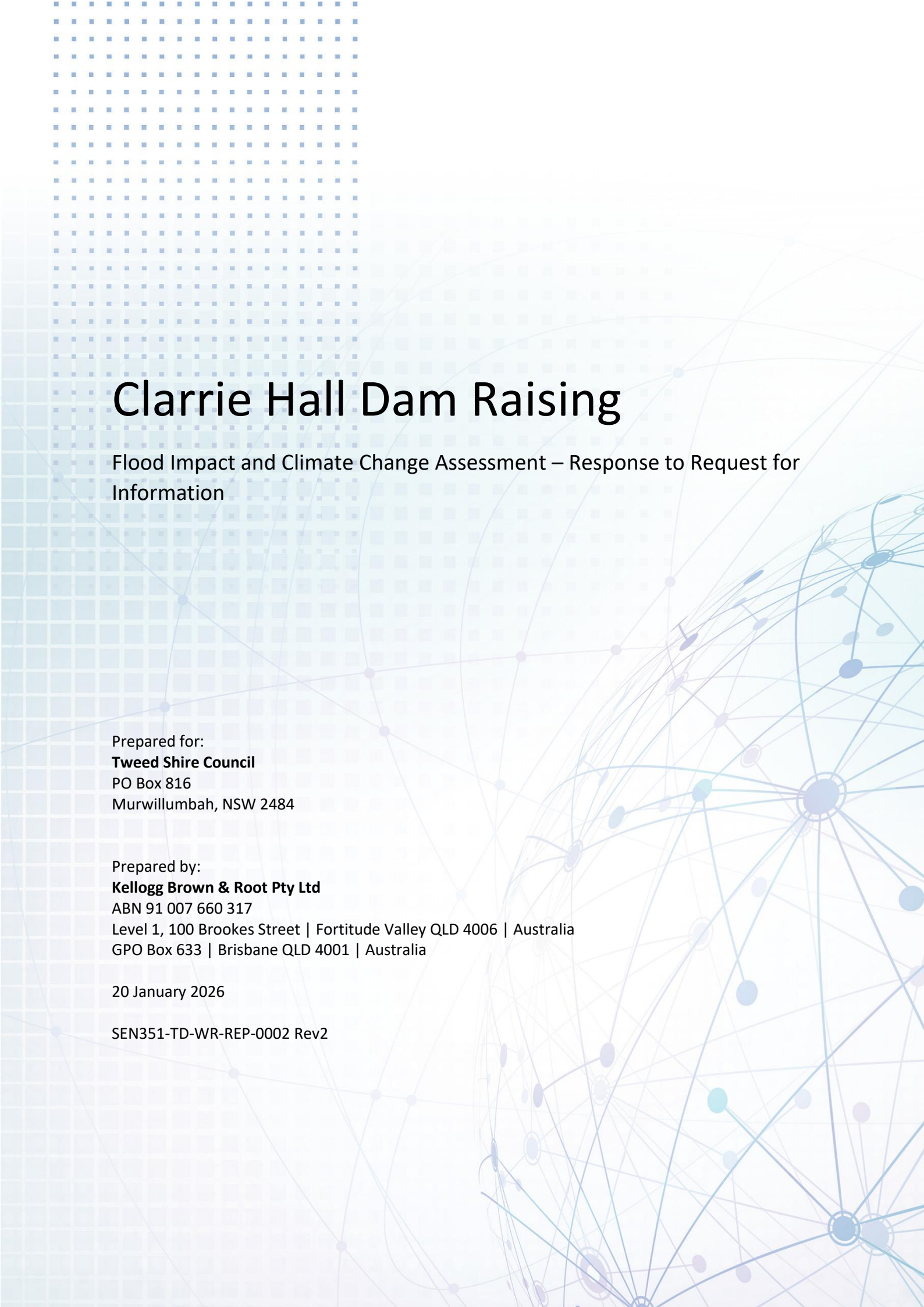




Clarrie Hall Dam Raising

Flood Impact and Climate Change Assessment – Response to Request for Information



Clarrie Hall Dam Raising

Flood Impact and Climate Change Assessment – Response to Request for Information

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Acknowledgments

KBR acknowledges the Traditional Custodians throughout Australia and their continuing connection to land, water, culture and community, and pays respect to their Elders past and present.

Limitations Statement

The sole purpose of this report and the associated services performed by Kellogg Brown & Root Pty Ltd (KBR) is to undertake a flood impact assessment in accordance with the scope of services set out in the contract between KBR and Tweed Shire Council ('the Client'). That scope of services was defined by the requests of the Client, by the time and budgetary constraints imposed by the Client, and by the availability of access to the site.

KBR derived the data in this report primarily from data provided by the Client and modelling. The passage of time, manifestation of latent conditions or impacts of future events may require further exploration at the site and subsequent data analysis, and re-evaluation of the findings, observations and conclusions expressed in this report.

In preparing this report, KBR has relied upon and presumed accurate certain information (or absence thereof) relative to the site provided by government officials and authorities, the Client and others identified herein. Except as otherwise stated in the report, KBR has not attempted to verify the accuracy or completeness of any such information.

The findings, observations and conclusions expressed by KBR in this report are not, and should not be considered, an opinion concerning existing facilities and projects in the local area. No warranty or guarantee, whether express or implied, is made with respect to the data reported or to the findings, observations and conclusions expressed in this report. Further, such data, findings, observations and conclusions are based solely upon information from the Client in existence at the time of the investigation.

This report has been prepared on behalf of and for the exclusive use of the Client, and is subject to and issued in connection with the provisions of the agreement between KBR and the Client. KBR accepts no liability or responsibility whatsoever for or in respect of any use of or reliance upon this report by any third party.

Revision History

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			Originated by	Checked by	Technical Approval	Project Approval
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1 Introduction

Kellogg Brown and Root (KBR) has been engaged by Tweed Shire Council to undertake an Environmental Impact Statement (EIS) for the Clarrie Hall Dam Raising (SSI-65020460). The EIS was submitted to the Department of Planning, Housing, and Infrastructure (the Department) under Section 5.17(6) of the Environmental Planning and Assessment Act 1979 on the 19th of September 2024.

As part of the EIS, KBR had previously prepared a flood impact assessment of the proposed dam raising spillway configuration. Since the completion of the previous scope of works, the Intergovernmental Plan on Climate Change (IPCC) released a new report detailing updated guidance on future climate modelling. Subsequently, Australian Rainfall and Runoff (ARR) released the Version 4.2 guidance in August 2024 to coincide with the updated climate guidance. The implications of the new guidance extend to the Probable Maximum Precipitation (PMP) and therefore modelling of the Probable Maximum Flood (PMF) event.

As such, the Department has requested additional information in consideration of the latest ARR and Climate guidance.

1.1 SCOPE OF WORKS

The Request for Information (RFI) and where it has been addressed is shown below.

- 1) The estimated spillway size required to pass the Probable Maximum Flood (PMF) without dam overtopping at the year 2050 using scenario SSP3-7.0 ('2050 Spillway Estimates') for the existing dam height and proposed dam height. The key spillway physical parameters used in modelling to produce this information must be reported, and hydrological characteristics of the spillway described (e.g. depth-discharge rating, flow m³/s) (refer to Section 3.3.2).
- 2) Comparison and analysis of flood events forecast for 2050 between the existing dam height and proposed dam height with the 2050 Spillway Estimates for 1, 0.5, 0.2, 0.1, 0.05 and 0.02 AEP (5) design events using scenario SSP3-7.0 ('2050 Spillway Estimates'). The comparison must include the following (refer to Section 4):
 - a. Discussion of results for the flood level, flood velocities and duration of inundation.
 - b. Mapping to identify differences to flood extent between the existing dam and proposed dam.
 - c. Mapping to identify differences to peak flood hazard between the existing dam and proposed dam.
 - d. Mapping to identify evacuation routes and evacuation centres used in local and state emergency management plan arrangements and discussion about the ongoing suitability of the evacuation routes and evacuation centres locations having regards to 2050 Flood Events.
 - e. Analysis and discussion comparing 2050 Flood Events with current flood planning levels in Tweed Shire Council LGA.

Note: Flood planning levels would include information about any 1% AEP flood planning level and other flood planning level used in planning decision making by Council that is not the 1% AEP level (e.g. based on historical flood information held by Council)

- 3) Identification and discussion of changes to instream hydrology and secondary environmental impacts comparing the existing dam height and proposed dam height for 2050 Flood Events (i.e. in stream depth, geomorphology, bank erosion, aquatic ecology).
- 4) The estimated spillway size that would be required to pass the PMF flow without dam overtopping at the year 2100 using scenario SSP-8.5 data and information or using scenario RCP8.5 data and information with the prior written agreement of the Department. The key spillway physical parameters used in the modelling must be reported, and the key spillway hydrological information described (e.g. depth – discharge, flow m³/s) (refer to Section 3.3.3).

This report addresses Items 1, 2 and 4 above. Item 3 has been addressed by EMM Consulting in separate standalone reports included as Appendix E and Appendix F. A summary has been provided in Section 3.5.

1.2 STUDY AREA

Clarrie Hall Dam is located approximately 15 km south-west of Murwillumbah, New South Wales (NSW) within the Local Government Area (LGA) of Tweed Shire (refer to Figure 1-1). The dam's main supply is flow from Doon Doon Creek, which includes the main tributaries of Pine Log Creek and Commissioners Creek (upstream of McCabes Bridge). Doon Doon Creek flows in a general northerly direction and joins the Tweed River approximately 1.5 km downstream of the dam. Following this, the Tweed River flows north-easterly through Uki, Dum Dum, Byangum, Bray Park, and Murwillumbah before discharging into the ocean at Tweed Heads.

Clarrie Hall Dam services a catchment area of approximately 60 km² and was constructed to provide a supply of drinking water to the Tweed District. The land upstream of the dam comprises predominantly rural areas made up of open space and highly vegetated land. Settlements located upstream of the dam consist of scattered isolated farmsteads.

1.3 DAM CONFIGURATION

Clarrie Hall Dam was previously upgraded in 2014, where the dam spillway was widened from 22 m to the current 36 m configuration. The existing spillway level is situated at 61.5 m AHD and corresponds to the current Full Supply Level (FSL). The dam embankment wall crest sits 8.9 m higher at 70.4 m AHD.

The proposed raising of the dam wall includes the raising of the spillway height by 8.5 m to 70.0 m AHD. The dam embankment crest level is also proposed to be raised by 6.6 m to 77.0 m AHD, thereby increasing the current storage capacity from 16,000 ML to 42,300 ML.

From the Clarrie Hall Dam Raising – Concept Design Report (Tweed Shire Council, 2018), it is reported that the existing spillway will be covered by the raised embankment (refer to Figure 1-2). The proposed spillway and the spillway channel are therefore indicated to be higher and constructed in the left (western) abutment. The EIS is based on a proposed spillway crest width of 40 m. One of the objectives of this report was to identify if the increased rainfall associated with the new climate change factors presented within the ARR Version 4.2 guidelines, will mean the proposed spillway crest width will require widening to prevent overtopping of the dam embankment.

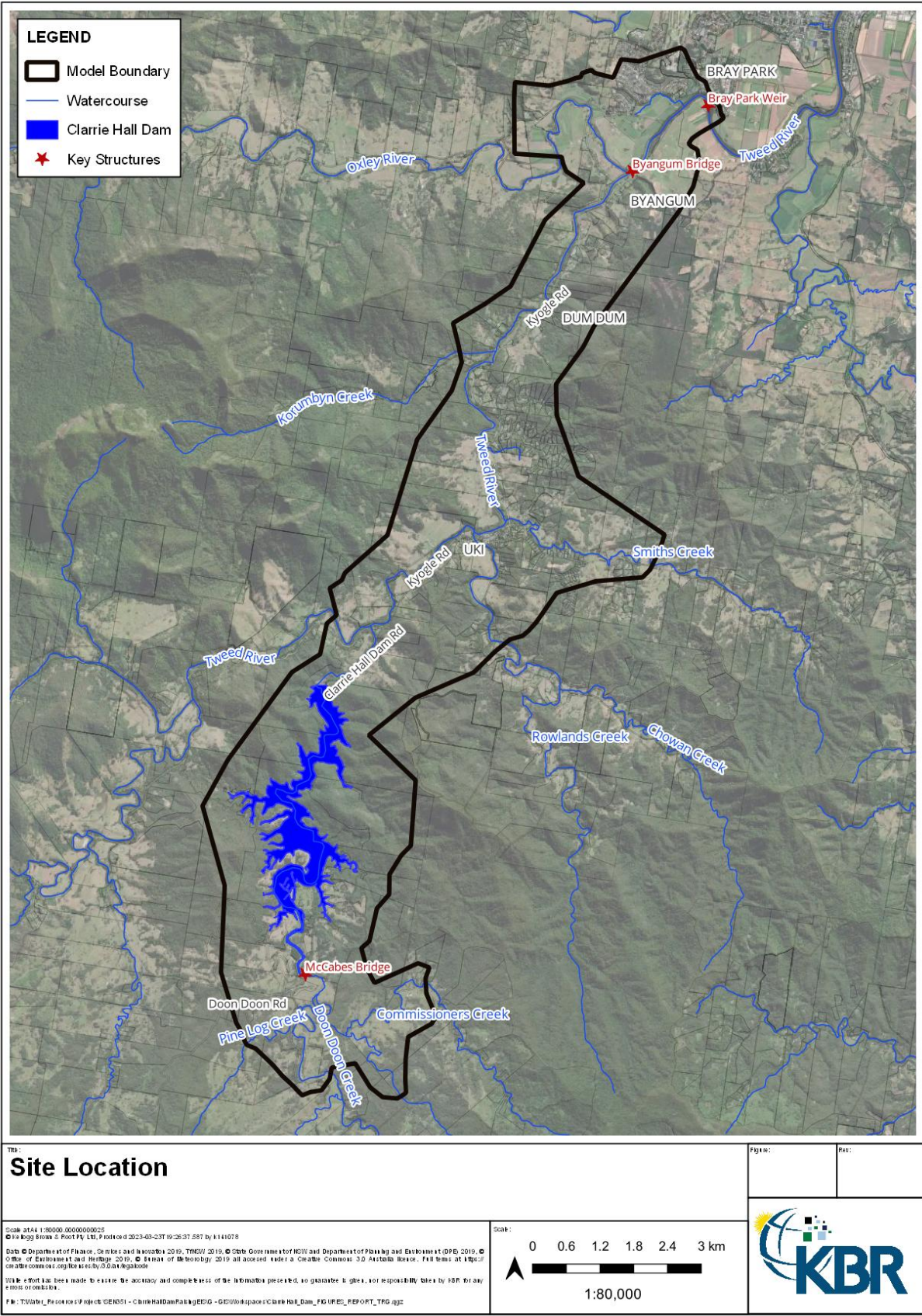


Figure 1-1 Site Location

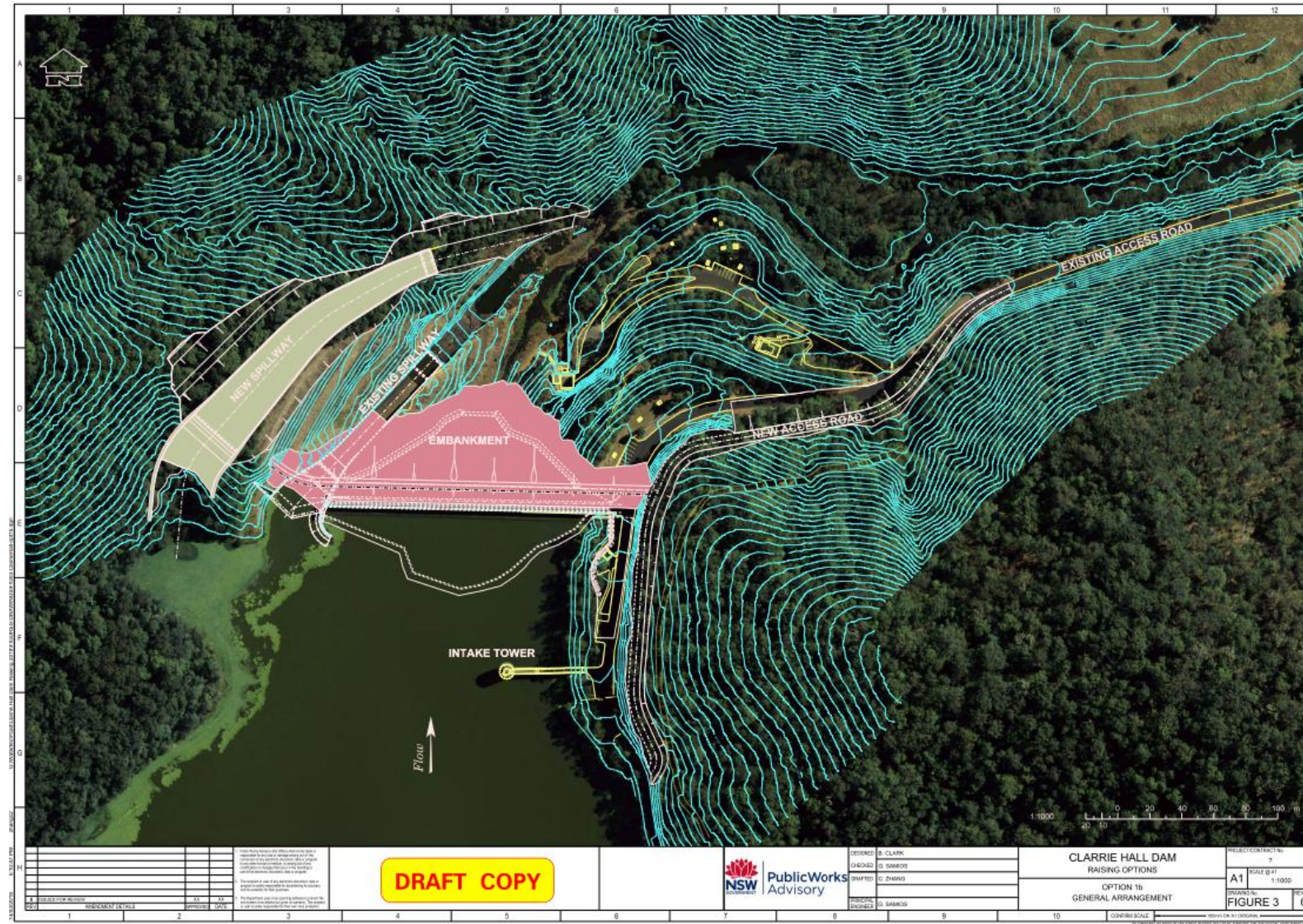


Figure 1-2 Proposed Spillway Configuration (Tweed Shire Council, 2018)

2 Data Review

2.1 REVIEW OF PREVIOUS STUDIES AND INVESTIGATIONS

Council has previously provided a number of studies relating to the hydrological and hydraulic modelling of the Clarrie Hall Dam. The studies that provide relevant information in regard to the hydraulic modelling analysis of the dam raising options have been detailed in the subsequent sections for completeness.

KBR has also undertaken a peer review of the previous Clarrie Hall Dam Raising Flood Impact Assessment (KBR, 2024) independent of the previous project team to ensure that the modelling is fit for purpose and in accordance with the recommendations of the latest Australian Rainfall and Runoff guidelines.

2.1.1 Flood Hydrology Study – Clarrie Hall Dam (WRM, 2017)

A RORB hydrologic model of the Clarrie Hall Dam and the Tweed River was developed by WRM to predict peak water inflows, outflows, and levels in the raised dam for a number of proposed spillway designs.

2.1.2 Clarrie Hall Dam Raising – Computational Fluid Dynamics Modelling (Advisian, 2018)

A Computational Fluid Dynamics (CFD) hydraulic analysis of the proposed spillway upgrade was conducted by Advisian using the Flow-3D software. The outputs of the modelling, including the spillway rating curves for each option were documented in the report.

2.1.3 Clarrie Hall Dam Raising – Concept Design Report (Tweed Shire Council, 2018)

Tweed Shire Council investigated a number of concept designs for the proposed raising of the Clarrie Hall Dam. The outcomes from earlier studies were used to compare the benefits of different concept design options, which included a number of spillway designs. The report concludes with the selection of a preferred dam raising option.

2.1.4 Clarrie Hall Dam Raising Environmental Impact Statement – Flooding Technical Report (Eco Logical Australia, 2021)

A HEC-RAS 2D hydraulic model of the Clarrie Hall Dam catchment down to the Bray Park Weir on the Tweed River was developed to simulate a range of design flood events. The existing dam and raised dam conditions were hydraulically simulated and their modelled flood outputs compared and documented.

2.1.5 Clarrie Hall Dam Safety Review – Existing Spillway Computational Fluid Dynamics Study (GHD, 2023)

CFD modelling was completed by GHD to characterise the hydraulic behaviour of the existing spillway. The Siemens Simcenter STAR-CCM+ CFD software package was utilised to determine the spillway rating curve for the existing dam configuration.

2.1.6 Clarrie Hall Dam Raising Flood Impact Assessment (KBR, 2024)

KBR was engaged by Tweed Shire Council to undertake a flood impact assessment of the proposed 40 m wide raised dam configuration. As a part of this assessment, the calibrated RORB hydrologic model previously developed by WRM was updated in accordance with the ARR Version 4.1 guidelines (2019). A new localised TUFLOW Heavily Parallelised Compute (HPC) hydraulic model was developed with upstream inflows derived from the RORB hydrologic model. Existing dam

configuration rating curves were informed by the GHD study with new rating curves for the proposed dam completed by Worley Consulting as a part of this assessment.

Both the existing and proposed dam configurations were modelled with flows, levels, velocities, and hazards reported on. The outcomes of the flood assessment indicate that due to the proposed dam upgrade, there is a small increase in flood risk upstream of the dam, mainly confined within the waterway corridors. The assessment also highlighted the risk of overtopping of the proposed dam embankment design for the PMF when future climate considerations are included.

2.1.7 Tweed Valley Flood Study Update and Expansion (WMA Water, 2024)

WMA Water was commissioned by Tweed Shire Council to update the latest existing flood study, completed by BMT WBM in 2009. The scope of works involved the development of a new WBNM model (superseding the previous XP-RAFTS model) and update of the existing TUFLOW hydraulic model. Both WBNM hydrologic and TUFLOW hydraulic models were calibrated to the February 2022, March 2017, February 2020, and March 1989 historic events.

The extent of the Tweed Valley includes the Clarrie Hall Dam. While updates were made to the hydrology to be in compliance with the ARR Version 4.1 guidelines, the latest Version 4.2 guidelines were not implemented as the study was completed prior to the release of the updated guidance. The future climate modelling was undertaken using the RCP 4.5 and RCP 8.5 scenarios for the 2090 year horizon, reflective of low and high emission scenarios.

2.2 DAM SPILLWAY RATING CURVES

The spillway rating curve for the existing dam configuration was obtained from the CFD modelling completed by GHD for the *Clarrie Hall Dam Safety Review – Existing Spillway Computational Fluid Dynamics Study*. The rating curve was provided by Council for use within the previous *Clarrie Hall Dam Raising Flood Impact Assessment* (KBR, 2024) and subsequently for this study. The existing spillway rating curve has been presented in Figure 2-1.

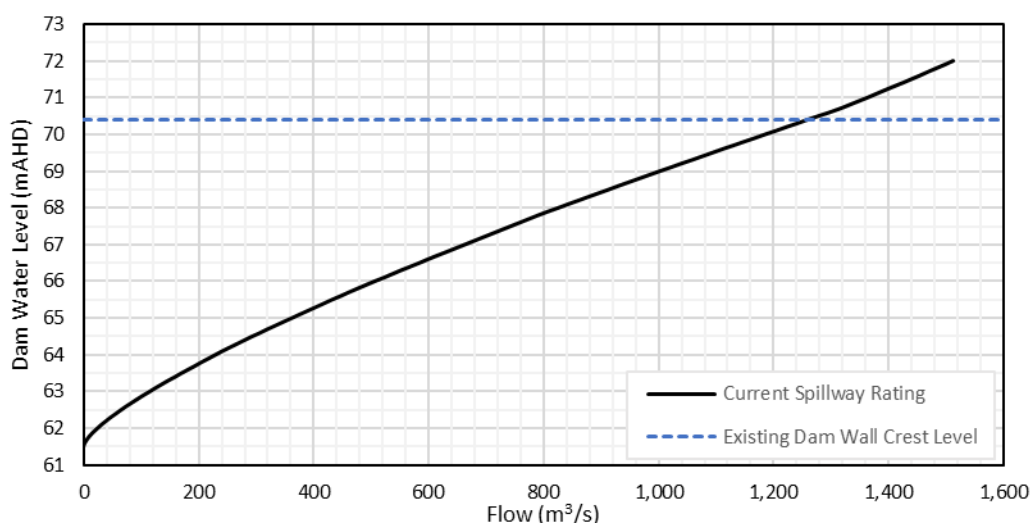


Figure 2-1 Existing Dam Configuration Spillway Rating Curve

As detailed in Section 1.1, alternative raised dam configurations were explored as a part of this study. KBR engaged Worley Consulting to undertake CFD modelling of several raised dam configurations to identify potential raised dam designs that would prevent the overtopping of the PMF event under the 2050 SSP3-7.0 and 2100 SSP5-8.5 scenarios. An iterative process was undertaken and described in further detail in Section 3.3.

