NEW BRIDGEWATER BRIDGE

Flood Hazard Report

8 November 2021

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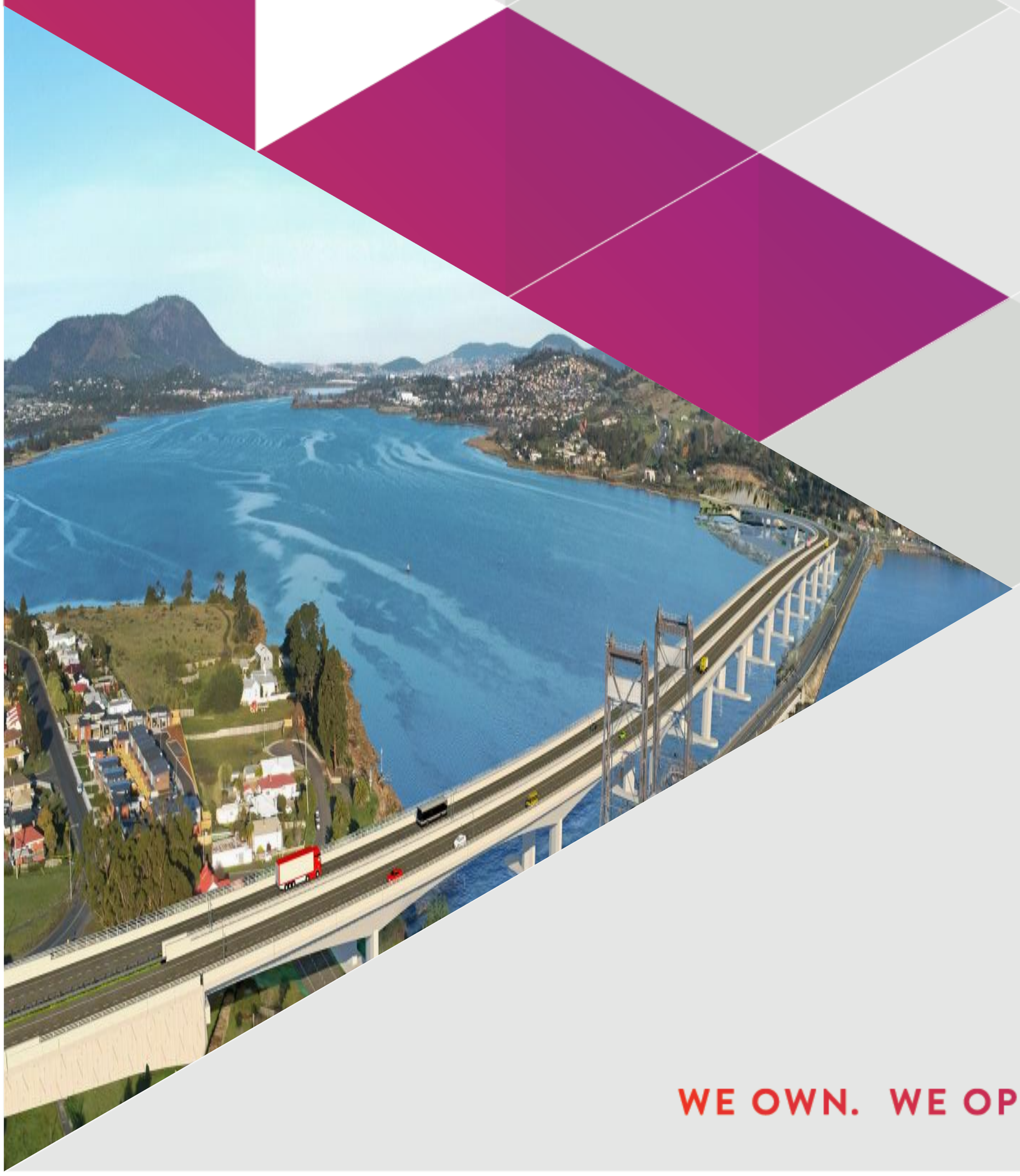

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Executive Summary

In support of the development of the Major Project Impact Statement (MPIS), this report provides an assessment of the changes in 1% annual exceedance probability (AEP) flood hazard arising from construction and operation of the New Bridgewater Bridge.

The proposed New Bridgewater Bridge has the potential to change stormwater overland flow paths on approaches to the bridge, and to restrict the flow of the River Derwent. These changes have the potential to increase flood risks to the surrounding people and property, and to the use of the project land.

Since the final design of the New Bridgewater bridge has yet to be finalised, a design similar to reference design Option 2 has been assumed. That is, a bridge supported by piles similar to the Bowen Bridge. The new bridge is separated from, and independent of, the existing causeway and bridge. The existing bridge is assumed to remain in place for the short-term but is noted to be removed for the longer term. There is also the potential for reclamation works on the river edges.

As sea levels are expected to rise and storm rainfall intensity is expected to increase under future climate conditions, the flood risk under both current (2021) and future (2090) climate conditions are assessed. There are flood risks for both current and future climates, with higher risks in the future.

Three hydraulic models were developed to assess the potential changes:

- River Derwent model to assess changes in flood hazard instream and on land adjacent to the river
- Northside model to assess changes in flood hazard arising from storm runoff near Bridgewater
- Southside model to assess changes in flood hazard arising from storm runoff near Granton.

The most significant changes in water flows and levels arising from the New Bridgewater Bridge are associated with the 1% AEP future climate riverine flood and Highest Astronomical Tide:

- the proposed New Bridgewater Bridge, with the existing bridge remaining in place, raises upstream water levels by approximately 66 mm compared to the existing system
- with the new works and removing the existing bridge and piers but leaving the existing causeway in place, water levels are approximately 22 mm lower than the existing system
- potential reclamation works increase levels upstream by approximately 3 mm when there is the New Bridgewater Bridge and existing bridge, and approximately 15 mm with the New Bridgewater Bridge and no existing bridge.

Therefore if the existing bridge and piers are removed post construction of the New Bridgewater Bridge, it is expected there would be a minimal change to upstream water levels and flood hazard on adjacent land even with the potential reclamation.

Other outcomes from the modelling indicate that the New Bridgewater Bridge project presents the following potential flood hazards during the 1% AEP flood in the current and future climates:

- Increase in water levels upstream of the existing causeway and proposed New Bridgewater Bridge when both bridges are in place which may result in:
    - additional overtopping of the existing causeway

- inundating a building on the south side of the river within the project land and some increase to flooding of twelve houses on the north side of the river (upstream of the bridge adjacent to the project land). Note these twelve dwellings were already inundated without the works for the 1% AEP design storm with a future climate, and some for the 10% AEP storm with future climate change.

- Reduced flood protection of 37 Black Snake Road within project land, but not inundating habitable areas. It is noted that this property will be demolished as part of the project prior to the construction of the New Bridgewater Bridge.

To achieve and maintain a tolerable flood risk for using the New Bridgewater Bridge over its 100 year asset life as a National Highway from a 1% AEP flood event there is a need for:

1. consideration of future climate impacts on rainfall and sea level scenarios as part of the detailed design process given they are key drivers of the inundation of project and adjacent land, noting there are flood risks in the current climate
2. upgrading of existing drainage infrastructure and the design of new infrastructure as part of detailed design to convey 1% AEP overland flow from waterways, local hillsides and roadways to keep dwellings and roadways safe, and convey the Black Snake Rivulet safely to the River Derwent; noting the main culvert conveying the rivulet under the Brooker Highway appears to require upgrading
3. setting the design levels of low-lying parts of the proposed roadway on the south side of the River Derwent, near the intersection of Main Road and Black Snake Road, high enough so they are not inundated in the current climate and with planning for sea levels rise, and protection works for sea surge and wind wave actions; alternatives to lifting levels could also be considered if they provide a similar level of protection and reliability
4. consideration of future linking to road upgrades outside the project land that may require higher surface levels to protect against rising sea levels, in particular the Lyell Highway within and immediately to the west of the project land; note that this part of the road network does not form part of the National Highway and therefore receives reduced levels of traffic
5. more detailed modelling during detailed design is expected to assess the potential for impact on existing dwellings and mitigation strategies, in particular for the period between construction of the New Bridgewater Bridge and the removal of the existing Bridgewater Bridge (keeping the existing causeway)
6. ongoing flood management planning and asset maintenance to manage the residual risk for events beyond 1% AEP and maintain the designed level of service.

Overall, apart from some minor increases in flood risk for existing inundated dwellings until the existing Bridgewater Bridge is removed, the other flood hazards posed by the New Bridgewater Bridge can be mitigated to a tolerable flood risk for the 1% AEP flood through adequately sized drainage infrastructure, elevated road levels (or equivalent alternatives), consideration of strategies to reduce flood risk on side roads, and ongoing administrative controls.

Glossary

Annual Exceedance Probability	Chance a storm event, or one larger, will occur in any year at a particular location. In this report expressed as a percentage or ratio (1:X); 1% = 1:100
Australian Height Datum (AHD)	Vertical reference system above which elevations are measured in metres (m AHD). In this report the 1983 Tasmania AHD is adopted.
Bathymetry	Terrain or shape of the bed (bottom) of a water body
Boundary condition	Representation of how the world outside a model domain interacts with the model, e.g. hydrographs, rain on grid, and tailwater levels
Climate change	Atmospheric alterations at a global or regional scale that in this report result in increased rain intensity and sea levels over time
Critical duration	Storm event duration that maximises the flood hazard at a particular location
Digital Elevation Model (DEM)	Electronic two-dimensional representation of the terrain using a regular square grid, with each grid cell having an elevation
Event	Transient single occurrence, in this report related to a storm with an annual exceedance probability and duration which is independent of other events
Flood hazard	Source of potential harm or a situation with potential to result in loss due to a combination of flood water flowing fast and deep, and timing of flood water
Flood risk	Combination of a flood hazard and probability of occurrence, with higher risks due to greater hazards that occur more often (risk = hazard × probability)
Flow rate	Volume per second of a fluid, which can vary with time and described as a hydrograph
Fluvial	Of or found in a river
Geometry	Shape and form of infrastructure works, described by engineering drawings annotated with levels and dimensions
GDA94	Geocentric Datum of Australia 1994, a horizontal reference system used to locate things relative to the Australian tectonic plate as it was in 1994
Hydraulic model	Simulation of fluid flow due to internal and external forces. In this report used in reference to two-dimensional (2D) depth averaged water modelling
Hydraulic roughness	Resistance to water flowing over a surface. In this report expressed as a Manning's n roughness coefficient (higher n values have higher hydraulic roughness)
Hydrograph	Variation of flow rate with time in a watercourse. In this report expressed as cubic metres per second (m^3/s) versus time
Hydrology	Science of the occurrence, distribution, movement, management and properties of water on the earth, underground and in the atmosphere
Model	Simulation of a real system that represents the understanding of how the system behaves under different scenarios. In this report a model is computer software that solves approximate versions of complex water equations to make predictions of future states of a water system from some initial state.

Model domain	Area that is the focus of a computer model simulation
Probability	The chance of an event occurring
Project land	Area where temporary and permanent works are proposed to take place
Rainfall losses	Reduction in rainfall to account for water that doesn't become runoff. For this study an initial loss continuing loss model is used. Initial loss includes interception from ground cover, depression storage, etc. Continuing loss includes infiltration into soil layers, evapotranspiration, etc.
Rain on grid	Applying rainfall to the hydraulic model domain directly, with rainfall losses
Reclamation	Civil works, such as earthworks, to extend the shoreline into the river
RORB	Hydrological modelling software for calculating catchment runoff (flow rate) based in rainfall and catchment properties
Runoff	Water flowing overland and in watercourses from rainfall that is in excess of the rainfall losses
Storm	Violent disturbance in the atmosphere or sea, in this report resulting in intense rainfall and high sea levels
Tailwater	Water level at the downstream end of the model domain, which can be static or time varying
Tolerable use	Acceptable to the community with administrative flood risk controls
Trunk drainage	Larger stormwater infrastructure, often pipes 600 mm in diameter or larger
TUFLOW HPC	Hydraulic modelling software using Heavily Parallelised Compute techniques to solve two-dimensional time varying water physics equations
TUFLOW QuadTree	A module for TUFLOW that allows the size of the computational grids to vary through the model domain

Common units

m	metre (distance)
m^2	square metres (area)
m^3	cubic metre (volume)
mm	millimetre (distance) = 0.001 m
km	kilometre (distance) = 1,000 m
ha	hectare (area) = 10,000 m^2
s	second (time)
m/s	metre per second (speed)
m^3/s	cubic metre per second (flow rate)
W	watt (power)

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1. Introduction

Entura was engaged by Burbury Consulting to complete a flood hazard report of the New Bridgewater Bridge in support the development of the Major Project Impact Statement (MPIS).

At this stage of the project development, there is no final design for the proposed bridge and associated works on the land.

For the purpose of this assessment the proposed bridge is assumed to be supported by piles. This is similar to the reference design Option 2, that is, a bridge separated from, and independent of, the existing causeway and bridge. The existing bridge is assumed to remain in place for the short-term but is noted to be removed for the longer term. The proposed bridge will be similar in character to the Bowen Bridge. There is the potential for some reclamation at the southern and northern sides of the bridge.

There are also works proposed on land, including roads and roundabouts to connect the bridge to the existing road network.

1.1 MPIS assessment criteria

Based on a submission by the Participating Regulator, the Environment Protection Authority (EPA), the Development Assessment Panel requires a flood hazard report to be submitted as part of the MPIS assessment criteria.

The flood hazard report must be prepared by a suitably qualified person and include:

(a) details of, and be signed by, the person who prepared or verified the report

(b) confirmation that the person has the appropriate qualifications and expertise

(c) confirmation that the report has been prepared in accordance with any methodology specified by a State authority, and

(d) conclusions based on consideration of the proposed use or development:

  (i) as to whether the use or development is likely to cause or contribute to the occurrence of flood on the site or on adjacent land

  (ii) as to whether the use or development can achieve and maintain a tolerable risk from a 1% annual exceedance probability (AEP) flood event, for the intended life of the use or development, having regard to:

    a. the nature, intensity and duration of the use
    b. the type, form and duration of any development
    c. the likely change in the level of risk across the intended life of the use or development
    d. the ability to adapt to a change in the level of risk
    e. the ability to maintain access to utilities and services
    f. the need for flood reduction or protection measures beyond the boundary of the site
    g. any flood management plan in place for the site and/or adjacent land, and

  (iii) any advice relating to the ongoing management of the use or development.

1.2 Scope

The scope of this flood hazard assessment includes:

- Assessment of flood risks arising directly from the River Derwent
- Assessment of flood risks from storm runoff for:
    - the southern side of the River Derwent including the Black Snake Rivulet catchment
    - the northern side of the River Derwent with part of Bridgewater.
- Comparison of flood hazards for the existing Bridgewater Bridge and the proposed New Bridgewater Bridge.

Items that are excluded from the scope include:

- detailed design and sizing of infrastructure
- modelled of the final design
- stormwater water quality modelling.

1.3 Background and qualification of author

This study has been undertaken by Entura with the

- Direction and supervision of
    - Technical Specialist **Dr Colin Terry**, BE(Civil), PhD CPEng MIEAust
- Oversight from
    - Principal **David Fuller**, BSc, PostGradCert(Hydrology), GradDipStats, MBA, MEc
- The work has been undertaken primarily by
    - Graduate Civil Engineer **Sammy Gibbs**, BE(Civil), with
    - Water Engineer/Scientist **Alex Wylie**, BSc.

Sammy and Alex have undertaken many flood modelling assessments in their three years of engineering experience. Colin has 30 years of civil engineering experience in design and water modelling, including many similar flood studies, and David has over 35 years of hydrology and modelling relevant to this work.

This team has authored the study in accordance with standard Australian industry practice and the accredited quality assurance processes of Entura.

2. The New Bridgewater Bridge

The proposed New Bridgewater Bridge is permanent civil infrastructure works designed to last for 100 years. These works include roads, roundabouts, bridges and drainage systems.

As a National Highway it will convey traffic 24 hours a day in varying intensities, including during a range of flood conditions. The infrastructure would be continuously used through its asset life.

The importance of this structure under the road design guidance will determine its level of service expressed as a rarity of floods. It is expected that the road should be trafficable during 1% AEP rain and sea storms, but also during more common events (e.g. 10% AEP).

The New Bridgewater Bridge makes a new crossing of the River Derwent immediately downstream (east) of the existing causeway and bridge (Figure 2.1)

- Upstream of the project land the river flows from alpine catchments through Lake St Clair, passing through the rural Derwent Valley, through several run-of-the-river hydro-electric reservoirs, the township of New Norfolk and its bridge, and past a paper mill. Significant freshwater flows are generated from this catchment that discharge through the project land.
- Downstream of the project land, the river flows past the Jordan River, the Bowen Bridge within the City of Glenorchy, a zinc works, City of Hobart and the Tasman Bridge, and finally at the Iron Pot the river joins the Tasman Sea.
- On the northern side of the bridge, flows from the immediate surrounding urban catchments upstream of the Bridge areas are captured and conveyed into the River Derwent by stormwater pits and pipes. Flows from catchments north of Bridgewater are discharged to an outlet west (upstream) of the project land into the River Derwent (Figure 3.3).
- On the southern side of the bridge, flows from the Black Snake Rivulet catchment (approximately 450 ha) and other smaller urban catchments also discharge to the River Derwent (Figure 3.4). These flows are currently conveyed under/around the existing road through water infrastructure including pits, pipes and culverts.

The proposed New Bridgewater Bridge has the potential to change stormwater overland flow paths and partially restrict the flow of the River Derwent. These changes have the potential to increase flood risks to the surrounding people and property.

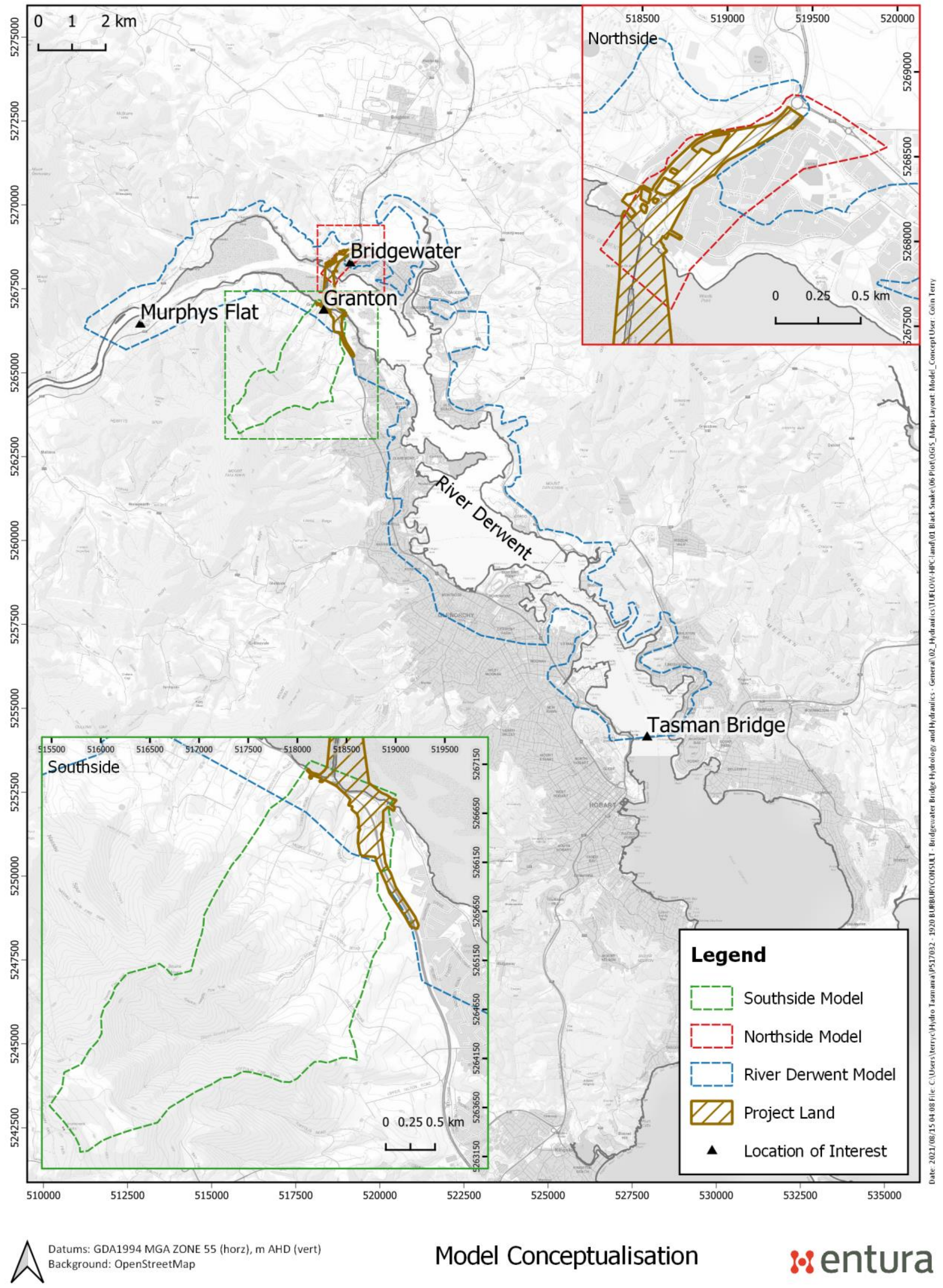

Figure 2.1: Model conceptualisation with project land

3. Methodology

An assessment of the potential impacts for the New Bridgewater Bridge was undertaken with a two-dimensional hydraulic computer model. The model software (TUFLOW HPC) was used to estimate flood hazards of the existing road and bridge configuration and the New Bridgewater Bridge, potential reclamation and approaches.

3.1 Three hydraulic models

Three separate hydraulic models were developed to assess the impact on project land and adjacent land (shown in Figure 2.1):

River Derwent model: To assess changes in flood hazard instream and on land adjacent to the river. The River Derwent model starts upstream of the bridge near Murphys Flat and extends to a tailwater level at the Tasman Bridge within Hobart

Northside model: To assess changes in flood hazard arising from storm runoff near Bridgewater. The model encompasses an area on the northern side of the bridge near Bridgewater with a tailwater level in the adjacent River Derwent.

Southside model: To assess changes in flood hazard arising from storm runoff near Granton. The model covers an area on the southern side of the bridge, including the Black Snake Rivulet catchment, with a tailwater level in the River Derwent adjacent to the model discharge.

Data sources used to develop the models are described in Section 3.4.

The models are described in Sections 3.5, 3.6, and 3.7 respectively.

Hydraulic modelling focussed on the quantification of flood risks including water movement, depths, velocities and flood hazard categories as discussed in Section 3.2.

3.2 Quantification of flood risk

To quantify flood risk, the important parameters of flood behaviour are its depth, velocity and timing of its flood waters. The potential hazard from deeper and faster moving water is drowning and damage to property. These hazards combined with the rarity of the rainstorm will give a flood risk. At a particular location

- higher risk comes from fast and deeper water occurring often
- lower risk comes from slow and shallow water occurring rarely.

Flood risk is quantified using Australian Rainfall and Runoff (ARR, 2019a), which suggests categories of flood risk based on the water's depth and velocity as shown in Figure 3.1. This is suitable for assessing the flood risks around people and urban environments and is in accordance with standard engineering practice in Tasmania.

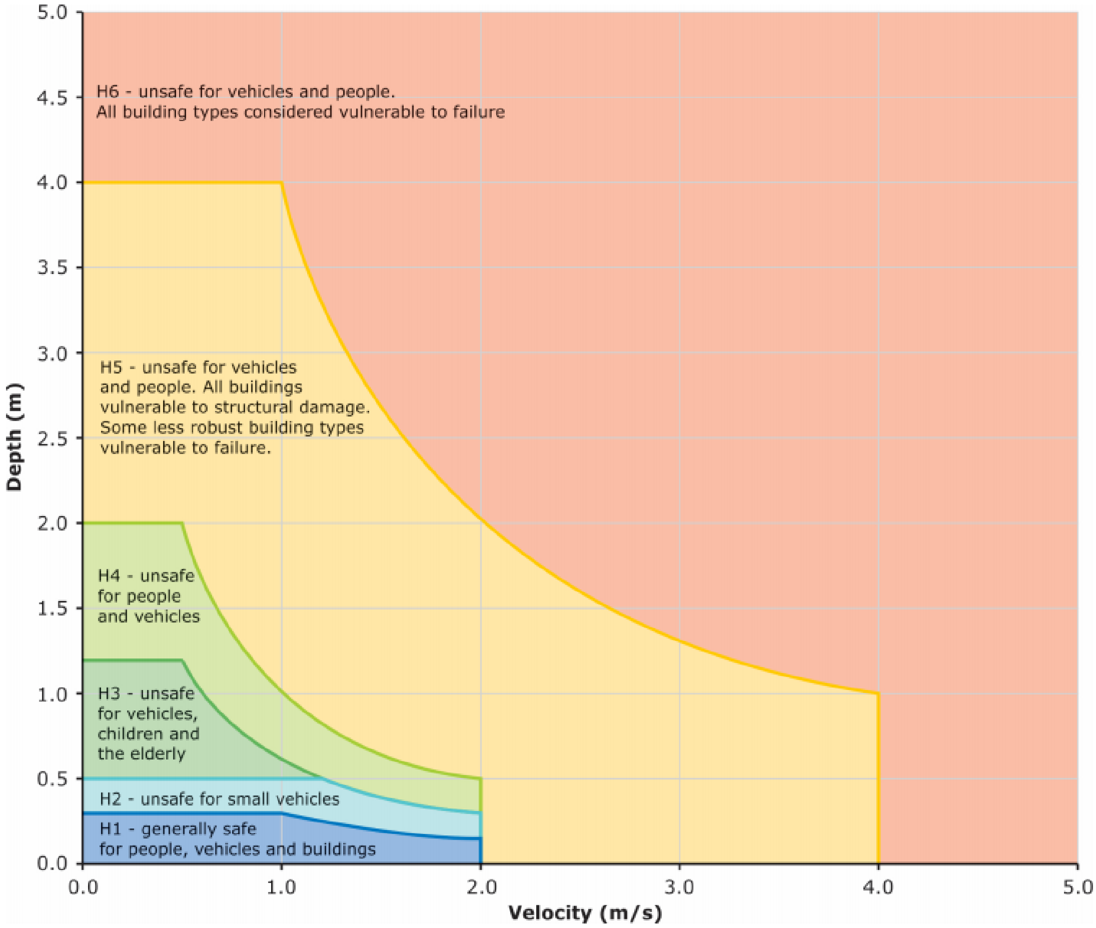

Figure 3.1: Flood hazard categories (ARR, 2019a)

For the purposes of this flood study and addressing the MPIS criteria, the focus is on floods with a one percent chance of being exceeded in any year. This is referred to as the 1% (or 1:100) annual exceedance probability (AEP) event. For a particular location, a 1% AEP event can be calculated for the deepest and fasted flowing flood water.

During detailed design of the New Bridgewater Bridge and road approaches other rainstorms and flood events may need to be considered for different aspects of the proposed works.

For the 100 year asset life of the New Bridgewater Bridge it is almost certain that at least one 10% AEP event would occur, but only a 63% probability of the 1% AEP event occurring at least once (Table 3.1).

Table 3.1: Probability (%) of a nominated storm event being exceeded at least once during a period

Storm event	1 year period	5 year period	10 year period	100 year period
10% AEP	10%	41%	65%	99.997%
1.0% AEP	1.0%	4.9%	9.6%	63%

Note: assumes there is a stationary climate with no climate change. It is standard engineering practice to account for climate change impacts by adjusting the magnitude of the storms at the most appropriate future point then compare the magnitude of the current and future flood events.

3.3 Geometric scenarios

To assess the change in flood risk due to the New Bridgewater Bridge development the following 1% AEP flood scenarios were modelled:

1. Existing Bridgewater Bridge and piers with current climate (2021)
2. Existing Bridgewater Bridge and piers with future climate (2090)
3. New Bridgewater Bridge with existing Bridgewater Bridge with current climate (2021)
4. New Bridgewater Bridge with existing Bridgewater Bridge with future climate (2090)
5. New Bridgewater Bridge without existing Bridgewater Bridge with current climate (2021)
6. New Bridgewater Bridge without existing Bridgewater Bridge with future climate (2090)
7. New Bridgewater Bridge and reclamation with existing Bridgwater Bridge with future climate (2090)
8. New Bridgewater Bridge and reclamation without existing Bridgwater Bridge with future climate (2090)

For scenarios 5 and 6, the existing bridge and piers were removed but leaving the existing causeway. For scenarios 7 and 8, the reclamation geometry was a modified version of the general reclamation shape used in other impacts statement documentation, and aimed to give a conservative impact for water quality but also used in this flood study for consistency between the hydraulic models.

3.4 Data sources

The data sources used in this study are provided in Table 3.2.

Table 3.2: Study data sources

Item	Source
Topographic data	Geoscience Australia Greater Hobart 2013 1 m resolution LiDAR x accuracy +/- 0.8 m y accuracy +/- 0.3 m
New Bridgewater Bridge land civil works design surface	Digital Elevation Model (DEM) (Burbury Consulting Pty Ltd, 2021)
Bathymetric data	Bathymetry from (Entura, 2021), (Entura, 2020), and Marine Solutions (*pers. comm 2021*)
Land use	TheList layer *Land Use 2019* and *Building Polygons 2D* (Tasmanian Government, 2008a) (Tasmanian Government, 2008b)
Aerial imagery	Topographic and Orthophoto basemap from TheList (Tasmanian Government, 2008c)
Storm rainfall data	Bureau of Meteorology (BOM, 2016), Appendix A
Temporal Patterns and Rainfall Losses	Australian Rainfall and Runoff Data Hub (ARR, 2019b)
Existing stormwater drainage infrastructure	Based on "*Bridgewater Bridge Survey and Control Framework*" (Jacobs, 2020)

Item	Source
	Pit depths assumed based on engineering judgement
Tide Data	Highest and lowest astronomical tides of 0.86 m AHD and -0.83 m AHD as recommended by DPIPWE (2019) Sea level rise of 0.85 m as per government guidelines (McInnes *et al.*, 2016) Sea surge estimated using CANUTE 3.0 (CSIRO, 2019)

3.4.1 Bathymetry

The River Derwent bathymetry around the Bridgewater Bridge has been modelled with a variety of datasets listed below:

- HEC Surveys and GIS Department survey for the Derwent River Sludge Study - Phase 2 (Tomat, 1990) between approximately 53 km and 67 km downstream of Meadowbank Dam (with the most downstream cross-section 1.37 km downstream of Bridgewater Bridge). These cross sections have been interpolated to form the basis for the channel bathymetry upstream and downstream of Bridgewater Bridge

Around Bridgewater Bridge, the modelled bathymetry is a combination of data:

- The levels within the main channel were taken from a survey completed as part of the project by Jacobs
- Shallow levels on the eastern side of the causeway were provided by Marine Solutions
- Other model bathymetry was sourced from Mineral Resources Tasmania, survey and interpolation.

Further information on the modelled bathymetry is described in the *New Bridgewater Bridge Hydrodynamic Assessment* report (Entura, 2021) and Section 3.5.1.

3.4.2 Hydraulic roughness

Manning's n hydraulic roughness coefficients were assigned to different land use categories based on Chow(1959) and AR&R Project 15 guidelines (Babister *et al.*, 2012) as shown in Table 3.3. Land use categories were derived from *Land Use 2019*[1] and *Building Polygons 2D* (Tasmania Government, 2008b) datasets for each model.

