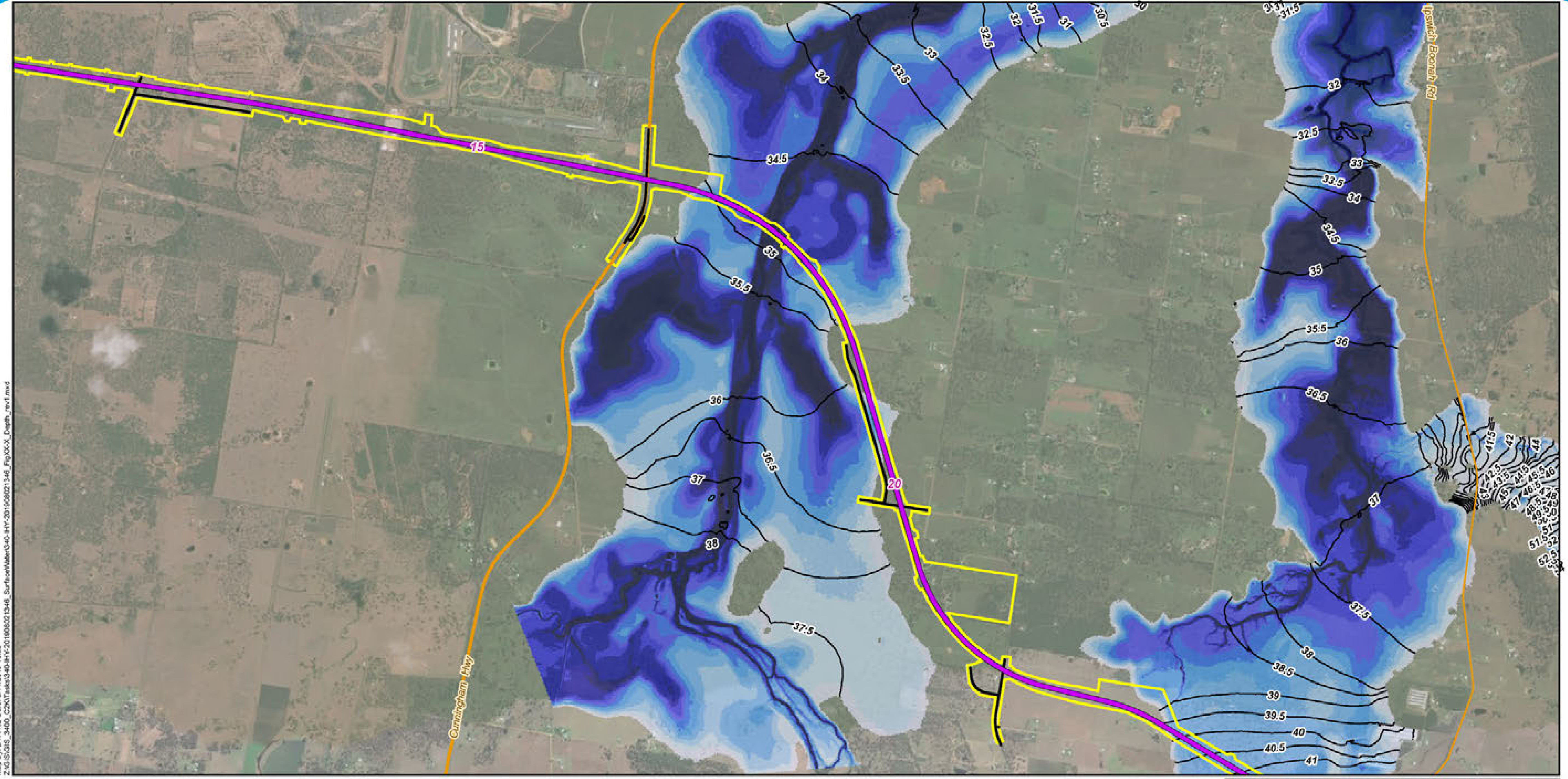
Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B9-B: 1 in 10,000 AEP event Developed Case afflux: Warrill Creek

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



Legend

- 5 Chainage (km)
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- 0.5m contour mAHD

Depth (m)

- 0 - 0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- 2.5 - 3.0
- 3.0 - 3.5
- 3.5 - 4.0
- 4.0 - 4.5
- 4.5 - 5.0
- > 5.0