2.3 EXISTING XP-RAFTS HYDROLOGIC MODEL

As described in Section 2.1.6, the calibrated RORB hydrologic model developed by WRM in 2017, was updated by KBR in accordance with the ARR Version 4.1 guidelines (2019). The original model was calibrated to the January 2008, January 2012, and January 2013 events prior to the 2014 upgrade of the dam. As part of the model calibration process, the RORB kc and m parameters were established to be 21.9 and 0.8 respectively. Initial and Continuing losses were established in accordance with the recommended values from ARR 1987.

As part of KBR's flood impact assessment, the original RORB model was updated in accordance with the recommendations from ARR Version 4.1 (2019). As the updates were limited to the hydrologic inputs only and not the model itself, the calibrated RORB routing parameters (kc and m) were maintained.

A summary of the changes implemented are presented in Table 2-1.

Table 2-1 ARR Version 4.1 Hydrologic Updates

Parameter	Original Parameters (WRM)	Updated Parameters (KBR)
Temporal Pattern	ARR 1987 temporal patterns	ARR Version 4.1 ensemble temporal patterns
Design Rainfall Depths	BoM 1987 design rainfall depths	BoM 2016 design rainfall depths extracted at four centroid locations: - Clarrie Hall Dam catchment, - Tweed River (upstream of the dam), - Tweed River (downstream of the dam), and - Oxley River.
Initial Loss	The following losses were adopted: - Tweed River: 25 mm - Oxley River 25 mm 0 mm initial loss was adopted for events rarer than the 1% AEP event.	Probability Neutral Burst Initial Loss (PNBIL)
Continuing Loss	The following losses were adopted: - Tweed River: 1.5 mm/hour - Oxley River 2.0 mm/hour 0 mm initial loss was adopted for events rarer than the 1% AEP event.	1.24 mm/hour (ARR Datahub continuing loss of 3.1 mm/hour factored by 0.4 as per the NSW specific state guidance).

2.4 EXISTING TUFLOW HYDRAULIC MODEL

A new TUFLOW HPC model was developed by KBR in 2024 for the *Clarrie Hall Dam Raising Flood Impact Assessment*. The TUFLOW HPC model was developed using the version 2020-10-AD-iSP release and covers the area from approximately 10 km upstream of the Clarrie Hall Dam spillway to approximately 15 km downstream of the dam (approximately 400 m downstream of the Bray Park Weir).

A variable cell size of 16 m for the dam's existing FSL storage at 61.5 m AHD and 8 m for the remainder of the model was established using the TUFLOW Quadtree (QPC) functionality. The benefits of using a quadtree mesh include improved hydraulic representation and computation at specific areas of interest, resulting in typically faster simulation times. A larger cell size was appointed to the FSL storage as there would be minor variation in hydraulic behaviour within this

area of predominantly free-standing water. Finer cell sizes were implemented in other areas, particularly to allow for the more refined representation of the major waterways.

Routed local inflows were injected at the outlet of each sub-catchment within the TUFLOW model domain. Total routed hydrographs were input at the model boundary, extracted from the RORB model. It should be noted that the same hydrologic inflows were utilised for both existing and proposed scenario modelling, as the differences in dam configuration were purely hydraulic in nature.

The existing RORB hydrologic and TUFLOW hydraulic models have been relied upon for the scope of works detailed within this report.

2.4.1 Model Topography

The TUFLOW HPC model relied upon the following topographic datasets in order of priority from highest to lowest (i.e. each following dataset was layered over the preceding dataset):

- Bathymetry survey of Doon Doon Creek and Tweed River (2023)
- Hydrographic survey of Clarrie Hall Dam (2017)
- 1 m LiDAR of the Clarrie Hall Dam catchment (2022)
- 0.5 m LiDAR of the Tweed River from the spillway up to the Bray Park Weir (2022)
- 1 m LiDAR – Murwillumbah201309-LID1-AHD (2013)
- 2 m DEM – Murwillumbah201709-LID2-AHD (2017).

The topographic datasets utilised have been illustrated in Figure 2-2.

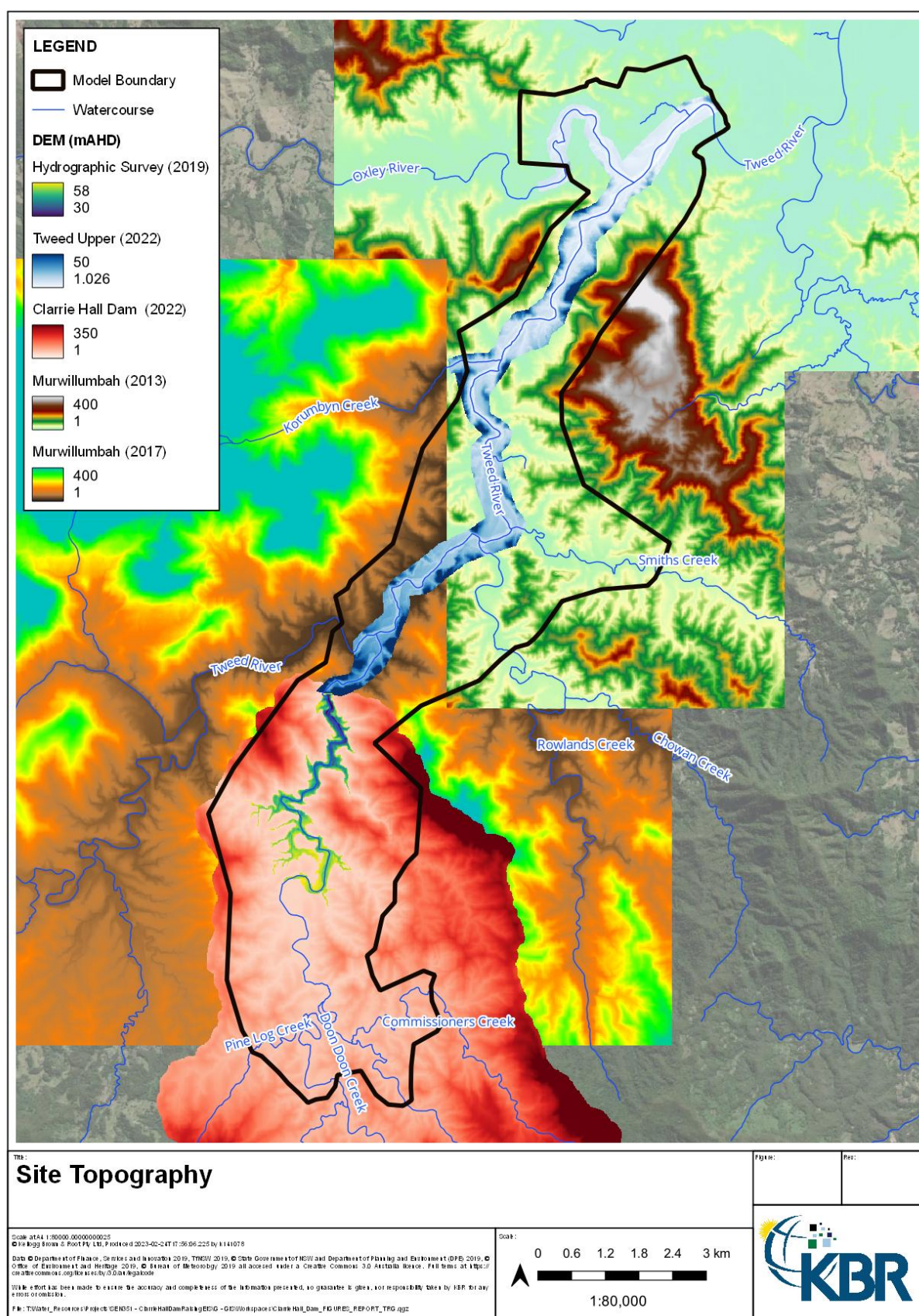


Figure 2-2 Topographic Datasets Utilised Within the TUFLOW HPC Model

2.4.2 Hydraulic Structures

Hydraulic structures in the form of bridges and cross-drainage culverts have been included within the TUFLOW HPC model (refer to Figure 2-3).

Bridges were modelled in the 2D domain as layered flow constrictions and are summarised in Table 2-2. It is noted that in the previous modelling of the proposed dam raising designs, the upgrades to McCabes Bridge have also been included. A bank of four (4) reinforced concrete box culverts have been modelled on Doon Doon Road at its crossing of Pine Log Creek (approximately 1.2 km upstream of McCabes Bridge) with six (6) reinforced concrete single barrel culverts included downstream of the dam on Clarrie Hall Dam Road (parallel to Doon Doon Creek).

Table 2-2 Summary of Modelled Bridges

Name	Description
Doon Doon Road 1	Doon Doon Road crossing Doon Doon Creek approximately 3.0 km upstream of McCabes Bridge.
Doon Doon Road 2	Doon Doon Road crossing Doon Doon Creek approximately 2.3 km upstream of McCabes Bridge.
McCabes Bridge	At Commissioner Creek Road crossing Doon Doon Creek upstream of the Clarrie Hall Dam. As part of the upgrade to the dam, this bridge is also proposed to be upgraded.
Kyogle Road 1	Kyogle Road crossing Doon Doon Creek downstream of the Clarrie Hall Dam near the confluence with the Tweed River.
Kyogle Road 2	Kyogle Road crossing Rowlands Creek close to the confluence with the Tweed River.
Kyogle Road 3	Kyogle Road crossing Smiths Creek close to the confluence with the Tweed River.
Byangum Bridge	Kyogle Road crossing the Tweed River.

2.4.3 Hydraulic Roughness

The hydraulic roughness schematisation was previously reported to have been determined using aerial imagery. The adopted Manning's 'n' values are presented in Table 2-3 and illustrated in Figure 2-4.

Table 2-3 Summary of Modelled Bridges

Type	Manning's 'n' Roughness Value
Open Space	0.045
Dam Spillway	0.020
Watercourse	0.040
Still Water	0.025
Dense Vegetation	0.100
Road Corridor	0.025
Urban Area	0.100

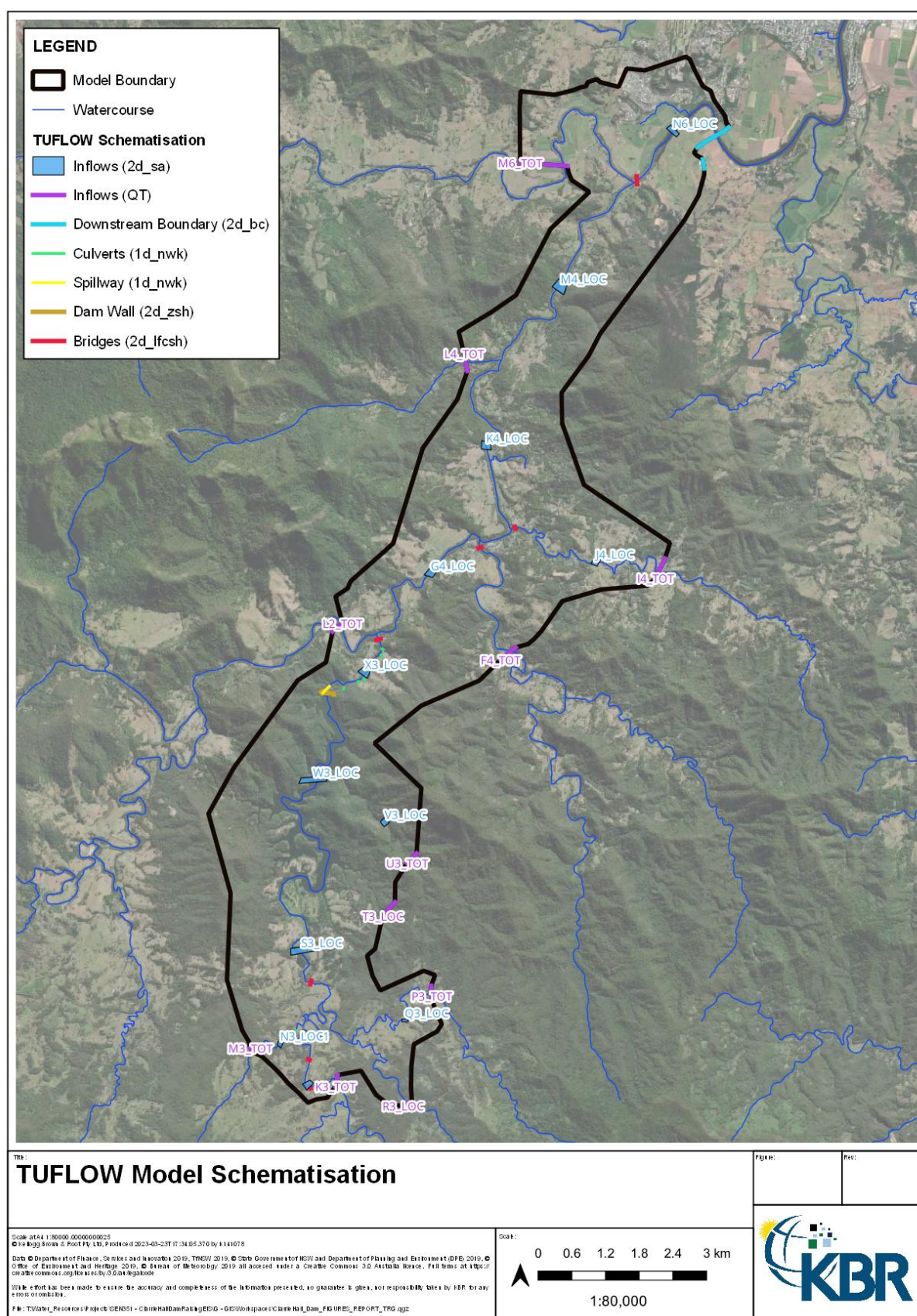


Figure 2-3 TUFLOW Model Schematization



2.5 EXISTING MODEL CALIBRATION AND VALIDATION

The original RORB hydrologic model was calibrated to the following historical events by WRM:

- January 2008
- January 2012
- January 2013.

For the January 2008 event, model calibration was undertaken by comparing modelled flows against the recorded flow-time series at the Uki (201900) and Eungella (201001) streamflow gauges. Additional comparisons were made to the Palmer (558018) streamflow gauge for the 2012 and 2013 events.

Reasonable convergence between the modelled and recorded/observed results was achieved in regard to magnitude, shape, and timing and of the flow hydrographs.

With the development of the new TUFLOW HPC model validation of the hydraulic model results was undertaken by comparing the modelled and recorded/observed flow hydrographs at the Uki (201900) streamflow gauge across the same three (3) historical events. The outputs from the TUFLOW model aligned well with the RORB model results, indicating converging catchment response and routing between the two models.

3 Response to RFI Modelling

In order to understand the impacts of the updated Australian Rainfall and Runoff climate guidance on the proposed raised dam spillway design, updates to the RORB hydrologic model were required. As per the scope of works detailed in Section 1.1, the proposed raised dam spillway was required to pass the PMF event without dam overtopping for the 2050 year horizon and SSP3-7.0 scenario.

3.1 AUSTRALIAN RAINFALL AND RUNOFF VERSION 4.2

In August 2024, ARR was updated from Version 4.1 to 4.2. The primary focus of the update was to revise the consideration of climate change in ARR to be in line with the Intergovernmental Panel on Climate Change (IPCC) 6th Assessment Report (AR6) and its associated studies. As a part of this update, the climate change scenarios were considered under Shared Socio-economic Pathways (SSP) as opposed to the previously adopted Reconciled Concentration Pathways (RCP) of the IPCC 5th Assessment Report, formerly adopted in ARR Version 4.1.

The implications of the updated guidelines not only encapsulate a new approach to the modelling of future climate scenarios, but also recommend the upscaling of design event rainfall, including the Probable Maximum Precipitation (PMP). The updated guidelines also recommend the upscaling of the associated hydrologic losses to be reflective of the climate change that has occurred since the development of the rainfall data.

For example, the Bureau of Meteorology 2016 Intensity-Frequency-Duration (IFD) curves were developed using data from historical gauged records up to 2012 with a midpoint between 1961-1990. Climate change has occurred over the period of the input dataset and continues to occur beyond the input data to the IFDs. The revised Version 4.2 guidelines attempt to factor in the climate change from the IFDs that has occurred from the IFD input data to a nominated point in time (i.e. present day).

ARR Version 4.1 climate change guidance presented a single rainfall uplift factor for each AEP applied uniformly to all durations. The new Version 4.2 update introduces dynamic scaling factors that are biased towards shorter storm durations. Unlike the rainfall upscaling, the scaling factor on both initial and continuing losses are independent of duration and only vary across SSP scenario and the projection year. Therefore, the updated guidance implies not only the increase in rainfall across the study area, but also the potential for changes in critical durations.

3.2 UPDATED BASELINE FUTURE CLIMATE MODELLING

As described in Section 3.1, the new Version 4.2 guidelines introduce new rainfall and loss scaling factors with impacts extending to the PMF event. In accordance with the Request for Information, KBR has simulated the 2050 year horizon SSP3-7.0 scenario through the existing RORB hydrologic model. The climate scaling factors were extracted from the ARR datahub and presented in Table 3-1 and Table 3-2.

Table 3-1 ARR Version 4.2 Rainfall Scaling Factors

Storm Duration	< 1 hr	1.5 hr	2 hr	3 hr	4.5 hr	6 hr	9 hr	12 hr	18 hr	> 24 hr
2050 SSP3-7.0	1.29	1.26	1.24	1.22	1.20	1.19	1.18	1.17	1.16	1.15
2100 SSP5-8.5	1.86	1.77	1.71	1.64	1.58	1.54	1.50	1.47	1.43	1.41

Table 3-2 ARR Version 4.2 Loss Scaling Factors

Storm Duration	Initial Loss (mm)	Continuing Loss (mm/hr)
2050 SSP3-7.0	1.04	1.07
2100 SSP5-8.5	1.09	1.18

As Probability Neutral Burst Initial Losses (PNBIL) were utilised in the previous modelling, KBR scaled the storm initial loss of 38 mm by 1.04 prior to the application of pre-burst. The previously adopted factored continuing loss (as recommended by ARR for NSW catchments) of 1.24 was scaled by 1.07 to 1.33.

Similarly, the updated hydrologic model outputs were simulated through the existing TUFLOW model to re-establish the 2050 year future climate conditions.

3.3 RAISED DAM SPILLWAY SIZING

With the baseline conditions redefined, KBR worked collaboratively with Worley Consulting to identify the width of the spillway required for the current dam and potential raised dam configurations. A detailed methodology and reporting associated with the CFD modelling has been prepared by Worley Consulting and has been included as Appendix A of this report.

3.3.1 Existing Dam Configuration

An initial assessment by Worley Consulting identified that the existing spillway width would require significant extension to pass the 2050 and 2100 year PMF events. This would result in a substantial length of the existing embankment needing to be removed as well as a significant modification to the chute spillway to cater for a smooth transition without causing the discharge flow to choke at the contraction. It was therefore concluded that such a design would not be feasible and efforts were diverted to identifying potential raised dam options that will mitigate overtopping of the future climate PMF events.

3.3.2 55 m Wide Spillway (2050 Year Horizon SSP3-7.0 PMF)

The 55 m wide raised dam spillway configuration, previously developed by Worley Consulting and KBR in 2024, was utilised to simulate the 2050 year horizon SSP3-7.0 PMF event. As depicted in Figure 3-1, it is evident that the 55 m wide raised dam spillway configuration prevents overtopping of the dam wall embankment across all simulated durations for the 2050 year horizon SSP3-7.0 PMF event, while achieving a freeboard of approximately 0.5 m. Similar flow time series outputs have been presented in Figure 3-2.

The width of the proposed spillway can be further optimised depending on the required freeboard below the dam embankment.

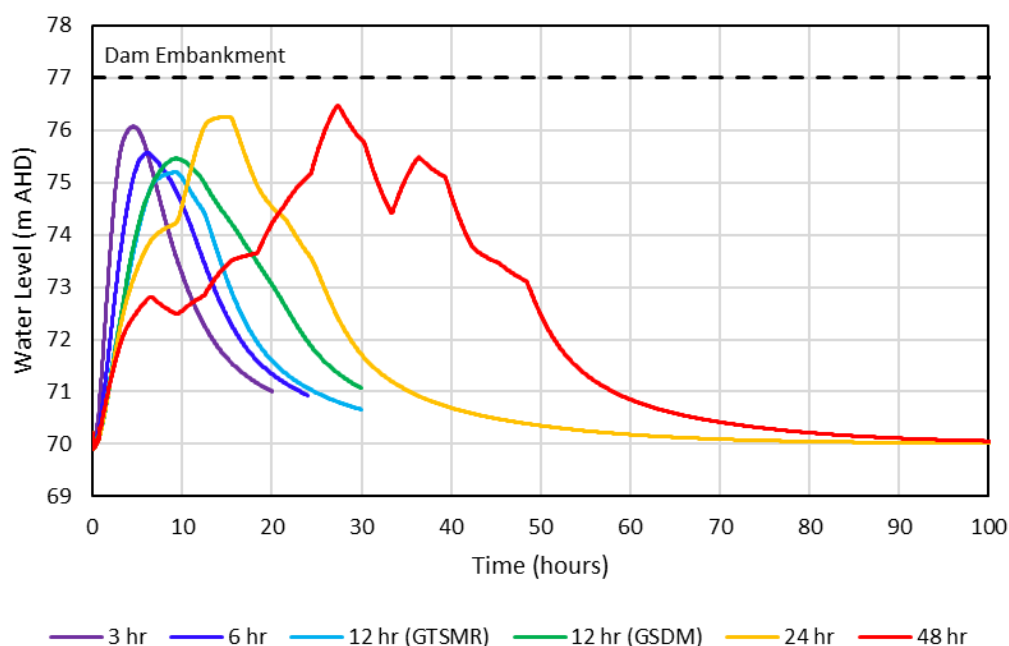


Figure 3-1 TUFLOW Water Level Time Series Output at the Dam Wall (2050 SSP3-7.0)

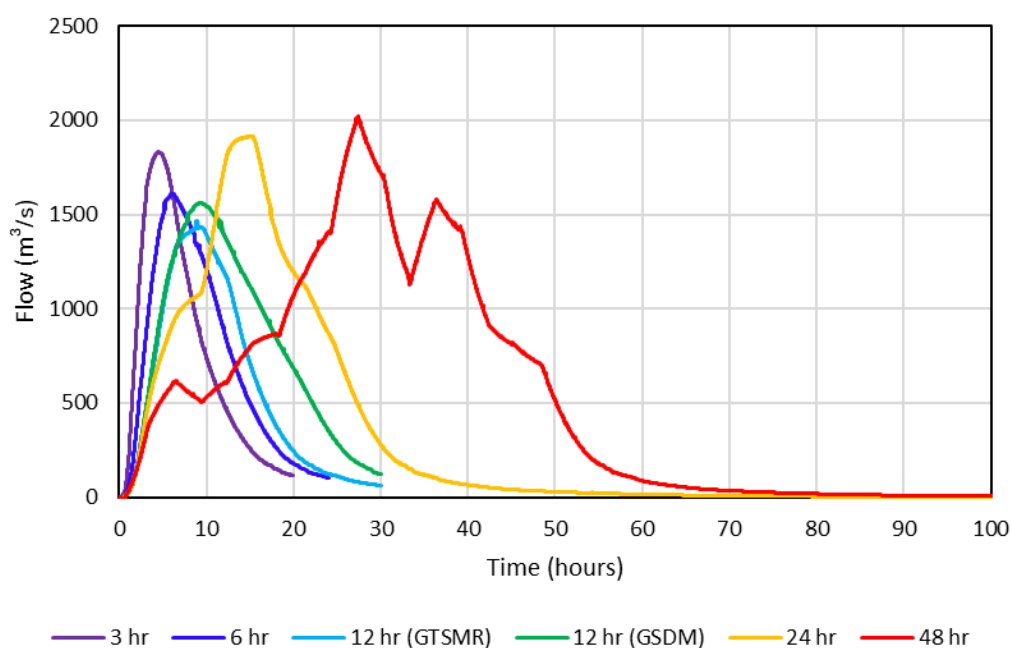


Figure 3-2 TUFLOW Flow Time Series Output at the Dam Wall (2050 SSP3-7.0)

3.3.3 80 m Wide Spillway (2100 Year Horizon SSP5-8.5 PMF)

The CFD model of the 55 m raised dam spillway configuration was modified to increase the spillway crest length to 80 m as depicted in Figure 3-3. The CFD modelling and the analysis methodology are consistent with those presented in the previous *Clarrie Hall Dam Raising Spillway Rating Curve Report* (Worley, 2024). It should be noted that the chute downstream of the spillway crest was not included within the CFD model so that the spillway hydraulic performance was not affected by any potential choking flow caused by the chute contraction. The results are therefore reflective of optimal spillway performance.