Table 3.3: Adopted Manning's n hydraulic roughness values

Land Use Category	Manning's n
Road reserves	0.03
Roads and paved areas	0.02
Open space / maintained grass (e.g. sporting fields)	0.035

[1] https://maps.thelist.tas.gov.au/listmap/app/list/map?bmlayer=3&layers=3296

Land Use Category	Manning's n
Medium maintained grass / open space	0.045
Agricultural	0.04
Vegetation	0.06-0.12
Commercial	0.15-0.2
Residential	0.08-0.2
River channel and marshland overbanks	0.025-0.08

3.4.3 Climate change assumptions

To model future climate conditions, the following assumptions were made:

- A 16% increase in storm rainfall by 2090 was adopted for the River Derwent catchment in accordance with Australian Rainfall Runoff (ARR, 2019b). This is indicative of the 8.5 W/m^2 representative concentration pathway (RCP) climate change scenario. Note 2090 is the limit of current climate projections and while this does not cover the full 100 year asset life it is considered suitable for this level of assessment.
- A more conservative 20% increase in storm rainfall by 2090 was adopted for the NorthSide and SouthSide models to account for smaller catchments that are considered likely to be more susceptible to climate change having shorter critical duration storm events. Noting there will be greater increase in rainfall intensity for shorter duration events from climate change (Fowler *et al.*, 2021).
- A sea level rise of 0.85 m by 2090 was adopted based on predicted sea level rises for Clarence, Brighton, Hobart and Glenorchy (DPAC, 2016). This was applied at the Tasman Bridge boundary for the River Derwent model; noting, the Northside and Southside models get their downstream boundary levels from the River Derwent model.

3.5 River Derwent model

A conceptual illustration of the River Derwent hydraulic model is shown in Figure 3.2. The model extends from 7.3 km upstream of Bridgewater Bridge to the Tasman Bridge and has been derived to contain a 1:2,000 AEP flood event. Note, there is some overlap of this model and the lowest part of the Northside and Southside models, which allows the River Derwent model to provide tailwater boundary conditions for the other two models.

The point of interest in the model, the Bridgewater Bridge, is located a third from the upstream boundary and at a sufficient distance from both flow rate upstream and water level downstream boundaries to minimise impacts of modelling artifacts from the implementation of the boundaries.

3.5.1 Model geometry

- TUFLOW HPC and the Quadtree module has been used for the model. This module allows for varying grid sizes within the model domain. The base grid cell is 60 m, which is nested with finer resolutions down to 3.75 m at the Existing and New Bridgewater Bridge locations.

- Model results can vary with grid size, and the results should converge to a common answer as grid sizes reduce. A 1 m grid cell size sensitivity has been run which highlights the water level convergence of the results for this the 3.75 m grid cell size.
- The model boundaries are far enough from the project land that the modelled 1% AEP flood behaviour is not affected by the boundary conditions.
- The existing Bridgewater Bridge piers were modelled based on design drawings provided by Burbury Consulting (*pers. comms.* A. Murray, 20/4/2021). In this study it has been assumed that the flood waters do not interact with the underside of the bridge deck which varies from 2.25 mAHD (Southern bank) to 3.2 mAHD (Northern bank) based on deck levels from LiDAR and an estimated deck thickness of 2 m. The impact of the existing deck was not included as flood modelling would minimise the impact of the existing bridge and show a conservatively larger impact of the New Bridgewater Bridge. (Note, the maximum water level of the 1% AEP near the existing bridge was 3.08 mAHD indicating some potential afflux that has not been including in this study.)
- The model's geometry has not enforced any of the crests of the roads, hence it is possible that the road elevations are slightly under-estimated, but this is suitable for this level of assessment.
- The datasets used in the modelled bathymetry are discussed in Section 3.4.1. The different datasets were reviewed for consistency and integrated to model a representative and smooth bathymetry around the bridge.

3.5.2 Hydraulic roughness

Manning's n roughness values were assigned to different land use classifications as per Table 3.3 and shown in Figure 3.2 as "bed material".

3.5.3 Boundary conditions

3.5.3.1 Inflows

The upstream boundary for the River Derwent model uses flow rate, as this forms a stable boundary condition and is easier to translate from other locations than a water level boundary.

The River Derwent model uses constant inflow rates that are run until the model is in equilibrium. This approach is slightly conservative, as it ignores the attenuation within the model domain from a time varying hydrograph, but is appropriate for modelling a small part of a larger river system such as the study area. It also reduced run times for the modelling.

Inflows are applied at the upstream boundary of the model based on catchment scaling of hydrograph peak flows from existing comprehensive flood modelling of the River Derwent catchment upstream of Bryn Estyn that included:

- Calibrated modelling using total storm events
- Monte Carlo design runs for current and future climate scenarios with varying rainfall depths
- Initial losses and temporal patterns sampled for durations ranging from 18 hours to 168 hours
- Fixed spatial patterns and 1% AEP rainfall depths for a 48 hour duration storm
- A 16% increase in rainfall depth for future climate as per AR&R guidelines for a RCP 8.5 scenario (Geoscience Australia, 2019)

- All hydropower reservoirs within the River Derwent's were assumed to be at Full Supply Level.
- There are no local inflows within the hydraulic model domain.
- The modelled peak inflows at Bridgewater are shown in Table 3.4.

Table 3.4: Peak inflows at Bridgewater Bridge

AEP (%)	Peak flow (m^3/s)	
	Current climate (2021)	Future climate (2090)
10	1,770	2,340
1	3,330	4,240

Note: The 10% AEP flood flows were used to estimate tailwater levels for the Northside and Southside models (see Table 4.1)

3.5.3.2 Tailwater

The downstream boundary for River Derwent model uses water level, as this hydraulically characterises the discharge of the river better than flow rate. There is also nearby data available to support this.

Fixed tailwater levels at the Tasman Bridge were used in the River Derwent hydraulic model. The adopted tailwater levels are shown in Table 3.5.

Table 3.5: Adopted tailwater levels for current and future climates

Tide conditions	Tailwater level (m AHD)	
	Current climate (2021)	Future climate (2090)
Lowest Astronomical Tide	-0.83	0.02
Highest Astronomical Tide	0.86	1.71
1% AEP sea storm	1.44	2.29

Future climate tailwater level = current tailwater level + 0.85 m

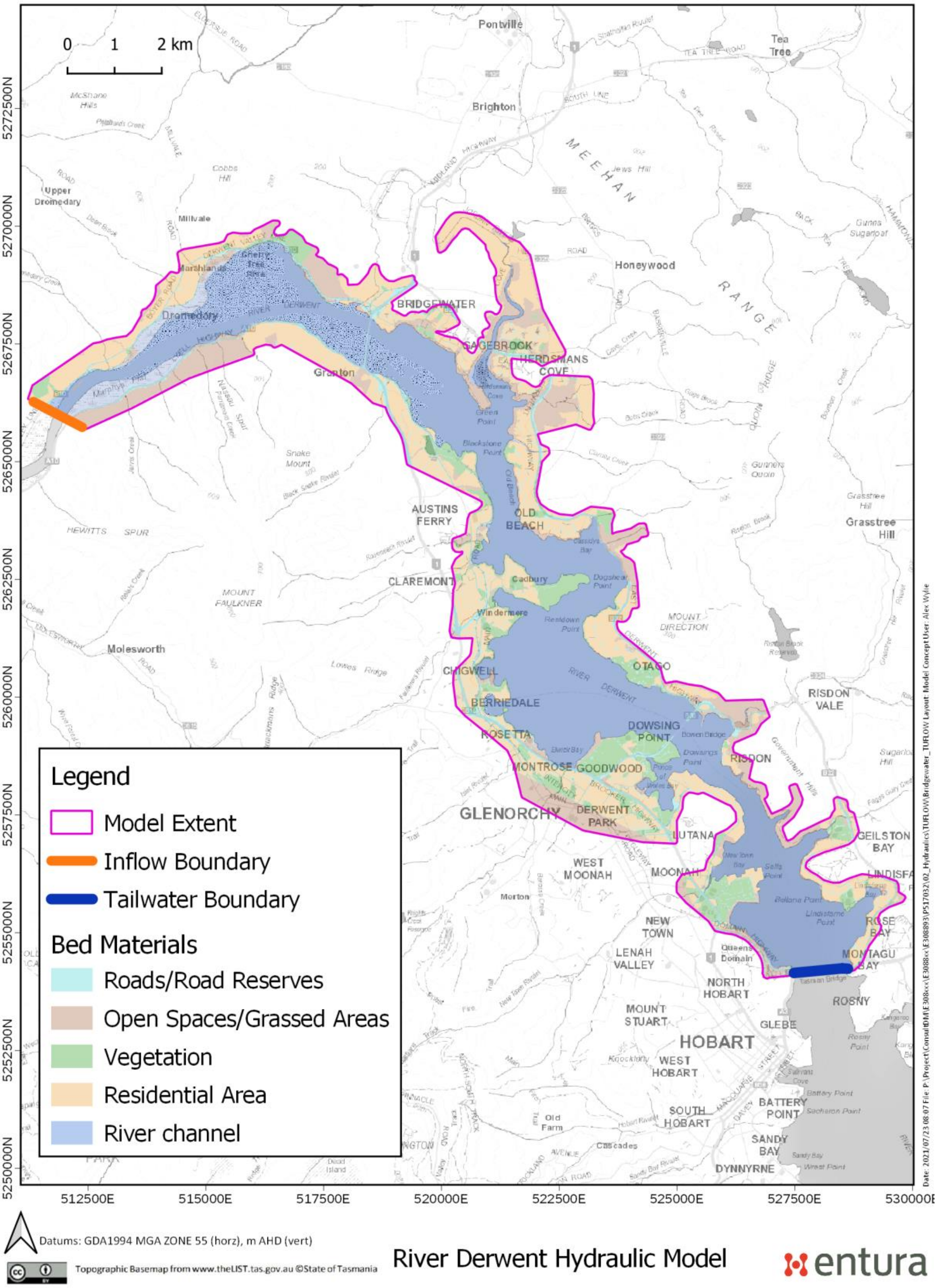

Figure 3.2: River Derwent hydraulic bed materials and boundary locations

3.6 Northside model

A conceptual illustration of the Northside model is provided in Figure 3.3. Key features/inputs of the model including model extent, hydraulic roughness, boundary conditions and climate data are described below.

3.6.1 Model geometry

As illustrated in Figure 3.3, the model extent was refined to include the immediate catchment area surrounding the proposed works. The extent was derived based on preliminary model run results which considered rainfall from the large catchment northwest of the project land. The results indicated that the prominent flow paths from the large catchment area, as shown in Figure 3.3, are discharged into the River Derwent west (upstream) of the project land or into the Jordan River downstream of the project. As the flows are directed away from the proposed works, the large catchment was not included in the Northside model to reduce computing time.

3.6.2 Hydraulic roughness

Manning's n roughness values were assigned to different land use classifications as per Table 3.3 and shown in Figure 3.3 as "bed roughness".

3.6.3 Boundary conditions

Model boundary conditions include open boundaries on land and level boundaries within the River Derwent. The open boundaries allowed flows on the western and eastern side of the model to flow out of the model, where required, to maintain model stability and avoid water accumulating artificially at boundaries where it would be "lost" from the model domain (not to return).

The tailwater level boundary condition was based on 10% AEP flood levels from the River Derwent model (Table 4.1) with the New Bridgewater Bridge and existing Bridgewater Bridge. For future climate scenarios the effect of sea level rise is via the effect this has on the River Derwent model tailwater levels.

3.6.4 Storm rainfall

The rainfall data for the 1% AEP event was from the Bureau of Meteorology (BOM, 2016) and is provided in Appendix A.1. The rainfall depths were distributed throughout the storm duration using 10 temporal patterns downloaded from Australian Rainfall and Runoff (ARR, 2019b). Durations of 15 minutes to 2 hours were modelled. (Note rainfall for the River Derwent is described in Section 3.5.3.1). No pre-burst was used for the storm rainfall, which was appropriate with the small urban initial losses. Sensitivity testing showed no impact of using pre-burst rainfall.

The hydraulic model used as "rain on grid" approach due to the relatively small urban catchment area and flat terrain. Continuous and initial rainfall losses were applied to the model based on the Land Use shown in Figure 3.3, and are tabulated in Appendix A.3.

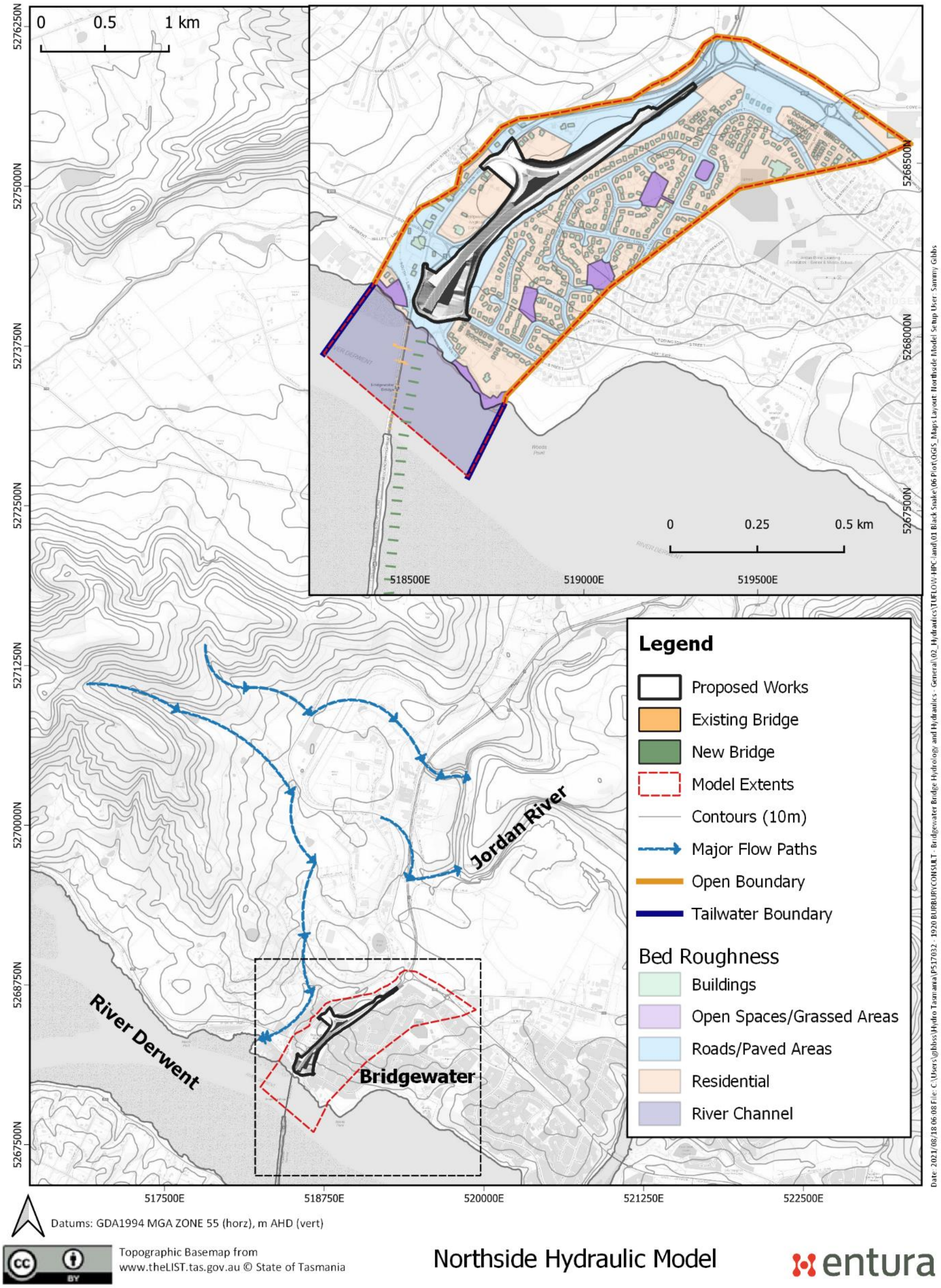

Figure 3.3: Northside hydraulic model bed roughness and boundary locations

3.7 Southside model

A conceptual illustration of the Southside model is shown in Figure 3.4. Key features/inputs of the model including extent, hydraulic roughness, boundary conditions and climate data are given below.

3.7.1 Model geometry

The hydraulic model extent captures the small urban and rural catchments immediately upstream of the proposed works. Inflow hydrographs from larger catchments further upstream were modelled separately using hydrological software RORB, then input to the hydraulic model. The larger catchments include Black Snake Rivulet and Forest Road. As they are modelled separately, these areas were excluded from the hydraulic model extent.

3.7.2 Hydraulic roughness

Manning's n roughness values were assigned to different land use classifications as per Table 3.3 and shown in Figure 3.4 as "bed materials".

3.7.3 Boundary conditions

Model boundary conditions include an open boundary on land, inflow points for Black Snake Rivulet and Forest Road hydrographs, and a tailwater level boundary within the River Derwent. The open boundary allowed flows on the western and eastern side of the model to flow out of the model where required, to maintain model stability and avoid water accumulating artificially at boundaries where it would be "lost" from the model domain (not to return). The level boundary condition was based on 10% AEP flood levels from the River Derwent model (see Table 4.1), as with the Northside model (Section 3.6.3).

3.7.4 Storm rainfall

The hydraulic model utilised rainfall in two ways – by accepting inflow hydrographs for Black Snake Rivulet and Forest Road catchments; and using a "rain on grid" approach for the smaller catchments within the hydraulic model extent. Rainfall is applied to the hydraulic model domain downstream of the RORB hydrological model catchments. The hydraulic model boundaries are shown in Figure 3.4.

The large catchment inflow hydrographs were generated using RORB (HARC, 2019), a hydrological rainfall run-off routing software, using the sub catchment areas delineated in Figure 3.4. Storm durations up to 168 hours were modelled using 1% AEP rainfall data (BOM, 2016) and 10 temporal patterns (ARR, 2019b). Estimated hydrological model parameters are provided in Appendix A.2, including the routing parameter 'kc' which was adopted in accordance with ARR (ARR, 2019a) for ungauged catchments in Tasmania.

The critical storm duration was adopted as 4.5 hour, as this duration reported the highest median peak flow rate. Inflow hydrographs were extracted from RORB for the 4.5 hour storm at the outlet of the Black Snake Rivulet and Forest Road catchments for the current and future climates, and are shown in Figure 3.5 and Figure 3.6 respectively.

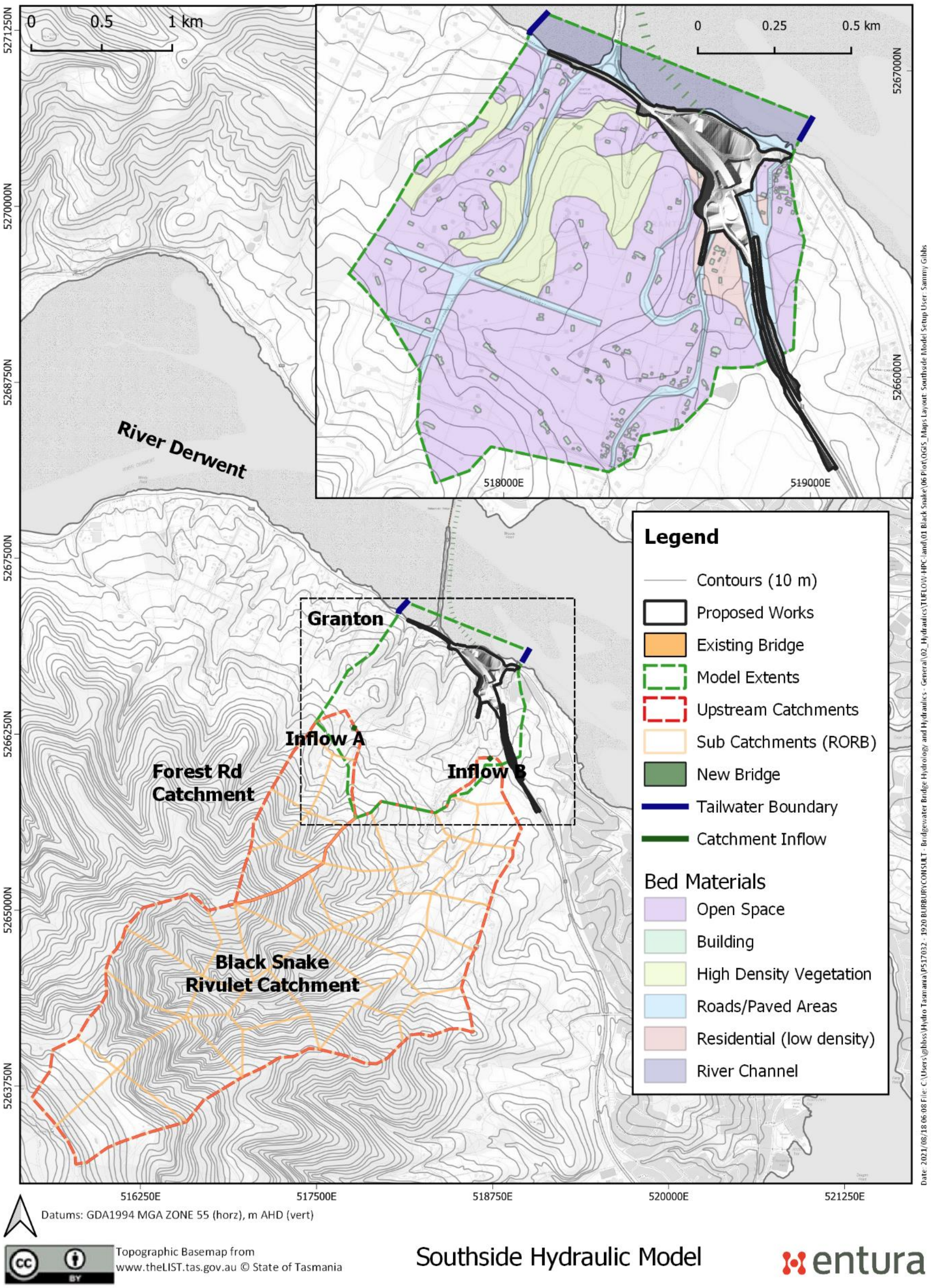

Figure 3.4: Southside hydraulic model bed material and boundary location

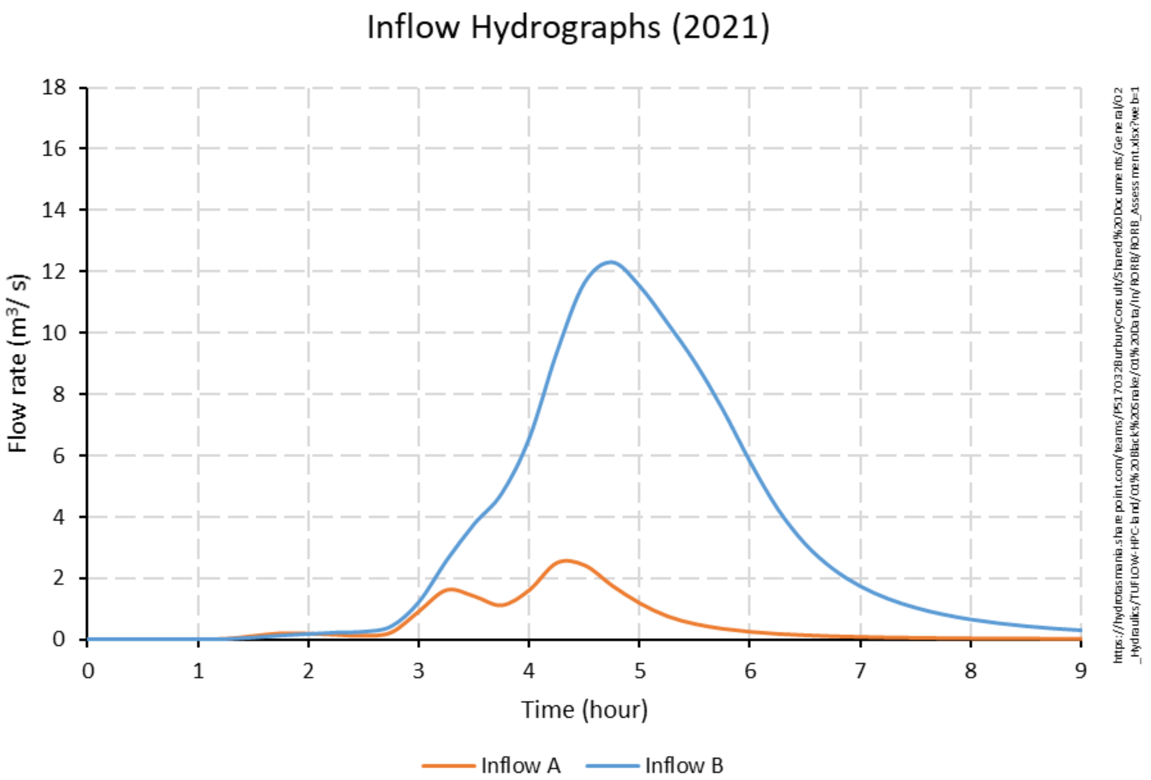

Figure 3.5: Estimated 1%AEP inflow hydrographs to hydraulic model (Current Climate – 2021)

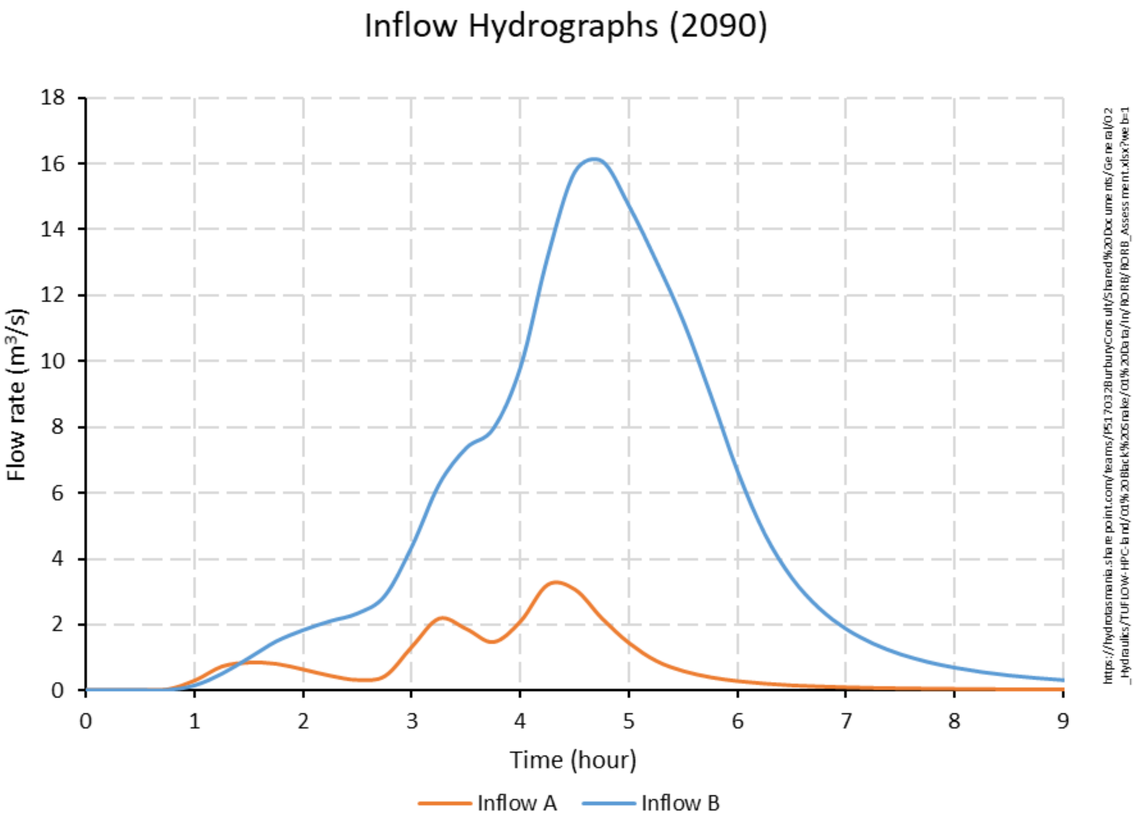

Figure 3.6: Estimated 1% AEP inflow hydrographs to hydraulic model (Future Climate – 2090)

3.8 Modelling assumptions and limitations

Modelling is subject to the following limitations and assumptions:

- The minor existing stormwater infrastructure has not been modelled (assuming its capacity is exceeded), but some (larger) trunk underground drainage infrastructure was modelled
- Existing and proposed minor longitudinal road drainage was not modelled
- Some critical proposed trunk drainage was modelled to the extent required to demonstrate to the authors that there are practical engineering solutions
- Wind waves and run-up were not modelled
- 20% culvert blockage was modelled for pipes and culverts associates with roads and none for the bridges. A risk based approach (ARR. 2019) was used to look at the source and mobilisation of debris from the reach upstream of the bridge. The small size of river side vegetation and the large span of the bridge openings meant the risk of blockage was low. A similar approach applied to urban catchments indicated an estimated 20% blockage from floating debris.
- Model results are presented without any extra freeboard to allow for uncertainties and phenomena the models do not consider (e.g. debris, blockages, waves from wind or bow waves from vehicles, and local obstruction)
- No calibration of the hydraulic models was undertaken to historical events as there was no data available
- 1 × 1 m LIDAR data was used in the land based models as the bed elevation
- The design surface (as a digital elevation model) provided to Entura by Burbury Consulting, was used in the hydraulic models for the New Bridgewater Bridge scenarios
- A single River Derwent 1:10 AEP flood event including the proposed New Bridgewater Bridge was used to provide tailwater levels for the Northside and Southside models. This is considered appropriate given the small impact of the New Bridge on the hydraulics of the land based models.
- Some erroneous triangulated surfaces were cut out of the New Bridgewater Bridge surface to mitigate unrealistic flow paths
- The new bridge piles were modelled with a size similar to the whole pile cap (3 m width)
- Flood risks from the River Derwent outside the scope of this analysis include the potential for events rarer than 1% AEP including the potential for dam break upstream and tsunamis
- Details of the circulation around the existing bridge piers is limited by the model resolution.

4. Results

The hydraulic models simulated scenarios to provide context to and quantify the potential changes in flood hazard arising from the proposed New Bridgewater Bridge. The models produced time varying two-dimensional data, that has been simplified into a set of static maps and graphs. These figures are used to assess the potential impacts of the New Bridgewater Bridge within the project land and on adjacent land, and the safe use of the New Bridgewater Bridge.

The summary results are presented below for the River Derwent, Northside and Southside models. The model maps are provided in Appendix B. As the "rain on grid" technique was used to apply rainfall to the model domain for the Northside and Southside models, the maps are filtered to remove water less than 50 mm to provide better clarity and removal of the low hazard (H1) zone. No freeboard has been added to the model results to account for phenomena that were not modelled (such as wind effects and debris blockages).

4.1 River Derwent model

To estimate the impact of the proposed New Bridgewater Bridge design, the system was model with and without the New Bridgewater Bridge. In both cases there was the existing bridge. In another check the system was modelled with the New Bridgewater Bridge and without the existing bridge. There is also a sensitivity check on adding land reclamation on the north and south ends of the bridge.