A3 scale: 1:35,000

0 0.25 0.5 0.75 1 1.25 km

Future Freight
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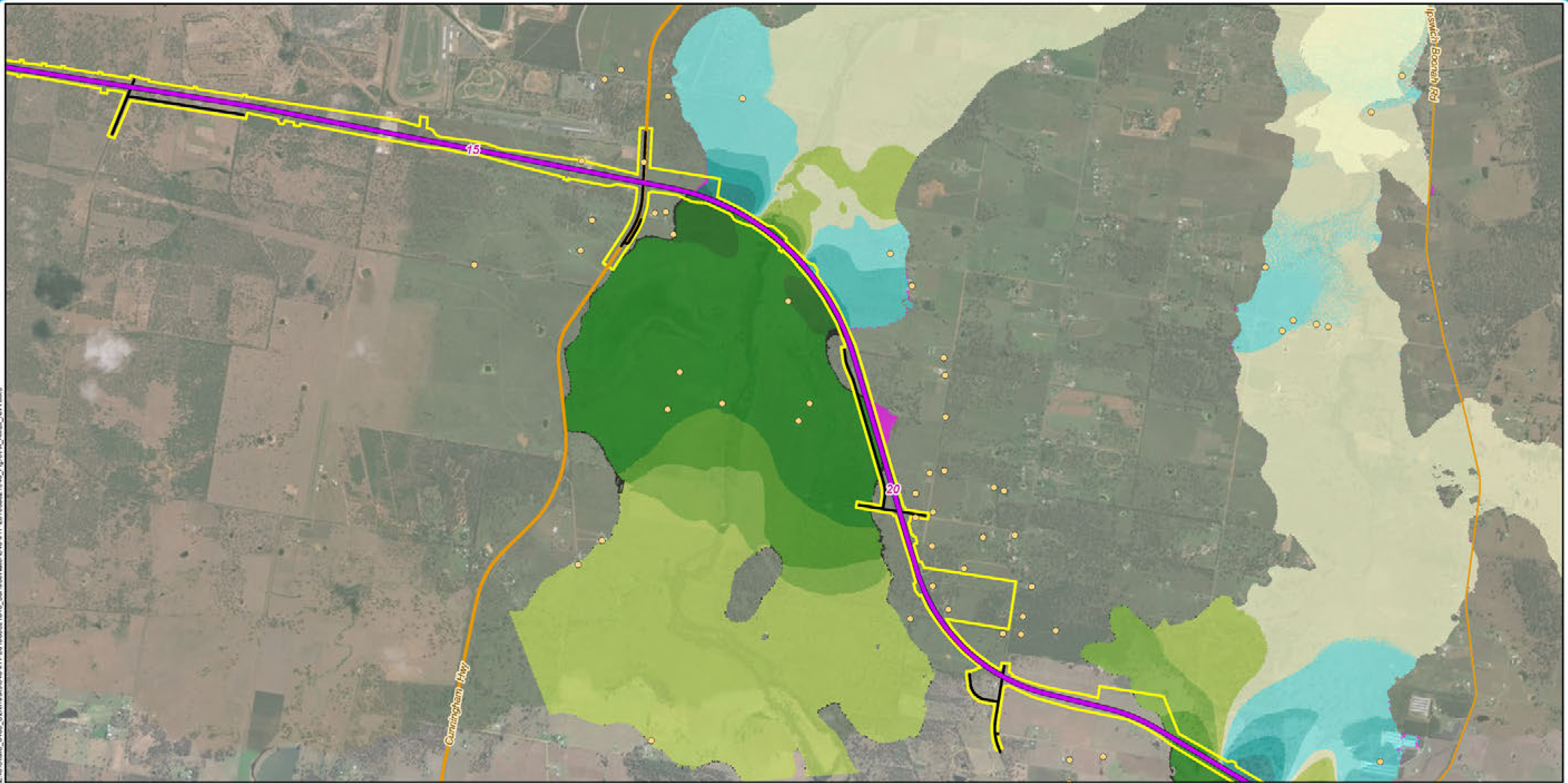
Issue date: 07/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B10-A: PMF event Existing Case inundation extent: Warrill Creek

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



Legend

- 5 Chainage (km)
- Flood sensitive receptors
- C2K project alignment
- Proposed roadworks
- Major roads
- Minor roads
- EIS disturbance footprint
- Was Wet Now Dry
- Was Dry Now Wet

Change in peak water levels (m)

- < -0.5
- -0.5 to -0.2
- -0.2 to -0.1
- -0.1 to -0.05
- -0.05 to -0.01
- -0.01 to 0.01
- 0.01 to 0.05
- 0.05 to 0.1
- 0.1 to 0.2
- 0.2 to 0.5
- > 0.5

A3 scale: 1:35,000

0 0.25 0.5 0.75 1 1.25 km

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Issue date: 08/11/2019 Version: 1
Coordinate System: GDA 1994 MGA Zone 56

Calvert to Kagaru

Figure B10-B: PMF event Developed Case afflux: Warrill Creek