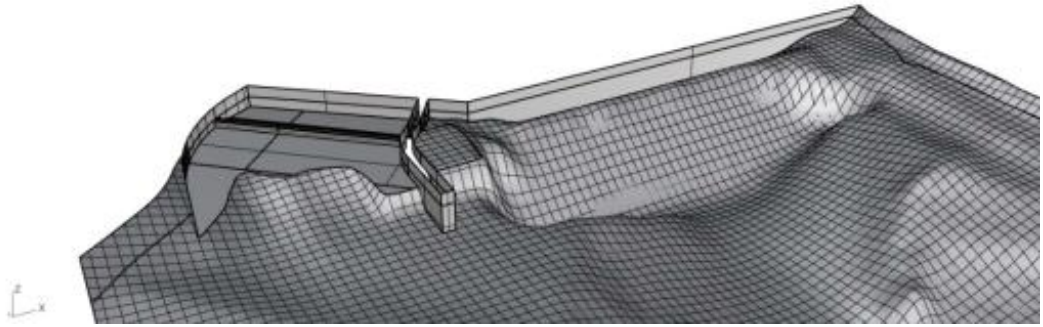


Figure 3-3 3D Model of the 80 m Raised Spillway Design

The level-flow rating curve generated from the CFD modelling was provided to KBR for the hydraulic modelling of the 80 m wide raised dam spillway design. No modifications to the dam embankment geometry were undertaken as part of the hydraulic modelling, with model updates limited to the update in rating curve.

As depicted in Figure 3-4, it is evident that the 80 m wide raised dam spillway configuration prevents overtopping of the dam wall embankment across all simulated durations for the 2100 year horizon SSP5-8.5 PMF event. Almost no freeboard is modelled in this instance. Similar flow time series outputs have been presented in Figure 3-5.

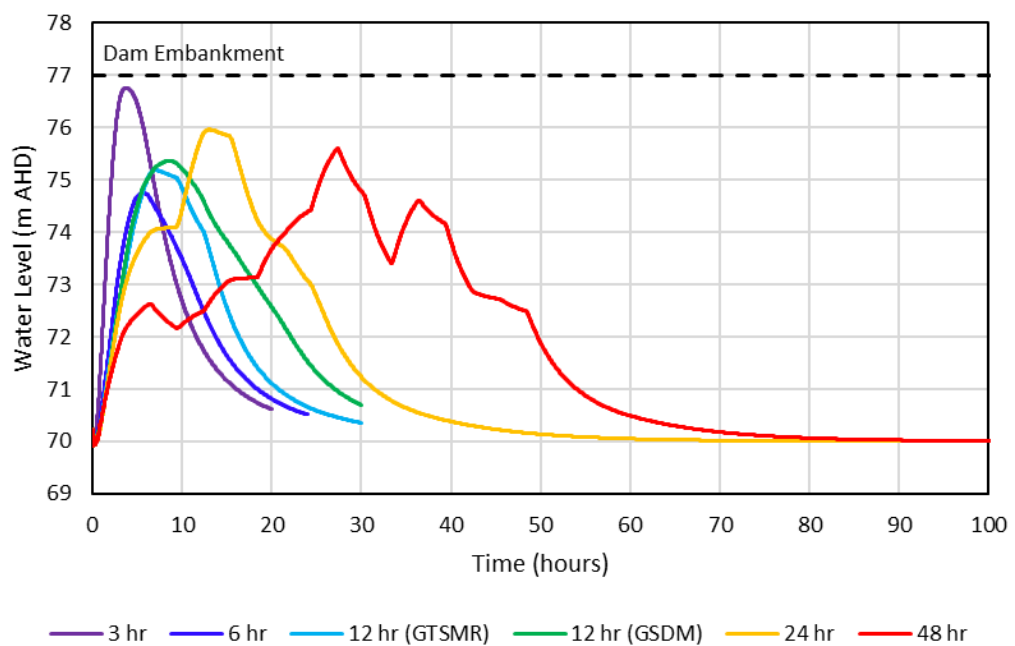


Figure 3-4 TUFLOW Water Level Time Series Output at the Dam Wall (2100 SSP5-8.5)

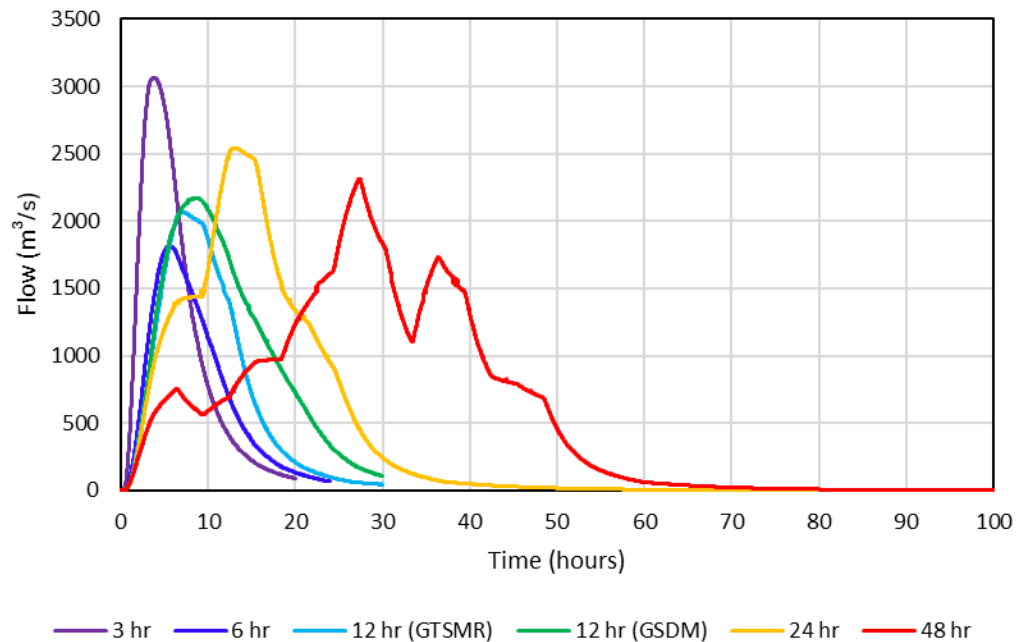


Figure 3-5 TUFLOW Flow Time Series Output at the Dam Wall (2050 SSP5-8.5)

3.4 CRITICAL DURATION ASSESSMENT

Due to the dynamic scaling factors introduced as part of the ARR Version 4.2 guidelines, there is a need to reassess the critical durations for the area of interest. That is, the rainfall scaling factors are no longer independent of storm duration with the updated rainfall scaling factors.

A critical duration assessment refers to the selection of durations that can best represent the flood behaviour of a specified design flood event. In accordance with the ARR guidelines, the critical duration assessment was undertaken for the rare temporal pattern bin, encapsulating the 2% AEP design events and rarer (refer to Figure 3-6). As per the methodology previously adopted, the critical duration assessment was reassessed using the calibrated RORB hydrological model at the Clarrie Hall Dam and the Uki streamflow gauge.

The most representative critical duration and temporal pattern across the 1%, 0.5%, 0.2%, 0.01%, and 0.05% was the 12 hour duration event. The representative temporal pattern that produced the closest to but biased above the mean peak flow was temporal pattern 4785. An example box and whisker plot of the 1% AEP event at the Clarrie Hall Dam is presented in Figure 3-7.

The critical duration and representative temporal pattern were maintained for the proposed dam raising scenario to present a like-for-like analysis. The increase in dam embankment crest level and corresponding increase in storage upstream of the dam could result in increases in critical durations upstream of the dam as more water accumulates behind the raised embankment.

For the sizing of the spillway, detailed in Section 3.3, all previously simulated durations for the PMF event were modelled to ensure that the proposed design captures all variations in critical durations associated with the new ARR guidelines and changes in upstream storage.

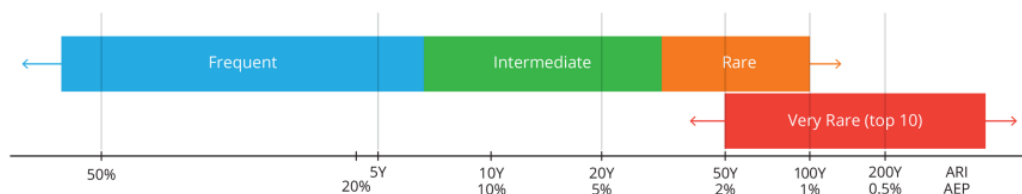


Figure 3-6 Australian Rainfall and Runoff Temporal Pattern Bins (Extracted from ARR Version 4.2 Book 2)

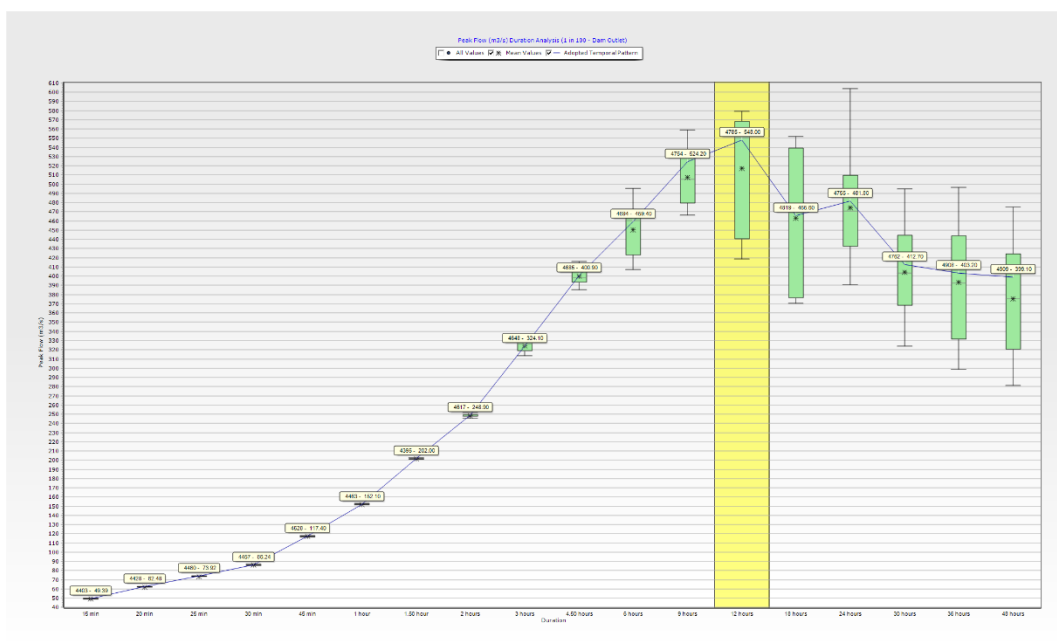


Figure 3-7 RORB Box and Whisker Plot for the 1% AEP event for the 2050 SSP3-7.0 Scenario

3.5

CHANGES TO INSTREAM HYDROLOGY AND SECONDARY ENVIRONMENTAL IMPACTS

The complete report for the streamflow analysis and river geomorphology has been prepared by EMM Consulting and has been included in Appendix E and Appendix F of this report respectively. The contents of the reports have been summarised within this section.

Flow regime modelling undertaken for the Environmental Impact Statement (EIS) concluded that the spillway on the raised dam would partially restrict outflows such that peak flows downstream during floods would be lower, and the recession of floods would be drawn out a little longer due to water being held within the reservoir.

Modelling with the wider spillway shows that the wider spillway will in general release flood waters as quickly as the existing spillway such that future peak flow and duration of high flow events will be very similar to current. A comparison between the EIS submission and the revised modelling for the wider spillway is provided below for the historical climate period 1976. The data produced during the EIS (Figure 3-8) presents the effects of the project as reduced peaks and extended recessions as discussed, while the modelling of the revised spillway (Figure 3-9) shows very little difference between the current and future hydrographs.

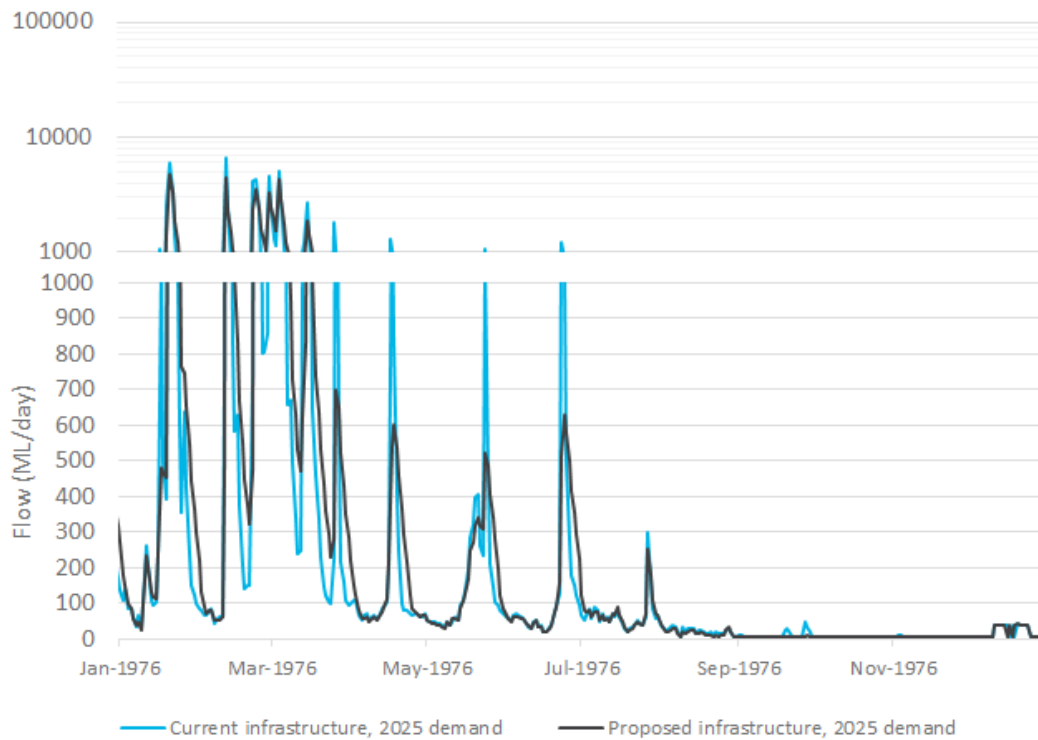


Figure 3-8 EIS Model Results: Modelled Flow in Doon Doon Creek

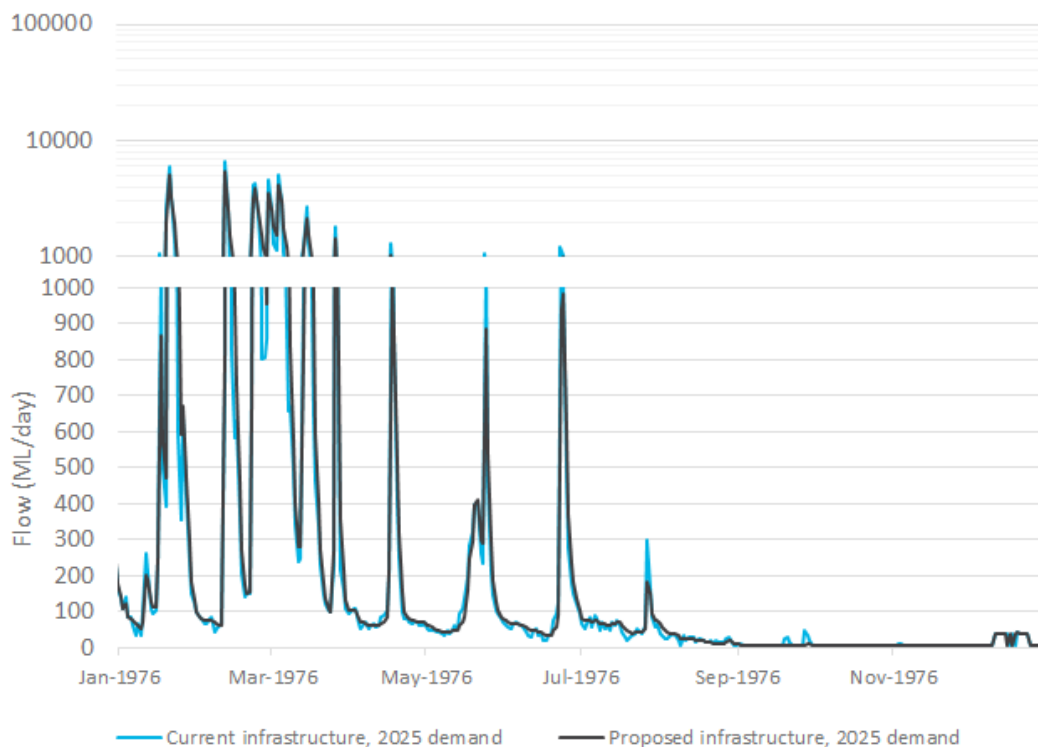


Figure 3-9 Revised Spillway: Modelled Flow in Doon Doon Creek

The revised wider spillway reduces the effects of the project on stream power, depth, and velocity within Doon Doon Creek, such that these flow descriptors are expected to be effectively unchanged by the project.

For example, Figure 3-10 illustrates bed shear stress in a Doon Doon Creek riffle as presented in the EIS, with differences in shear stress between current and proposed infrastructure in the order of 5 N/m² for certain flow rates. Figure 3-11 illustrates the same model data updated with the wider spillway, with shear stresses almost identical for both infrastructure arrangements.

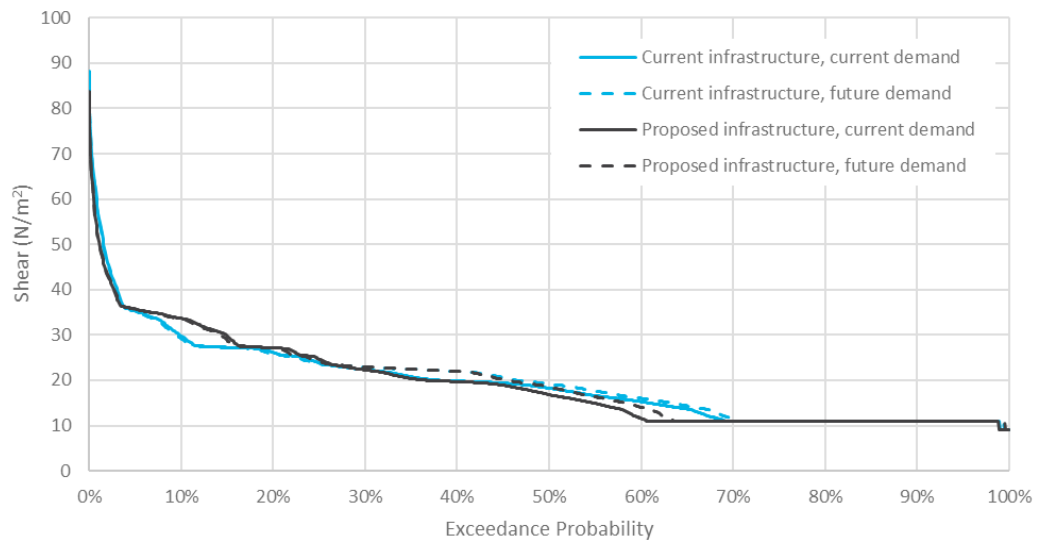


Figure 3-10 EIS Model Results: Modelled Shear Stress in Doon Doon Creek Riffle

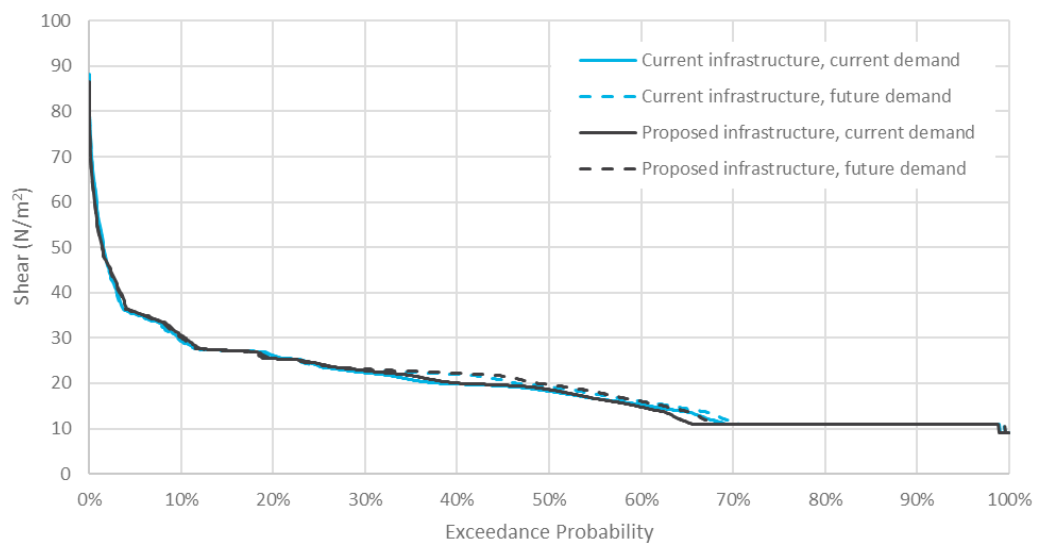


Figure 3-11 Revised Spillway: Modelled Shear Stress in Doon Doon Creek Riffle

Overall, this analysis shows that the wider spillway would result in reduced change to the streamflow regime and stream hydraulics.

4 Modelled Results

The RORB hydrologic and TUFLOW hydraulic models were simulated for the 1%, 0.5%, 0.2%, 0.1%, and 0.05% AEP events for the 2050 year horizon SSP3-7.0 scenario. The suite of design events was simulated for both existing dam and proposed raised dam with 55 m wide spillway configurations.

4.1 FLOOD MAPPING

One of the benefits and outcomes of 2D modelling is the ability to visualise the spatial distribution of model outputs, such as peak flood level, depth, and velocity as a high-definition flood map. The visualisation of the various model outputs is a critical component in developing an understanding of and appreciation of the flood behaviour across the study area.

Flood mapping undertaken as a part of this assessment is presented in Appendix B for both existing and proposed dam configurations. The following outputs have been mapped:

- Peak flood depth,
- Peak flood velocity, and
- Peak flood hazard categorisation.

4.1.1 Flood Hazard Categorisation

Flood hazard is typically derived from a combination of peak flood depth and velocity. The visualisation of flood hazard provides for a better understanding of the potential flood risk within the study area. Handbook 7 – Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (2013) provides a revised hazard classification, which adds clarity to the hazard categories and what they mean in practice. The revised classifications were formally adopted by the DCCEE in the Flood Risk Management Manual (NSW Government, 2023). The classification is divided into six (6) categories as depicted in Figure 4-1. These categories indicate the restrictions on people, buildings, and vehicles:

- H1 – No constraints,
- H2 – Unsafe for small vehicles,
- H3 – Unsafe for all vehicles, children, and the elderly,
- H4 – Unsafe for all people and all vehicles,
- H5 – Unsafe for all people and all vehicles. Buildings require special engineering design and construction, and
- H6 – Unsafe for all people and vehicles. All building types considered vulnerable to failure.