4.1.1 Sensitivity checks

A range of sensitivity checks were made including:

- A sensitivity between flood event and sea surge was undertake to determine which is the critical scenario (Figure 4.2)
- A sensitivity on bridge pier thickness (Figure 4.5)
- A sensitivity for the impacts on the reclamation area (Section 4.1.2.3).

A longitudinal section with location shown in Figure 4.1, is used to give indicative of the water levels for the events of interest (10% and 1% AEP for present and future climate) (Figure 4.6). The location of the longitudinal section is on the main river channel and extends far enough upstream and downstream to show most of the bridge impacts on water levels.

To understand if sea-storms or river floods are the most important driver for water levels at Bridgewater Bridge two events with approximately the same probability were considered[2]:

- 10% AEP river flood with a 1% AEP sea storm tailwater level
- 1% AEP river flood with a highest astronomical tide tailwater level.

[2] a more detailed joint probability assessment should be considered during detailed design

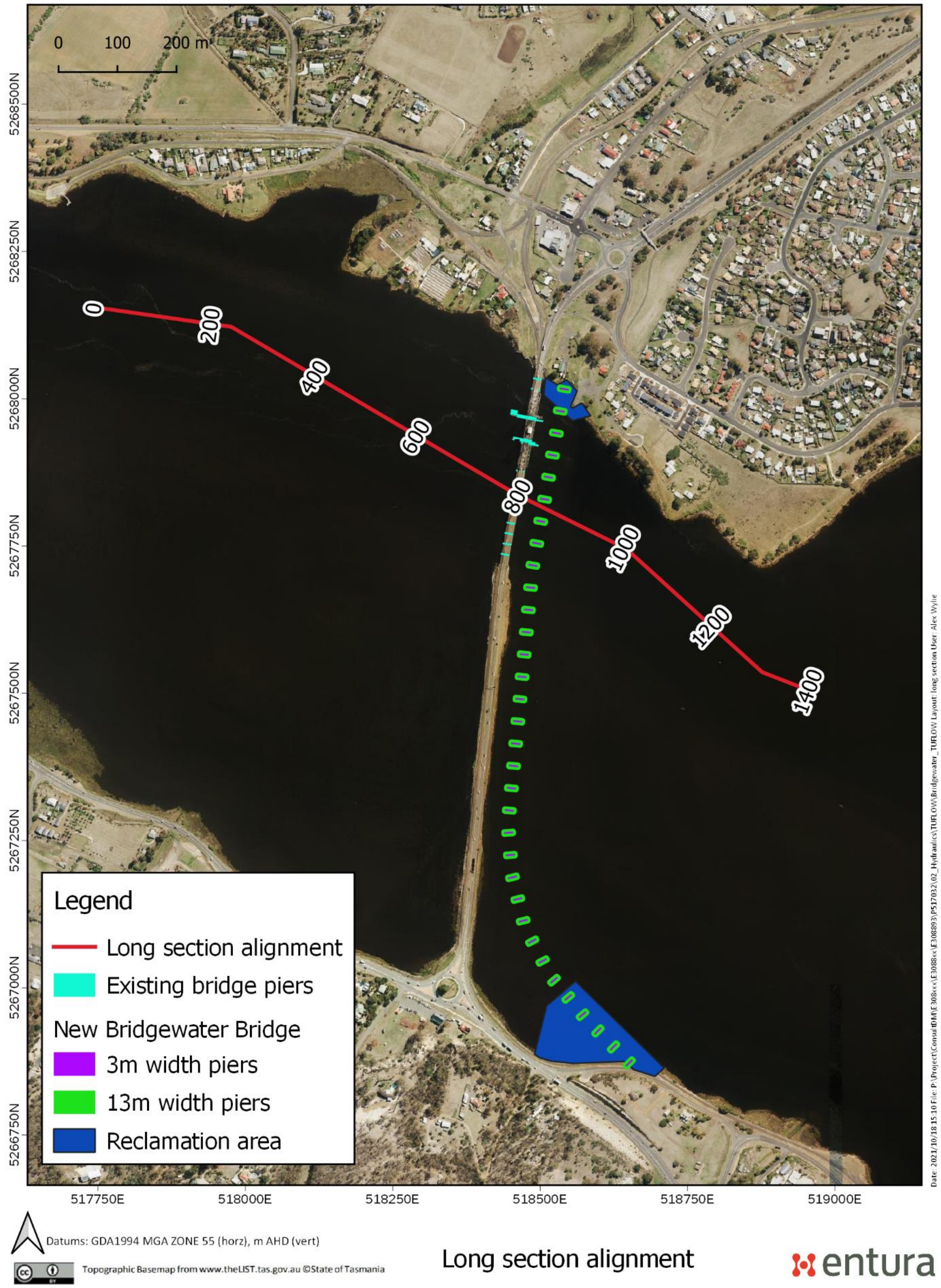

Figure 4.1: Existing and New Bridgewater Bridge with longitudinal section alignment

It is evident from Figure 4.2 that a 1% AEP flood inflow with highest astronomical tide tailwater produces significantly higher levels than the sea storm for both existing and future climates. This combination of events was therefore used for the assessment in Section 4.1.2.1.

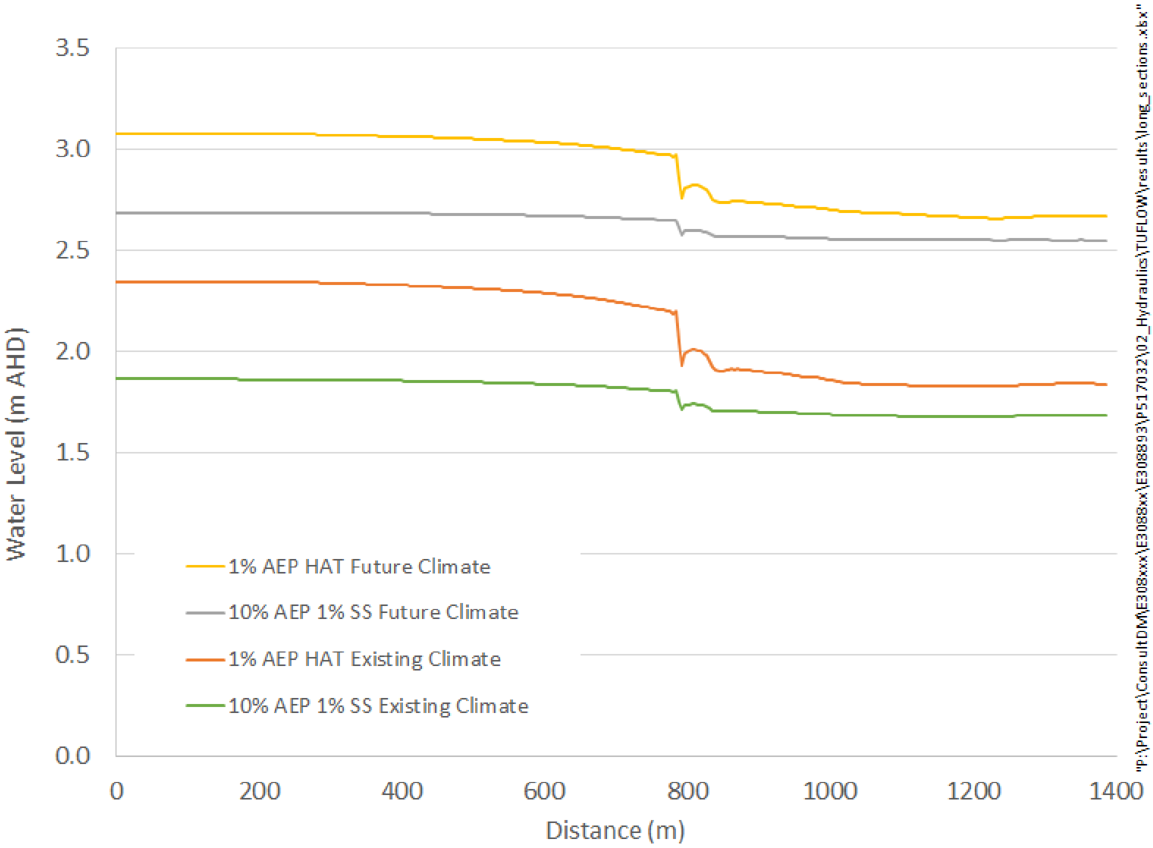

Figure 4.2: Water level long sections – joint flood analysis for existing and future climates (1% AEP or 10% AEP - river flood; 1% SS - 1% AEP Sea storm; HAT - Highest Astronomical Tide)

4.1.2 New Bridgewater Bridge

4.1.2.1 Changes due to New Bridgewater Bridge

To provide an overview of the River Derwent flood behaviour and interaction with the existing causeway and New Bridgewater Bridge, a level inundation map with velocity vectors around the project land is shown below in Figure 4.3. These results for the 1% AEP event shows:

- The slope of the water surface away from the bridge is small, but higher around the bridge
- The main channel has the largest flow rates within the project land
- The existing causeway overtops, with locally higher velocities as water runs over it
- Most of the causeway is inundated except for a small island at the northern end of the causeway
- Flow direction is relatively uniform across the river where the causeway is overtopped, with local redirections around the northern end of the causeway.

Flood depth difference maps showing the impact of the New Bridgewater Bridge for the current and future climates assuming the existing Bridgewater Bridge and causeway are retained are shown in Figure B.1 and Figure B.2 (in Appendix B.1).

For the New Bridgewater Bridge and existing Bridgewater Bridge, the extent of flooding from the River Derwent is shown in Figure 4.4. This gives the 10% AEP and 1% AEP floods for both existing and future climate. The 10% AEP future climate (red) and 1% AEP existing/current climate (cyan) are very close to each other, and when the 1% AEP existing/current climate line is not visible it is the same as the 10% AEP future climate.

There are areas inside and outside the Project Land which are inundated by these events. Of note there is flooding on the southern banks for the river, including the intersection of Black Snake Road and Main Road in Granton (downstream of bridges), and to the north banks of the river around Riverside Drive (upstream of bridges). Also the flooding over the New Bridgewater Bridge approaches (southside) and existing dwellings (northside) occurs during both existing and future climates.

Flood depth difference results with the New Bridgewater Bridge and the existing Bridgewater Bridge and piers removed, are shown in Figure B.3 and Figure B.4 for the current and future climates respectively.

In general, the water levels are higher upstream of the existing Bridgewater Bridge due to the additional head loss through the New Bridgewater Bridge piers, and slightly lower downstream of the New Bridgewater Bridge. As shown by the entire map (Figure B.3 and Figure B.4), the raised water levels continue upstream to the model boundary. However, these upstream differences are approximately 0.03 m less than the raised water levels at the New Bridgewater Bridge.

The two inserts in Figure B.3 and Figure B.4 show the locations of buildings which are inundated, or further inundated, due to the New Bridgewater Bridge (without the existing Bridgewater Bridge). The hazard classification maps are provided in Figure B.5 to Figure B.8.

The water levels results for the modelled 10% AEP fluvial flood and highest astronomical tide tailwater have been extracted at the outlets of the Northside and Southside models to be adopted as tailwater levels for these models. The adopted tailwater levels are shown below in Table 4.1.

Roads surrounding the project are inundated for all modelled floods. The lengths of road inundated with each hazard classification are tabulated in Table 4.2 to Table 4.4. There are some increases and decreases in flood hazard categories, but the total length of road inundated increases compared with existing conditions for constructed the New Bridgewater Bridge. If the existing Bridgewater Bridge is then removed, the length of road inundated is similar to the existing conditions. The impact on the length of road inundated is greater in the current climate compared to the future climate (approximately five times the percentage change for the Lyell Highway and Riverside Drive locations). As the Main Road location is downstream of the development, there is a slight decrease in H2 and H3 inundation lengths because of the restriction from the New Bridgewater Bridge.

Note, the model has not enforced the crests of the roads, hence it is possible that the road elevations are under-estimated in the model.

The hazards are less for Main Road Granton for the New Bridgewater Bridge scenarios due to the additional head loss lowering the water levels downstream of the bridge.

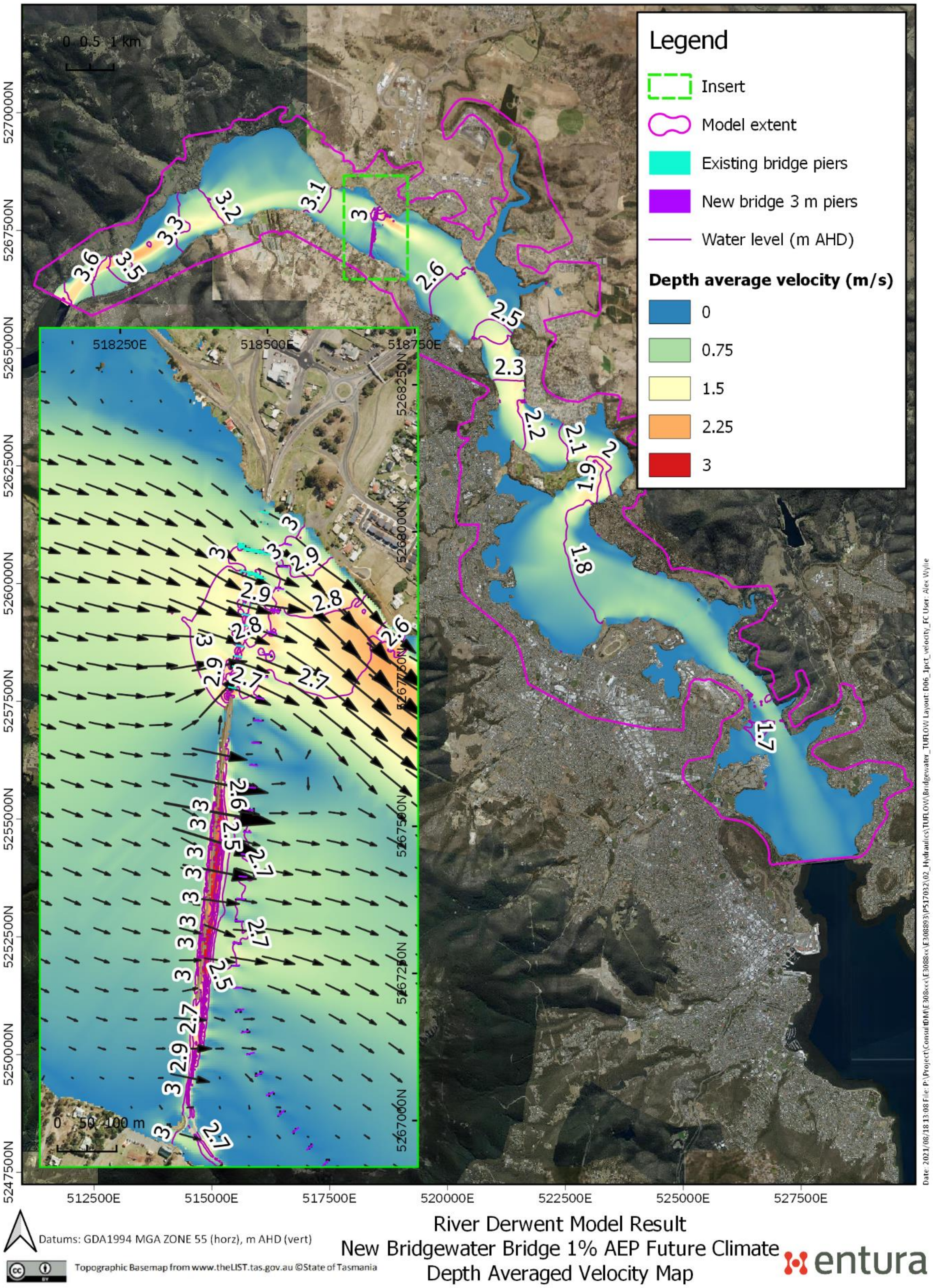

Figure 4.3: 1% AEP velocity map with velocity vectors and water level contours

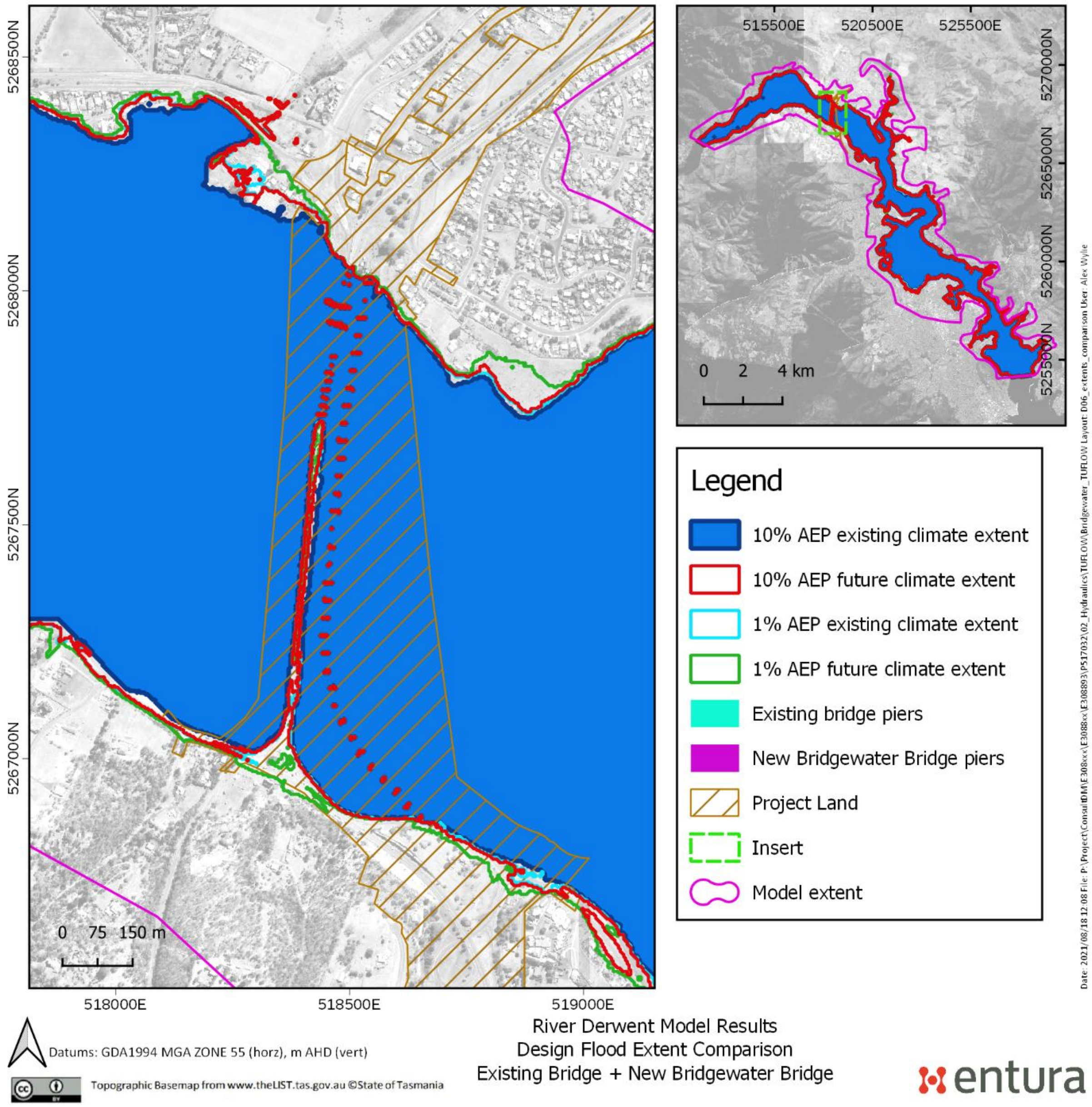

Figure 4.4: Flood extends for New Bridgewater Bridge with existing Bridgewater Bridge

Table 4.1: Modelled River Derwent levels input to land models – 10% AEP flood (m AHD)

Scenario		Southside (Granton)		Northside (Bridgewater)	
Bridges	Climate	West (Upstream) of the Bridge	East (Downstream) of the Bridge	West (Upstream) of the Bridge	East (Downstream) of the Bridge
Existing bridge	Existing	1.40	1.22	1.37	1.31
Existing bridge	Future	2.25	2.05	2.23	2.16
Existing bridge and New bridge	Existing	1.44	1.22	1.41	1.35
Existing bridge and New bridge	Future	2.29	2.05	2.27	2.20

Table 4.2: Inundated road lengths for 1% AEP flood - Lyell Highway (m)

Bridges	**Climate**	**Flood hazard classification**		
		H1	**H2**	**≥ H3**
Existing bridge	Existing	1,009	907	579
Existing bridge	Future	318	1,100	3,043
New bridge	Existing	985	882	559
New bridge	Future	319	1,087	3,076
Existing bridge + New bridge	Existing	1,129	1,065	672
Existing bridge + New bridge	Future	297	880	3,391

H1: Generally safe; H2: Unsafe for small vehicles; ≥ H3: Unsafe for vehicles and people

Table 4.3: Inundated road lengths for 1% AEP flood - Riverside Drive (m)

Bridges	**Climate**	**Flood hazard classification**		
		H1	**H2**	**≥ H3**
Existing bridge	Existing	131	918	1126
Existing bridge	Future	114	618	2155
New bridge	Existing	120	954	1065
New bridge	Future	114	609	2155
Existing bridge + New bridge	Existing	143	872	1305
Existing bridge + New bridge	Future	123	591	2215

H1: Generally safe; H2: Unsafe for small vehicles; ≥ H3: Unsafe for vehicles and people

Table 4.4: Inundated road lengths for 1% AEP flood - Main Road (m)

Bridges	Climate	Flood hazard classification		
		H1	H2	≥ H3
Existing bridge	Existing	136	21	0
Existing bridge	Future	113	277	454
New bridge	Existing	146	21	0
New bridge	Future	203	262	379
Existing bridge + New bridge	Existing	146	21	0
Existing bridge + New bridge	Future	203	262	379

H1: Generally safe; H2: Unsafe for small vehicles; ≥ H3: Unsafe for vehicles and people

4.1.2.2 Sensitivity to pier group size and existing bridge

A key uncertainty is the final geometry of the New Bridgewater Bridge – as changes in geometry will impact the flood behaviour of the river. In particular, larger pier groups would cause a higher restriction on flow, hence increasing water levels upstream. The New Bridgewater Bridge piers were modelled with a 3 m width, and a 5 m buffer has been applied to see how sensitive the model is to pier width, for a width of 13 m.

To compare the results of the sensitivity to pier group size, a longitudinal section has been extracted along the alignment shown below in Figure 4.1 (chainage in metres). The location of the section has been selected to be on the main river channel, with an extent far enough upstream and downstream to show most of the bridge impacts on water levels.

The long sections for the New Bridgewater Bridge sensitivity model results for the 1% AEP future climate storm are shown below in Figure 4.5. Note sometime after construction of the New Bridgewater Bridge, the existing bridge is expected to be decommissioned (leaving the existing causeway) and so this scenario was also included.

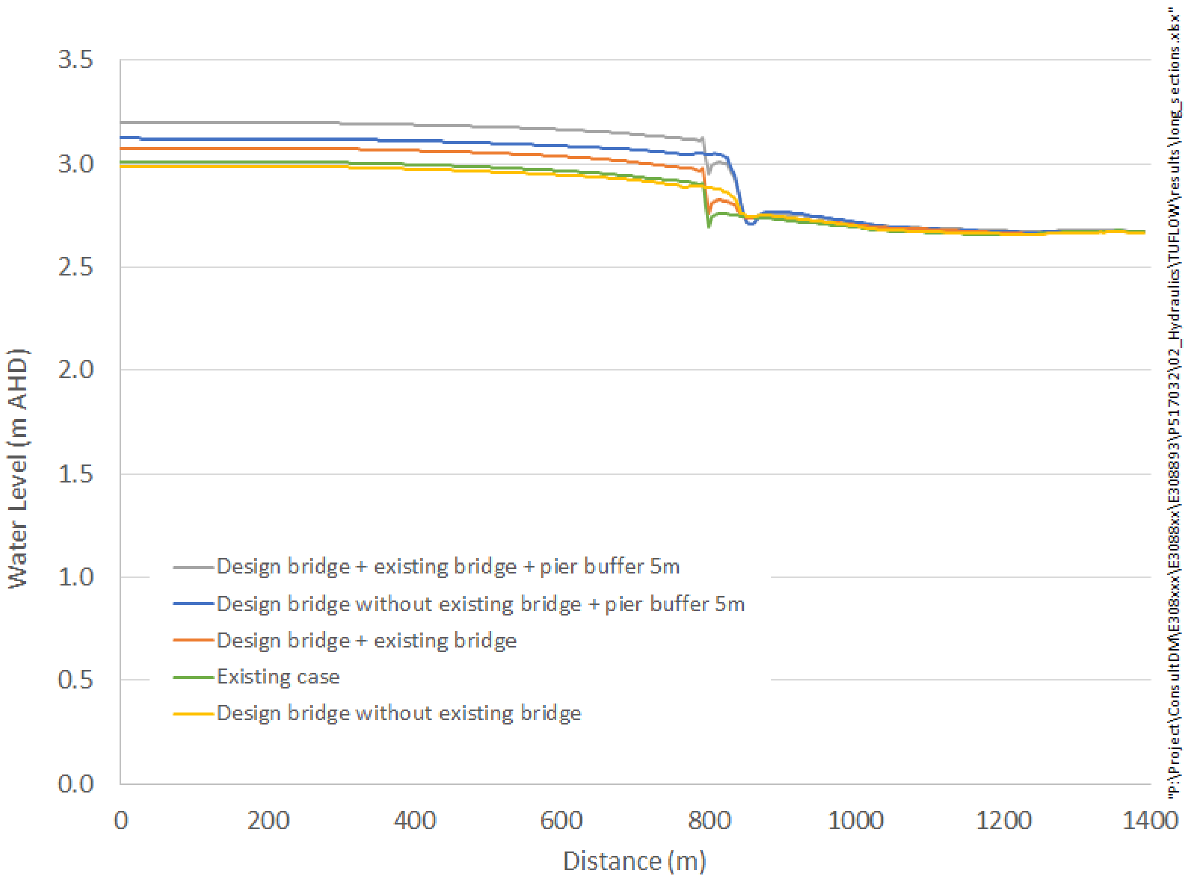

Figure 4.5: New Bridgewater Bridge (Design bridge) sensitivity testing - long sections

The outcomes of the New Bridgewater Bridge sensitivity scenario for the 1% AEP future climate storm are:

- The proposed New Bridgewater Bridge with 3 m piers raises upstream water levels by 0.07 m compared to the existing Bridgewater Bridge
- Widening the new bridge piers to 13 m raises the upstream water levels by another 0.12 m
- Removing the existing bridge and piers (whilst retaining the existing causeway) lowers the upstream water level 0.08 m compared to the existing Bridgewater Bridge for both the 3 m and buffered case.

The scenario adopted for map outputs in this study is the 3 m wide proposed New Bridgewater Bridge pier group with the existing bridge and piers included in the model.

Note the results show water levels that would have some minor interaction with the soffit of the New Bridgewater Bridge deck, on its southern portion, but this is not expected to have a material impact on the conclusions.

4.1.2.3 Reclamation of land on river banks

As part of the proposed scope of works for the New Bridgewater Bridge, reclamation of both the North and South River banks is an option, as shown in Figure 4.1.

To assess the impacts of reclamation it was assumed that the areas would be filled to 1 m AHD then the water levels upstream and downstream of the bridge under a 1% AEP future (2090) climate flood event were assessed under the following scenarios:

- New Bridgewater Bridge with retention of existing Bridge – with and without reclamation
- New Bridgewater Bridge with removal of existing Bridge – with and without reclamation
- Existing Bridgewater Bridge without reclamation (existing model water levels for comparison)

Long section results are shown in Figure 4.6. The peak values at the upstream of the section are used to give the impacts of the options, and are given in the legend. With the construction of the New Bridgewater Bridge and retention of the existing Bridge there is less than 0.01 m difference in water levels compared to the no reclamation case.

With the construction of the New Bridgewater and removal of the existing Bridge, reclamation raises the upstream water levels by upto 0.02 m. Even with this rise, the modelled water levels remain below those with existing bridge and no reclamation.

On the basis of these results the optional reclamation does appear to have any significant impact on 1% AEP flood water levels in the River Derwent.

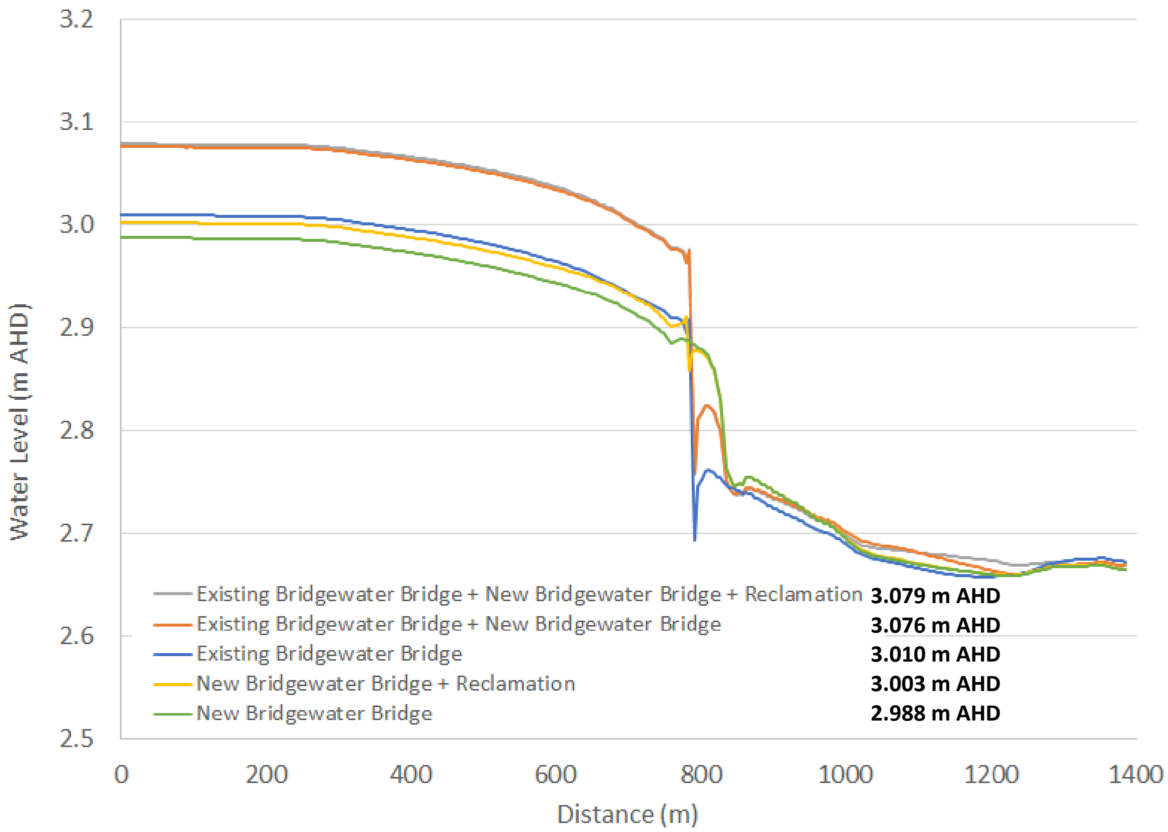

Figure 4.6: New Bridgewater Bridge and reclamation areas sensitivity with maximum values

4.2 Northside model

The critical storm duration was determined by running the hydraulic model with the proposed works and future climate. This was done for storm durations of 10 minutes to 2 hours using the climate data discussed in Section 3.6.4, and the tailwater levels listed in Table 4.1. The median depth out of all the temporal patterns for each duration was compared, and the storm duration resulting in the greatest maximum depth flood was adopted as the critical storm. This was found to be the 30 minute storm. The changes from existing to proposed works would not effect this duration as there were no significant changes in catchment storage from the proposed works.