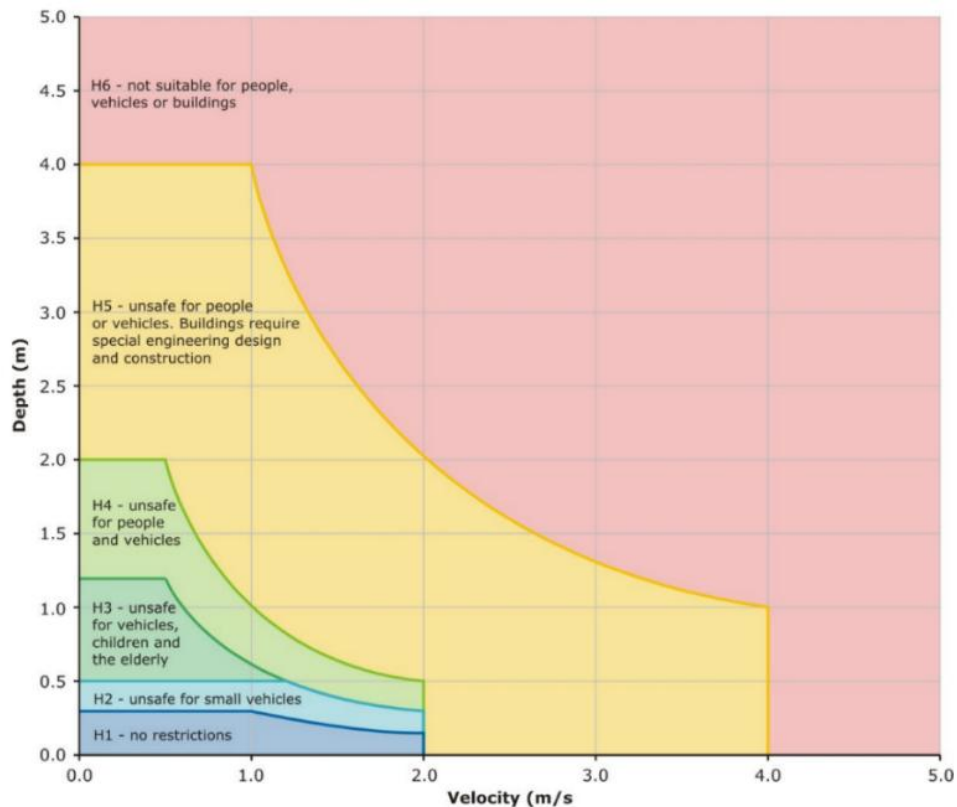


Figure 4-1 Combined Hazard Categories (AIDR, 2017)

4.1.2 Peak Flood Level Difference Mapping (Afflux)

The difference in peak flood level and hazard categorisation (commonly referred to as afflux) outputs between the proposed dam and existing dam configurations has been mapped and presented in Appendix C of this report. The change in peak flood extents has also been included for each comparison.

4.1.3 Reporting Locations

Key reporting points (RP) have been established both upstream and downstream of the dam for the extraction of peak flood levels and velocities in subsequent sections of this report. The reporting points have been indicated in Figure 4-2.

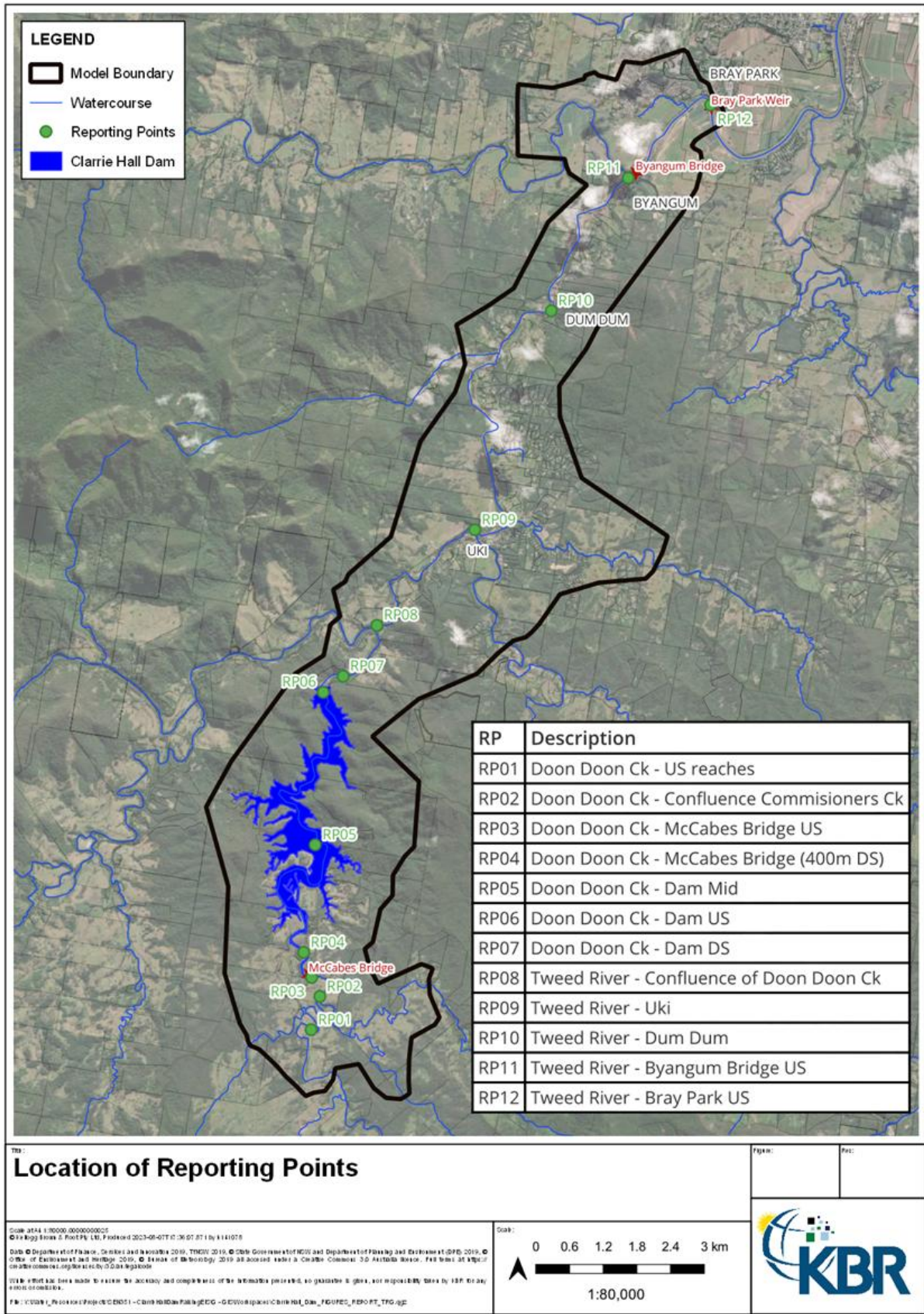


Figure 4-2 Key Reporting Point Locations

4.2 RESULTS AT THE CLARRIE HALL DAM

Peak flows through the dam spillway under existing and proposed configurations for the 2050 year horizon SSP3-7.0 scenario have been provided in Table 4-1. Similarly, peak flood levels upstream of the spillway have been presented in Table 4-2. Existing and proposed dam rating curves are presented in Figure 4-3 and Figure 4-4 respectively.

For the suite of design events, no overtopping of the dam embankment has been simulated. However, overtopping in the existing dam configuration is identified in the PMF with an additional peak overtopping flow of 815 m³/s modelled.

Table 4-1 Peak Flow (m³/s) Comparison at the Clarrie Hall Dam Spillway and Embankment

Design Event	Existing Dam	Proposed Dam (55 m Wide Spillway)	Difference
1% AEP	653	742	+89
0.5% AEP	685	778	+93
0.2% AEP	767	881	+114
0.1% AEP	829	958	+129
0.05% AEP	891	1,033	+142
PMF	2,289 (1,474) *	2,009	-280

*The PMF event under the existing dam configuration overtops the dam embankment. Total flow through the spillway and over the embankment has been provided with the flow through the spillway only provided in brackets.

Table 4-2 Peak Dam Water Level (m AHD) Comparison at the Clarrie Hall Dam Spillway

Design Event	Existing Dam	Proposed Dam (55 m Wide Spillway)	Difference
1% AEP	66.95	73.25	+6.30
0.5% AEP	67.14	73.36	+6.22
0.2% AEP	67.66	73.67	+6.01
0.1% AEP	68.03	73.89	+5.86
0.05% AEP	68.38	74.10	+5.72
PMF	71.78	76.48	+4.70

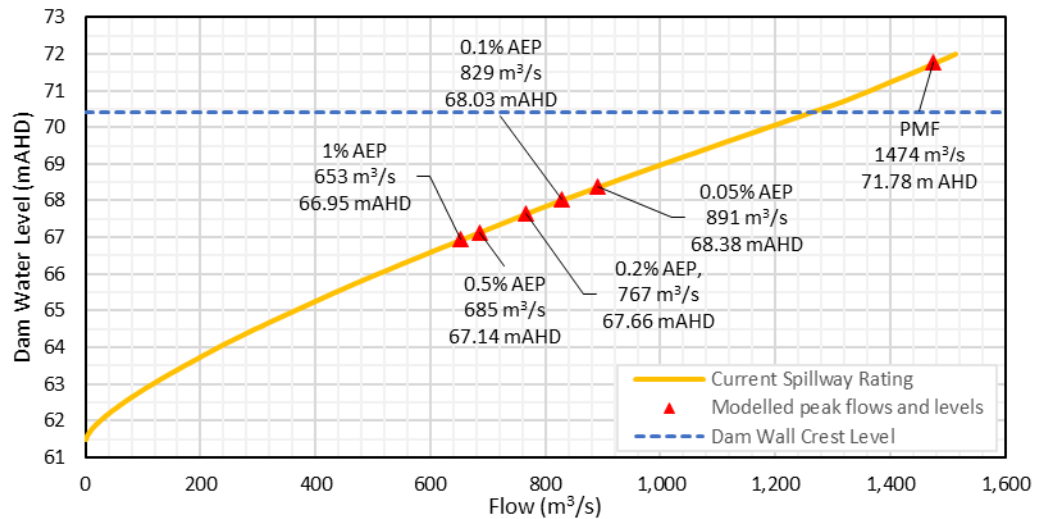


Figure 4-3 Existing Dam Rating Curve and Modelled Results

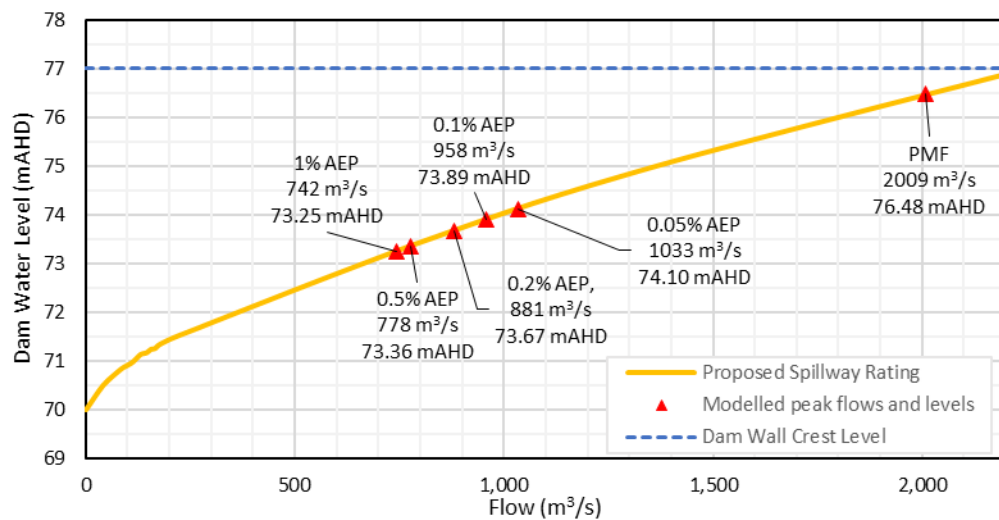


Figure 4-4 Proposed Raised Dam (55 m Wide Spillway) Rating Curve and Modelled Results

4.3 RESULTS UPSTREAM OF CLARRIE HALL DAM

Peak flood levels upstream of the dam have been presented in Table 4-3 with the difference between proposed and existing dam configurations presented in Table 4-4. Similarly, peak flood velocities have been reported in Table 4-5 and Table 4-6 respectively.

With the raising of the dam spillway and embankment crest levels, peak flood levels upstream of the dam have naturally increased. It should be noted that the peak flood level for the PMF event is lower than the required 77 m AHD. Peak flood velocities are generally lower upstream of the dam as flood waters back up behind the raised embankment. However, in the vicinity of the spillway, peak flood velocities increase with the increased discharge capacity of the spillway.

Large increases in flood extent are noted upstream of the dam, correlated with the increase in peak flood levels. The effect is most noticeable closer to the dam with little change towards the upstream model boundary (beyond the confluence of Doon Doon Creek and Commissioner's Creek).

Due to the significant depths of water within Doon Doon Creek and the Tweed River, the majority of the modelled flood extent for the existing dam configuration is classified as a H6 flood hazard for the 1% AEP event. As such, even with the increased flood depths upstream of the dam and

larger discharges through the spillway, minimal change in flood hazard categorisation is noted for the proposed raised dam configuration.

Table 4-3 Peak Flood Level (m AHD) Upstream of the Clarrie Hall Dam

#	1% AEP		0.5% AEP		0.2% AEP		0.1% AEP		0.05% AEP	
	EXG	D55	EXG	D55	EXG	D55	EXG	D55	EXG	D55
RP01	75.97	75.99	76.01	76.08	76.24	76.28	76.36	76.41	76.47	76.53
RP02	70.18	73.42	70.29	73.54	70.61	73.86	70.84	74.09	71.06	74.30
RP03	68.67	73.34	68.78	73.45	69.03	73.77	69.22	73.98	69.41	74.20
RP04	67.11	73.27	67.30	73.39	67.80	73.70	68.16	73.92	68.50	74.13
RP05	67.00	73.27	67.19	73.38	67.72	73.70	68.09	73.92	68.45	74.13
RP06	66.95	73.25	67.15	73.37	67.67	73.68	68.04	73.90	68.39	74.11

Table 4-4 Difference in Peak Flood Level (m) Upstream of the Clarrie Hall Dam

#	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP	0.05% AEP
RP01	+0.02	+0.07	+0.04	+0.05	+0.06
RP02	+3.24	+3.25	+3.25	+3.25	+3.24
RP03	+4.67	+4.67	+4.74	+4.76	+4.79
RP04	+6.16	+6.09	+5.90	+5.76	+5.63
RP05	+6.27	+6.19	+5.98	+5.83	+5.68
RP06	+6.30	+6.22	+6.01	+5.86	+5.72

Table 4-5 Peak Flood Velocity (m/s) Upstream of the Clarrie Hall Dam

#	1% AEP		0.5% AEP		0.2% AEP		0.1% AEP		0.05% AEP	
	EXG	D55	EXG	D55	EXG	D55	EXG	D55	EXG	D55
RP01	2.26	2.27	2.27	2.27	2.29	2.29	2.31	2.31	2.32	2.32
RP02	3.71	1.77	3.74	1.81	3.80	1.93	3.82	2.01	3.83	2.07
RP03	2.61	1.17	2.66	1.20	2.80	1.30	2.90	1.36	3.00	1.42
RP04	2.83	0.69	2.85	0.70	2.87	0.75	2.94	0.79	3.03	0.83
RP05	0.23	0.11	0.24	0.11	0.25	0.12	0.26	0.13	0.28	0.13
RP06	0.14	0.41	0.15	0.41	0.16	0.41	0.17	0.41	0.18	0.41

Table 4-6 Difference in Peak Flood Velocity (m/s) Upstream of the Clarrie Hall Dam

#	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP	0.05% AEP
RP01	+0.01	0.00	0.00	0.00	0.00
RP02	-1.94	-1.93	-1.87	-1.81	-1.76
RP03	-1.44	-1.46	-1.5	-1.54	-1.58
RP04	-2.14	-2.15	-2.12	-2.15	-2.20
RP05	-0.12	-0.13	-0.13	-0.13	-0.15
RP06	+0.27	+0.26	+0.25	+0.24	+0.23

4.4 RESULTS DOWNSTREAM OF CLARRIE HALL DAM

Peak flood levels downstream of the dam have been presented in Table 4-7 with the difference between proposed and existing dam configurations presented in Table 4-8. Similarly, peak flood velocities have been reported in Table 4-9 and Table 4-10 respectively.

In comparison to the increase in flood levels upstream of the dam, minor increases in peak flood level (generally less than 0.20 m) downstream of the dam are modelled. This can be attributed to the increase in discharge capacity of the spillway. The scaled-up rainfall associated with the new ARR Version 4.2 future climate factors result in more total runoff to be routed through the system. While the spillway crest level itself has increased, flood waters are able to reach the higher spillway into larger discharge from the dam more readily compared to present day rainfall without the inclusion of future climate factors.

A similar trend in peak flood velocity differences is noted downstream of the dam.

Like the results upstream of the dam, almost no change in flood hazard categorisation is noted downstream of the dam.

Table 4-7 Peak Flood Level (m AHD) Downstream of the Clarrie Hall Dam

#	1% AEP		0.5% AEP		0.2% AEP		0.1% AEP		0.05% AEP	
	EXG	D55	EXG	D55	EXG	D55	EXG	D55	EXG	D55
RP07	31.67	32.01	31.83	32.17	32.24	32.60	32.52	32.91	32.79	33.21
RP08	29.88	30.01	30.04	30.16	30.45	30.58	30.72	30.85	30.96	31.11
RP09	24.08	24.21	24.29	24.42	24.82	24.96	25.18	25.33	25.52	25.68
RP10	15.18	15.32	15.43	15.57	16.08	16.23	16.52	16.69	16.95	17.12
RP11	10.79	10.83	10.94	10.99	11.33	11.39	11.60	11.66	11.86	11.92
RP12	7.86	7.90	8.01	8.06	8.41	8.46	8.68	8.74	8.95	9.01

Table 4-8 Difference in Peak Flood Level (m) Downstream of the Clarrie Hall Dam

#	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP	0.05% AEP
RP07	+0.34	+0.34	+0.36	+0.39	+0.42
RP08	+0.13	+0.12	+0.13	+0.13	+0.15
RP09	+0.13	+0.13	+0.14	+0.15	+0.16
RP10	+0.14	+0.14	+0.15	+0.17	+0.17
RP11	+0.04	+0.05	+0.06	+0.06	+0.06
RP12	+0.04	+0.05	+0.05	+0.06	+0.06

Table 4-9 Peak Flood Velocity (m/s) Downstream of the Clarrie Hall Dam

#	1% AEP		0.5% AEP		0.2% AEP		0.1% AEP		0.05% AEP	
	EXG	D55	EXG	D55	EXG	D55	EXG	D55	EXG	D55
RP07	2.31	2.37	2.33	2.40	2.40	2.50	2.47	2.59	2.52	2.65
RP08	3.09	3.10	3.13	3.14	3.25	3.27	3.32	3.35	3.40	3.43
RP09	2.88	2.86	2.86	2.86	2.81	2.82	2.75	2.76	2.70	2.67
RP10	1.85	1.85	1.85	1.85	1.89	1.89	1.94	1.94	1.96	1.97
RP11	2.11	2.14	2.14	2.17	2.22	2.25	2.27	2.31	2.33	2.37

#	1% AEP		0.5% AEP		0.2% AEP		0.1% AEP		0.05% AEP	
	EXG	D55	EXG	D55	EXG	D55	EXG	D55	EXG	D55
RP12	4.17	4.18	4.18	4.18	4.19	4.20	4.20	4.20	4.20	4.20

Table 4-10 Difference in Peak Flood Velocity (m/s) Downstream of the Clarrie Hall Dam

#	1% AEP	0.5% AEP	0.2% AEP	0.1% AEP	0.05% AEP
RP07	+0.06	+0.07	+0.10	+0.12	+0.13
RP08	+0.01	+0.01	+0.02	+0.03	+0.03
RP09	-0.02	0.00	+0.01	+0.01	-0.03
RP10	0.00	0.00	0.00	0.00	+0.01
RP11	+0.03	+0.03	+0.03	+0.04	+0.04
RP12	+0.01	0.00	+0.01	0.00	0.00

4.5

DURATION OF INUNDATION

An extended model simulation period of 150 hours was undertaken for the 2050 year horizon SSP3-7.0 future climate scenario using the PMF events under the existing and proposed dam configurations (55 m wide spillway design). The 48 hour event was utilised as the duration of inundation is correlated with the storm duration. The extended 48 hour event modelling allows for an assessment of the duration of inundation for the area upstream of the dam.

The time series outputs for both the existing and proposed dam configurations upstream of the dam embankment are presented in Figure 4-5. Under the existing dam configuration, upwards of 150 hours are required for the dam to return to the existing full supply/spillway level of 61.5 m AHD. Due to the increased discharge capacity of the proposed spillway, approximately 60 hours are required to return to the proposed full supply/spillway level of 70 m AHD.

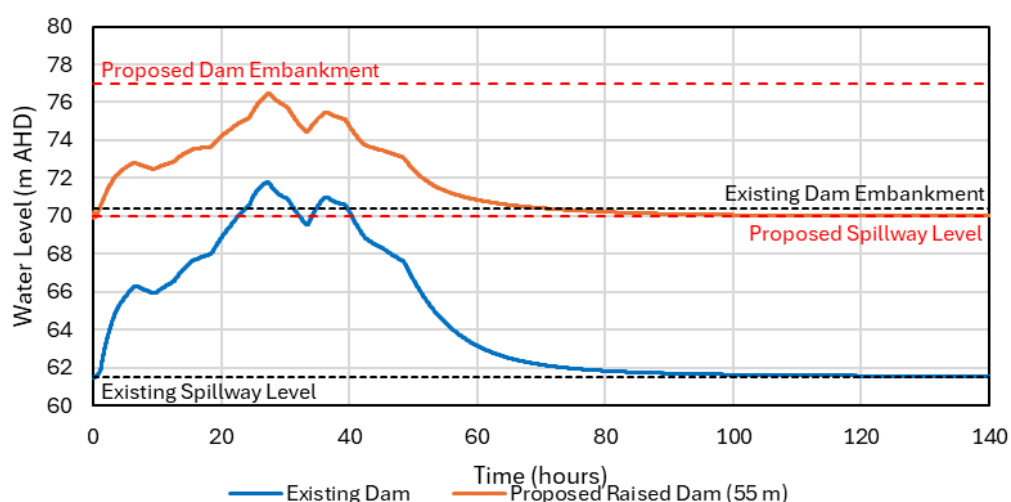


Figure 4-5 Duration of Inundation Analysis at Clarrie Hall Dam

Similarly, the time series outputs for both the existing and proposed dam configurations at the Uki gauge on the Tweed River (downstream of Clarrie Hall Dam) are presented in Figure 4-6. The results indicate minor reductions in the time of duration of inundation downstream of the dam, with a faster receding falling limb. The time of duration of inundation downstream of the dam is largely insensitive to the raised dam design in comparison to the area upstream of the dam.

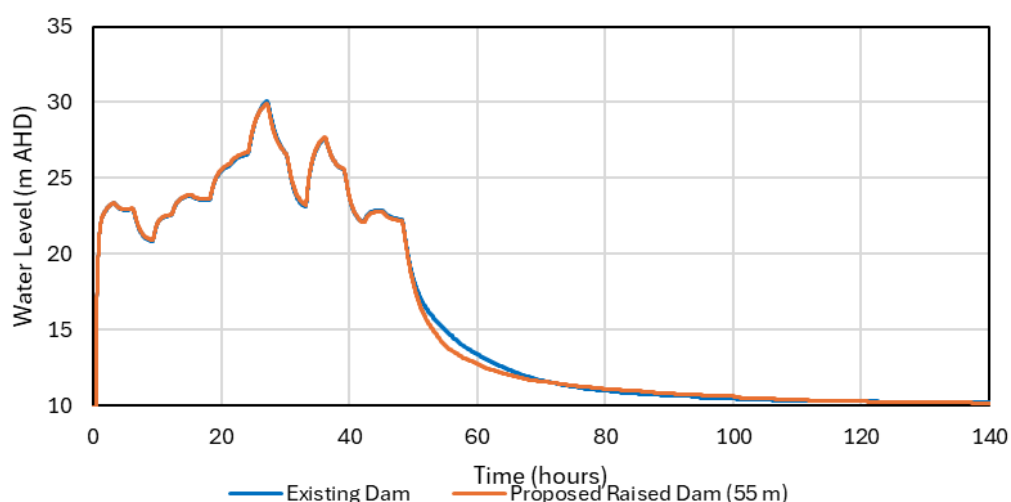


Figure 4-6 Duration of Inundation Analysis at the Uki Gauge

4.6

EVACUATION MANAGEMENT

In order to identify the potential impacts to existing evacuation routes and centres as a result of the proposed dam raising, an understanding of the location of the existing evacuation routes and centres was required. As such, KBR consulted with Council and the State Emergency Service (SES). The correspondences with Council confirmed that the Uki Public Hall (1462 Kyogle Road) is the only evacuation centre within the study area. No evacuation routes were identified by the SES or Council.

Mapping of the existing and proposed dam raising flood extents for the 2050 year horizon across the range of design events is illustrated in proximity to the Uki Public Hall in Figure 4-7. Under both existing and proposed climatic conditions, the Uki Public Hall is inundated for the 1% AEP event and should therefore be reconsidered for the purposes of future evacuation management.

In lieu of further information surrounding an existing evacuation management plan, KBR has provided high-level commentary on the major waterway crossings within the study area. Peak flood levels have been extracted at key bridge bridges under both existing and proposed dam configurations and presented in Table 4-11.

Under both existing and proposed dam configurations for the 2050 year horizon SSP3-7.0 future climate scenario, major roads upstream of the dam (Commissioners Creek Road and Doon Doon Road) are both free from mainstream flood affectation in the 1% AEP event. Apart from the waterway crossing locations, Doon Doon Creek is mostly contained within its watercourse banks upstream of the dam. However, it is noted that McCabes Bridges is modelled to flood 1.28 m above the proposed bridge deck level for the proposed dam configuration as the raising of the dam wall increases peak flood levels notably upstream of the dam (refer to Table 4-4). It is further noted that local roads leading to McCabes Bridge such as Doon Doon Road would be closed due to flooding.

Downstream of the dam, Kyogle Road becomes overtopped at multiple points as flood waters break the banks of the Tweed River. The increased discharge capacity of the spillway results in a general increase in peak flood levels downstream of the dam. The modelling of the proposed raising of the dam wall and spillway results in all bridges to be inundated above the deck level.

However, it should be noted that even for the existing dam configuration, all bridges apart from the Kyogle Road bridge near the intersection with the Clarrie Hall Dam Road are overtopped. The impact to the existing evacuation routes is therefore minimal as a result of the proposed dam

raising as most roads in proximity to the main waterway are overtopped in both existing and proposed cases.

Evacuation centres should be ideally situated outside of the PMF extent, however it should be noted that an overland flooding assessment should be undertaken to confirm their appropriateness.

Table 4-11 Summary of Peak Flood Levels at Key Bridges for the 1% AEP event (2050 SSP3-7.0)

Location	Proximity to Dam	Bridge Deck Level (m AHD)	Existing (m AHD)	Proposed (m AHD)
McCabes Bridge (existing)	Upstream	66.5	68.37	73.28
McCabes Bridge (proposed)		72.0		
Kyogle Road near the intersection with Clarrie Hall Dam Road	Downstream	30.40	30.26	30.41
Kyogle Road near the Mount Warning Hotel	Downstream	21.10	24.01	24.14
Kyogle Road near the intersection with Smiths Creek Road	Downstream	17.00	22.19	22.34
Byangum Bridge	Downstream	6.00	10.76	10.73

It should be noted that the hydrologic and hydraulic modelling developed for the original flood impact assessment only considered the mainstream flooding mechanisms of Doon Doon Creek and the Tweed River. An overland flooding mechanism is not considered within the modelling and corresponding flood extents. The limitations of such modelling should be considered for the purposes of evacuation management.

However, it is acknowledged that Council has recently commissioned the *Tweed Valley Flood Study Update and Expansion* (WMA Water, 2024) in August 2024. The 2024 study considers both overland and mainstream flooding and should therefore be considered in the development of emergency management for the LGA. While commentary surrounding evacuation management is sparse within the report, the study and associated modelling should be relied upon should further emergency management related information be sought.

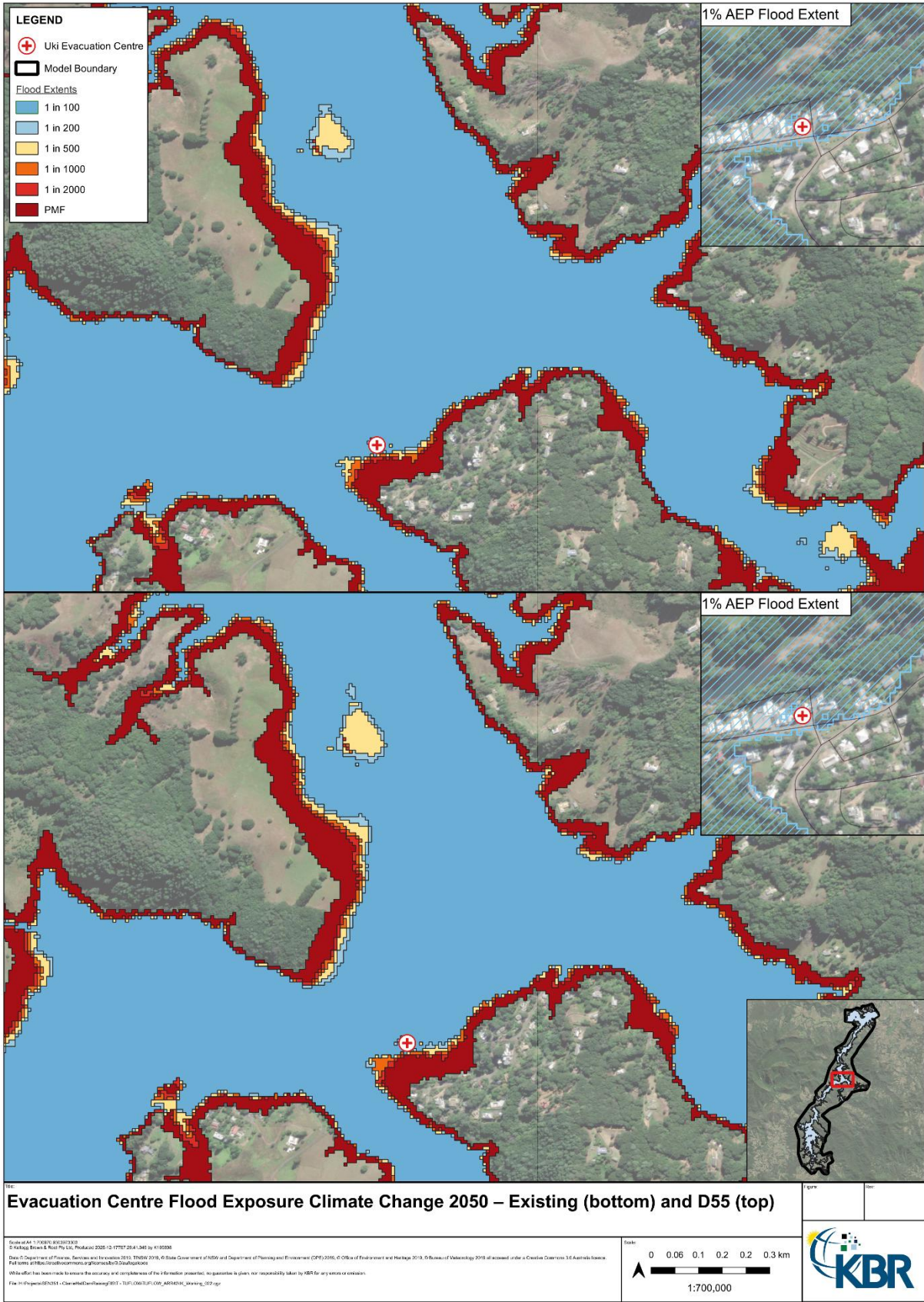


Figure 4-7 Uki Public Hall Evacuation Centre

4.7 FLOOD PLANNING LEVELS

The Flood Planning Level (FPL) for urban areas as defined in Tweed Shire Council's Development Control Plan (DCP) (2024), is the 1% AEP flood level plus 0.5 m freeboard. The minimum level to be adopted is 2.6 m AHD. For critical facilities, it is understood that the minimum level to be adopted is the PMF level.

As described in Section 4.6, the recently completed *Tweed Valley Flood Study Update and Expansion* (WMA Water, 2024) considers both overland and mainstream flooding mechanisms and should be relied upon for re-assessment of Council's Flood Planning Levels. The modelling undertaken within this study is a mainstream assessment only and should not be solely relied upon for planning purposes.

With the difference in objectives and subsequent modelling approach between the 2024 study and this study, a direct comparison of the flood mapping outputs generated between the two studies would not be appropriate. However, the modelled outputs from this study for the 2050 year horizon can be used to infer potential changes in peak flood levels as a result of the modelling of the proposed dam raising with climate. As described in Section 4.2 to Section 4.4, peak flood levels are modelled to increase both upstream and downstream of the Clarrie Hall Dam. As a result, flood planning levels for properties in proximity to the Tweed River could be expected to increase based on modelled future climate scenarios at 2050 using climate modelled scenario of SSP3-7 (noting that this study is a mainstream assessment). The modelling indicates that peak flood levels upstream of the dam increase more notably than those downstream due to the increase in flood storage capacity afforded by the raising of the dam embankment.

5 Conclusion

Acknowledging the increased rainfall associated with the newly released climate change guidance KBR has updated the existing hydrologic and hydraulic modelling of the Clarrie Hall Dam. The increased volume of rainfall that is routed through the system has resulted in the inability of the existing dam as well as the previously proposed raised dam configuration to prevent the overtopping of the Probable Maximum Flood Event. As such, KBR in collaboration with Worley Consulting has defined new 55 m wide and 80 m wide spillway designs to successfully prevent the overtopping of the PMF event with the consideration of the new climate change factors for the 2050 (SSP3-7.0) and 2100 (SSP5-8.5) future climate scenarios respectively. It is noted that there is sufficient width to widen the spillway within the existing embankment for both future climate scenarios without impacting on the proposed construction footprint.

An initial assessment by Worley Consulting identified that the existing spillway would require significant extension to pass the future PMF events. As this would result in a substantial length of the existing embankment needing to be removed and significant modification of the spillway design, it was concluded that such a design would not be feasible without raising the dam spillway and embankment crest levels.

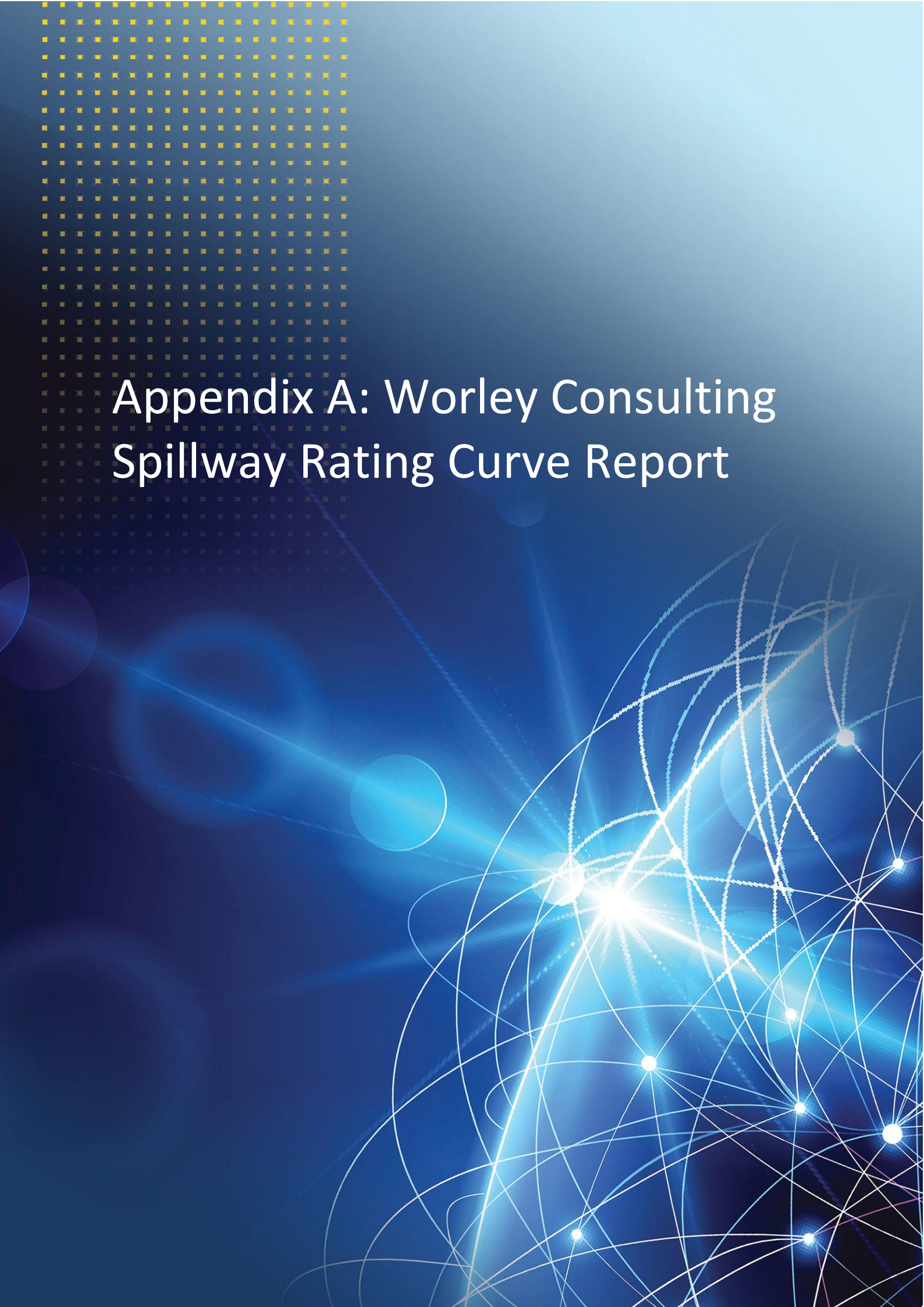
Flood mapping and associated commentary have been included for the existing dam and proposed 55 m wide spillway raised dam configurations. The 1%, 0.5%, 0.2%, 0.01%, and 0.05% AEP events were modelled through both dam configurations for the 2050 year horizon using the SSP3-7.0 scenario.

An assessment of climate change modelled for 2050 with SSP 3-7 found widespread increases in peak flood levels both upstream and downstream of the proposed dam wall. However, due to the existing flood depths and high hazards identified for the existing dam configuration, minimal change in flood hazard categorisation is induced by the proposed dam raising configuration. Due to the increased discharge capacity of the spillway, the time required to return the dam to full supply level following a 48 hour storm was modelled to decrease by upwards of 90 hours. Minimal change in the time of duration of inundation downstream of the dam wall was modelled.

High-level commentary on the emergency management and flood planning levels has also been included with all roads in close proximity to the Doon Doon Creek and Tweed River inundated under both existing and proposed dam configurations. Due to the flood affected nature of the study area under the existing dam configuration, minimal change in the emergency management is posed by the proposed dam raising.

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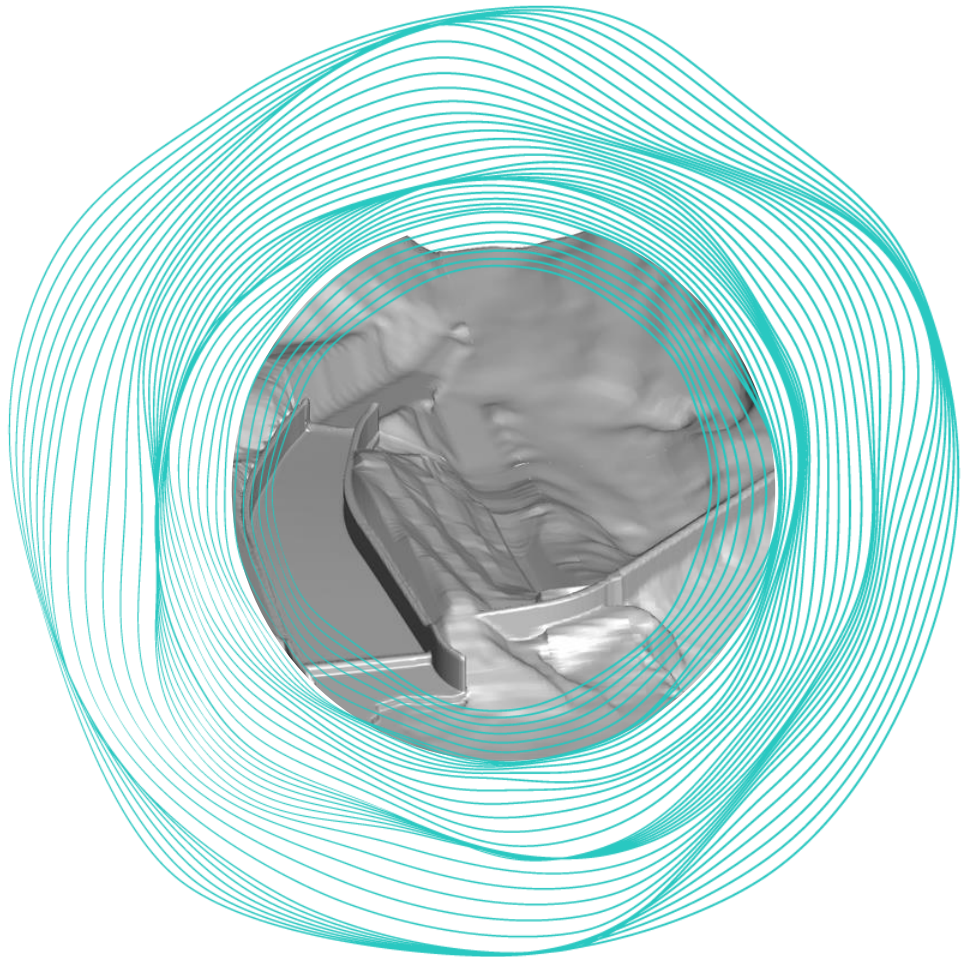
Appendix A: Worley Consulting Spillway Rating Curve Report

KELLOGG BROWN & ROOT PTY LTD

Clarrie Hall Dam Raising

Spillway Rating Curve Report

Document no. Rev 1: 311023-56044-RP002



24 October 2025

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PROJECT 311023-56044 - 311023-56044-RP002: Clarrie Hall Dam Raising - Spillway Rating Curve Report

Rev	Description	Originator	Reviewer	Worley Approver	Revision Date	Customer Approver	Approval Date
Rev A	Internal review	ECKL	DKH	DKH	22 Sep 25	N/A	N/A
		E Lo	D Ho	D Ho		N/A	
Rev 0	Issued for client review	ECKL	DKH	DKH	26 Sep 25	N/A	N/A
		E Lo	D Ho	D Ho		N/A	
Rev 1	Revised Issue	ECKL	DKH	DKH	24 Oct 25		N/A
		E Lo	D Ho	D Ho		N/A	

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1. Introduction

Kellogg Brown & Root Pty Ltd (KBR) was engaged by Tweed Shire Council (Council) to undertake flood modelling for the Clarrie Hall Dam Raising project. In 2024, KBR engaged Worley Consulting (Worley) to perform computational fluid dynamics (CFD) modelling of the proposed raised spillway (55 m wide) to determine the rating curve to cope with the Probable Maximum Flood (PMF) that considered the effect of climate change (CC).

In July 2025, the Department of Planning, Housing and Infrastructure (DPHI) requested Council to provide additional information on Clarrie Hall Dam Raising. KBR, on behalf of Council, requested Worley to perform further CFD modelling.

1.1 Scope of Work

The objectives of the CFD modelling are to update the rating curve for future 2050 and 2100 (SSP5-8.5)¹ PMF events for the existing spillway and for the proposed raised spillway. If these spillways are inadequate to cope with the flood events, they need to be widened such that the embankment dam crest is not overtopped. The crest details of each dam/spillway are as follows:

Existing dam/spillway

- Dam crest level: 70.4 m AHD
- Spillway crest level: 61.5 m AHD
- "L-shaped" spillway crest length: 36 m (PWA, 2018)

Raised dam/spillway

- Dam crest level: 77.0 m AHD
- Spillway crest level: 70.0 m AHD
- A straight spillway crest length: 55 m (Worley, 2024)

The methodology, inputs, assumptions, results, discussion and conclusion are presented in this study report.

¹ Shared Socioeconomic Pathways (SSPs) are climate change scenarios of projected socioeconomic global changes up to 2100. SSP5-8.5 refers to Fossil-Fuelled Development and very high greenhouse gas emissions.

2. Methodology

The following tasks were performed in this study.

- Review the inflow and outflow hydrographs of both 2050 and 2100 PMF events for both spillways provided by KBR.
- Create the existing spillway CFD model from the geometry information previously provided by NSW Public Works/Public Works Advisory (PWA). Perform CFD modelling of the existing spillway.
- Perform CFD modelling of the raised spillway model created by Worley in 2024. The width of the spillway was widened based on the provided inflow and outflow hydrographs.

The CFD modelling was performed using ANSYS CFX, which is licensed to Worley.

2.1 Review of Inflow/Outflow Hydrographs

The provided inflow hydrographs data for 2050 and 2100 events are plotted in Figure 2-1 to Figure 2-4. The time series outflow (downstream end of the chute spillway) and storage level (just upstream of the spillway entrance) for both 2050 and 2100 flood events are shown in Figure 2-5 to Figure 2-8 for the existing spillway (spillway crest length of 36m) and Figure 2-9 to Figure 2-12 for the raised spillway (spillway crest length of 55m). These data are based on the rating curve of the existing spillway, and the rating curve from the CFD modelling (Worley, 2024) of the raised spillway.

It can be observed that the existing spillway cannot pass the 2050 and 2100 flood events without overtopping the dam crest. The raised spillway (55m crest length) is adequate to pass the 2050 floods but under the 2100 floods, the raised dam crest will be overtopped.

Worley performed a high-level estimation of how much spillway widening is required to pass the 2100 (3 hr duration) outflow, that is, the highest flow rate out of the reservoir, for both the existing spillway and the raised spillway based on the supplied outflow and water level time series data, and assuming the water level was at the spillway crest level when the outflow occurred. The calculation used the average discharge coefficients of the respective rating curves. The results indicated the width required to pass the 2100 flood event is:

Existing spillway width: ~ 95 m (Figure 2-13) ($C_d = 1.25$)

Raised spillway width: ~ 80 m (Figure 2-14) ($C_d = 2.1$)

For the existing spillway, the required spillway width is considered to be quite significant, that is, a substantial length of the embankment will need to be removed to give way to the widened spillway. Note that the embankment dam is approximately 175m long (see Figure 2-15). Furthermore, a significant modification to the chute spillway will be required to cater for a smooth transition without causing the discharge flow choking at the contraction. Worley understands from the discussion between KBR and Council regarding the above, Council does not want to proceed with the widening option of the existing spillway. As such, the CFD modelling focused on the raised spillway widening.