The flood results indicate that the critical scenario, is the future climate case due to the increased rainfall (20%) and rise in sea level. The maximum flood depth results for the existing bridge/road configuration and the New Bridgewater Bridge under the future climate scenario are shown in Figure 4.7 and Figure 4.8. All flood maps are provided in Appendix B.2.

4.2.1 Existing Bridgewater Bridge

Hydraulic modelling results Figure 4.7 include:

- Runoff from the catchment east of the civil works for the New Bridgewater Bridge is conveyed under the Midland Highway in a 0.9 m diameter concrete culvert and is discharged on t
- he eastern side of Old Main Road (region A). Flow drains south where it connects to the pipe network downstream of the roundabout (region C), that discharges into the River Derwent.
- Pooling at region B will be captured and conveyed by smaller road drainage infrastructure, which have not been included in the hydraulic model.
- Flows that are not conveyed through the culvert at region A are shown on the map along the sides of the Midland Highway. This flow is captured and conveyed by existing stormwater pits and pipes and is discharged into the River Derwent east of the Midland Highway (region D).
- Flood hazard category H5 and H6 flows are prominent at the shore of the River Derwent, inundating the existing discharge outlet and part of Nielsen Esplanade for the future climate scenario (region E).

4.2.2 New Bridgewater Bridge

Outcomes of the hydraulic modelling for the proposed works Figure 4.8 and Figure 4.9 include:

- Runoff similar to the existing conditions, where runoff from the catchment west of the works is conveyed under the Midland Highway in a 0.9 m diameter concrete culvert and is discharged on the eastern side of Old Main Road (region A). Flow drains south where it connects to the pipe network east of the proposed main road at region E.
- Pooling at region B is expected to be captured and conveyed by smaller road drainage infrastructure which was not included in the hydraulic model.
- Runoff confined along the side of the Midland Highway is directed east due to the proposed slip lane to the east of the existing Midland Highway (region C).
- Flows from the road at region C are directed immediately towards the properties at the top of Gunn Street. As shown by Figure 4.8, approximately 2 m^3/s of flow is able to be captured and conveyed underground through new stormwater pits and pipes and discharged into the River Derwent with a new river outlet/end of pipe system for the 1% AEP. This is a conceptual design

to demonstrate there are practical engineering solutions, but other configurations could be investigated during detailed design. Note, there is existing overland flow (mainly from the north east) that this new drainage infrastructure would also need to convey.

- Flood hazard category H5 and H6 flows are again prominent at the shore of the River Derwent (region D), inundating the existing discharge outlet and part of Nielsen Esplanade for the future climate scenario.

4.3 Southside model

The flood results indicate that the critical scenario is the future climate case due to the increased rainfall (20%) and rise in sea level. The tailwater levels used in the model were based on the results from the River Derwent model provided in Table 4.1.

The maximum flood depth results for the existing bridge/road configuration and the New Bridgewater Bridge under the future climate scenario, are illustrated in Figure 4.10 and Figure 4.11. All flood maps are provided in Appendix B.3.

4.3.1 Existing Bridgewater Bridge

Outcomes of the hydraulic modelling for the existing Bridgewater Bridge include:

- Runoff from the Black Snake Rivulet catchment is conveyed through a box culvert (2.1 × 2.5 m) underneath Brooker Highway at region A into the downstream creek before flowing out into the River Derwent through another box culvert (region B).
- Notable flows with a flood hazard category of H5 are present along Black Snake Road (region C) due to the local catchment west of the highway. This flow is suspected to be confined in table drains along the side of the road which was not captured in the hydraulic model. These flows are conveyed into the Black Snake Rivulet through a culvert underneath Black Snake Road, downstream of the Brooker Highway (region D).
- Ponding can be seen in region F as the ground level at Black Snake Road was modelled in this area and the overpass was removed. Flow in this area is therefore confined to the underpass and does not overtop the Brooker Highway.
- There is inundation at the downstream end of the model at the intersection between Main Road and Black Snake Road (region G) due to flows from the underpass along Black Snake Road and a high tailwater (noting this tailwater is the 10% AEP Derwent River flood). Appropriately sized infrastructure would be able to capture and discharge the flow into the River Derwent under the current climate. However, inundation at the downstream extents is significantly intensified for the future climate scenario, due to the rise in sea level and increased rainfall (20%), inundating Main Road and region G completely as shown in Figure 4.10.
- There is also inundation at the roundabout near the entrance to the existing causeway, including Lyell Highway, and part of the Brooker Highway under the future climate scenario.
- Flow, with a flood hazard category of H5, pools at the main box culvert headwall (region A) and encroaches the nearby houses but does not inundate the property at 37 Black Snake Road.

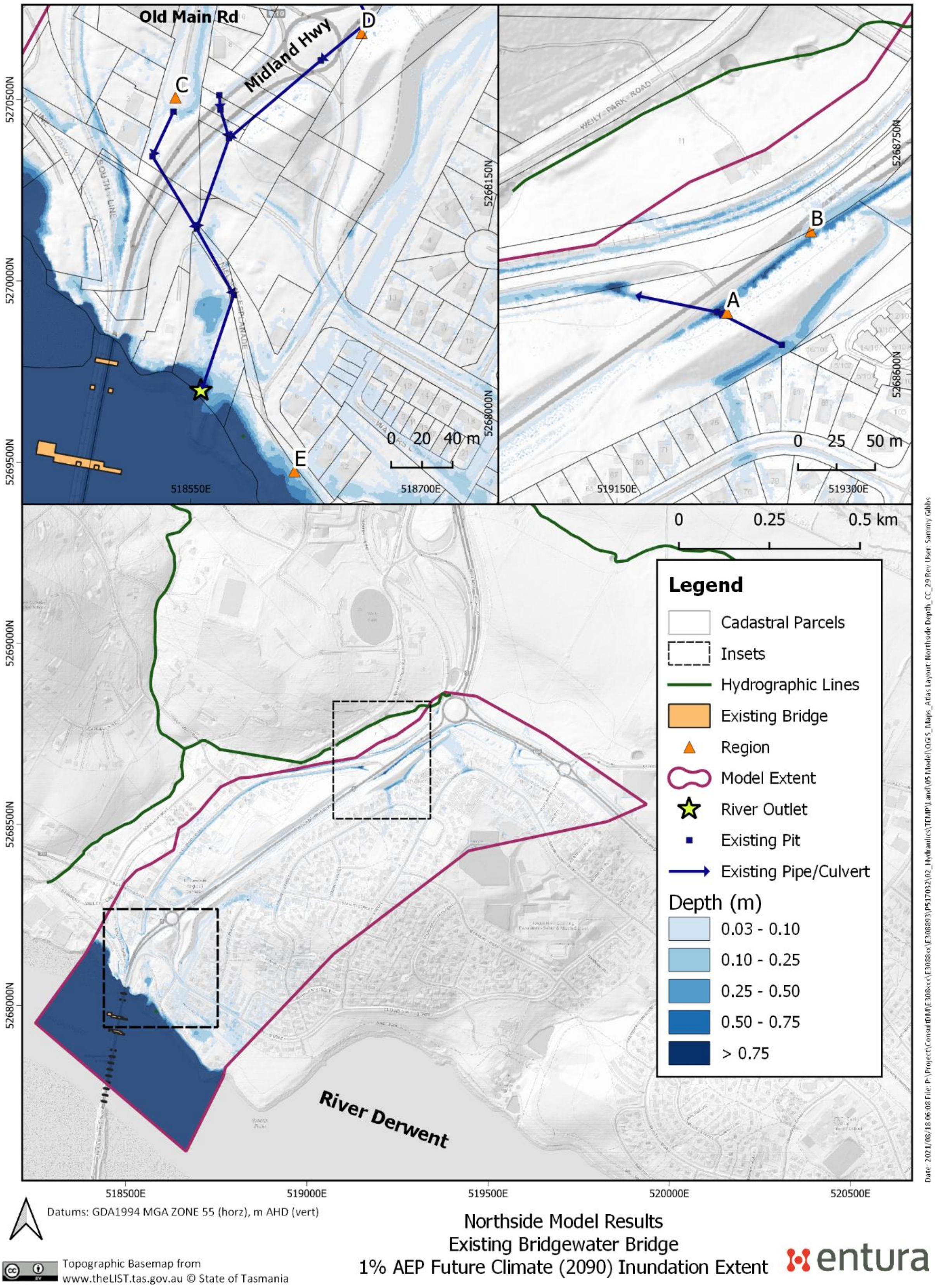

Figure 4.7: Northside model results - existing Bridgewater Bridge (2090)

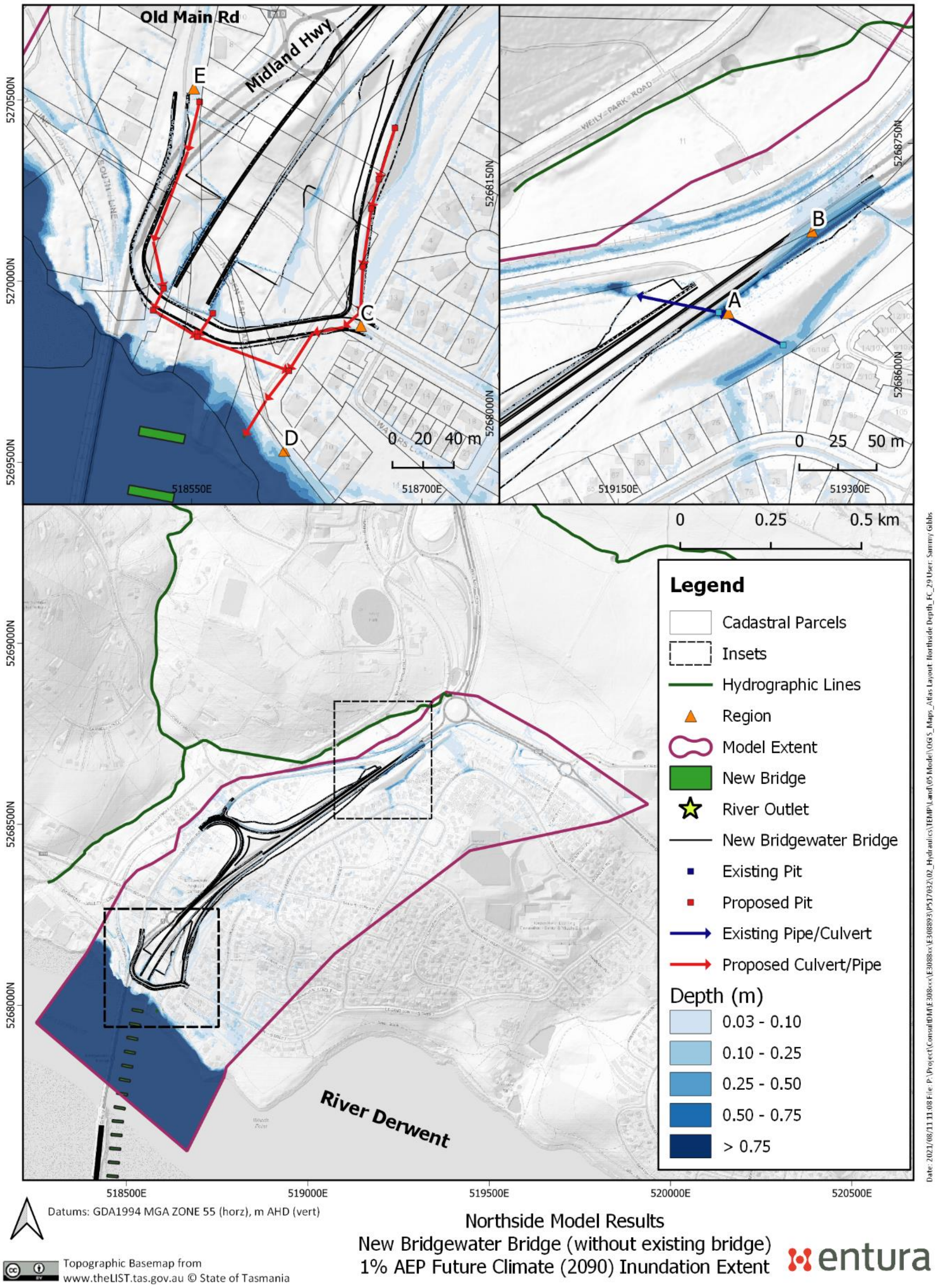

Figure 4.8: Northside model results – New Bridgewater Bridge (2090)

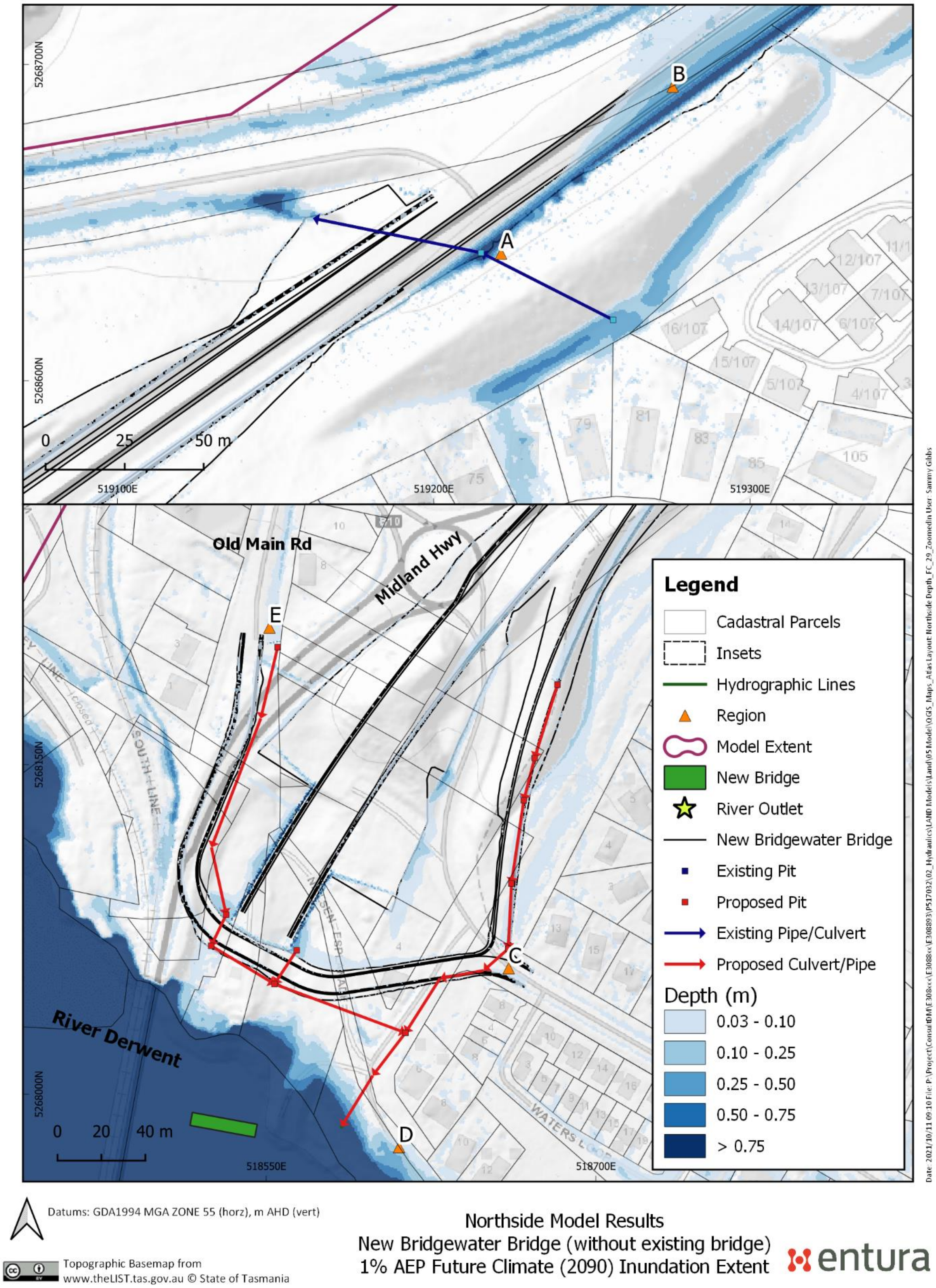

Figure 4.9: Northside model results (zoomed in) – New Bridgewater Bridge (2090)

4.3.2 New Bridgewater Bridge

Outcomes of the hydraulic modelling for the proposed works, as shown in the zoomed in figure in Figure 4.11, include:

- The location of the headwall at the inlet of the main box culvert (2.5 × 2.1 m) (see region A) running underneath the Brooker Highway, is pushed upstream due to the proposed service road obstructing the Black Snake Rivulet. This now causes pooling on the edges of the 37 Black Snake Road property, increasing the likelihood of inundation. Entura has been advised that the property has been purchased with the intention of demolition.
- The new roundabout blocks the side drainage along the existing Black Snake Road, causing pooling and overtopping of the road on the southern side of the roundabout (see region B). It is expected that modifications to the design of civil works and installation of appropriately sized drainage infrastructure carried out as part of the final design would convey the flow and reduce the hazard category from H5.
- Flow from the natural flow path shown at region C, is unable to drain downstream due to the new road approaching the roundabout. As a result, pooling occurs at the culvert downstream of region C and additional flow is discharged into the main box culvert underneath the Brooker Highway.
- Flow is able to be captured and conveyed into the main culvert running underneath the Brooker Highway, however an upgrade of the existing culvert is likely to be required. (Two box culverts instead of the existing one were used in this modelling.) Flow is then discharged into the Black Snake Rivulet and the River Derwent at region D.
- Flows from the smaller catchments west of the proposed roundabout, drain onto the road near region E. As shown by Figure 4.11 this water is able to be captured and conveyed around the roundabout using stormwater pits and pipes. The remaining water on the map is indicative of flows around 1.5 m^3/s and can be managed through additional stormwater infrastructure or larger pipes.
- Similar to the existing Bridgewater Bridge results, there is ponding on the roads at the downstream end of the model at the intersection between Main Road and Black Snake Road (region F) which is significantly increased for the future climate case with sea level rise, inundating the junction entirely (noting the tailwater in the maps is for the 10% AEP Derwent River flood).
- As previously noted, inundation can also be seen at the roundabout near the entrance to the existing causeway and part of the proposed Brooker Highway under the future climate scenario.

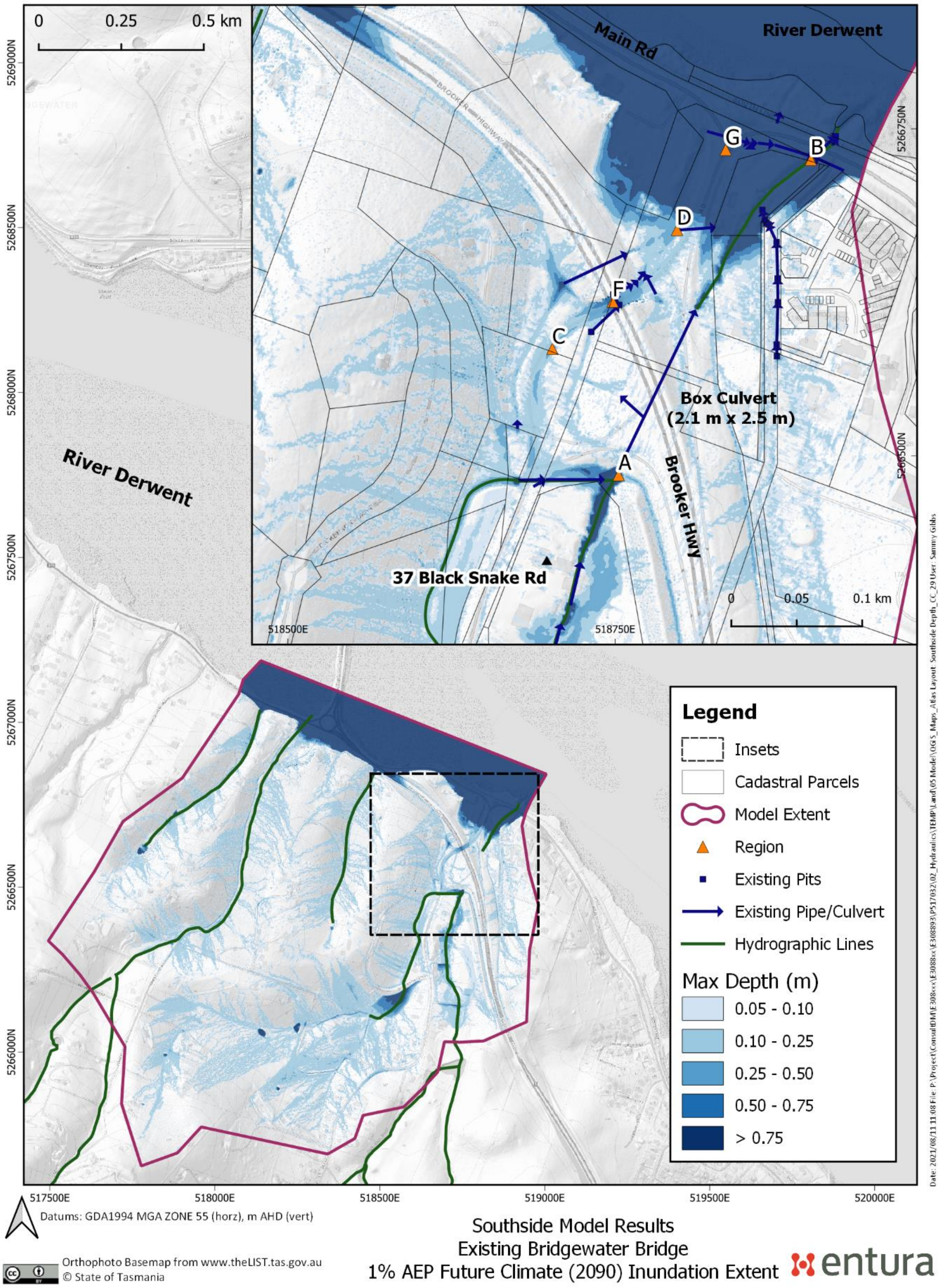

Figure 4.10: Southside model results – existing Bridgewater Bridge (2090)

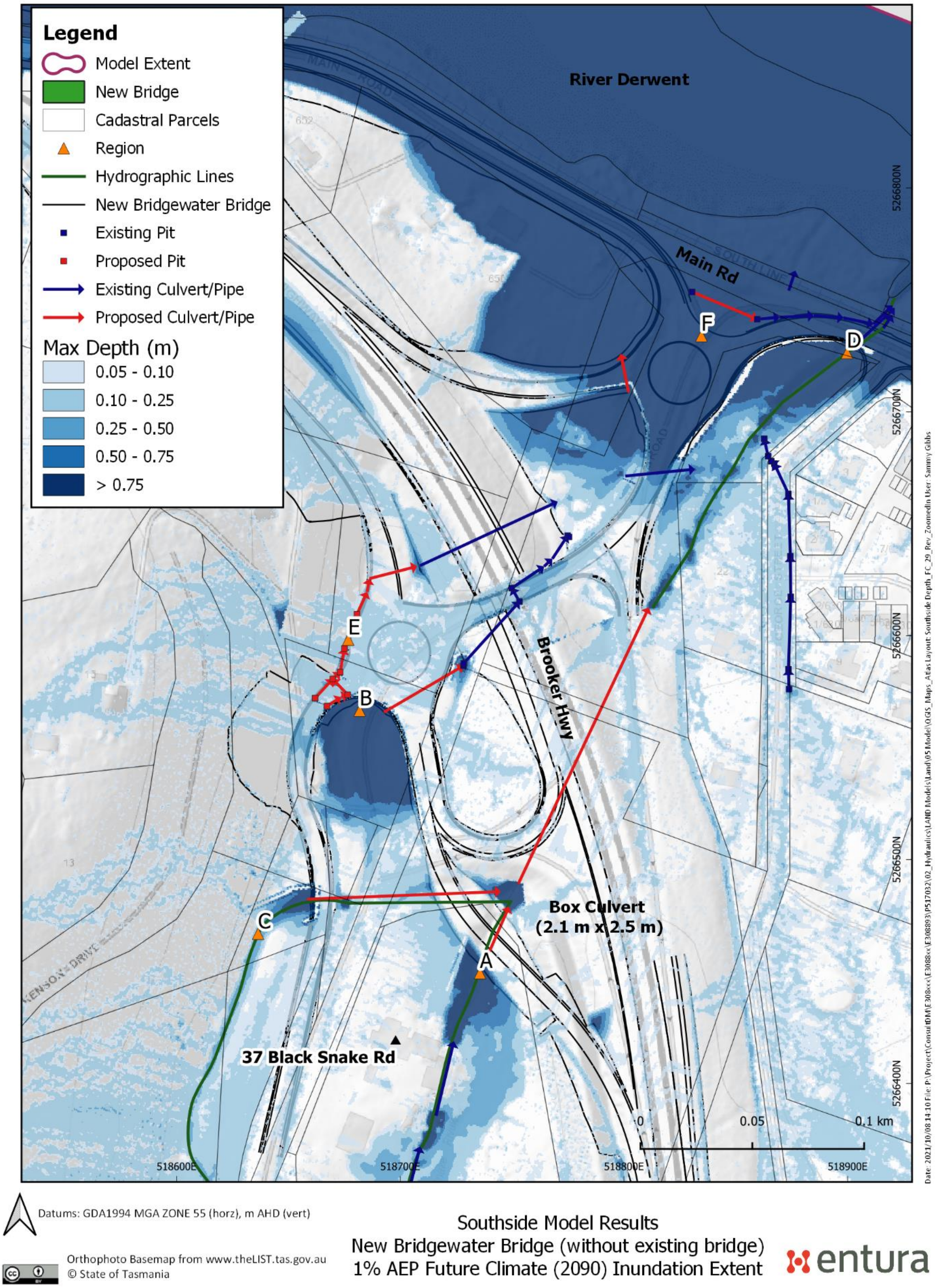

Figure 4.11: Southside model results (zoomed in) – New Bridgewater Bridge

5. Discussion

5.1 Model build and confidence in results

The model is suitable to be used to undertake the impacts assessment, and has followed industry standard practice. It also has uncertainty of the results due to assumptions, uncertainty of the inputs and approximations in the analysis. The key sources of uncertainty include model parameters, using a square grid to describe the design geometry, and hydrology.

5.1.1 Grid size and turbulence

As part of setting up the hydraulic model, key parameters were tested for their impact on the model outputs. The two main parameters tested are the size of the computation grid and how turbulence is modelled. Turbulence is part of energy loss and leads to an increase in water levels upstream of the bridge. This testing helps build an understanding of the model uncertainty.

Sensitivity testing has been carried out on the grid cell size for the 1% AEP future climate scenario with both the existing Bridgewater Bridge and New Bridgewater Bridge.

- Modelling with a 1 m grid cell size raises the water level by 26 mm upstream of the bridge compared to using a 3.75 m grid.
- In the context of the uncertainty of the final bridge design the 26 mm is not considered significant, and a 3.75 m grid cell size has been adopted for this assessment, as this allowed for quicker model run times.

Sensitivity testing has also been carried out for turbulence parameters.

- The default “Wu” turbulence parameters are adopted as the base case for the sensitivity check. The model is sensitive to turbulence parameters, with the software’s alternative “Wu” coefficients causing an increase in the upstream water levels of 193 mm.
- The Smagorinski turbulence approach, which was the default for older versions of the software, has 63 mm lower water level.
- Due to the unavailability of calibration data, the default “Wu” parameters have been adopted. This is because the relative impacts are of interest for this assessment, and the impact of errors in the turbulence parameters is expected to be similar for the existing and New Bridgewater Bridge cases (so would cancel each other out).
- This highlights the need for further investigation during detailed design, where the absolute levels are more important than they are for this study.

5.1.2 Fidelity of converting design to a grid

As part of setting up the model the geometry of the New Bridgewater Bridge, described by the outline of the bridge pier groups, are converted to a square computational grid. This introduces rounding errors, and sometimes features smaller than the grid size can disappear.

To check the sensitivity to this gridding process, the design pile geometry was enlarged and gridded. Initially there was visual inspection of how well the gridded representation of the design aligned with the geometry, which showed that both the original size and enlarged size picked up the key elements of the design.

Both sized pier groups were modelled to confirm the bridge pier groups affected the circulation around them as expected. These results showed around each pier group

- lower velocity immediately upstream and downstream
- higher water levels immediately upstream and lower water levels immediately downstream
- higher velocity at the sides, and
- redirection of flow around the pier groups as expected.

5.1.3 Hydrology

There was some cross checking between the hydrology and hydraulic parameters (e.g. RORB against the Regional Flood Frequency Analysis (RFFA)), hydraulic roughness used literature values, and the geometry a mixture for design and survey and LIDAR. There was no calibration of the hydraulic model against historical flooding due to a lack of data.

There was calibration of the hydrological model used for the River Derwent inflows. The calibration was further upstream than the flood model in this study. The scaling of flows to the model inflow locations used standard hydrological practice[3], but this is an approximation that introduces some uncertainty. Other areas (Black Snake Rivulet and Bridgewater) are ungauged, and they had no calibration.

As an example of uncertainty, the 5th percentile and 95th percentile error bounds for the RFFA on the Black Snake Rivulet 1% AEP flows are 1.3 m^3/s and 24.3 m^3/s. The expected value is 5.9 m^3/s. This means there is 90% confidence the 1% AEP is between 1.3 m^3/s and 24.3 m^3/s. The modelled RORB peak flow is 12.3 m^3/s (adopted for this study); which used literature values for input parameters. As the expected adopted value is higher than the RFFA expected value, the adopted value is conservative, but it is within the 90th percentile error bounds for the RFFA approach (noting higher 1% AEP flows are possible).

Sensitivity runs on model parameters and design geometry have provided a better understanding of the model uncertainty. For example the width of the proposed bridge pier group was increased from 3 m to 13 m to look at the water levels upstream of the bridge, which approximately tripled. When the design is finalised a more accurate representation of the structure can be reassessed.

Sensitivity runs were also conducted on the Black Snake Rivulet RORB model parameters including storage routing term (kc), initial rainfall loss and preburst conditions. Comparison of the peak flow rate estimated using the adopted kc value (2.03) and a value of 2.75 which is based on an empirical relationship derived from Australia wide data, resulted in a reduced peak flow of approximately 24%. Pre-burst rainfall depths up to 1.5 mm was conservatively reduced from the initial rainfall loss and found to have a negligible impact on the peak flow rate. Assuming no initial losses and continuous losses found a 50% increase in the peak flow rate.

There is uncertainty around the climate change assumptions, including the expected intensity of rainfall and sea level for 2090. Whilst the assumptions adopted in this assessment have been appropriate for this level of study, further work may consider sensitivity of the adopted increase in rainfall intensity (i.e. 30% on the southern side and 25% on the northern side) and other sea level

[3] Peak flows are scaled between catchments based on ratio of catchment areas raised to the power of 0.8

rises over time. In the study the larger River Derwent catchment has a 16% increase in rainfall applied for the impacts of climate change to 2090, and slightly larger 20% increase for the land based smaller models to account for the climate impacts to be larger for shorter duration events.