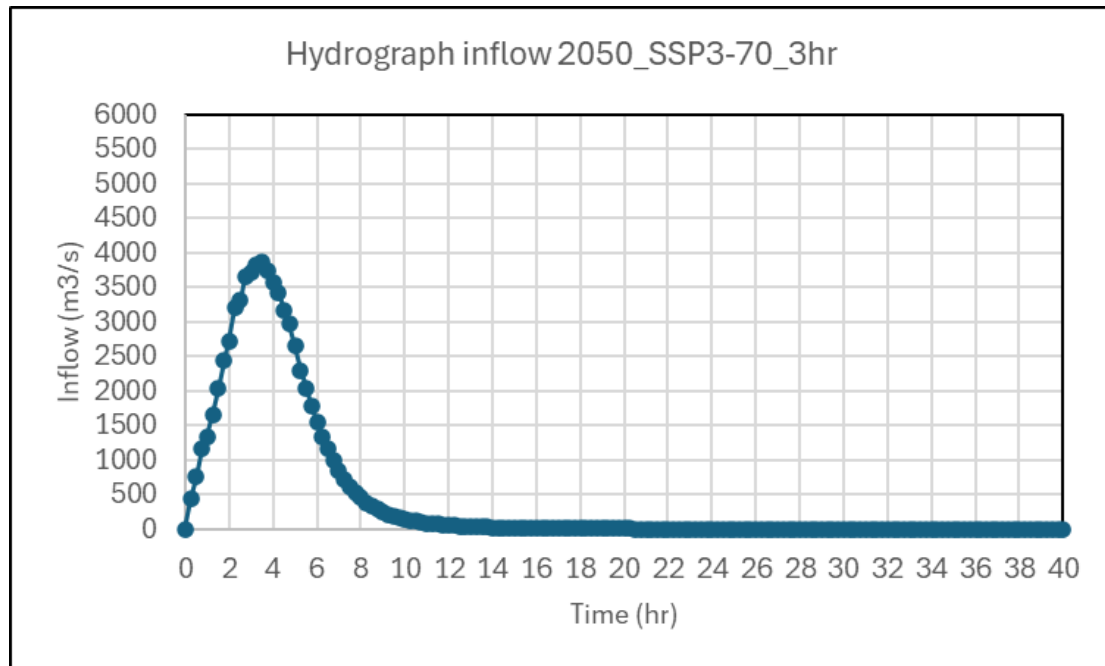


Figure 2-1: Inflow hydrograph 2050 event (3 hr duration) (Source: KBR (2025))

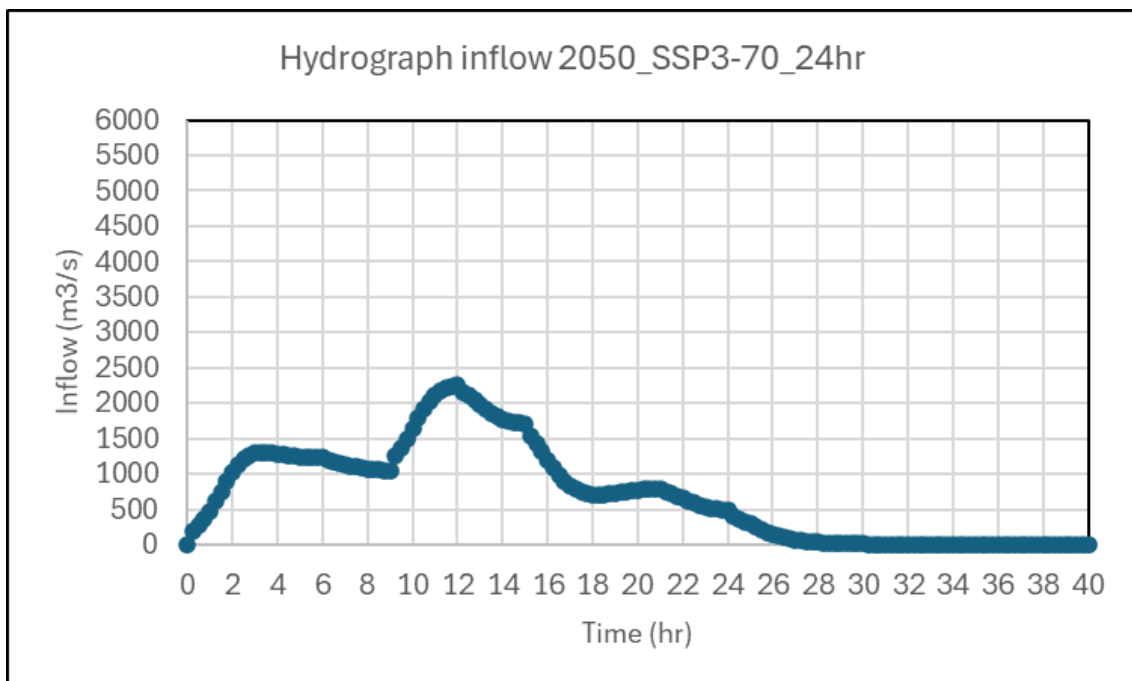


Figure 2-2: Inflow hydrograph 2050 event (24 hr duration) (Source: KBR (2025))

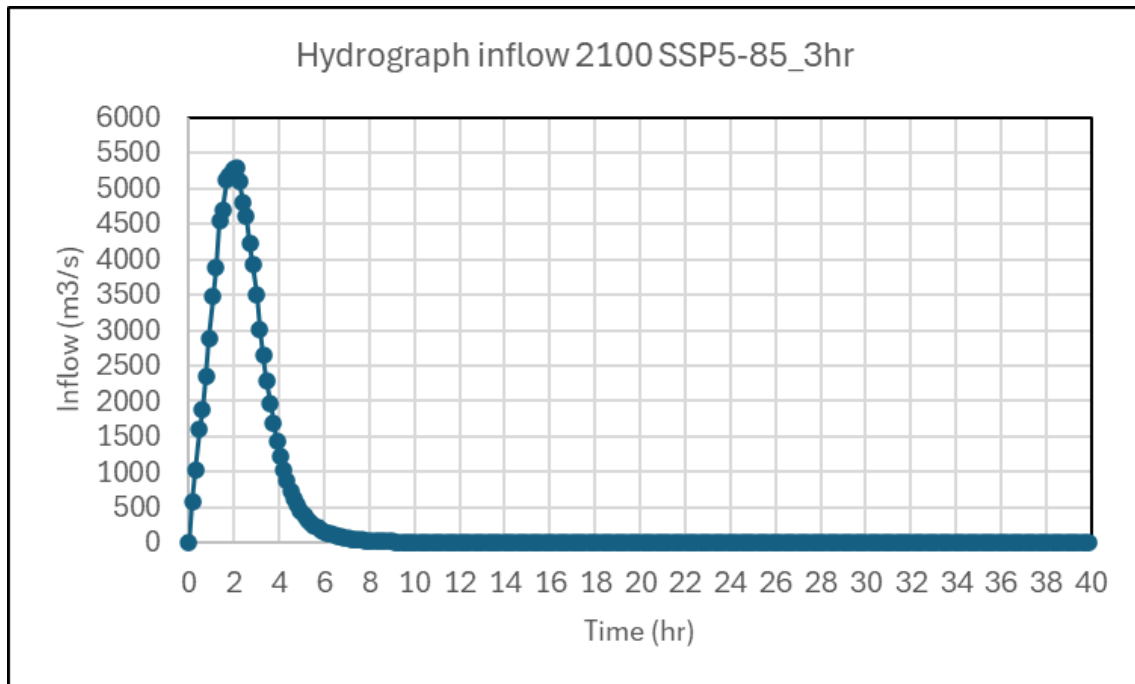


Figure 2-3: Inflow hydrograph 2100 event (3 hr duration) (Source: KBR (2025))

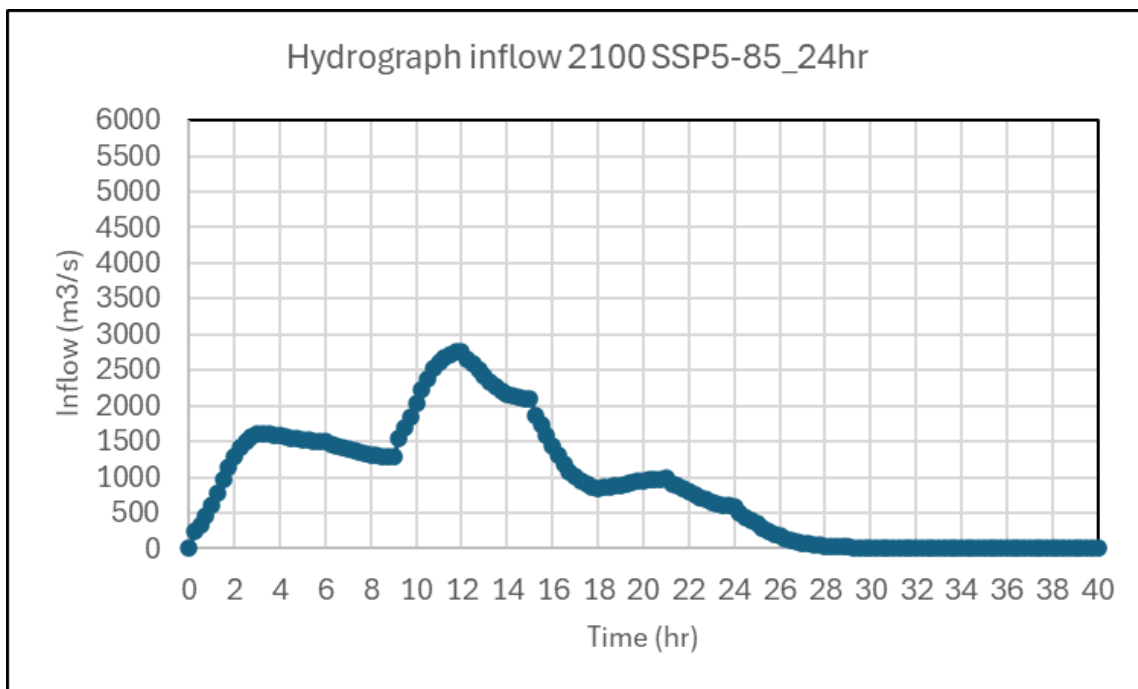


Figure 2-4: Inflow hydrograph 2100 event (24 hr duration) (Source: KBR (2025))

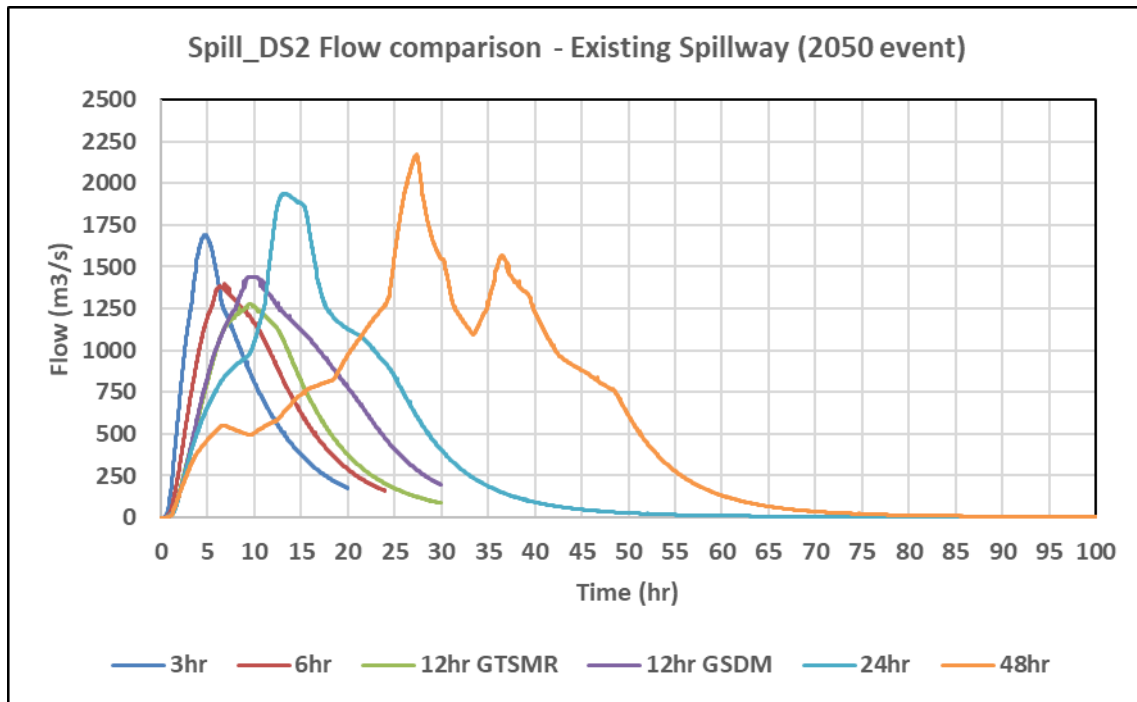


Figure 2-5: Existing Spillway - Outflow hydrograph 2050 event (Source: KBR (2025))

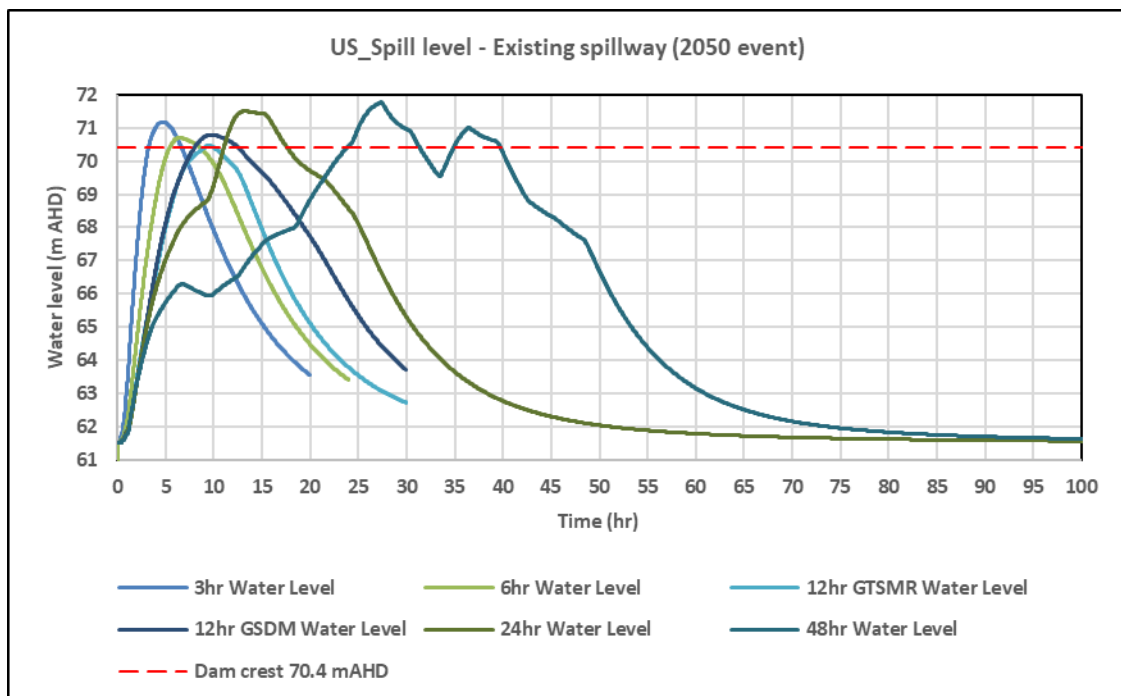


Figure 2-6: Existing Spillway – Water level upstream of spillway 2050 event (Source: KBR (2025))

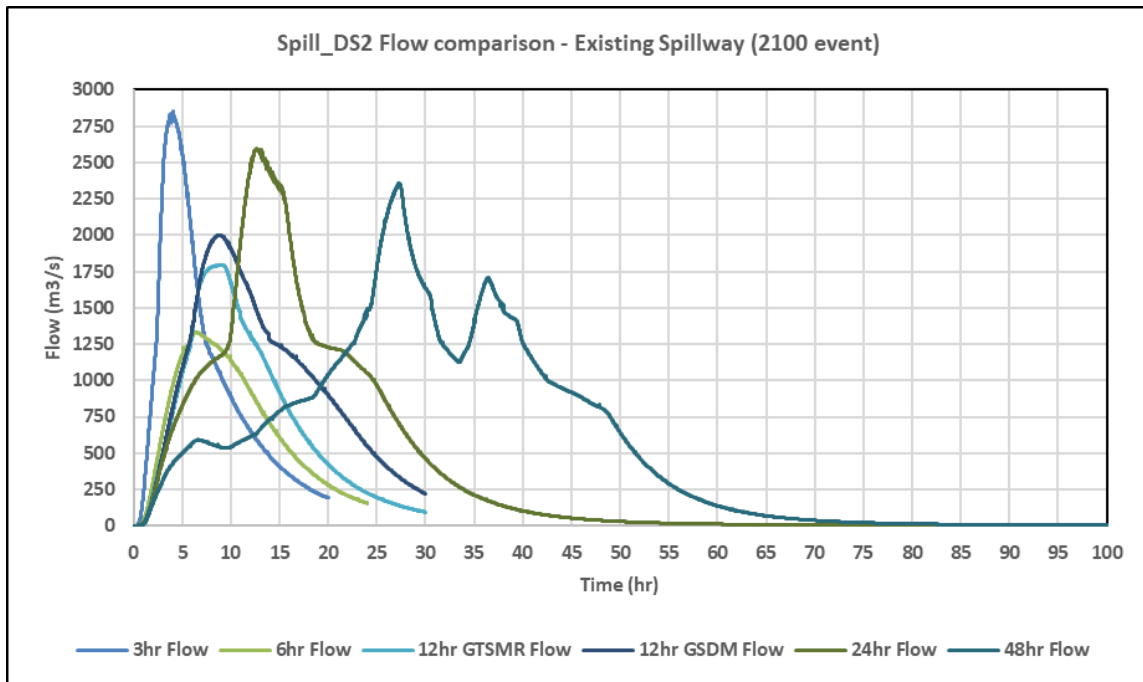


Figure 2-7: Existing Spillway - Outflow hydrograph 2100 event (Source: KBR (2025))

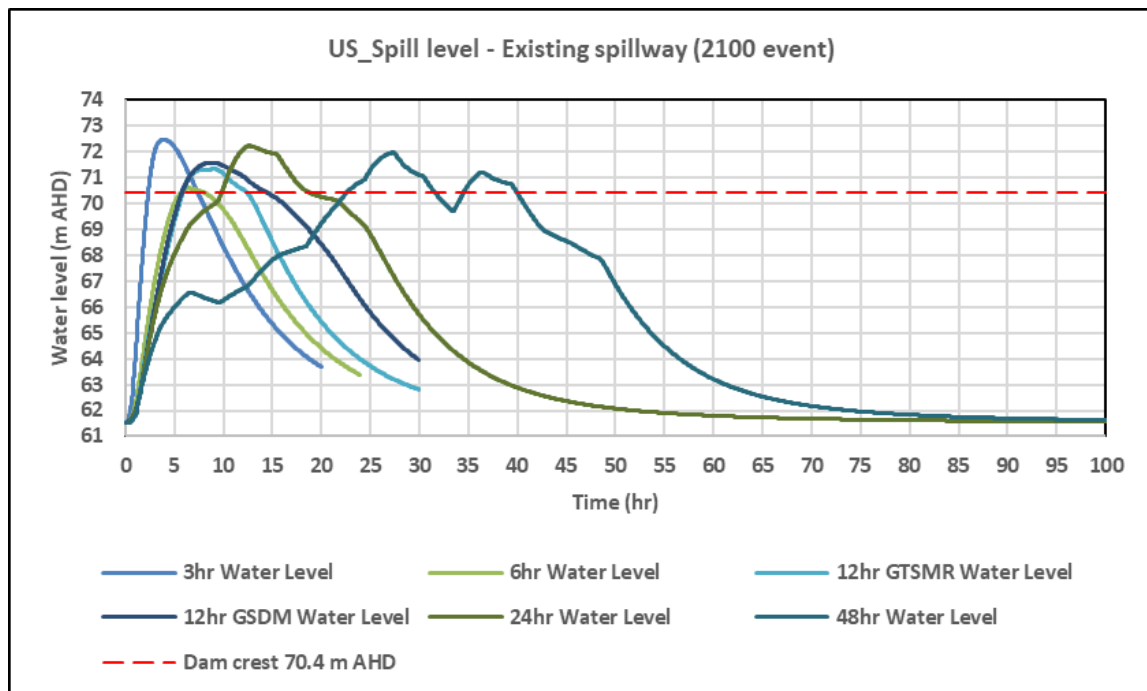


Figure 2-8: Existing Spillway – Water level upstream of spillway 2100 event (Source: KBR (2025))

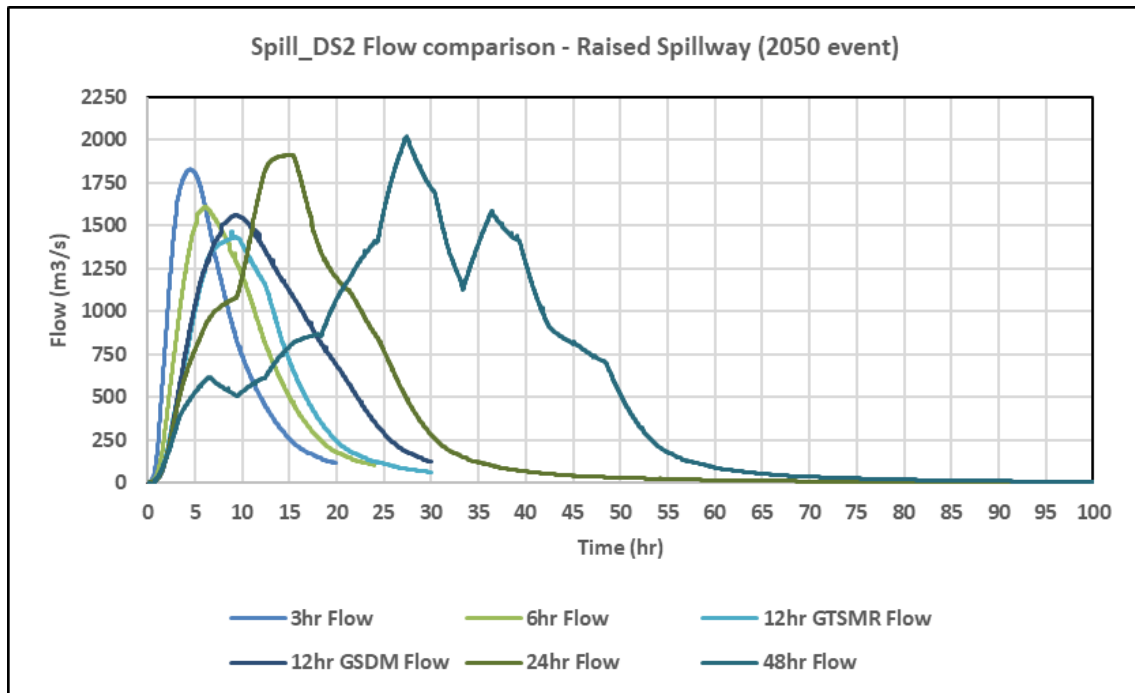


Figure 2-9: Raised Spillway - Outflow hydrograph 2050 event (Source: KBR (2025))

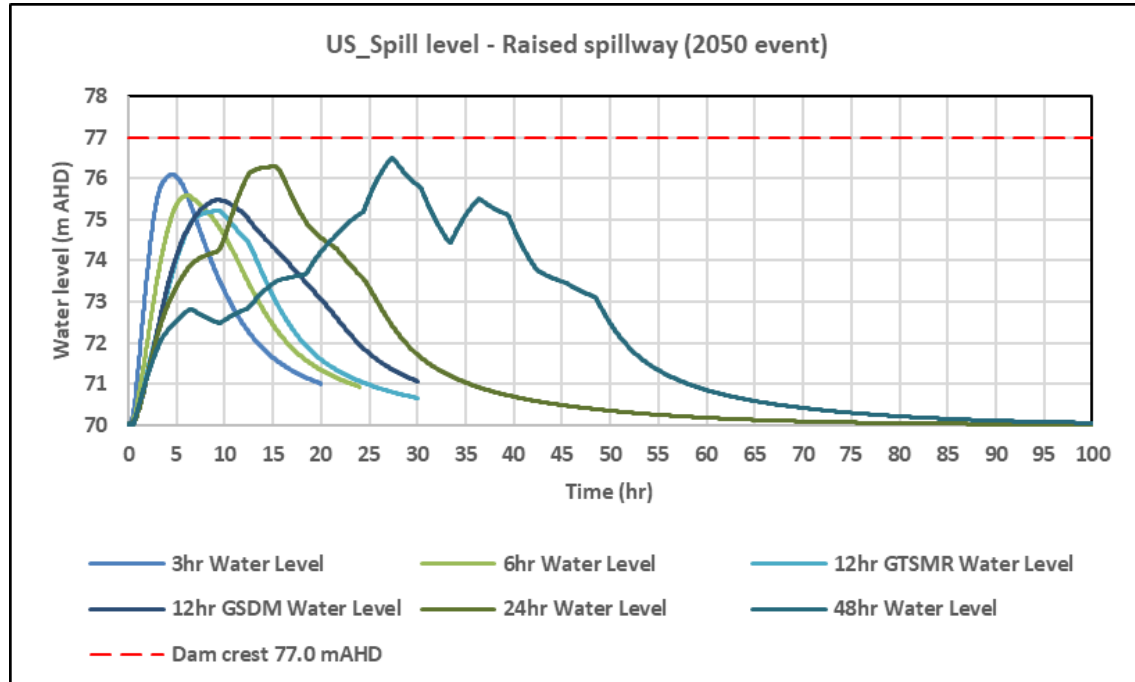


Figure 2-10: Raised Spillway Water level - 2050 event (Source: KBR (2025))