The absolute impact of climate change is more of an issue for the detailed design stage, in setting levels and sizing culverts, but does have some implications for this assessment. In particular, the rise in sea level scenario adopted in this study meant that some houses upstream of the bridge were already inundated during the 1% AEP event, which in turn meant any restriction in the bridge opening with the new works would have some effect on these dwellings. If the sea level rise values adopted was much lower or higher, then the effect of the bridge would be different.

At this stage of the project the key uncertainties are

- natural variability in hydrology and joint probability of fluvial and sea storms
- impact of future climate
- hydraulic parameters, given there is no calibration
- geometry of new bridge
- representation of bridge piers and flow behaviour around bridges.

During detailed design these uncertainties can be better defined and some reduced.

5.2 Flood risk for the existing Bridgewater Bridge

The New Bridgewater Bridge crosses the River Derwent and has works on the southern and northern side of the river. There are flood risks to these areas from overland flow, rivers and the sea during rain and sea storms.

The storms range in rarity from climate average, seasonal, through to rare and extreme events. Rarer events have higher flow rates, and pose a greater flood risk. For a particular rarity of event, there are a number of storms that have the same chance of occurring but different characteristics, such as their duration and rain volume. The modelling has considered a range of events to calculate the combination which gives the worst case 1% AEP scenario for each model.

There is not a single 1% AEP storm that will give the worst case for all three flow areas, e.g. the critical durations are 48 hours for the River Derwent, 4.5 hours for Black Snake Rivulet and 30 minutes for the urban area around Bridgewater.

Combinations of river and sea storms have a joint probability. In this assessment a preliminary method was used. The preliminary work used a simple rule of thumb combination of river and sea storms, with the 1% AEP from one combined with the 10% AEP from the other. The logic is that as the land and sea storms are not independent, and when there is a large river storm there is a link to there being a sea storm of some scale, and vice versa.

5.2.1 River Derwent

A significant risk for existing flood conditions is the inundation of the surrounding roads located on the flood plains of the River Derwent. The inundation lengths for hazard classification bands have been provided in Table 4.2 to Table 4.4. The hazard classifications for the southern side of

Bridgewater Bridge are shown in inserts in Appendix B.1. This gives a measure of the flood risk for 10% and 1% AEP floods.

The existing flood risk for the River Derwent is substantial for all of the modelled floods i.e. 10% AEP and rarer. The main factor contributing to flood risk, is the future climate and associated sea level rise. The Lyell Highway, which has a historical annual average daily traffic volume of over 9 000 vehicles[4], is mostly affected. Main Road and Boyer Road are also inundated for the modelled flood events.

For the Lyell Highway a 10% AEP future 2090 climate flood event with the existing bridge is modelled to impact 2.4 km of the highway. In comparison, a 10% AEP storm with the current climate and the New Bridgewater Bridge is modelled to only inundate 0.2 km of road. This highlights that the rising sea levels and increase in rainfall intensity are expected to have a significant impact of flood risks.

In comparison, a 1% AEP rain storm with existing highest astronomical tide and existing rainfall conditions is modelled to inundate 2.6 km of the Lyell Highway with the existing bridge, and with the New Bridgewater Bridge is to inundate 3.0 km of the highway. With predicted future climatic conditions, a 10% AEP event is modelled to inundate a similar length of the Lyell Highway as the current 1% event (2.4 km versus 2.6 km of inundated road) – hence the impact of climate change over the next 70 years increases the flood risk approximately tenfold for this one area.

Additional flood risks from the River Derwent which are omitted for direct analysis in from this study include the potential for a dam break to occur upstream, events rarer than the 1% AEP and tsunamis.

Details of the circulation around the existing bridge piers is limited by the model resolution. While the resolution adopted is suitable for a planning stage risk assessment focused on water levels, further modelling with higher resolutions would give more accuracy – in particular for velocities.

5.2.2 North of the Bridgewater Bridge near Bridgewater

The project land is sited on a hill side, east of a larger catchment. The majority of flows are currently directed around the project land as illustrated in Figure 3.3, with runoff discharging into the River Derwent or Jordan River. As a result, the upstream catchment is limited to the immediate surrounding, mostly urban area, hence the general risk of flooding is relatively low.

Similar to the southern side of the bridge, although not assessed in this study, the existing urban stormwater pipes and pits are expected to only convey minor storms: typically the 20% to 5% AEP events. Should blockage of the stormwater pits and pipes occur along the Midland Highway, flow cannot be safely conveyed into the underground pipe network, causing pooling and flooding of adjacent roads.

5.2.3 South of the Bridgewater Bridge near Granton

The major overland flow path on the southern side of the bridge is the Black Snake Rivulet with an upstream catchment of approximately 450 ha. Runoff is also generated from other smaller catchments including the catchment upstream of Forest Road (60 ha) and the hill side immediately west of the proposed New Bridgewater Bridge works.

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[4] http://geocounts.com/traffic/au/stategrowth Traffic ID A0197103P

There is a currently a reliance on underground drainage infrastructure, which include a large box culvert under the Brooker Highway. Hence flows from the Black Snake Rivulet and other smaller catchments present flood risks if the stormwater infrastructure designed to capture and convey the runoff is blocked by debris or its capacity is exceeded. Water pooling overroads or flooding of the 37 Black Snake Road property upstream of the main box culvert which drains underneath the Brooker Highway, is likely to occur if flow cannot drain downstream.

Local hillside runoff close to the Brooker Highway is collected in table drains and culverts. In the 1% AEP rain storm some of this flows in the service roads, and under the highway.

Black Snake Rivulet flows under Main Road at Granton and a railway embankment through a box culvert into the River Derwent. The railway embankment appears higher than Main Road, and so blockage of the box culvert under Main Road or during events with flows higher than its capacity, will cause significant ponding.

The low lying areas at Main Road and Lyell Highway and existing bridge causeway are currently at risk to flooding from the River Derwent. This risk increases with rising sea levels.

There is overland flow and pipe discharges for urban stormwater into the River Derwent from on both the eastern and western side of the Midlands Highway.

5.3 Impacts on project land

Results from the 1% AEP storm event indicate that there are some flood impacts within the project land, which is delineated in Figure 2.1. These impacts are described in the following sections based on outcomes from the River Derwent, Southside and Northside hydraulic models.

5.3.1 River Derwent

The additional bridge piers modelled as part of the proposed New Bridgewater Bridge increase water levels on the upstream side of the existing causeway and existing bridge, and decrease water levels marginally downstream of the piers, as observed in the depth difference maps in Figure B.1 and Figure B.2. After the New Bridgewater Bridge is constructed and the existing Bridgewater Bridge is removed (leaving the existing causeway), the difference compared to the existing Bridgewater Bridge is insignificant, as shown in maps in Figure B.3 and Figure B.4.

The most significant inundation of project land occurs on the southern side of Bridgewater Bridge, and the hazard classification results are shown in the inserts in Appendix B.1.

Due to the proposed works, the additional incremental inundation depths for the 1% AEP future 2090 climate for the Lyell Highway within the project land is 0.20 m. The maximum hazard classification is unchanged due to the proposed bridge design, as remains mostly H1 for the 1% AEP current climate and H3 for the 1% AEP future climate. As discussed above in Section 5.2.1, the predicted future 2090 climate has a large impact on the project land.

5.3.2 North of the Bridgewater Bridge

Results from the Northside model indicate that the proposed works has an impact on the existing stormwater overland flow paths, surrounding stormwater infrastructure and neighbouring properties within the project land. However, whilst there are impacts caused by the New Bridgewater Bridge, there are design solutions to mitigate the flood risks.

As illustrated by Figure 4.8, longitudinal drainage infrastructure will be required to capture and convey the runoff that is now directed east of the existing Midland Highway due to the new slip lane. The additional stormwater pits and pipes will redirect the runoff into a new outfall/end of pipe system and into the River Derwent. This should be designed to convey the direct road runoff and also existing overland flow that flows into this slip lane (mainly from the north east).

Given the potential flood hazard caused by this slip lane stormwater, events of at least 1% AEP rain storm should be collected and conveyed safely to the River Derwent – with suitable allowance for climate change and blockage scenarios.

The proposed drainage system at the top of Gunn Street will protect the properties on the corner of Gunn St and Nielsen Esplanade from inundation. These properties include:

- 13 Gunn Street
- 4 Waters Loop
- 6 Waters Loop
- 8 Waters Loop.

5.3.3 South of the Bridgewater Bridge

The results from the Southside model indicate that the proposed works has an impact on the stormwater infrastructure and property within the project land. However, whilst there are impacts caused by the New Bridgewater Bridge, there are design solutions to mitigate the flood risks. Some of the trunk elements of a potential solution have been tested in this study to give confidence there are practical solutions.

Flood risks can typically be managed through additional stormwater infrastructure as well as potential upgrades of some existing stormwater pipes/pits and headwalls. As shown in Figure 4.11, stormwater flows from the hillside west of the proposed works onto the project land, and will need to be captured and conveyed safety underneath road infrastructure. This would involve installation of new stormwater drains, headwalls, pipes and pits. Significant flows from the Black Snake Rivulet will also need to be conveyed. This is likely to require an upgrade[5] of the existing main box culvert underneath the Brooker Highway to account for climate change, the existing flows, new upstream headwall inlet location and additional inflows from the west.

Further work during detailed design would appropriately size the required stormwater infrastructure to ensure that drainage work is capable of collecting water from the hillside and larger upstream catchments (e.g. Black Snake Rivulet). Drainage systems should be designed to ensure runoff onto roads is restricted to direct rainfall only, and that non-road water is conveyed safely next to or under roads for rain storms of at least 1% AEP. Roadways (in particular the underpass for the Brooker Highway) should not be used for overland flow paths unless it can be demonstrated that this will

[5] a duplication of the existing box culvert was used in this study as a preliminary solution, but this would need more analysis during detailed design as this is potentially a large cost item

have a low flood risk to road users. Blockage of underground and overland flows would also be incorporated into the detailed design analysis.

Results from the Southside model indicate that frequency of flooding is expected to increase at property 37 Black Snake River Road as the headwall of the main culvert is moved upstream. This is illustrated by Figure 5.2, indicating that the maximum water depth at 37 Black Snake River Road is greater for the 1% AEP storm event for the Bridgewater Bridge and proposed works. A long section of the maximum water elevation, illustrated in Figure 5.1, shows that the amount of freeboard from the water level in the Black Snake Rivulet to the house is reduced from approximately 1.7 m to 1 m due to the proposed works. However, Entura has been advised that the property has been purchased for demolition, and this reduction in freeboard is therefore not considered a hazard.

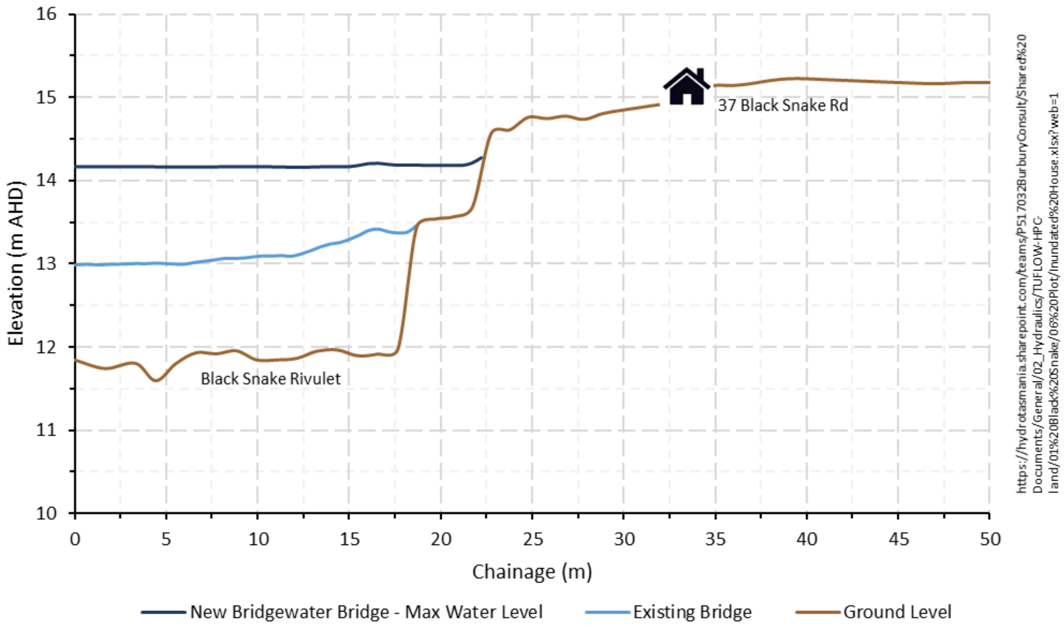

Figure 5.1: Section with flood levels at 37 Black Snake Road

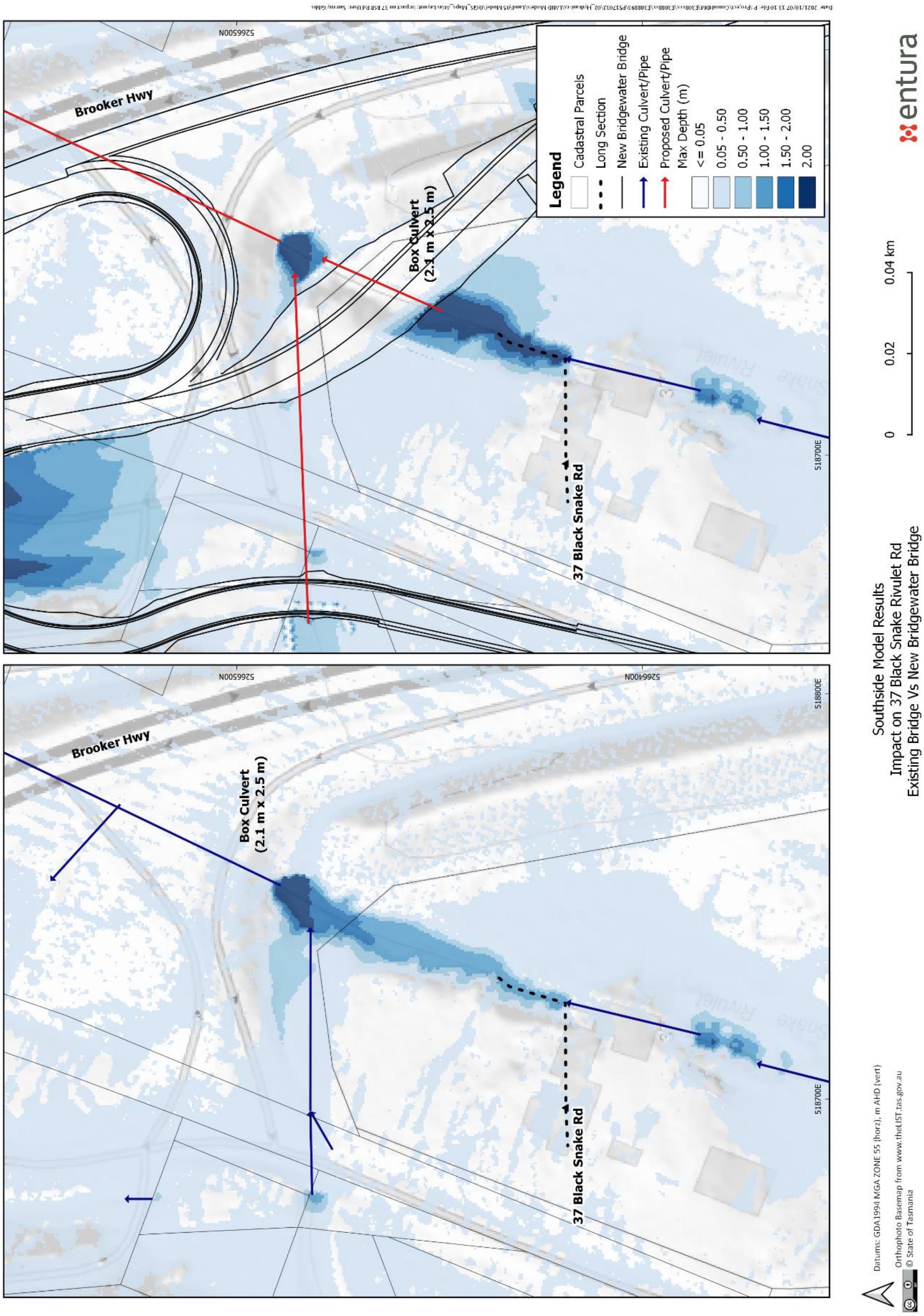

Figure 5.2: Impact on 37 Black Snake Rivulet Rd (existing bridge and new bridgewater bridge)

5.4 Impact on adjacent land

Modelling of a 1% AEP event was used to assess whether the New Bridgewater Bridge project could cause an increase in flood hazard on neighbouring people, buildings, property, services/infrastructure. There are changes to flood hazard on the land adjacent to the River Derwent.

5.4.1 Land adjacent to the River Derwent

The constriction in the main channel caused by the proposed New Bridgewater Bridge will increase water levels upstream of the bridge during floods. However, the proposed future removal of the existing bridge and piers whilst retaining the existing causeway, would effectively offset this increase.

There are low lying buildings which are currently flood prone upstream of the existing bridge and existing causeway. These are also impacted by the New Bridgewater Bridge and are shown in the flood depth difference maps inserts in Figure B.1 and Figure B.2.

On the southern side of existing Bridgewater Bridge, the DPIPWE managed building at 1 Lyell Highway is inundated due to the New Bridgewater Bridge for the modelled 1% AEP future 2090 climate flood by up to 0.25 m depth relative to the LiDAR ground level. On the north side of the existing Bridgewater Bridge, there are a range of residential buildings which are impacted by the New Bridgewater Bridge on Riverside Drive and Wallace Street. However, these buildings would not be inundated under current and future climate 1% AEP floods if the existing bridge and piers are removed.

With both the existing Bridgewater Bridge and the New Bridgewater Bridge, the inundation depths are increased by 0.07 m and 0.09 m for the 1% AEP existing and future climate respectively. For the scenario with just the New Bridgewater Bridge, both the 1% AEP current climate and future climate have decreased inundation water depths by 0.02 m.

The dwellings impacted by the New Bridgewater Bridge's pier groups partially restricting the flow in the River Derwent are

- 1–7 Wallace Street
- 1–5 Riverside Drive.

Until the existing Bridgewater Bridge is removed there is a potential for increasing the flood risk to existing dwellings, hence once the New Bridgewater Bridge design has been confirmed further work with more accurate survey of floor levels could assess this, and also provide options for mitigation if required considering the timing for the removal of the existing bridge. Mitigation options could involve the modifications to the shape and location of proposed New Bridgewater Bridge piers, the installation of levees, and flood management planning.

5.4.2 Land north of the existing Bridgewater Bridge

Results from the Northside model indicate that the impact of the works is contained within the project land (see Section 4.2).

5.4.3 Land south of the existing Bridgewater Bridge

Results from the Southside model indicate that the impact of the works is contained within the project land (see Section 4.3).

5.5 Tolerable risk for use

Results from the modelling indicate the future climate presents a considerable potential flood risk to both the existing Bridgewater Bridge and the New Bridgewater Bridge. Outcomes from all models for the future climate scenario suggest an increase on the inundation extent and flood hazard on low lying roads, with some areas in the current climate. The detailed design would need to consider this in setting its design levels, stormwater infrastructure capacity, as well as protection against sea surge, run-up and wind wave storms.

5.5.1 Nature, intensity and duration of use

The use of the New Bridgewater Bridge will be continuous through the asset life of 100 years. As part of the National Highway, it will convey traffic 24 hours a day in varying intensities, including during a range flood conditions. The importance of this structure under the road design guidance will determine its level of service expressed as a rarity of floods. It's expected that, as a minimum, the road should be safely trafficable during 1% AEP rain and sea storms, including the impact of future climate changed expected over its asset life.

5.5.2 Type, form and duration of development

The proposed New Bridgewater Bridge is permanent civil infrastructure works designed to last 100 years. These works include roads, roundabouts, bridges and drainage systems.

5.5.3 Change in risk level across life of development

Flood risks are expected to increase over time due to climate change. This was demonstrated by the modelling results comparing the current climate and future climate scenarios (e.g. Section 4.1.2.1). The expected long term changes in the future will be more intense rainfall and higher sea levels, both increasing flood risks on the land, estuarine and coastal areas. The actual impact of climate change remains uncertain with the rate of climate change dependent on community, earth system feedback loops and global government response.

This study only considered the direct flood water changes from climate change, but there is the potential for complex interactions with other aspects of climate change with hydrological processes and flood risk. For example, temperature increases could lower the strength of asphalt, more variable annual rainfall could shrink and swell road sub-base which deforms the asphalt, both increasing the cracking of the asphalt seal, and in turn making roads more erosion prone in large overland flows and so less safe for drivers.

Risk of flood inundation is expected to increase at the downstream extents of the Southside model including Main Road, Black Snake Road and portions of the Lyell Highway, and the road to the existing bridge. This will occur over time due to rising sea levels. Elevating the levels of the design road would reduce the risk of inundation and flood hazard.

Climate change also presents an increased risk of exceeding the capacity of stormwater infrastructure systems causing overflow and water pooling on adjacent lands.

As context for the uncertainty changes to risk duration the New Bridgewater Bridge's asset life, there is some certainty about the occurrence of flood events, which is why they have been considered in this work. Hydrologically, the probability of a least one 1% AEP flood occurring during the asset life is approximately 63%, and an almost certain chance of a 10% AEP flood. In the current climate there are areas of the project land that would be flooded in the 1% AEP flood unless the design levels were raised and the future climate areas with the 10% AEP flood that would cause similar flooding. Hence for relatively constant use, for a tolerable flood risk for the community, the design levels should be to at least the 1% AEP flood based on an appropriate future climate.

5.5.4 Ability to adapt to a change in risk level

With civil infrastructure there is limited capacity to adapt to increases in flood risk without large costs. It is usually more cost effective to design infrastructure to cope with the future flood risks, or to accept that future levels of service will decrease potentially below currently acceptable levels.

Stormwater infrastructure and design road elevations for the New Bridgewater Bridge should consider future climate during the detailed design, in particular the lower areas where Main Road and Black Snake Road meet. Alternative solutions to increasing road elevations could be considered if they provided a similar level of protection and reliability to this protection. One alternative that could be constructed later as sea levels rise, would be levees. Levees could also requiring pumps to protect the "dry" side of the levee from local runoff building up behind the levee. If pumps are required they may not be a reliable as solutions without the need for mechanical (e.g. one-way valves or gates) or human intervention (e.g. manually installing flood gates).

The staging and timing of new works adjacent to the project land should be adaptive to a changing climate. This would include low lying and flood prone roadways and bridges, such as the Lyell Highway immediately west of the project land. Plans for this adaption should be considered as part of the detailed design for the New Bridgewater Bridge, so as to reduce the cost of future rework for how the New Bridgewater Bridge connects to other road infrastructure. For example, the Lyell Highway may need to be raised in the future to reduce its risk of flooding, and this potential increase in level within and adjacent to the project land may modify the concept for how the New Bridgewater Bridge transitions to the existing and potential increased levels.

5.5.5 Ability to maintain access to utilities and services

To provide safe use of the approach roads and New Bridgewater Bridge, the road levels, overland flow paths and underground drainage conveyance need to be designed to maintain access without inundation of hazardous surface water up to the 1% AEP design event. The importance of providing safe use is flood waters can damage roadways and bridges to make them unserviceable and floodwaters can inundate driving surfaces to make them unsafe. There are risk of drowning for people caught in flood waters or driving into them.

As the civil design of the New Bridgewater Bridge and associated roadworks are not finalised, to manage the risk of flood hazards to acceptable levels, further flood modelling is expected to be undertaken during the detailed design of the New Bridgewater Bridge. This will consider future climate impacts, and adequately size the required stormwater infrastructure to discharge flows safely into the River Derwent. Design levels of the road and bridge should also be revised to ensure the infrastructure is not inundated by rises in sea level, or alternatives devised to provide a similar level of protection.

While this assessment focuses on the 1% AEP flood, as context it is noted the proposed New Bridgewater Bridge can be subject to rain storms other rarities down to the probable maximum flood, and also floods from dam breaks and tsunamis. These storms would include the 1:2000 AEP flood, which would be used for the ultimate limit states design of the bridge structure. During such an event, the River Derwent flood waters will interact with the superstructure of the bridge. These events would be considered during detailed design and in other flood management planning.

5.5.6 Need for flood protection measures beyond the boundary of the project land

Flood protection measures may be required beyond the boundary of the project land to:

- Ensure connectivity to the New Bridgewater Bridge. As inundation of the Lyell Highway is expected to occur more frequently over the life of the development due to climate change, the proposed design of the New Bridgewater Bridge and associated roadworks should consider future design solutions of the roads external to the project land. Note that this part of the road network does not form part of the National Highway and therefore receives reduced levels of traffic.
- Mitigate the increased flood risk on the northern side of the river, just upstream from the bridge around Riverside Drive. Further modelling during detailed design will be required to assess if mitigation is required, which would involve surveying floor levels of potentially impacted dwellings and surrounding land, then using a similar flood modelling approach for a range of climate and hydrological scenarios. If required, mitigation beyond the project land may involve levees, compensation and emergency management planning. Consideration would be given to the fact there is an existing flood risk without the proposed New Bridgewater Bridge and the timing[6] of the removal of the existing bridge.

5.5.7 Flood management plan

There will be a residual flood risk to be managed due to rain and sea storms beyond those designed for, and if infrastructure does not perform as expected (e.g. due to design, construction or maintenance issues).

Flood management planning will help manage this residual risk, and would include emergency and evacuation planning with the State Emergency Services and relevant asset owners (Department of State Growth, local Councils and the Hydro-Electric Corporation). This work could be part of the Safety in Design process undertaken during the detailed design, and after works are complete as part of existing processes with State Emergency Services and Tasmania Police.

There are strategies the stormwater assets and risk from climate change, but currently relevant Council Flood management planning is relatively early days. There has been some flood modelling undertaken, which will form into future plans – but to date no criteria have been publicly released for acceptable flooding levels. For this study guideance is taken from the flood hazard parts of Australian Rainfall and Runoff.

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[6] The most common event that caused an intolerable flood hazard within the period prior to the existing Bridgewater Bridge being removed, would give a probability of that hazard (similar to Table 3.1)

5.6 Advice on ongoing management

After the works are complete there is an expectation the infrastructure will be maintained or upgraded to manage flood risks to acceptable levels. This would involve regular inspections, maintenance and less frequently the re-assessment of flood risks (in particular in the context of a changing climate, but also considering land use and planning changes).

Underground drainage infrastructure is most at risk from a lack of management and premature asset failure. There is potential for inlets to be blocked, culverts and their outlets to become silted up, and culverts structurally fail. Adequate design can help reduce the sensitivity of infrastructure to poor maintenance and also facilitate good practices. This includes designing safe access for maintenance, self cleaning and erosion control.

Even with good design, there will always be some management to maintain the integrity of the infrastructure and help manage residual flood risks (Section 5.5.7).

6. Conclusions

- This assessment has created three two-dimensional hydraulic models for areas around the proposed New Bridgewater Bridge. They extend from 7.3 km upstream of the Bridgewater to the Tasman Bridge, and encompass the land areas around the civil works on the northern and southern sides of the river. The models in this study were used to describe the effect of the New Bridgewater Bridge during a 1% Annual Exceedance Probability (AEP) storm during the current and future climates. The flood hazard impact was assessed for the completed works. A comparison was made with and without the New Bridgewater Bridge, primarily during the future climate as this was a more adverse scenario.
- Based on a simple joint probability approach, suitable for a planning level assessment:
  - The combination of 1% AEP river flood with Highest Astronomical Tide, gave higher flood levels than a 10% AEP river flood with 1% AEP sea storm levels;
  - The Southside and Northside models used a 1% AEP storm with tailwater levels from a 10% AEP River Derwent flood (Table 4.1).
- During the future climate with a 0.85 m sea level rise, the modelled 1% AEP flood under current conditions (i.e. without the proposed New Bridgewater Bridge) shows there are existing intolerable flood risks:
  - Overtopping of the existing causeway in some areas
  - Flooding of some low lying properties on the northern side of the River Derwent, just upstream of the existing bridge
  - Overland flows through some properties in Bridgewater
  - Flows over roadways around Black Snake Rivulet.
- During the future climate with a 0.85 m sea level rise, the 1% AEP flood with the proposed New Bridgewater Bridge completed and existing bridge and piers retained:
  - Water levels increase upstream of the existing causeway and proposed New Bridgewater Bridge approximately 0.07 m, causing an increase in flood risk which may require mitigation due to
    - More overtopping of the existing causeway
    - Minor increase in flood extent over a dwelling on the south side of the river and 12 houses on the north side of the river; dwellings that were already inundated without the works
  - Reduced flood protection at 37 Black Snake Road, but not inundating the habitable areas and so is still tolerable. (Note: This building is to be demolished as part of the project.)
- The expected subsequent removal of the existing bridge and piers whilst retaining the existing causeway will approximately offset the increase in flood risk to the houses upstream of New Bridgewater Bridge during the 1% AEP flood in the current and future climates.
- The potential reclamation works at the south and north side of the bridge are expected to have a negligible impact on flood risk.

- To allow for a tolerable flood risk for the use of the New Bridgewater Bridge there is a need for
  - Upgrading of existing drainage infrastructure and design of new infrastructure as part of detailed design; this should safely convey overland flow during the 1% AEP event off roadways and away from dwellings, in particular to convey the Black Snake Rivulet, local hillside runoff around the on/off ramps
  - Lifting the design levels of low lying parts of the proposed roadway on the south side of the River Derwent near the intersection of Main Road and Black Snake Road, so they are not inundated as sea levels rise, and allowing for sea surge and wind wave actions, or provide an alternative with a similar level of protection and reliability
  - Consideration of linking to roads inside and adjacent to the project land that may require higher surface levels in the future to protect against rising sea levels, in particular the Lyell Highway within and immediately to the west of the project land.
- As part of detailed design it is expected flood hazards will be reassessed along with the need for potential mitigation, in particular due to the increased flood risk to dwellings upstream of the existing Bridgewater Bridge, to the New Bridgewater Bridge and to the existing causeway. Subject to the final design and timing of the removal of the existing bridge, no further mitigation may be required to have a tolerable flood risk.
- Residual flood risks and maintenance will require the administrative control of ongoing management, as would be normal for this type of civil infrastructure to have a tolerable flood risk.