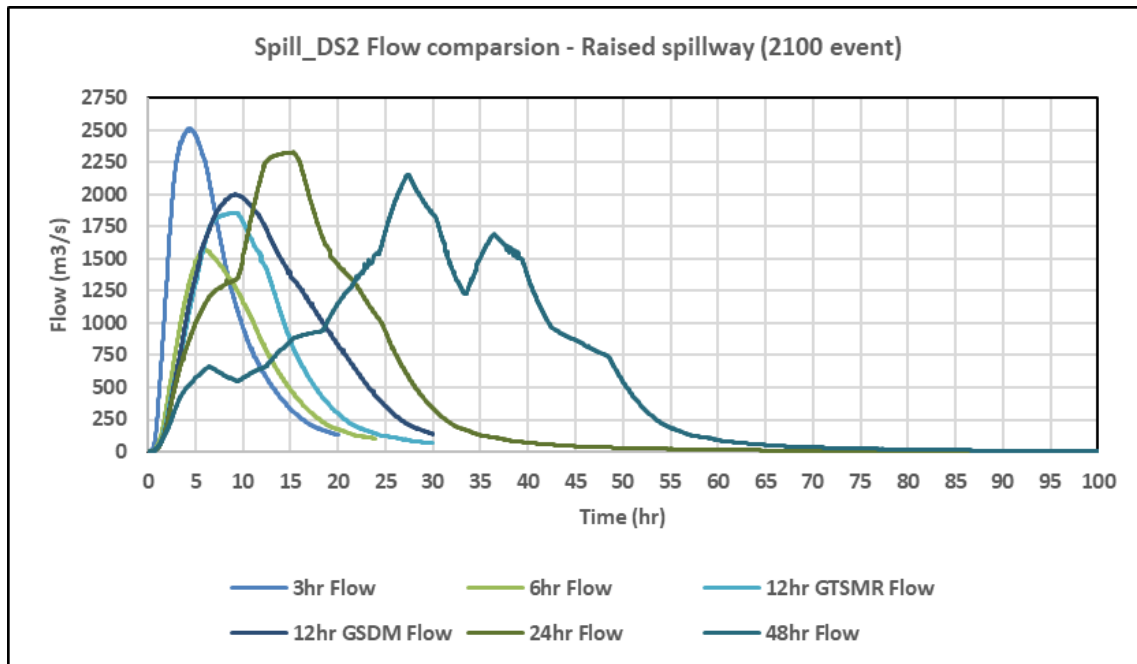


Figure 2-11: Raised Spillway - Outflow hydrograph 2100 event (Source: KBR (2025))

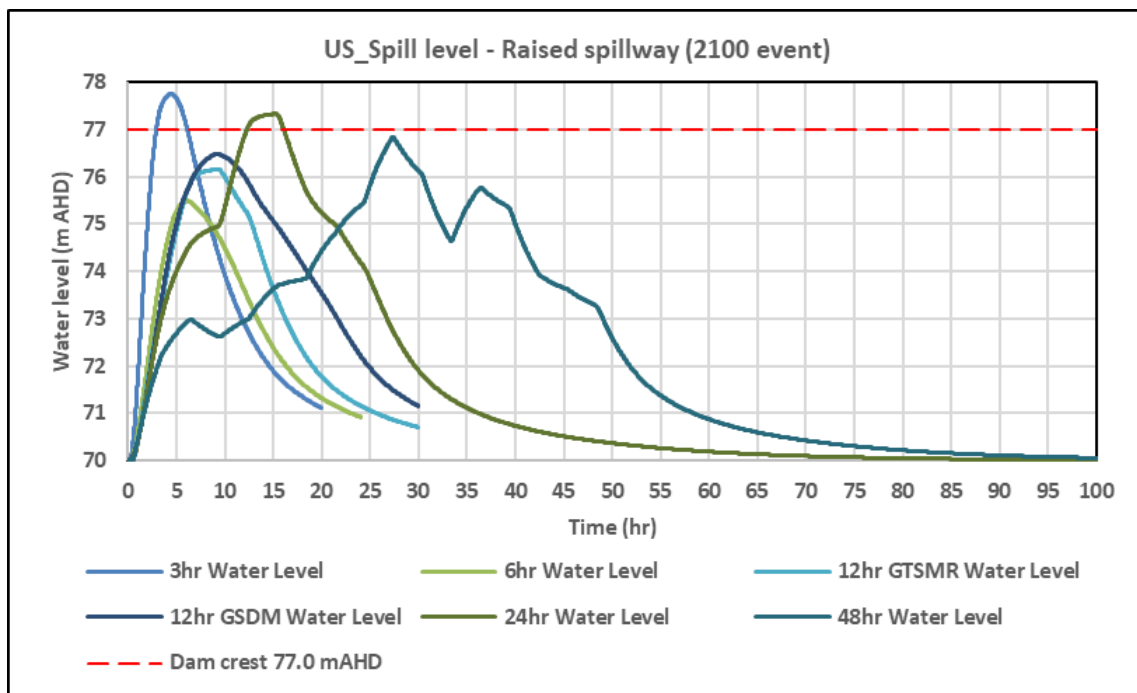


Figure 2-12: Raised Spillway Water level - 2100 event (Source: KBR (2025))

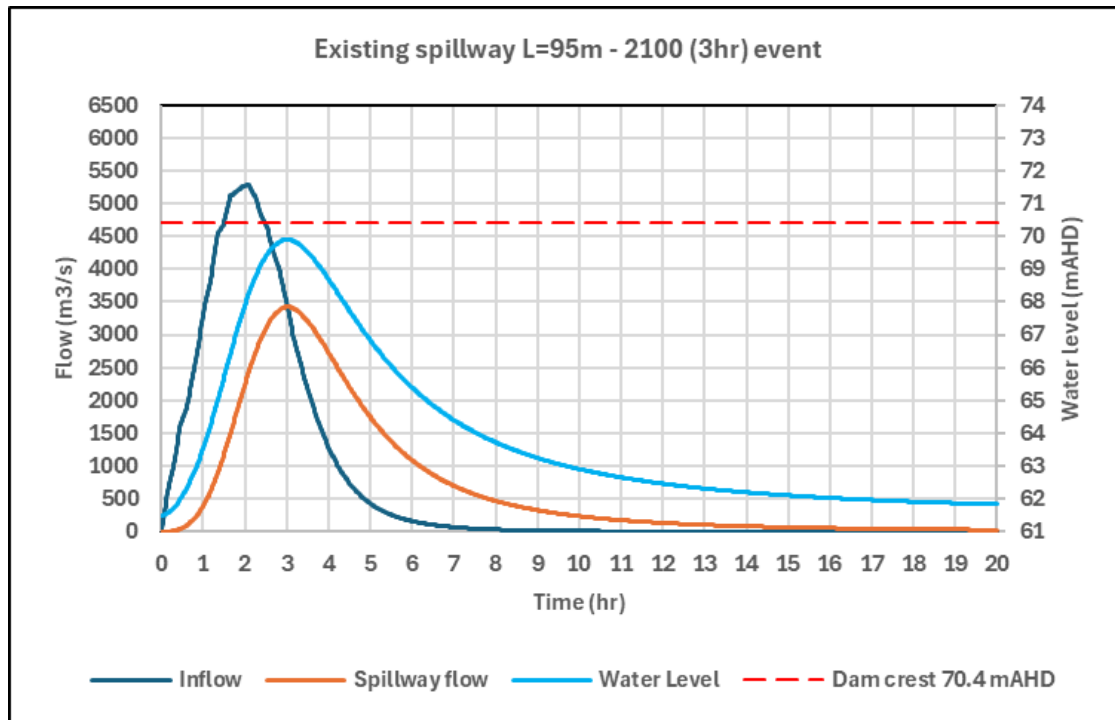


Figure 2-13: Existing Spillway 95m wide ($C_d = 1.48$) – Routing calculation 2100 (3hr) event

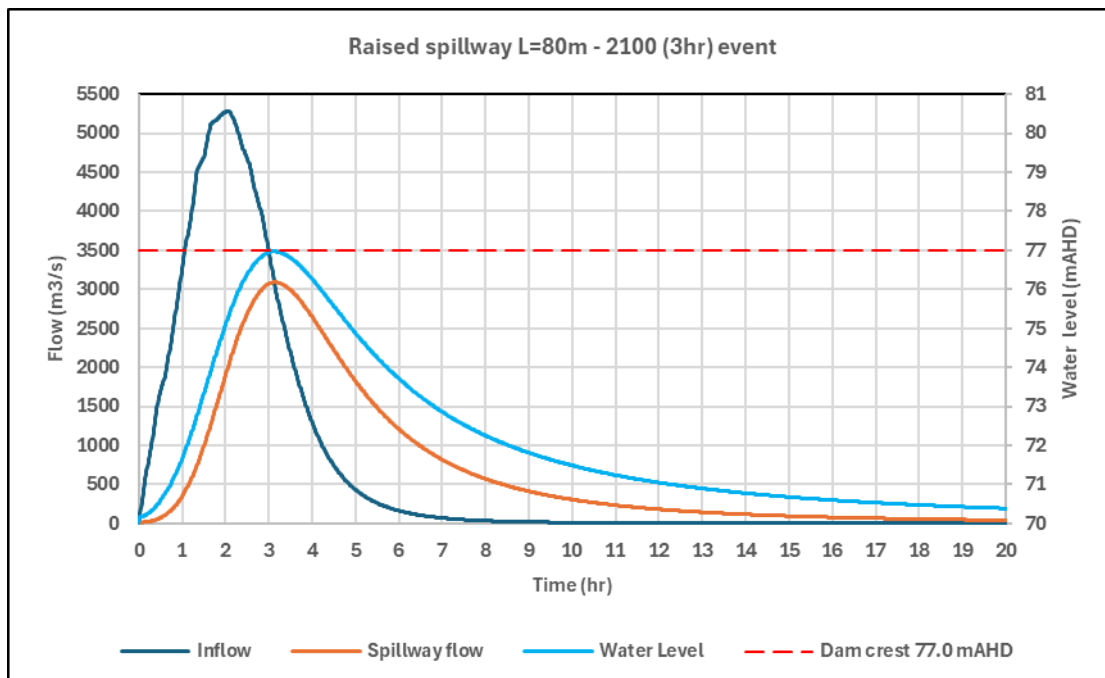


Figure 2-14: Raised Spillway 80 m wide ($C_d = 2.10$) – Routing calculation 2100 (3hr) event



Figure 2-15: Existing Spillway and Dam (Source: Google Maps)

2.2 Existing Spillway

The existing spillway was re-constructed from the original spillway in the upgrade project in 2013/14 (see photos in Appendix A). The rating curve of the as-built existing spillway with a spillway crest length of 36 m has not been confirmed by the previous CFD modelling performed by WorleyParsons in 2012.

In order to validate the rating curve, the as-built spillway geometry was created as shown in Figure 2-16. The CFD modelling and analysis methodology are the same as for the raised spillway (Worley, 2024) and they are not repeated in this report. However, some details are provided in Sections 2.4 to 2.9.

Only one case was performed for the storage level at the dam crest (70.4 mAHD), that is, the dam crest flood (DCF).

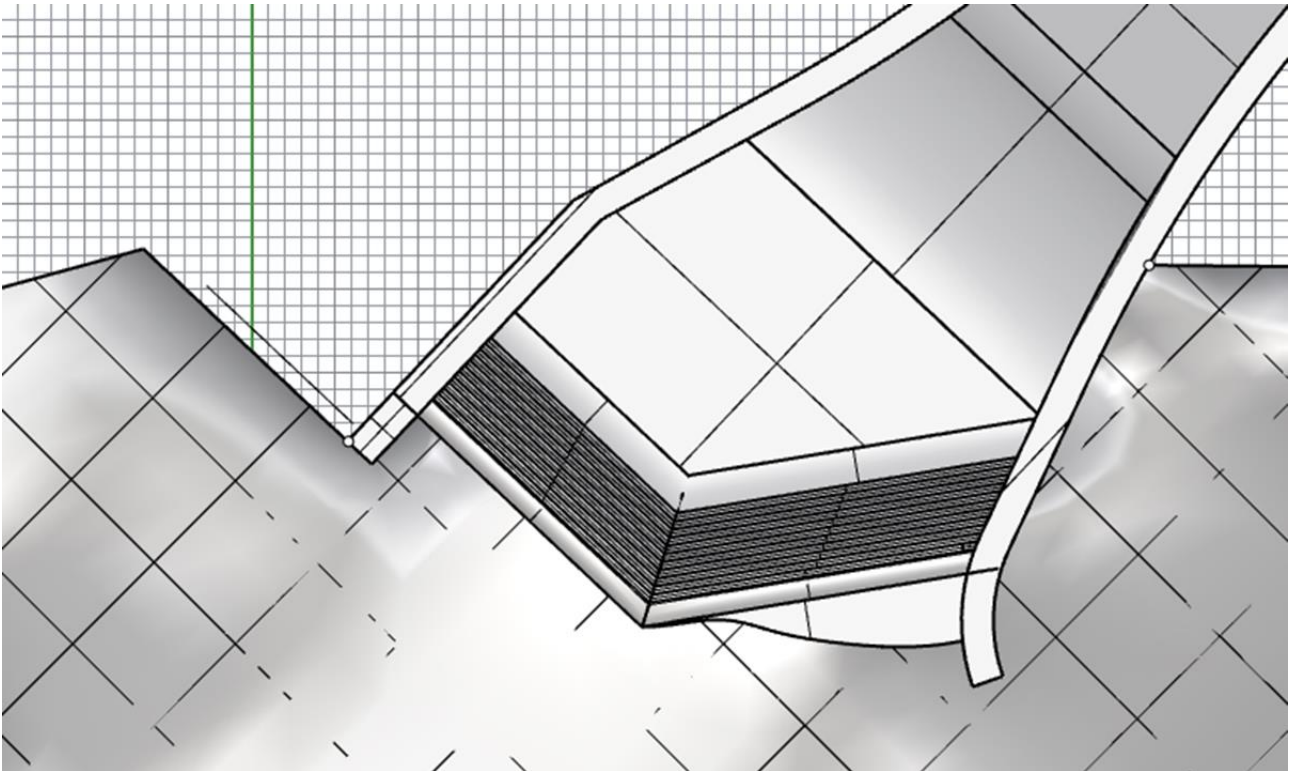


Figure 2-16: Geometry model of the existing spillway (plan view)

2.3 Raised Spillway

The CFD model of the raised spillway from the previous study (Worley, 2024) was modified to increase the spillway crest length to 80m as shown in Figure 2-17. The CFD modelling and analysis methodology are the same as for the raised spillway (Worley, 2024) and they are not repeated in this report. However, some details are provided in Sections 2.4 to 2.9.

It should be noted that the chute downstream of the spillway crest was not included in this model. This was done so that the spillway hydraulic performance will not be affected by any potential choking flow caused by the chute contraction. Therefore, the results represents the best spillway performance to discharge the flow.

A total of six steady-state cases were performed. The reservoir water level ranges from RL72.0 mAHd to RL77.0 mAHd.

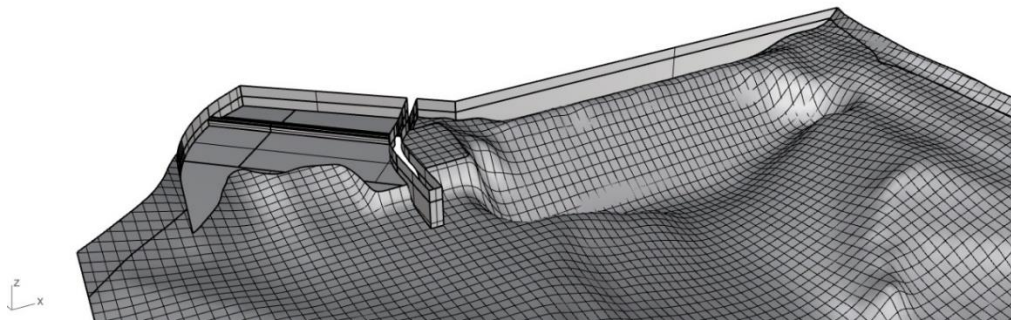


Figure 2-17: Geometry model of the raised spillway showing the spillway entrance with an 80m wide spillway crest length (iso-view)

2.4 Boundary Conditions

The inflow and outflow boundaries are shown in Figure 2-18.

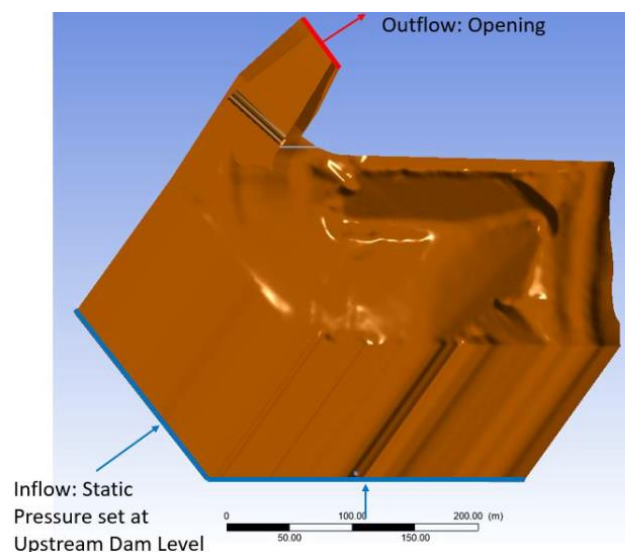


Figure 2-18: Plan view of the model showing the inflow and outflow boundaries

2.5 Fluid Properties

Both air and water were included in the model. Their properties at 20°C are provided in Table 2-1. The water was assumed to be an incompressible fluid.

Acceleration due to gravity of 9.81 m/s² was applied to the model.

Table 2-1: Fluid properties

Property	Units	Water	Air
Density	kg/m ³	1000	1.185
Dynamic viscosity	kg/m/s	0.001	1.8E-5
Surface tension water/air interface	N/m	0.072	0.072

2.6 Surface Roughness

The surface roughness assigned to the model is shown in Table 2-2. A smooth concrete surface was assumed.

Table 2-2: Surface roughness

Region	Unit	Value
Concrete surface (smooth)	mm	0
Terrain	mm	3

2.7 Turbulence Model

The shear stress transport (SST) turbulence model was used. It is a widely used model for simulating turbulent flow. Especially in predicting complex flow behaviors, particularly in high-speed and boundary-layer-dominated scenarios at high Reynolds Number.

2.8 Air Entrainment

The model allows air to be entrained in the flow through turbulent mixing in the analysis.

2.9 Assumptions and Limitations

The following assumptions were made for the CFD model.

- Water was incompressible
- Air and water properties were at 20°C
- Cavitation modelling was not considered
- Wind-induced wave effects were not considered

- Thermal stratification in the reservoir was not considered

The following items were excluded from the study:

- Model validation against physical model results
- Determine the adequacy of the chute wall to contain the flow
- Pressure along the entire spillway wall/floor
- Hydraulic performance at the flip bucket
- Hydraulic performance beyond the flip bucket – that is, flow in the river including at the toe of the embankment dam
- Cavitation erosion assessment
- Verification of spillway design

3. CFD Modelling Results

The spillway rating curve equation is given by:

$$Q = C_d L H^{1.5} \quad (\text{Equation 1})$$

where Q = spillway discharge (m^3/s)

C_d = discharge coefficient

L = spillway crest length (m)

and H = head above the spillway crest (m)

For an ogee crest spillway, the discharge coefficient ranges between 2.0 to 2.3. This value depends on a number of factors such as the approach flow conditions, spillway geometry, head over the crest, surface roughness and aeration. Typically, the discharge coefficient varies with head. However, for most practical purposes, an average value over the design head is used.

3.1 Existing Spillway

The computed discharge at DCF ($H = 8.9\text{m}$) is $1290 \text{ m}^3/\text{s}$, which overestimated the existing rating curve discharge by 2.4%. The CFD result compares reasonably well with the supplied discharge (see Figure 3-1). The CFD result implies a discharge coefficient of 1.35 based on a spillway crest length of 36m. This is likely due to the narrow downstream spillway causing flow to back up the spillway crest thus reducing the efficiency of the spillway. Supercritical flow is not developed until a short distance downstream of the crest (Figure 3-3).