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Appendices

A Data

A.1 Rainfall Data (1% AEP)

Duration	Northside rain depth (mm)	Southside rain depth (mm)
1 min	3.17	3.33
2 min	4.77	5.03
3 min	6.51	6.88
4 min	8.11	8.56
5 min	9.55	10.1
10 min	14.8	15.5
15 min	18.2	18.9
20 min	20.6	21.4
25 min	22.5	23.3
30 min	24.0	25.0
45 min	27.6	28.9
1 hour	30.3	32.1
1.5 hour	34.8	37.5
2 hour	38.6	42.3
3 hour	45.2	51.0
4.5 hour	53.9	62.5
6 hour	61.5	72.9
9 hour	74.7	91.1
12 hour	85.8	107
18 hour	104	131
24 hour	117	150
30 hour	128	164
36 hour	136	175
48 hour	148	191
72 hour	161	208
96 hour	167	215
120 hour	169	218
144 hour	170	220
168 hour	170	222

A.2 RORB Hydrological Inputs

Table A.1: Hydrological model parameters for ungauged catchments near Granton

Item	Black Snake Rivulet	Forest Road Catchment	Source
Catchment Area (ha)	448.5	60	Measured
Kc	2.03	0.64	Western Tasmania (kc = 0.86 × $A^{0.57}$) (ARR, 2019a)
Initial Loss (mm)		27	(ARR, 2019a)
Continuing Loss (mm/hour)		3.8	(ARR, 2019a)

A.3 Hydraulic Rainfall Losses

Table A.2: Rainfall losses applied per land use in the hydraulic models

Land Use Category	Initial Loss (mm)	Continuing Loss (mm/hr)
Road reserves	2	0
Roads and paved areas	2	0
Open space / maintained grass (e.g. sports fields)	10	2
Medium maintained grass / open space	10	2
Agricultural	10	2
Vegetation	10	2
Commercial	2	0
Residential	2	0
River channel and marshland overbanks	2	0

B Flood Maps

B.1 River Derwent model outputs

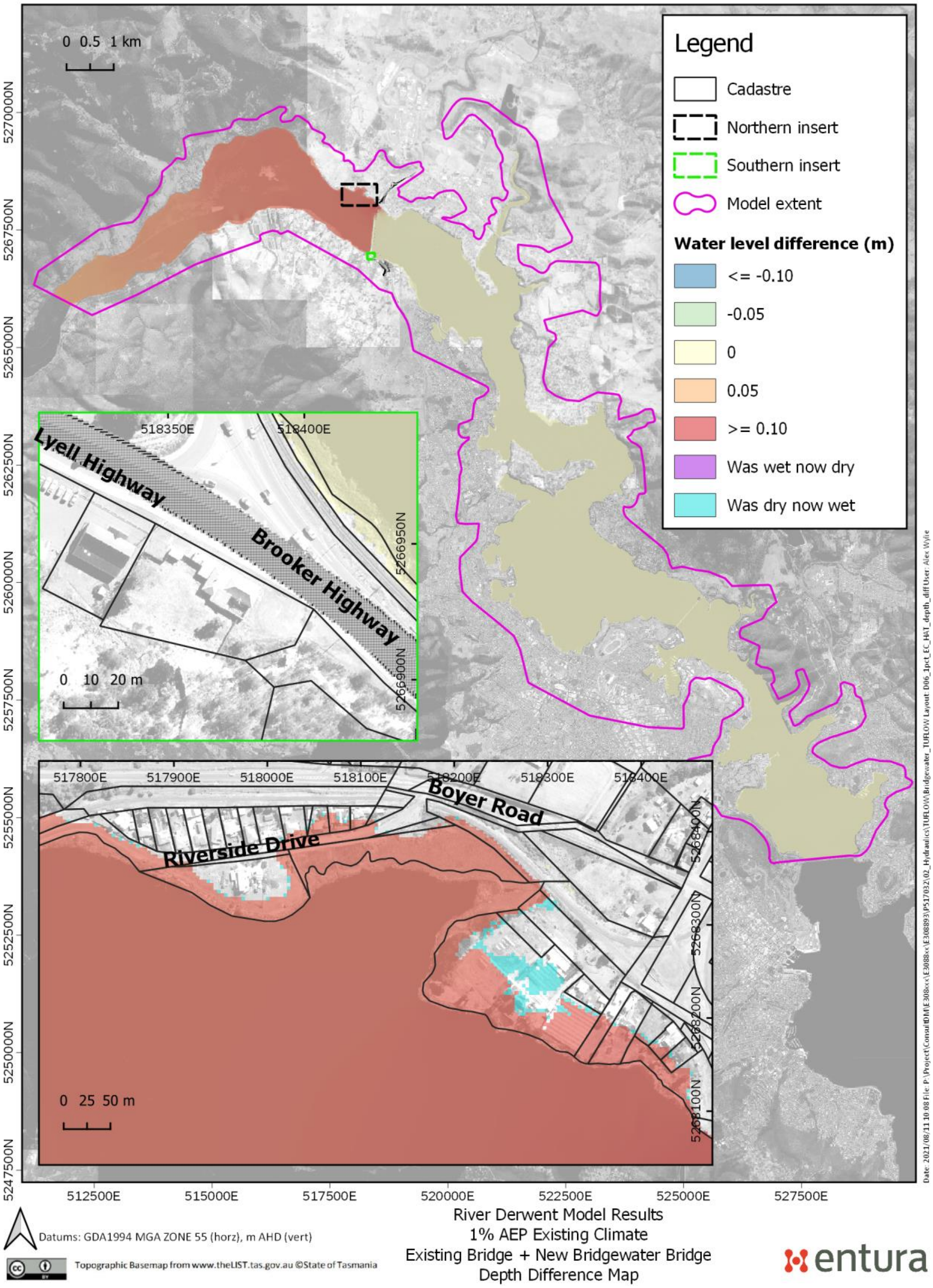

Figure B.1: New Bridgewater Bridge + existing Bridge current climate flood depth difference

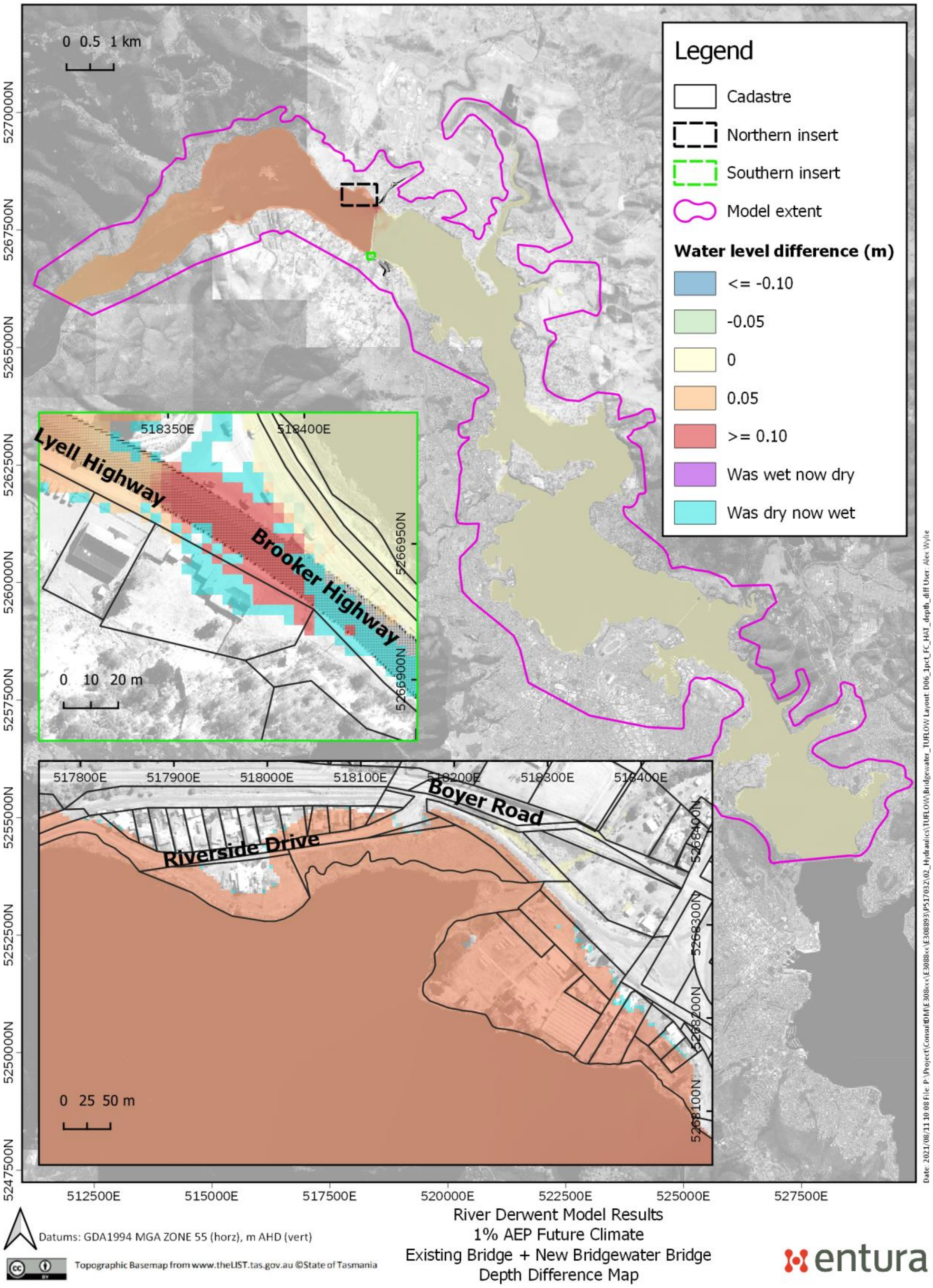

Figure B.2: New Bridgewater Bridge + existing Bridge future 2090 climate flood depth difference

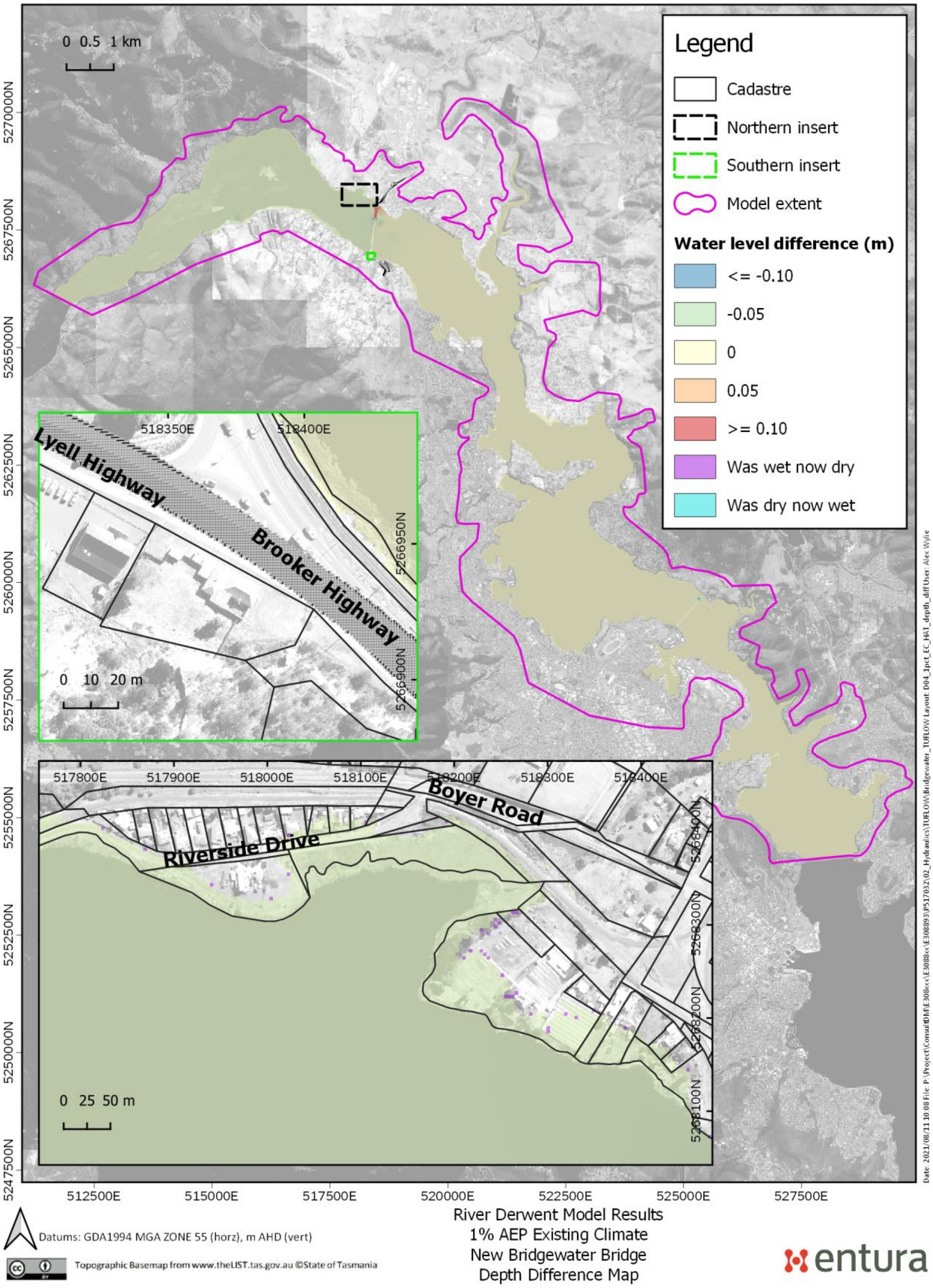

Figure B.3: New Bridgewater Bridge current climate flood depth difference

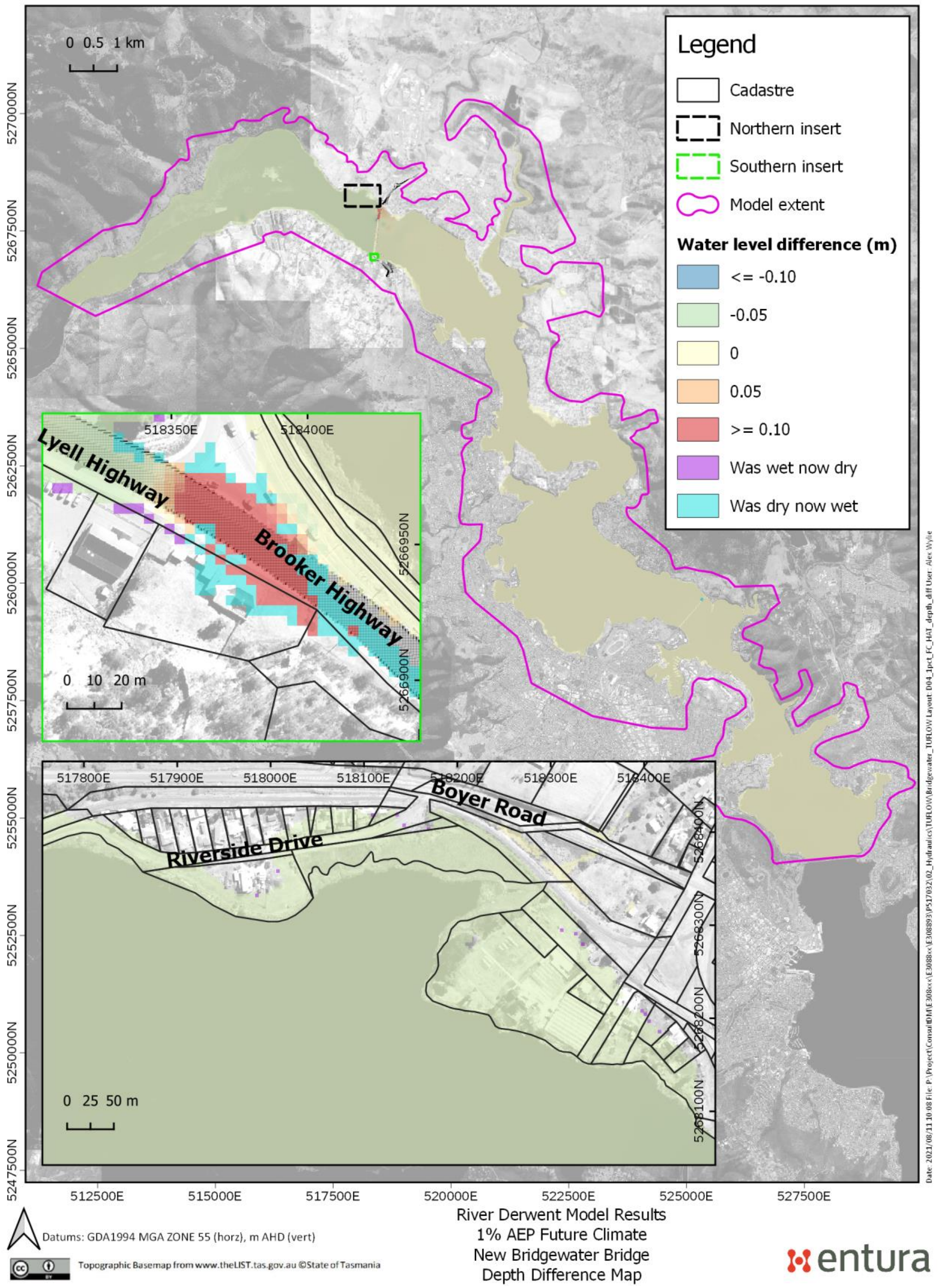

Figure B.4: New Bridgewater Bridge future 2090 climate flood depth difference

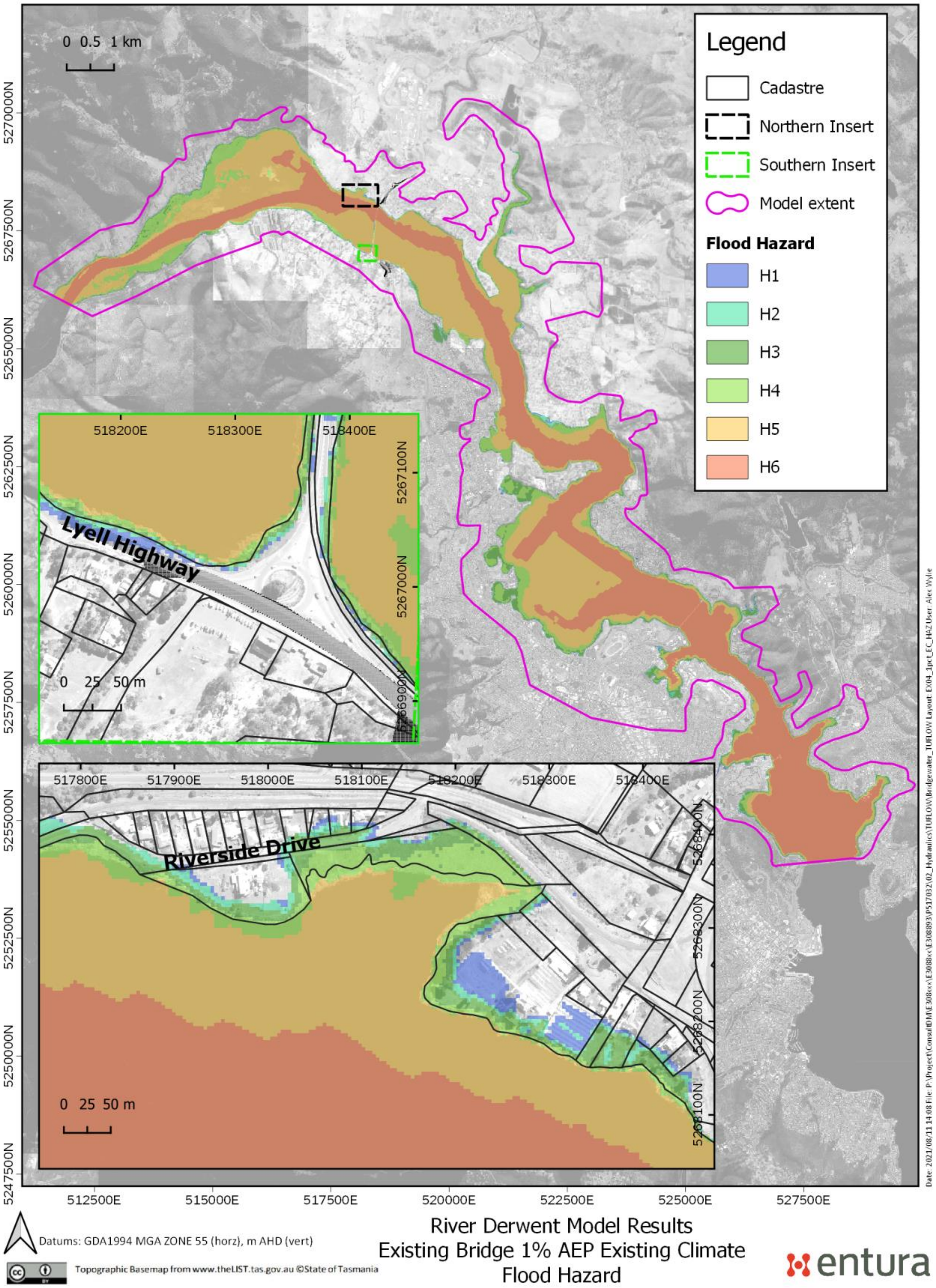

Figure B.5: Existing Bridge current climate flood hazard classification

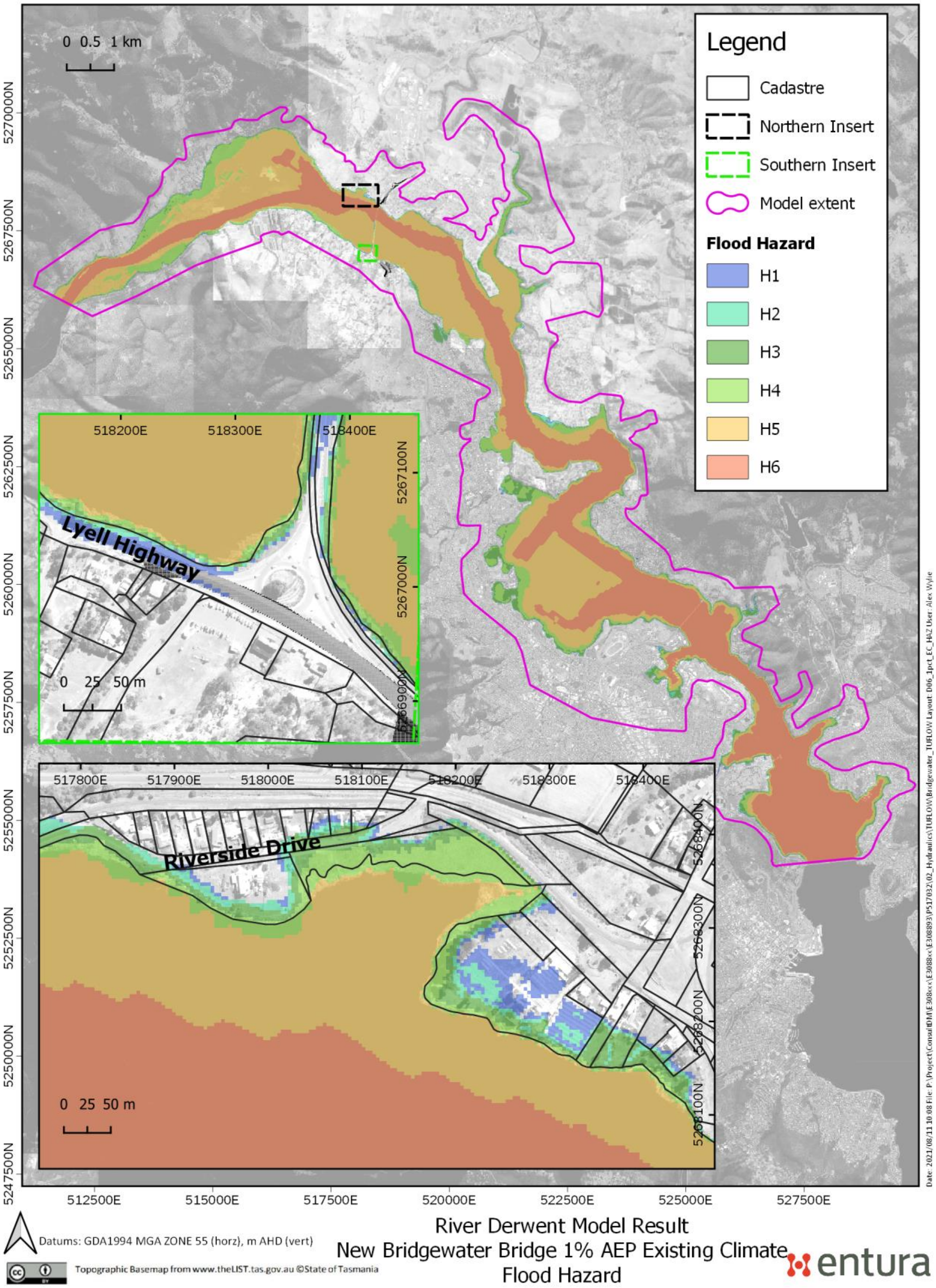

Figure B.6: New Bridgewater Bridge current climate flood hazard classification

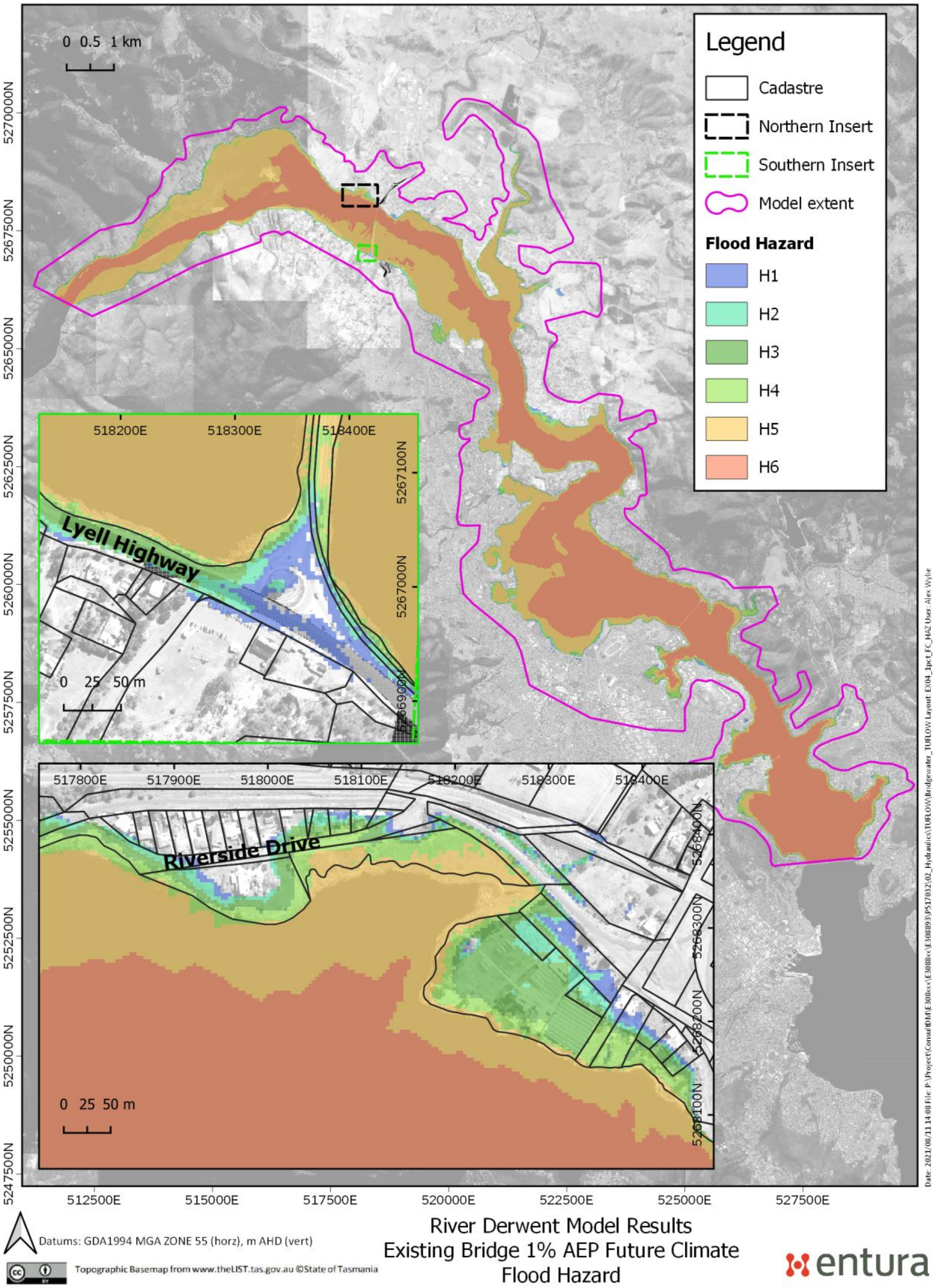

Figure B.7: Existing Bridge future 2090 climate flood hazard classification

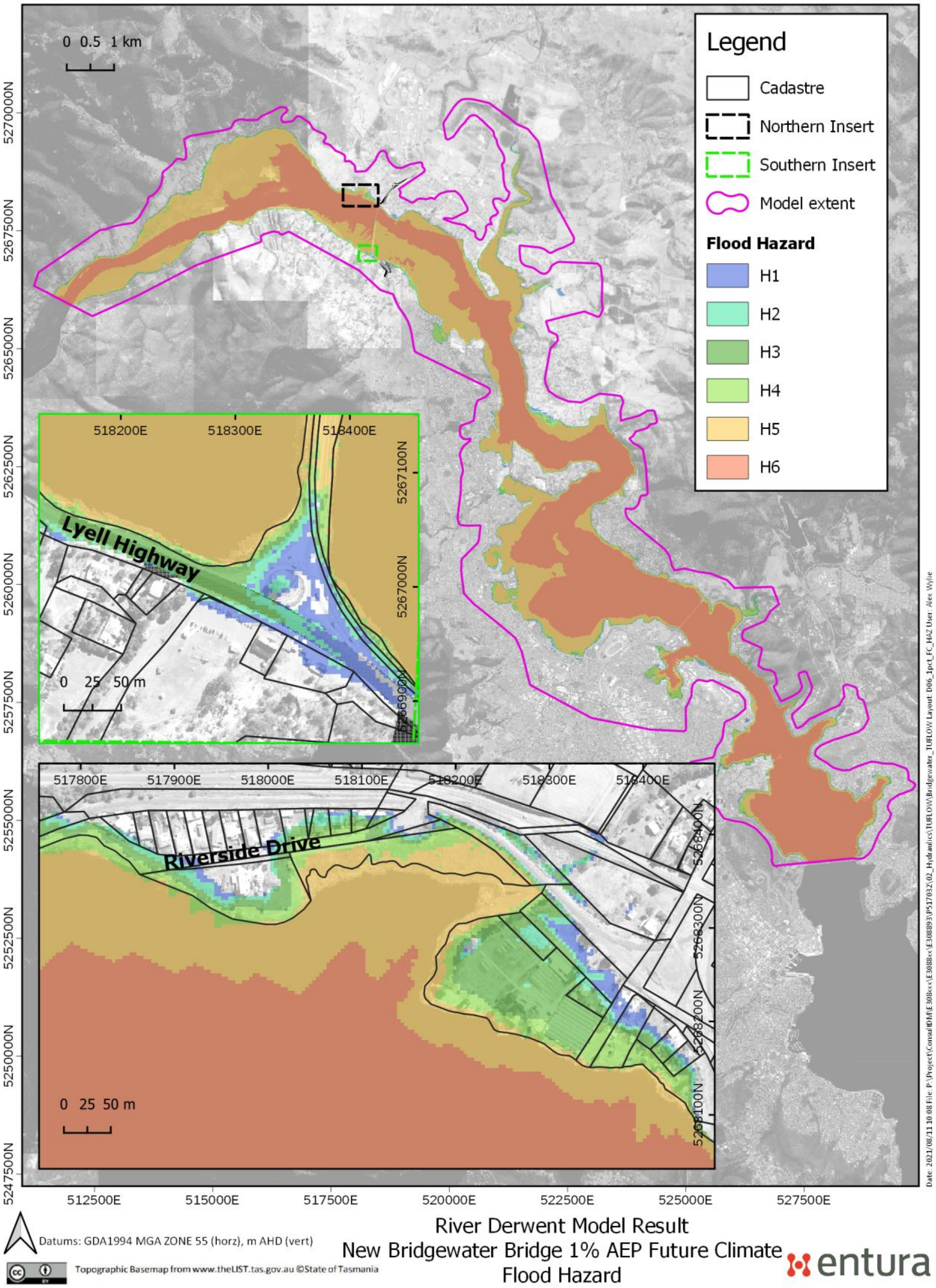

Figure B.8: New Bridgewater Bridge future 2090 climate flood hazard classification

B.2 Northside model outputs

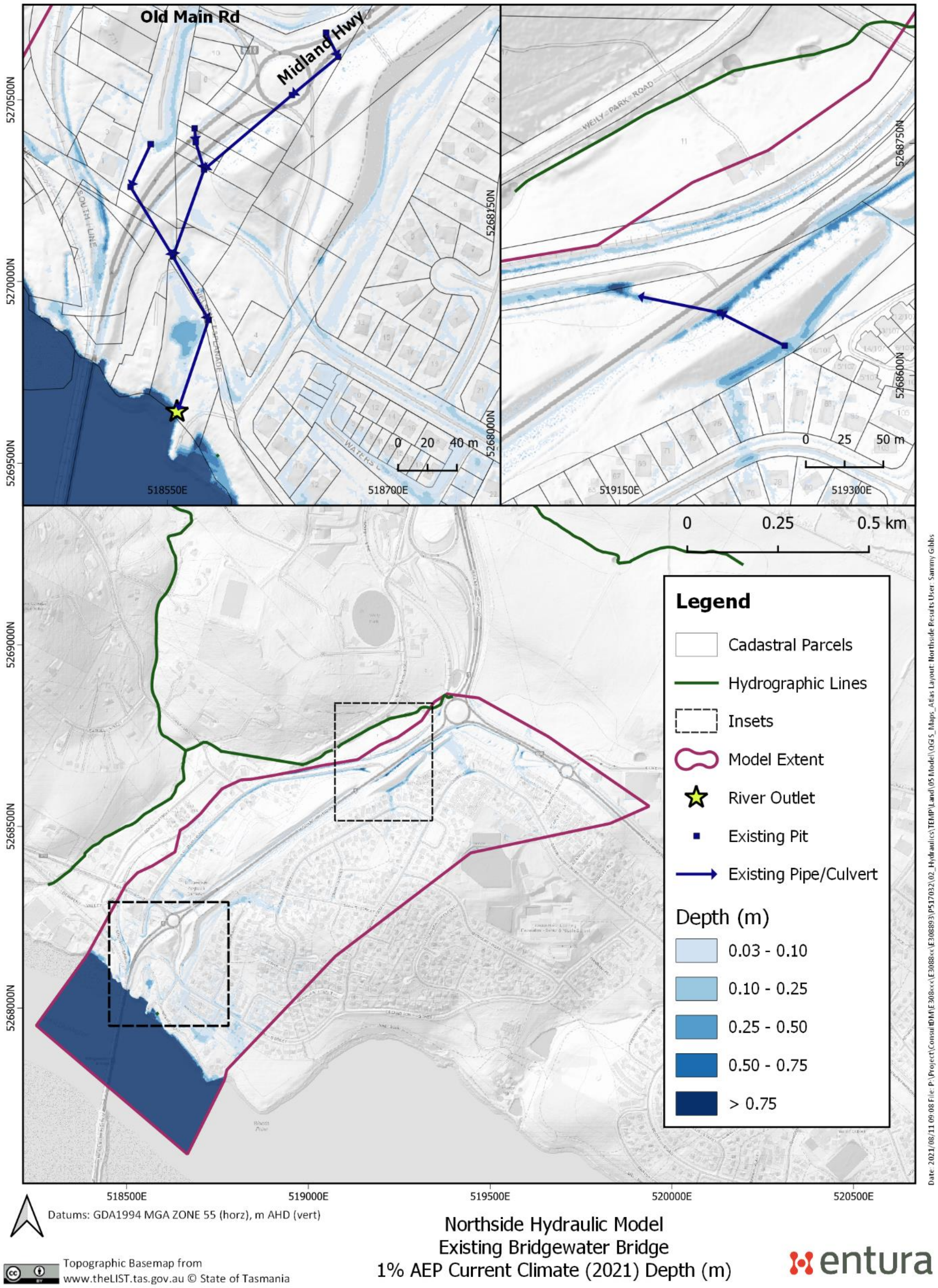

Figure B.9: Existing Bridgewater Bridge current climate (2021) depth

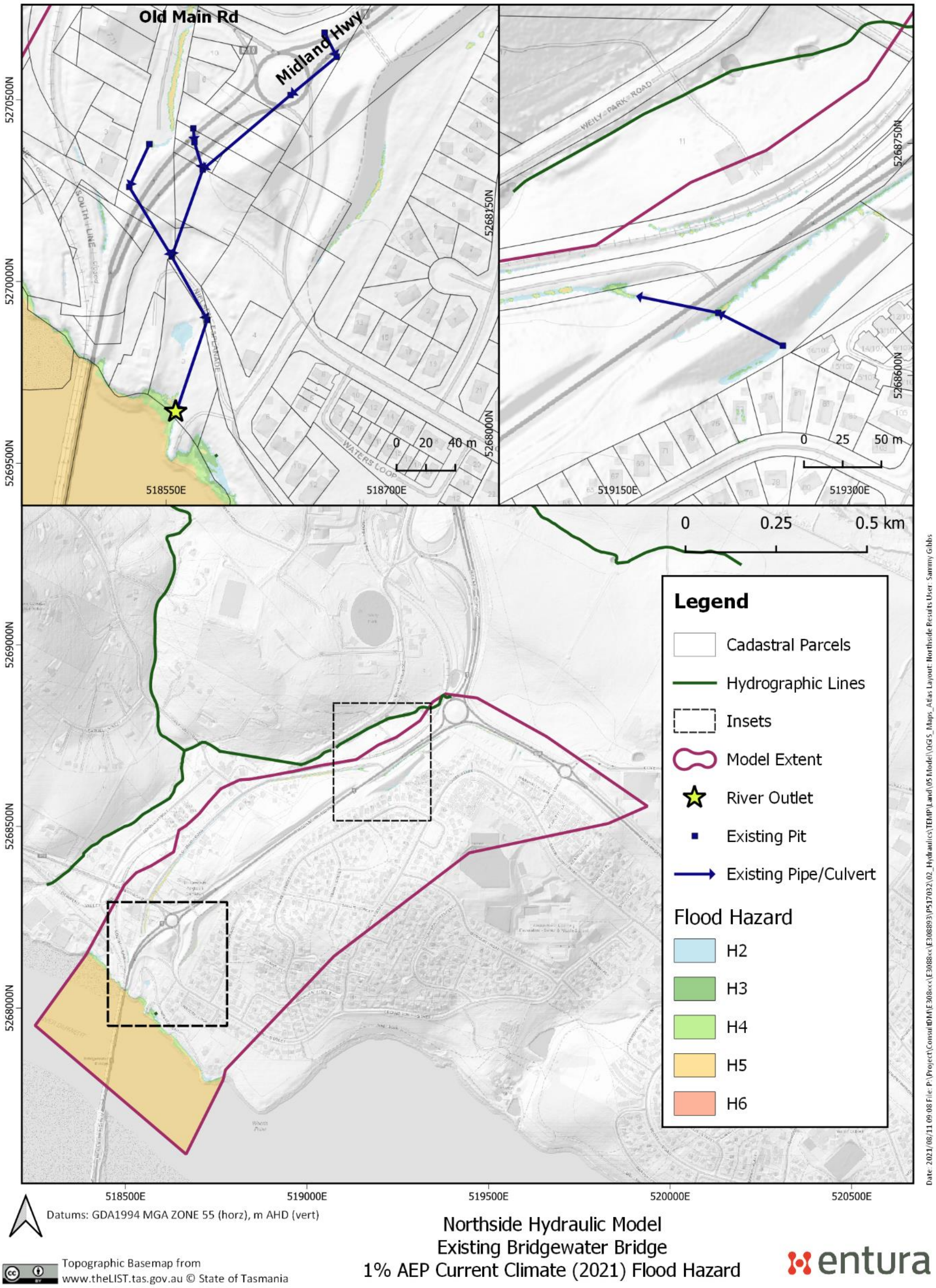

Figure B.10: Existing Bridgewater Bridge current climate (2021) flood hazard

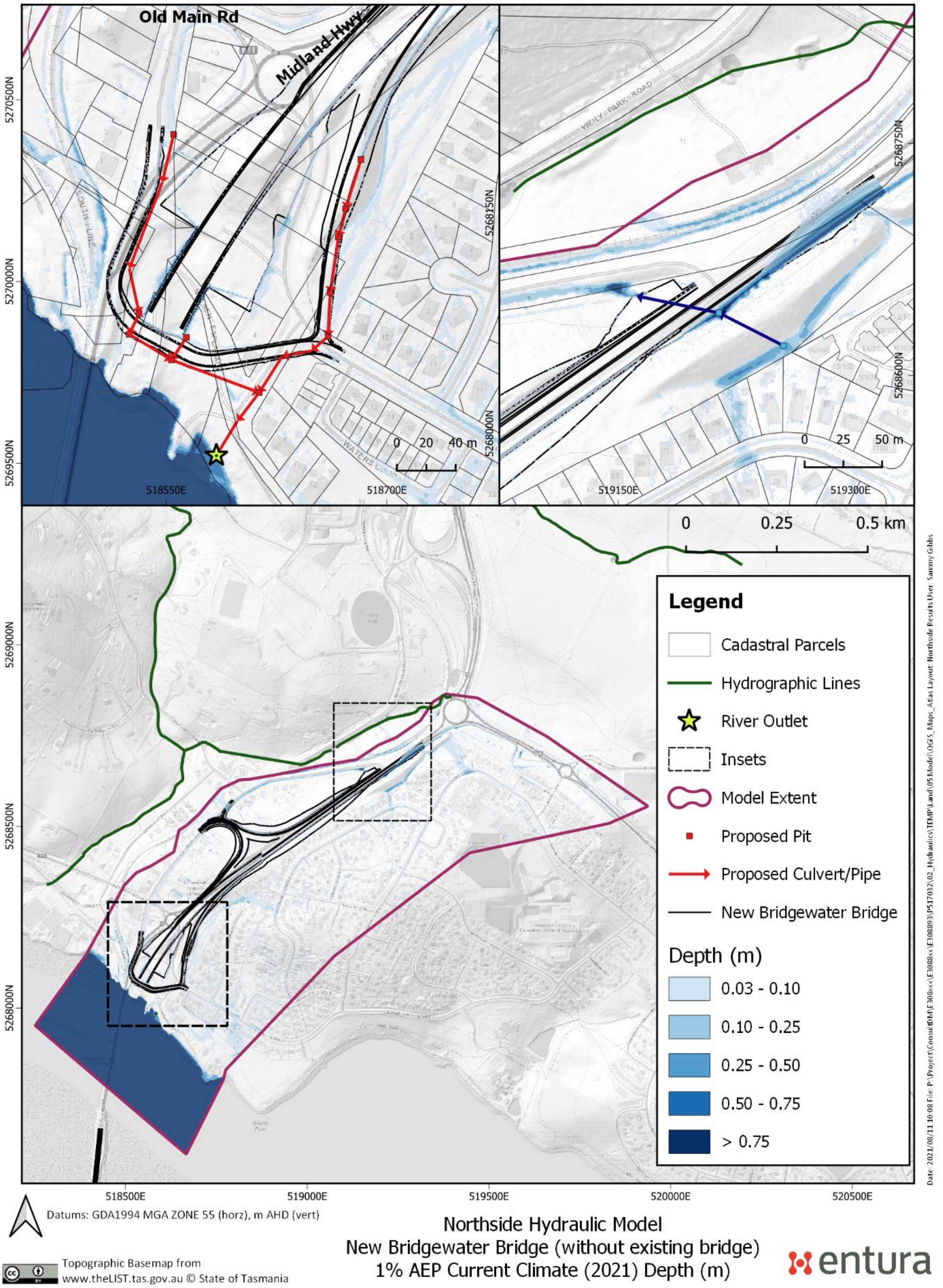

Figure B.11: New Bridgewater Bridge current climate (2021) depth

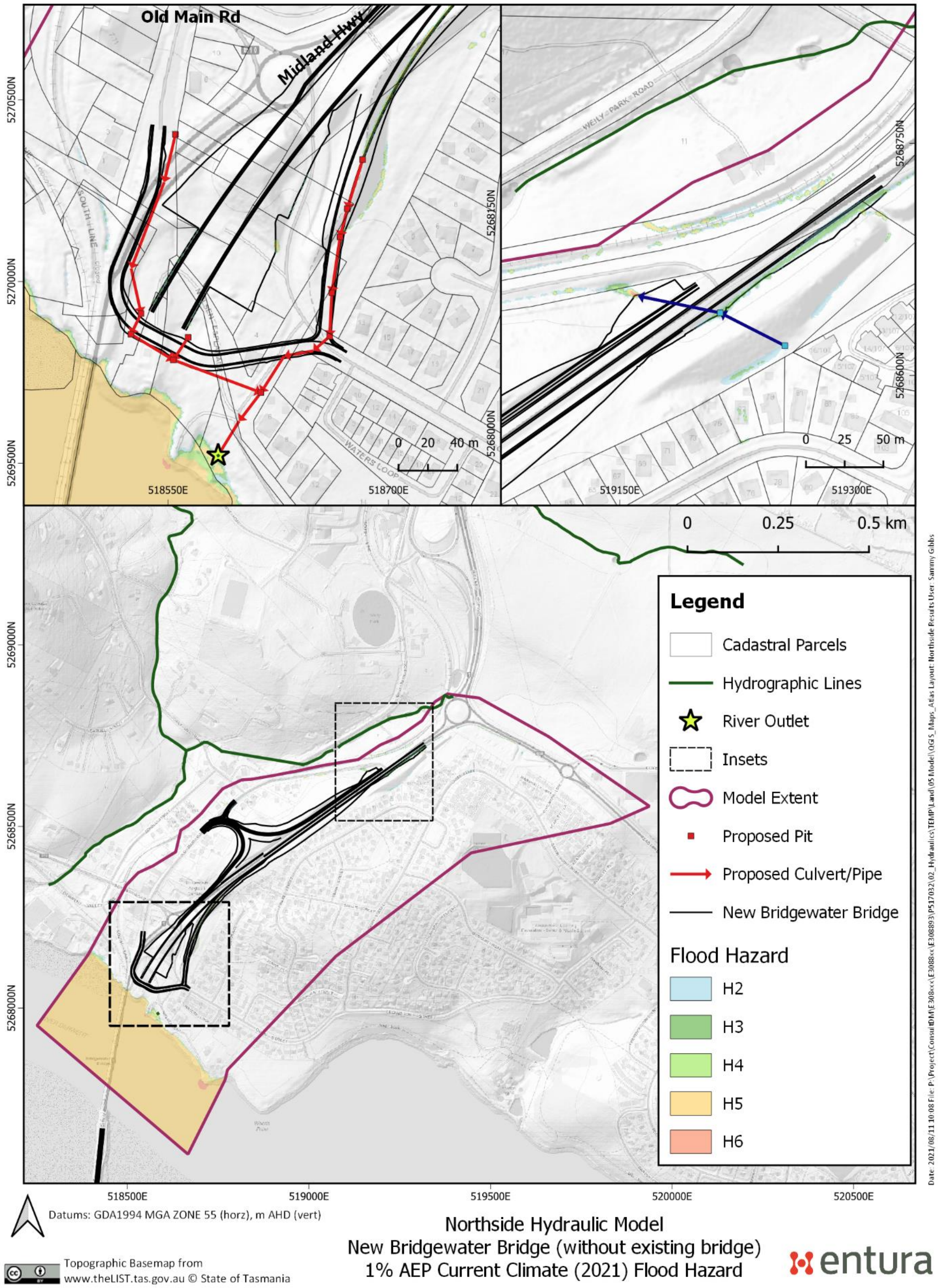

Figure B.12: New Bridgewater Bridge current climate (2021) flood hazard

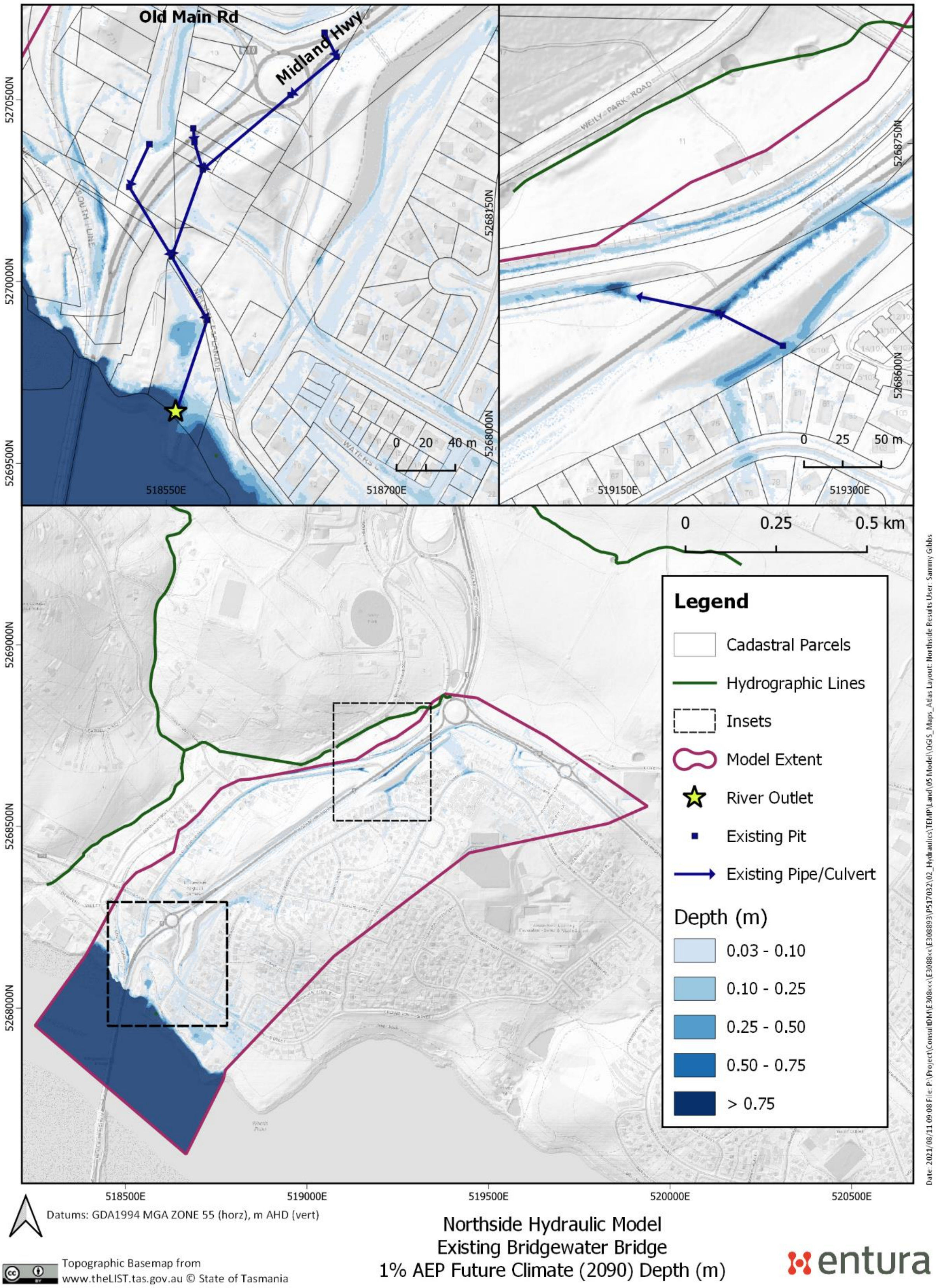

Figure B.13: Existing Bridgewater Bridge future climate (2090) depth

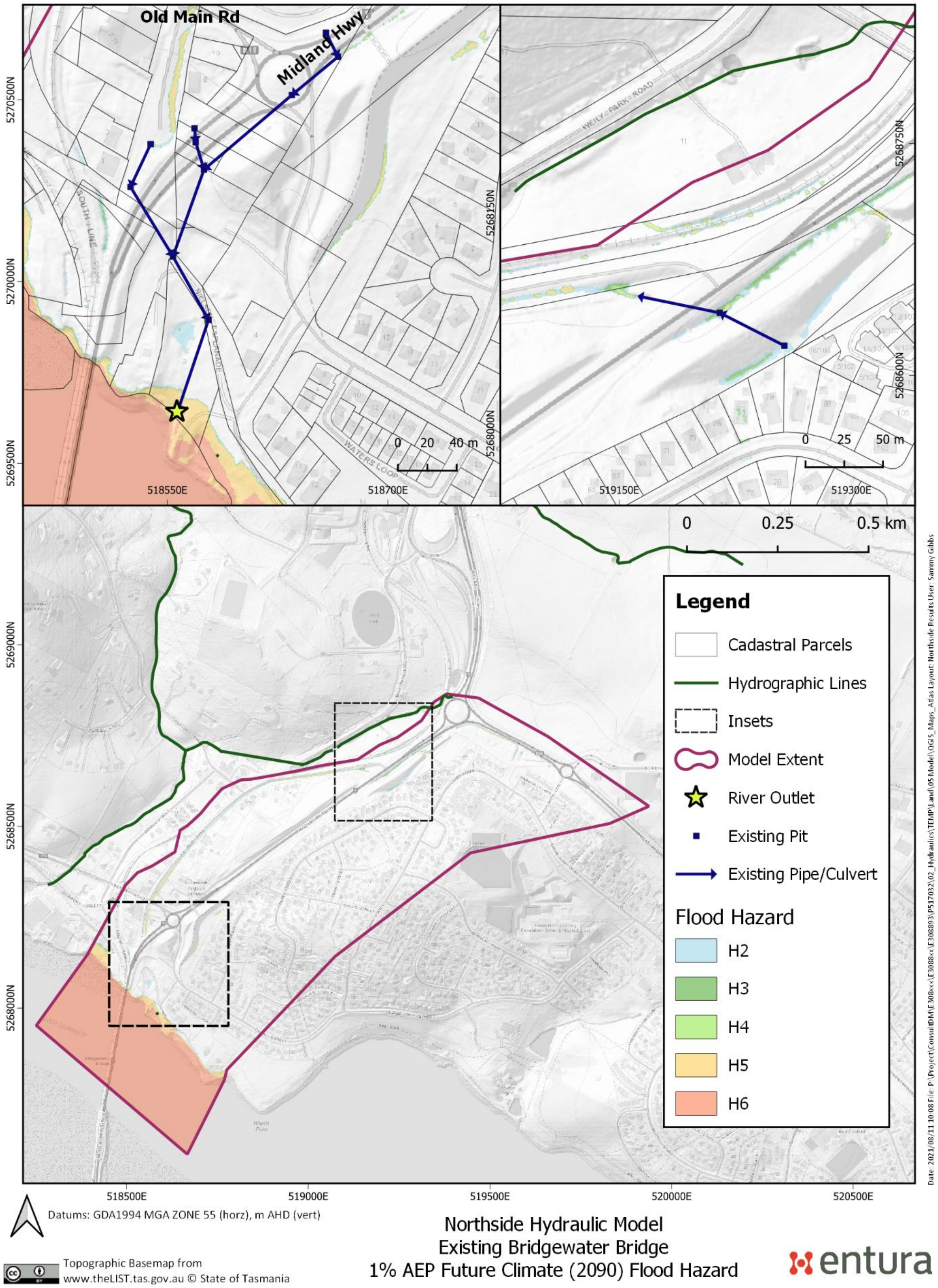

Figure B.14: Existing Bridgewater Bridge future climate (2090) flood hazard

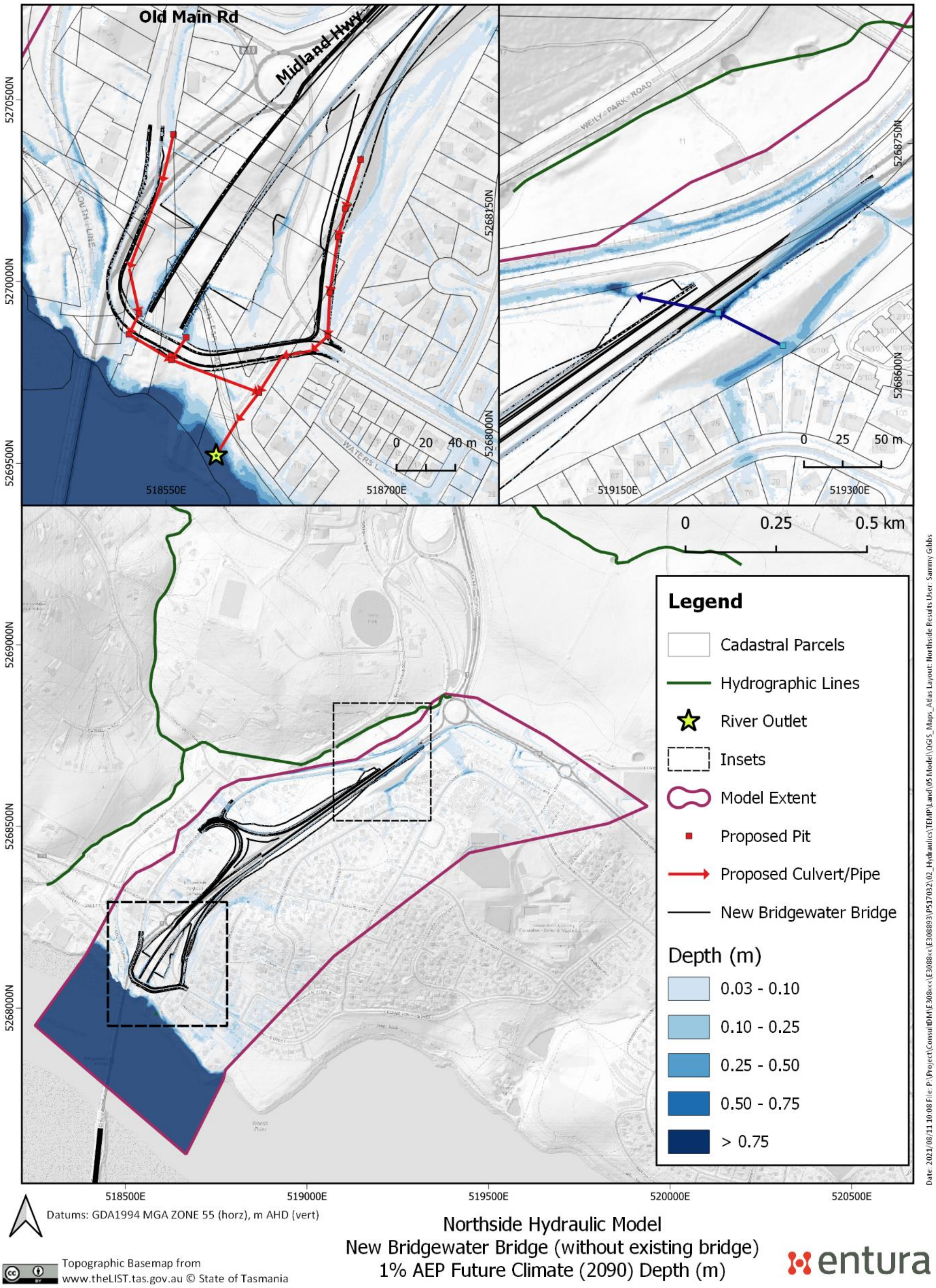

Figure B.15: New Bridgewater Bridge future climate (2090) depth

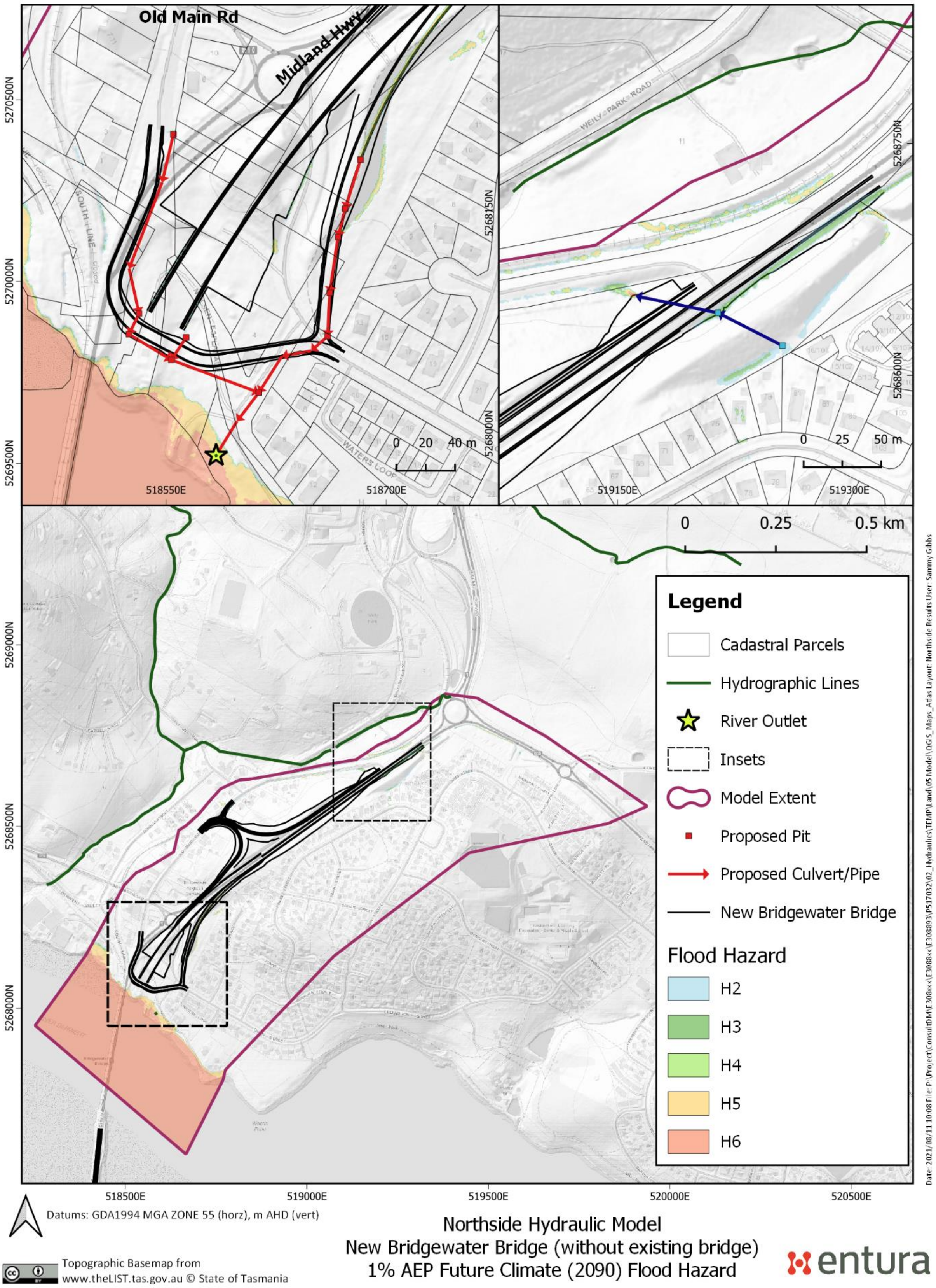

Figure B.16: New Bridgewater Bridge future climate (2090) flood hazard

B.3 Southside model outputs

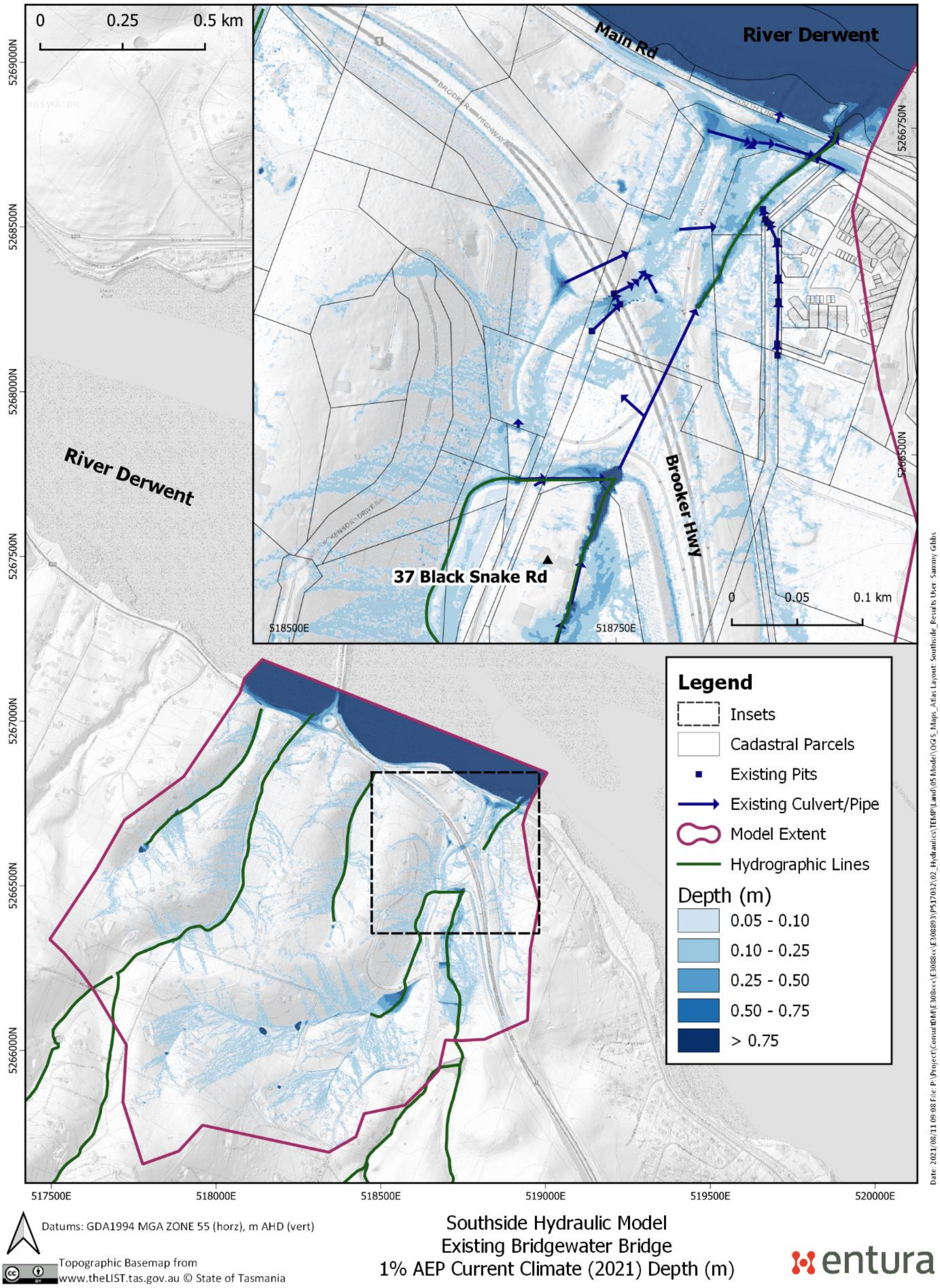

Figure B.17: Existing Bridgewater Bridge current climate (2021) depth

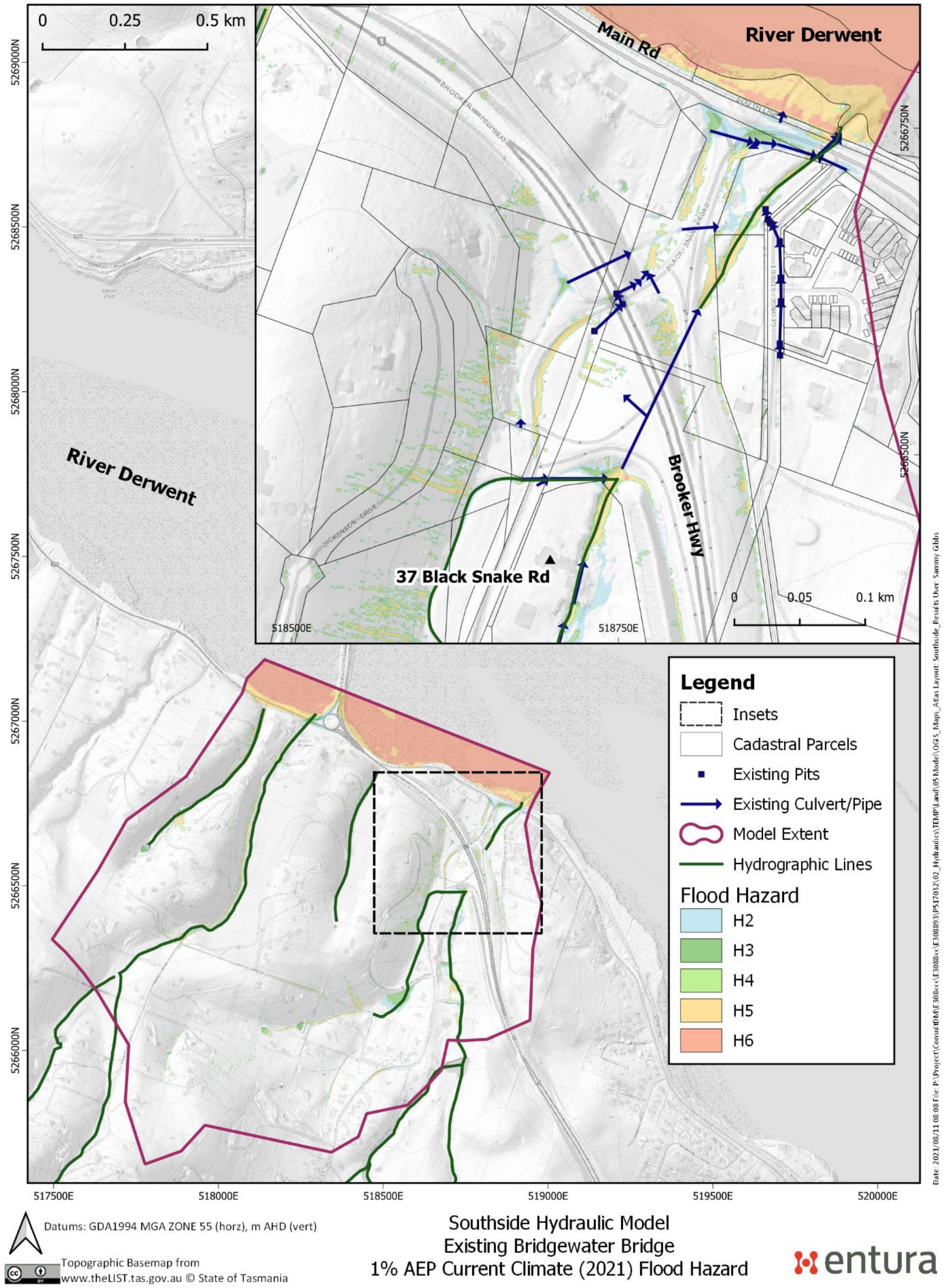

Figure B.18: Existing Bridgewater Bridge current climate (2021) flood hazard

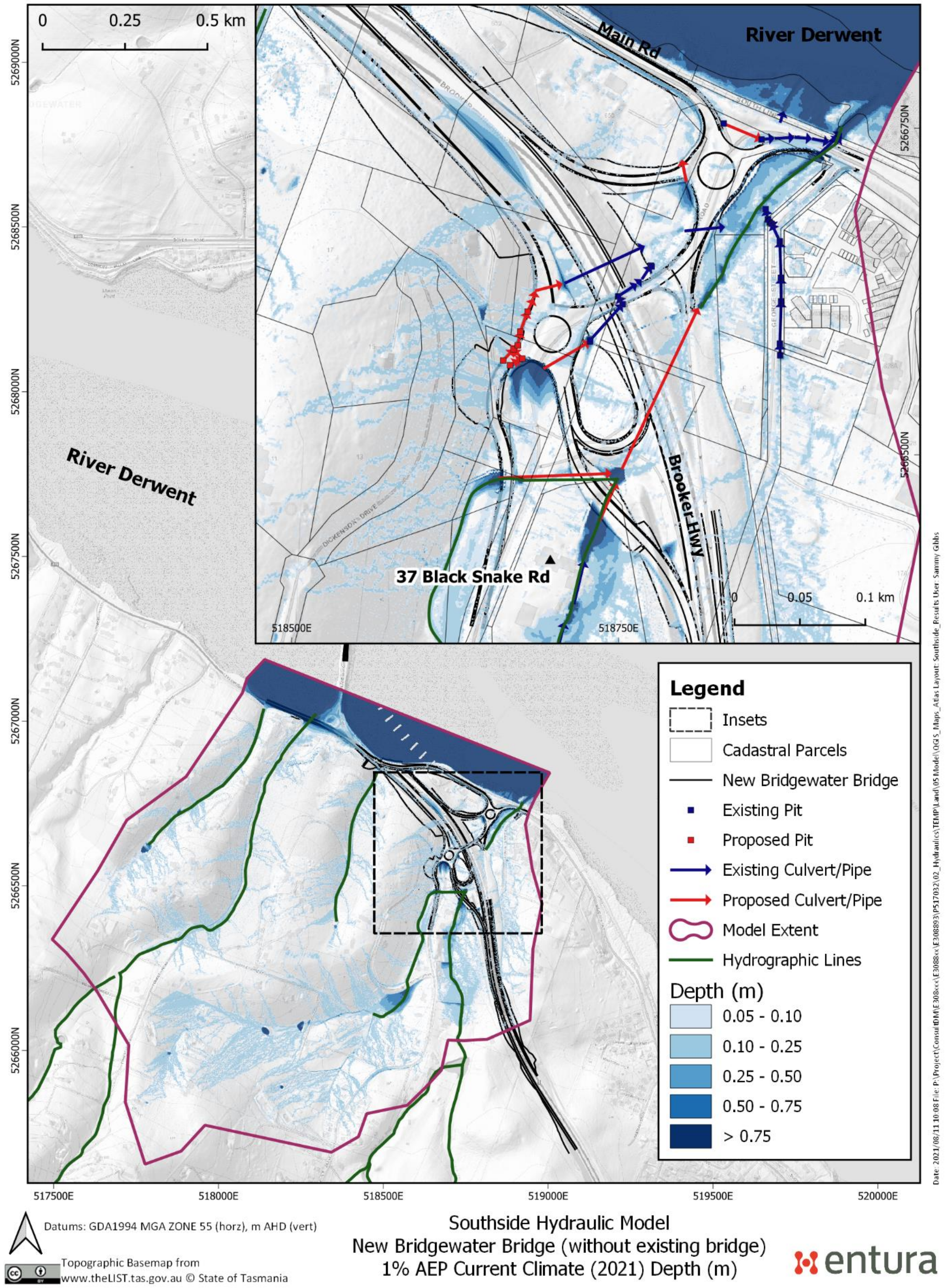

Figure B.19: New Bridgewater Bridge current climate (2021) depth

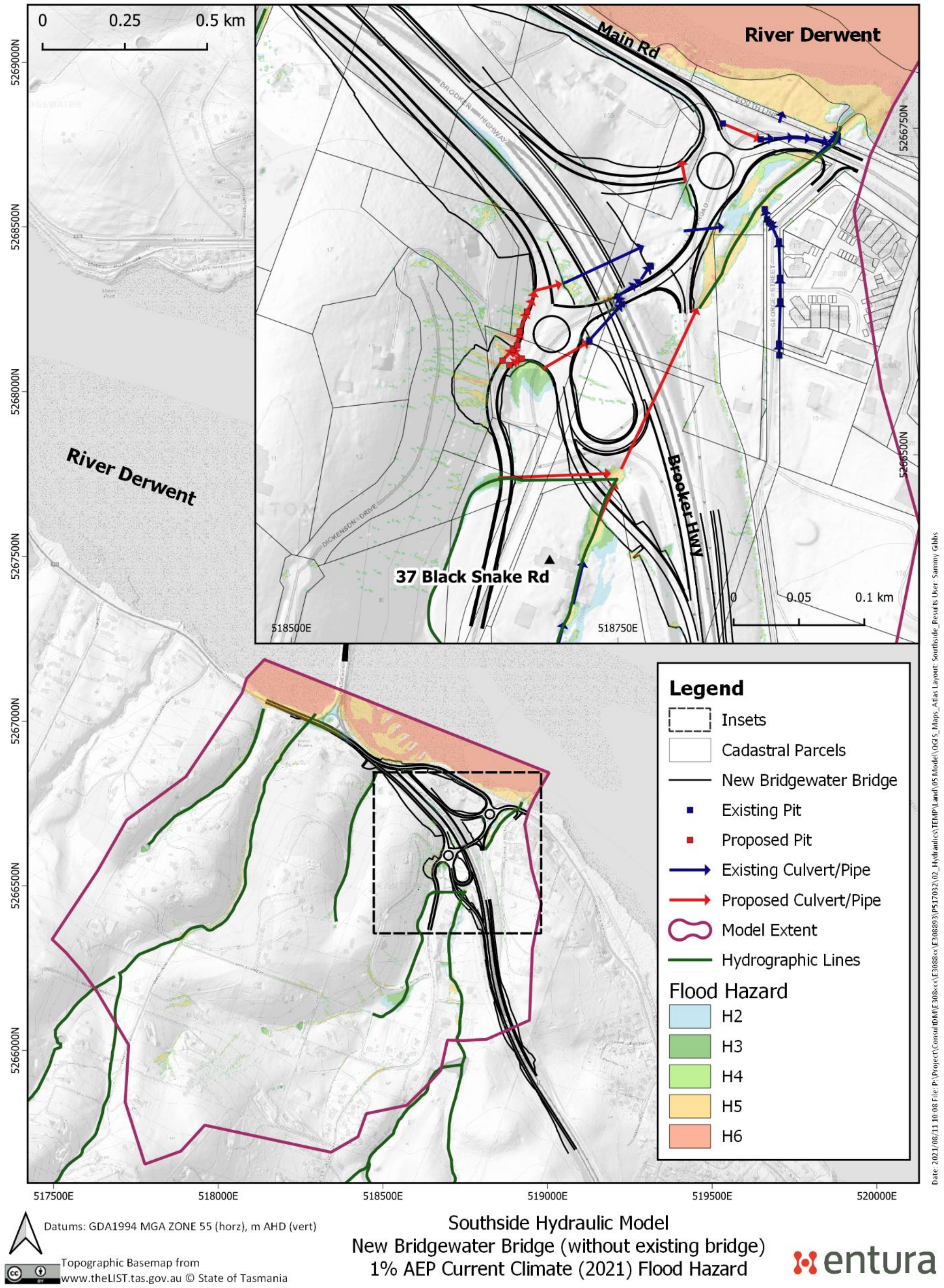

Figure B.20: New Bridgewater Bridge current climate (2021) flood hazard

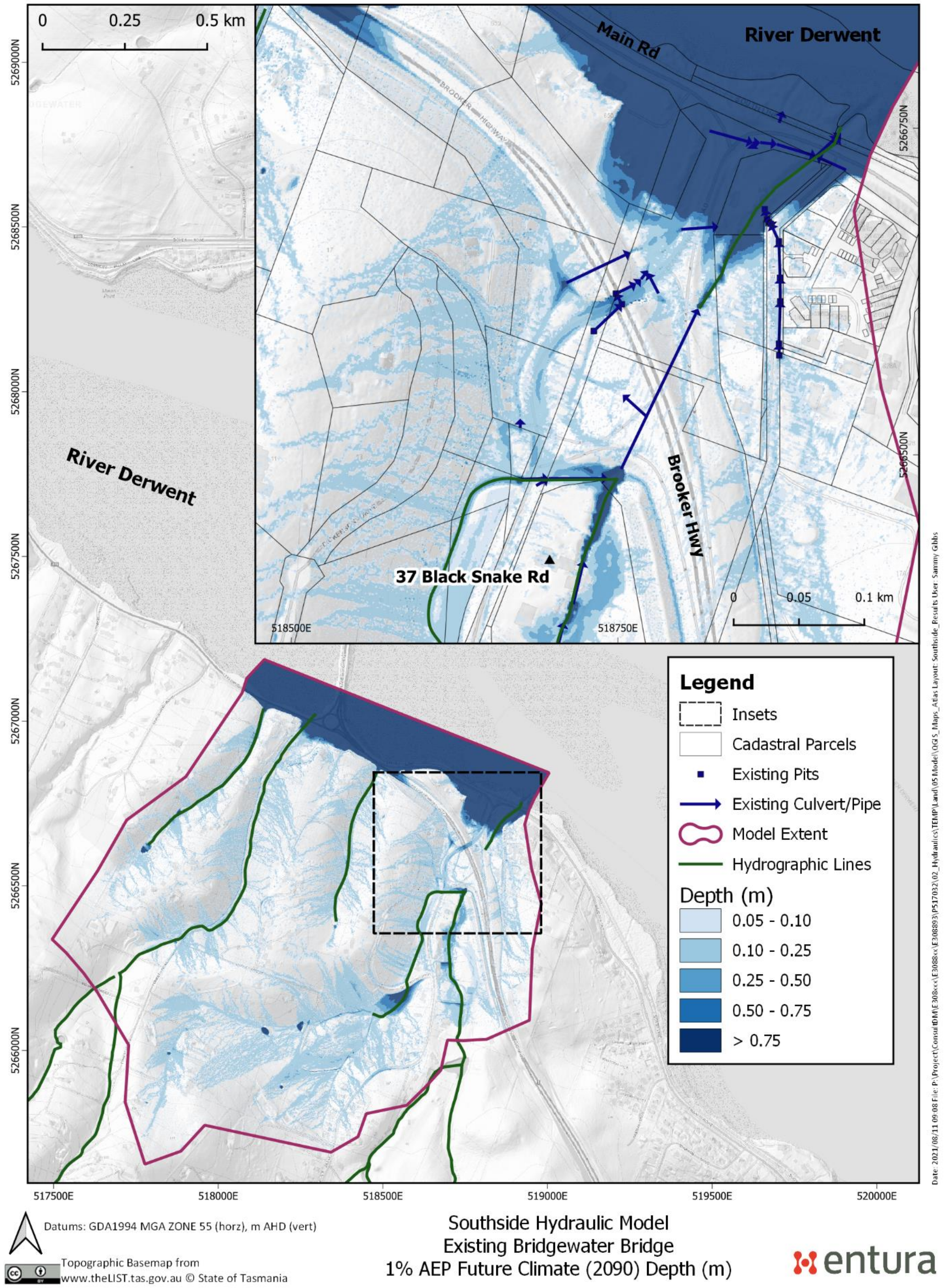

Figure B.21: Existing Bridgewater Bridge future climate (2090) depth

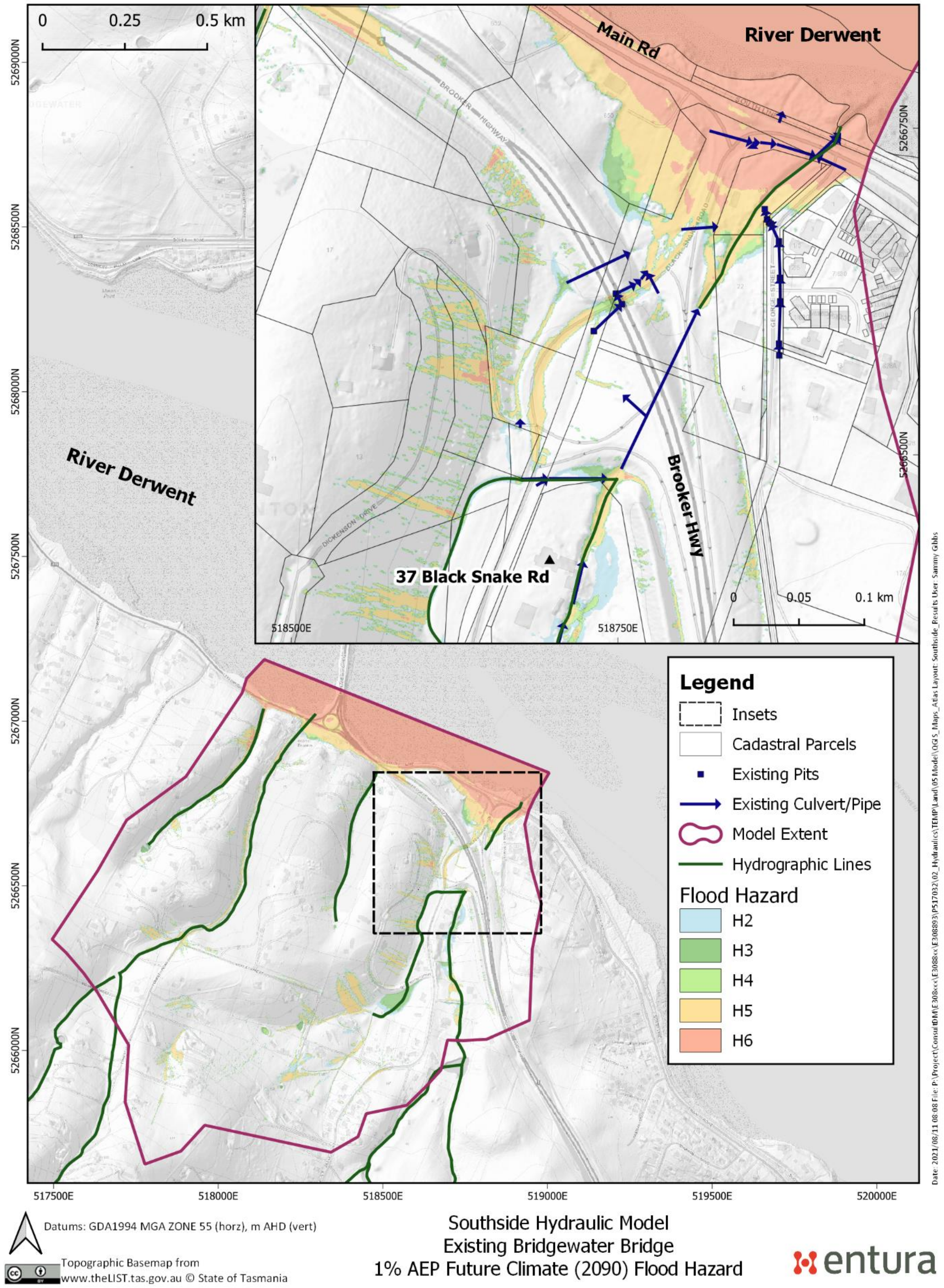

Figure B.22: Existing Bridgewater Bridge future climate (2090) flood hazard

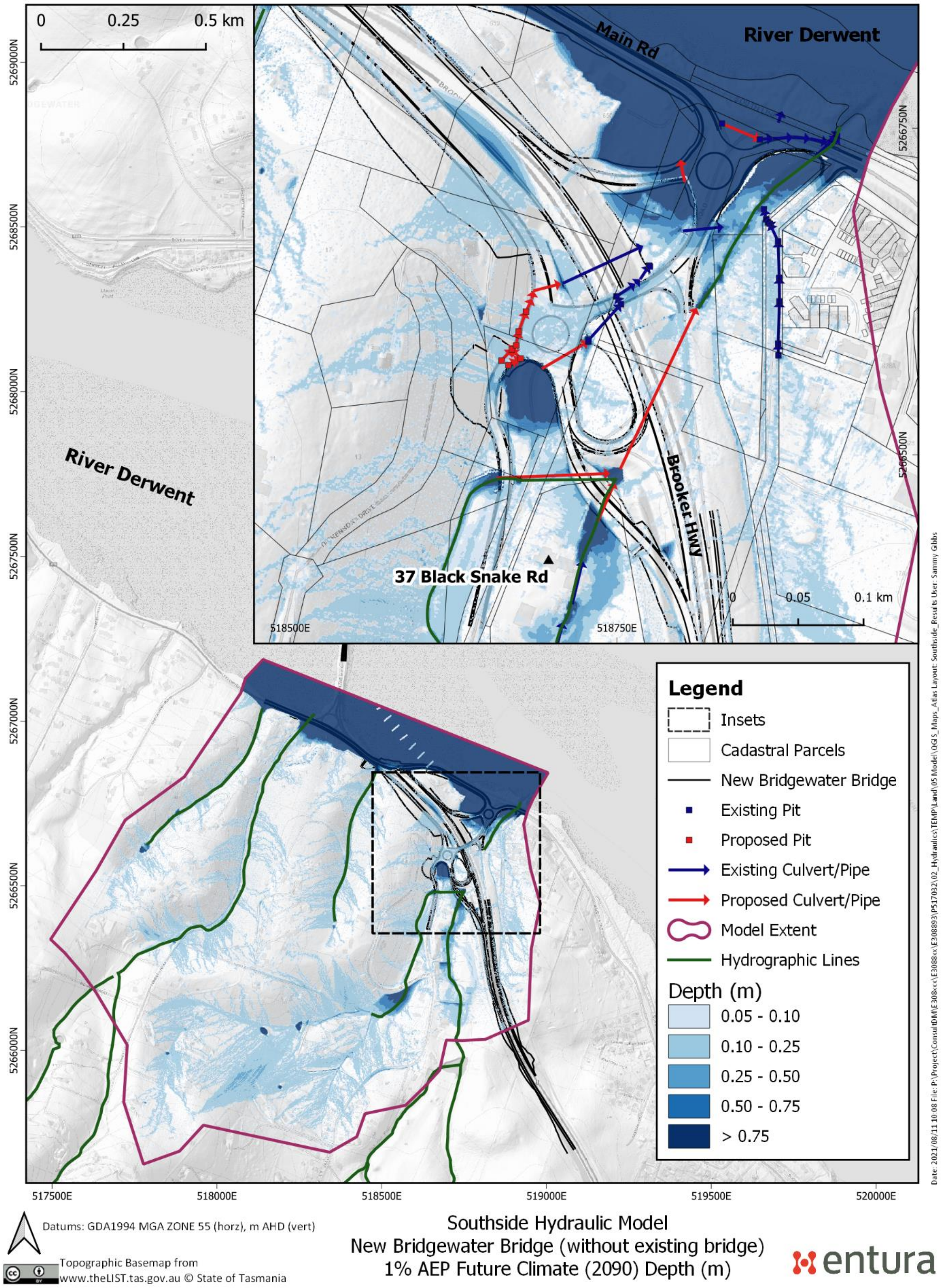

Figure B.23: New Bridgewater Bridge future climate (2090) depth

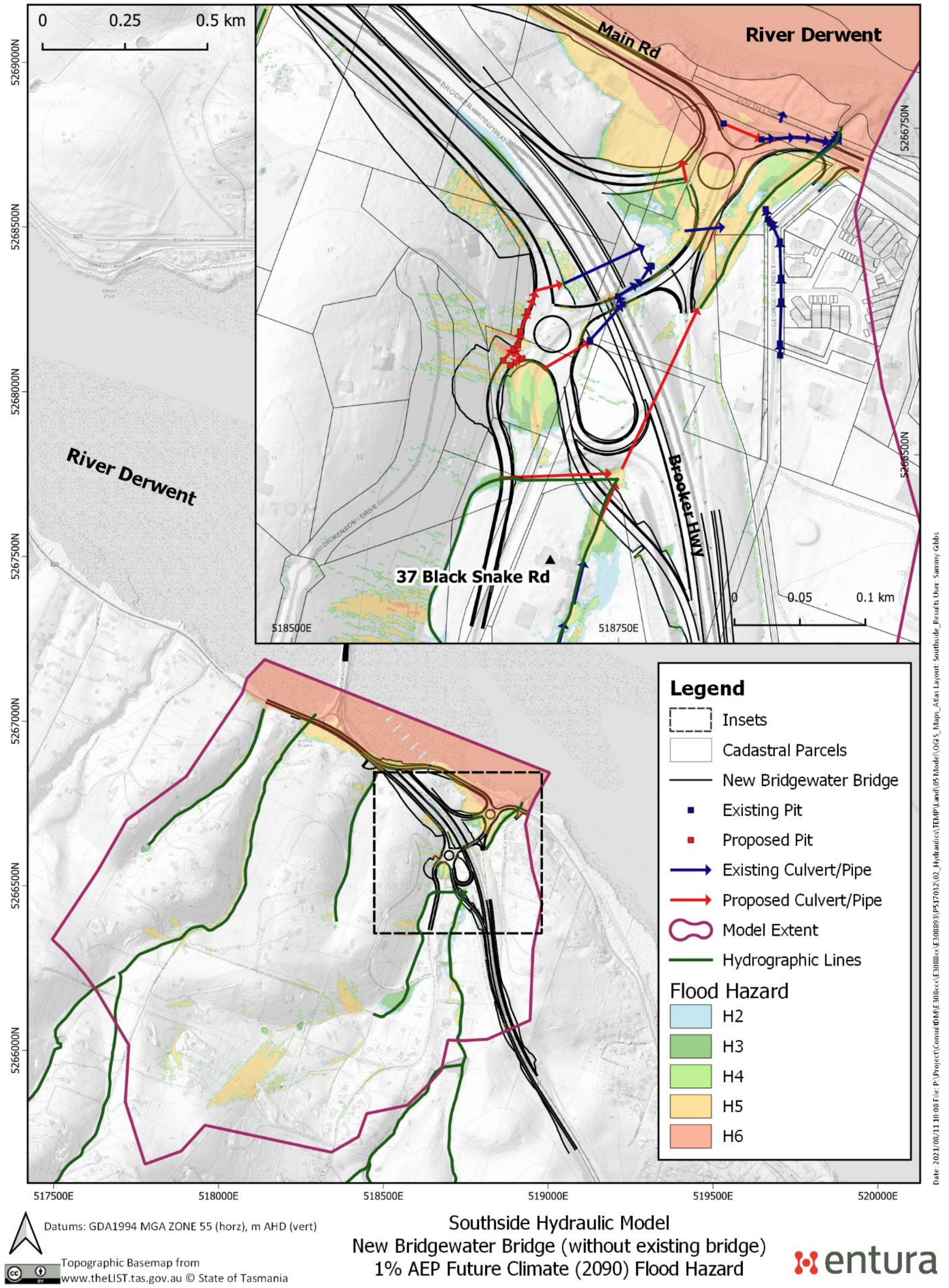

Figure B.24: New Bridgewater Bridge future climate (2090) flood hazard