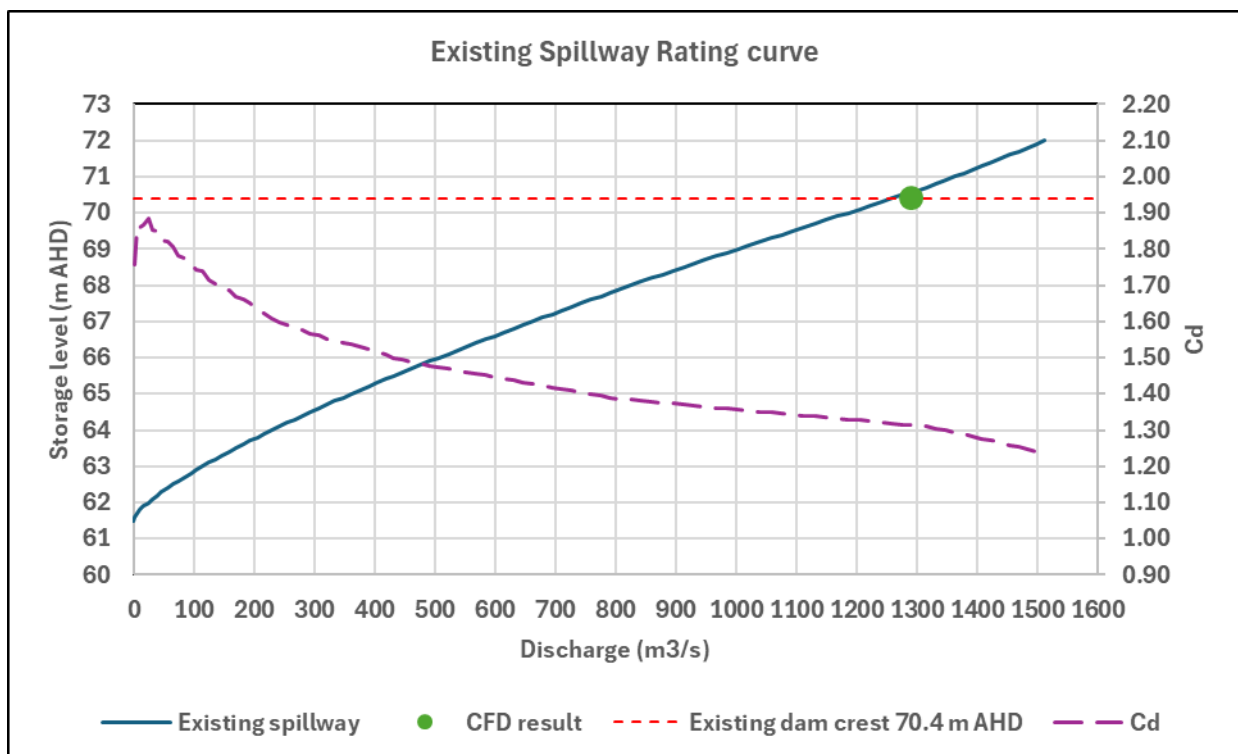


Figure 3-1: Existing rating curve

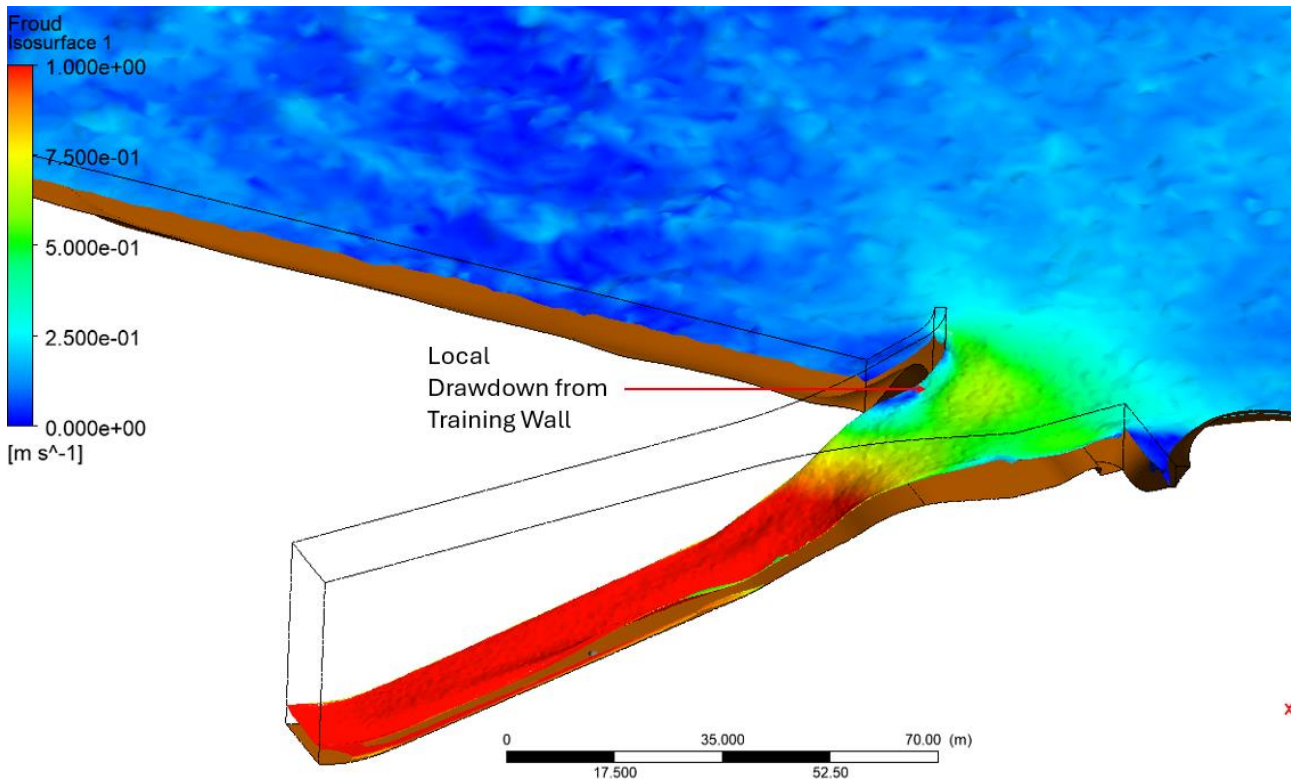


Figure 3-2: Existing Spillway - Water Surface Velocity, note local drawdown on right training wall

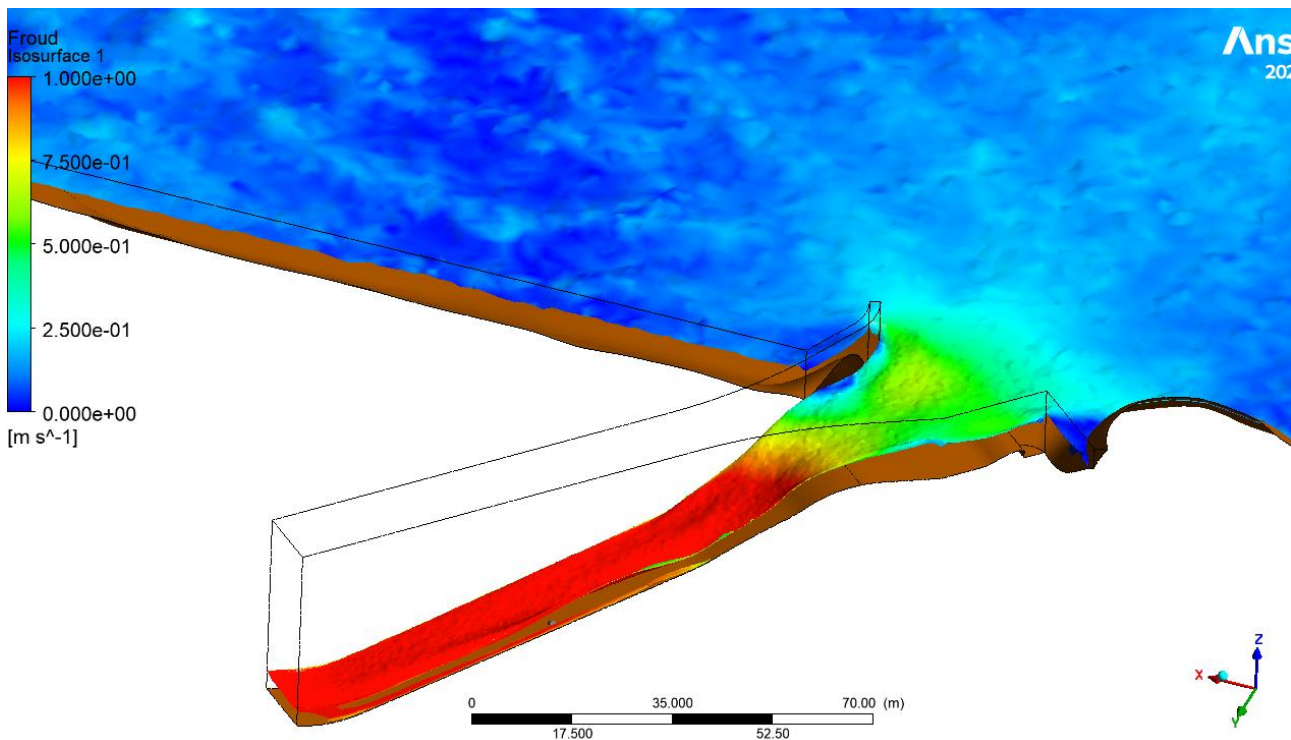


Figure 3-3: Existing Spillway – Froude Number, note supercritical flow not developed directly downstream of ogee crest, suggests flow is backing up onto crest reducing the efficiency of the spillway.

3.2 Raised Spillway

The head-discharge results are summarized in Table 3-1, and the rating curve based on a C_d of 2.2 is shown in Figure 3-4. With an 80 m spillway, the flow distribution remains uniform, indicating no significant bias. The discharge coefficient (C_d) of 2.2 is near the upper limit typically associated with well-formed ogee crest profiles, indicating efficient hydraulic performance.

The hydraulic performance for RL 77 mAHD head is shown in Figure 3-5 to Figure 3-8.

Table 3-1: Head-discharge summary of the raised spillway 80m wide

Storage level (mAHD)	Head (m)	Discharge – 80 m Spillway (m^3/s)	Discharge Coefficient – 80m Spillway	Comments
70.0	0	0.0	-	Water at spillway crest level
72.0	2	400	2.16	
73.0	3	800	2.13	
74.0	4	1300	2.28	
75.0	5	2000	2.24	
76.0	6	3000	2.32	
77.0	7	3300	2.23	Dam crest flood
78.0	8	3984	2.20	Flow can only be discharged via spillway
79.0	9	4772	2.21	Flow can only be discharged via spillway
80.0	10	5589	2.21	Flow can only be discharged via spillway

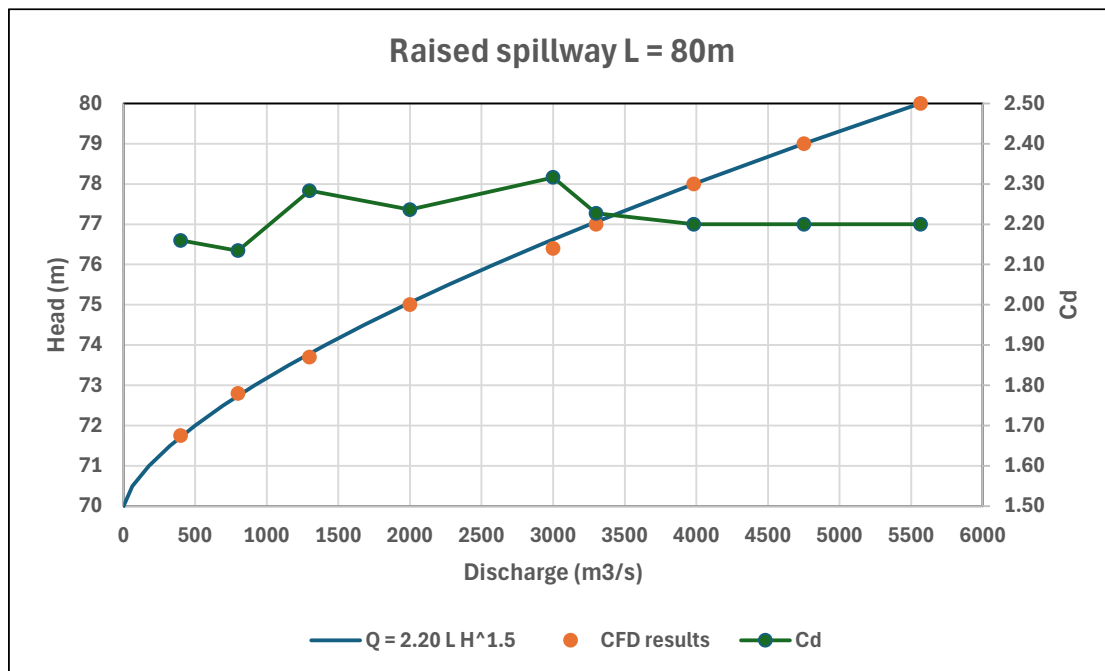


Figure 3-4: Raised spillway 80m wide – rating curve

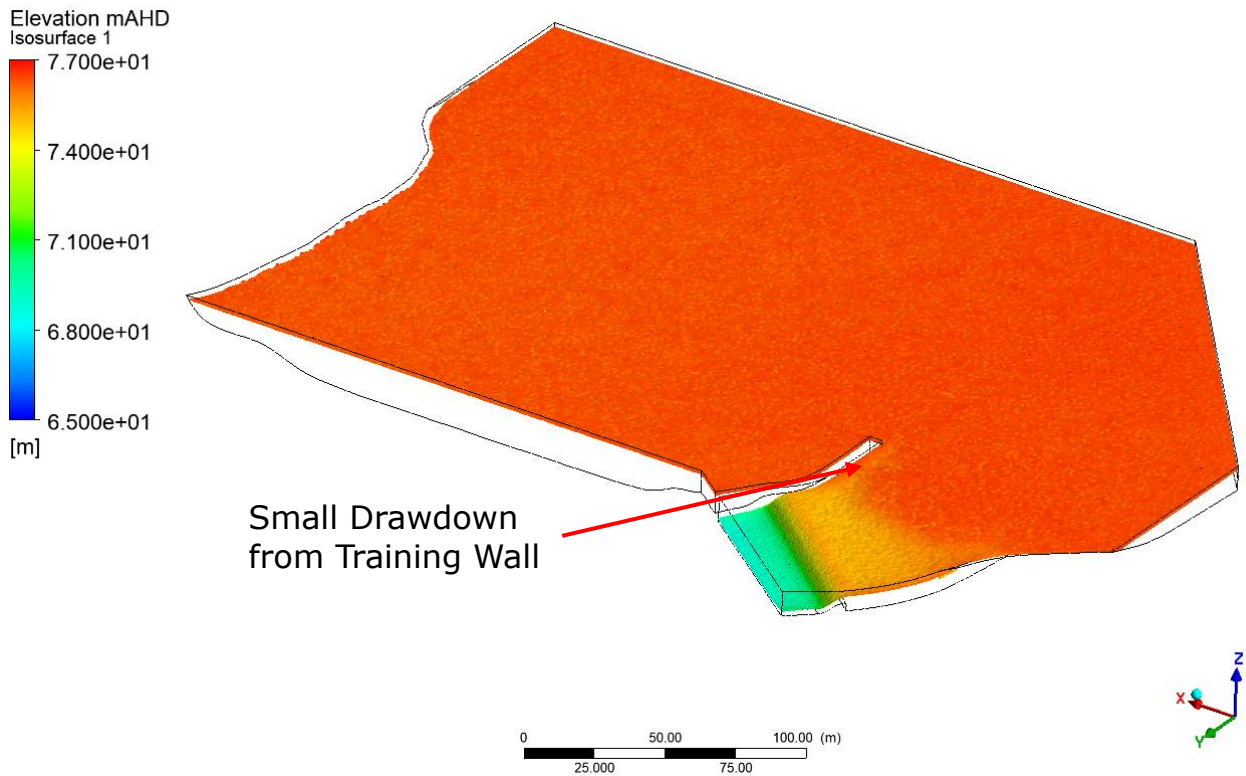


Figure 3-5: Raised spillway 80m wide, Head 77 m AHD – water level contour (m AHD)

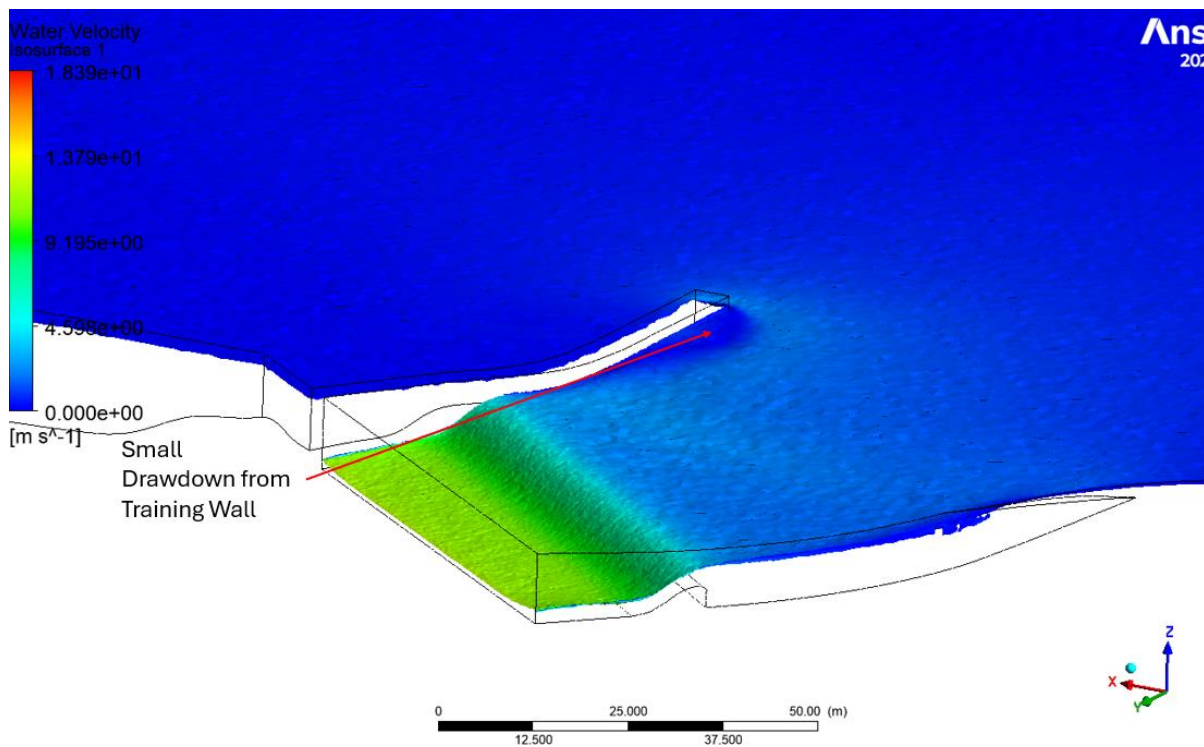


Figure 3-6: Raised spillway 80m wide, Head 77 m AHD – close-up view of water elevation (m AHD)

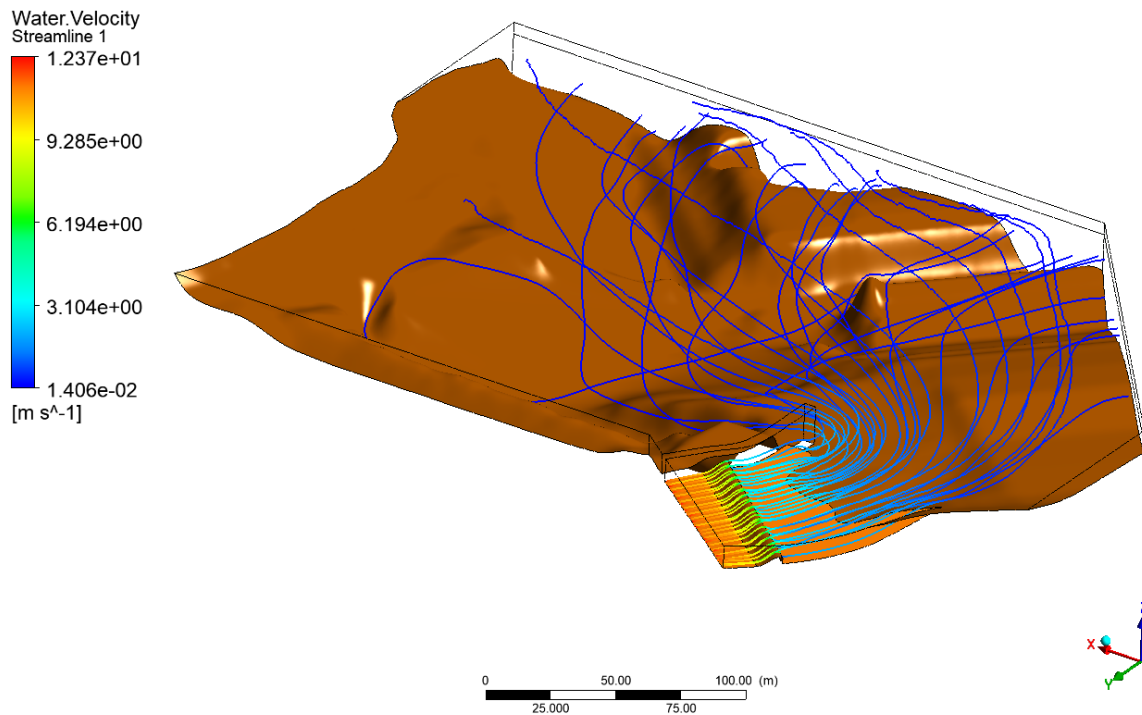


Figure 3-7: Raised spillway 80m wide, Head 77 m AHD – velocity streamlines

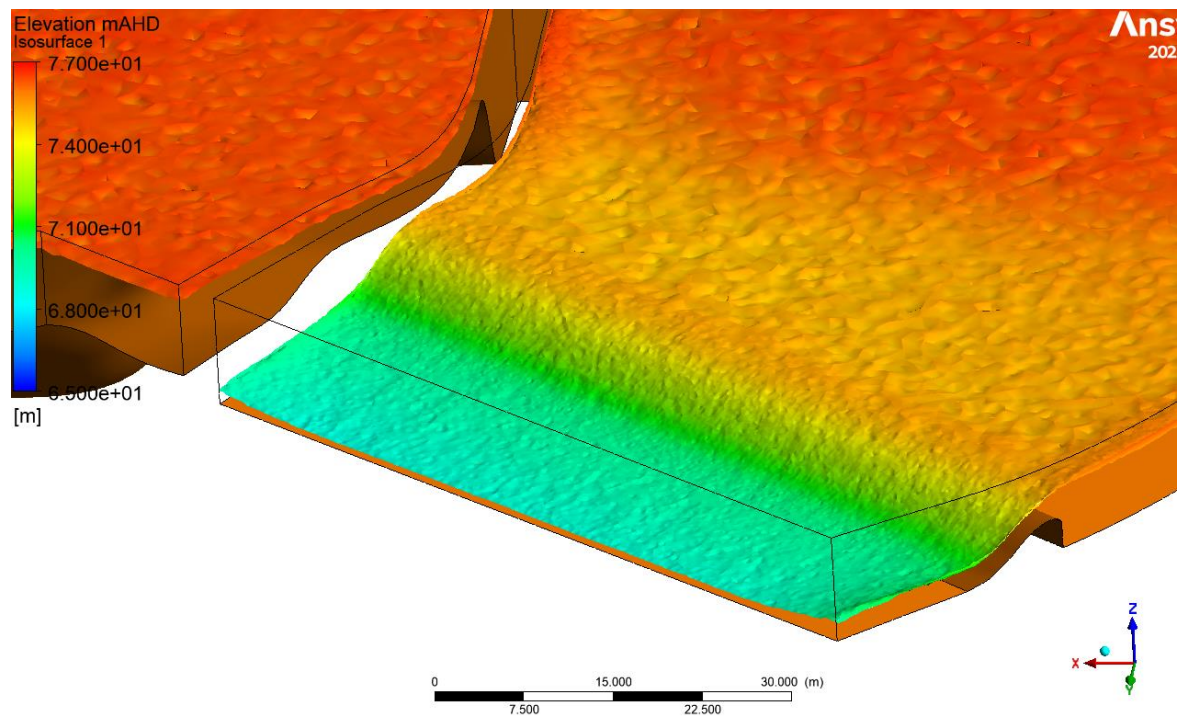


Figure 3-8: Raised spillway 80m wide, Head 77 m AHD – water surface across spillway crest

4. Conclusions and Recommendations

4.1 Conclusions

The following conclusions are made based on the results of this study.

Existing Spillway

From a high-level assessment, the existing spillway crest length needs to be approximately 95m long to pass the highest inflow 2100 (3hr) flood event to prevent overtopping of the dam crest.

From the CFD modelling the computed discharge for the DCF is in good agreement with the rating curve discharge. The back-calculated discharge coefficient of 1.2 to 1.35 indicates the ogee crest spillway is not efficient.

Raised Spillway (80m wide)

The CFD results showed the 80m long straight length ogee spillway crest achieved a discharge coefficient of approximately 2.20. The rating curve is provided in Figure 3-4.

The spillway is able to pass the PMF (SSP5-8.5 at 2100) without overtopping the dam crest. This was confirmed by the routing study conducted by KBR who used the CFD-derived rating curve. Note that CFD modelling did not consider the required freeboard as well as ignoring any wind-induced waves.

4.2 Recommendations

Existing Spillway

The current rating curve can be used in a routing study to confirm the 2050 and 2100 flood events can cause overtopping of the dam crest if the spillway is not widened.

Raised Spillway (80m wide)

The computed rating curve can be used in a routing study to confirm the 2050 and 2100 flood events cannot cause overtopping of the dam crest.

In detailed design, the geometry of the chute spillway should be designed such that it will not impede the hydraulic performance, such as choking effect as shown in the existing spillway CFD model. The width of the chute spillway may need to be increased to accommodate a smooth contraction/transition downstream of the 80m wide spillway. Standing waves can occur along the chute spillway and the chute walls should be high enough to contain the flow. Further CFD modelling can be carried out to investigate the hydraulic performance and to optimize the geometric arrangement during detailed design.

5. References

5.1 Supplied Information

Three emails from Isaac Kim (KBR) with (Excel files) attachments:

20 Aug 2025 20250820_CHDR_for_Worleys_Updated.zip
9 Sep 2025 20250905_CHDR_for_Worleys_2050_Time Series
11 Sep 2025 20250909_CHDR_for_Worleys_TiemSeries

5.2 Other Information

Advisian (2018) Clarrie Hall Dam Raising: Computational Fluid Dynamics Modelling. 301015-03773-REP001-0. 20 July 2018.

Public Works Advisory (2018) Clarrie Hall Dam Raising Concept Design Report. ISR18033. 27 July 2018.

Worley (2024) Clarrie Hall Dam Raising Spillway Rating Curve Report. 311023-56044-RP001 Rev 0, 14 August 2024.

WorleyParsons (2012) Computational Fluid Dynamics – Analysis of Clarrie Hall Dam Spillway. 301015-02904-RP001-0, 18 April 2012.

Appendix A. Existing Spillway (2013/14 upgrade)



Photo showing construction of the spillway upgrade in 2013 (Source: Entracon bulletin Summer/Autumn 2013 Vol.2 Issue 4)



Photo showing the completed spillway crest (Source: Entracon bulletin Summer/Autumn 2013 Vol.2 Issue 4)

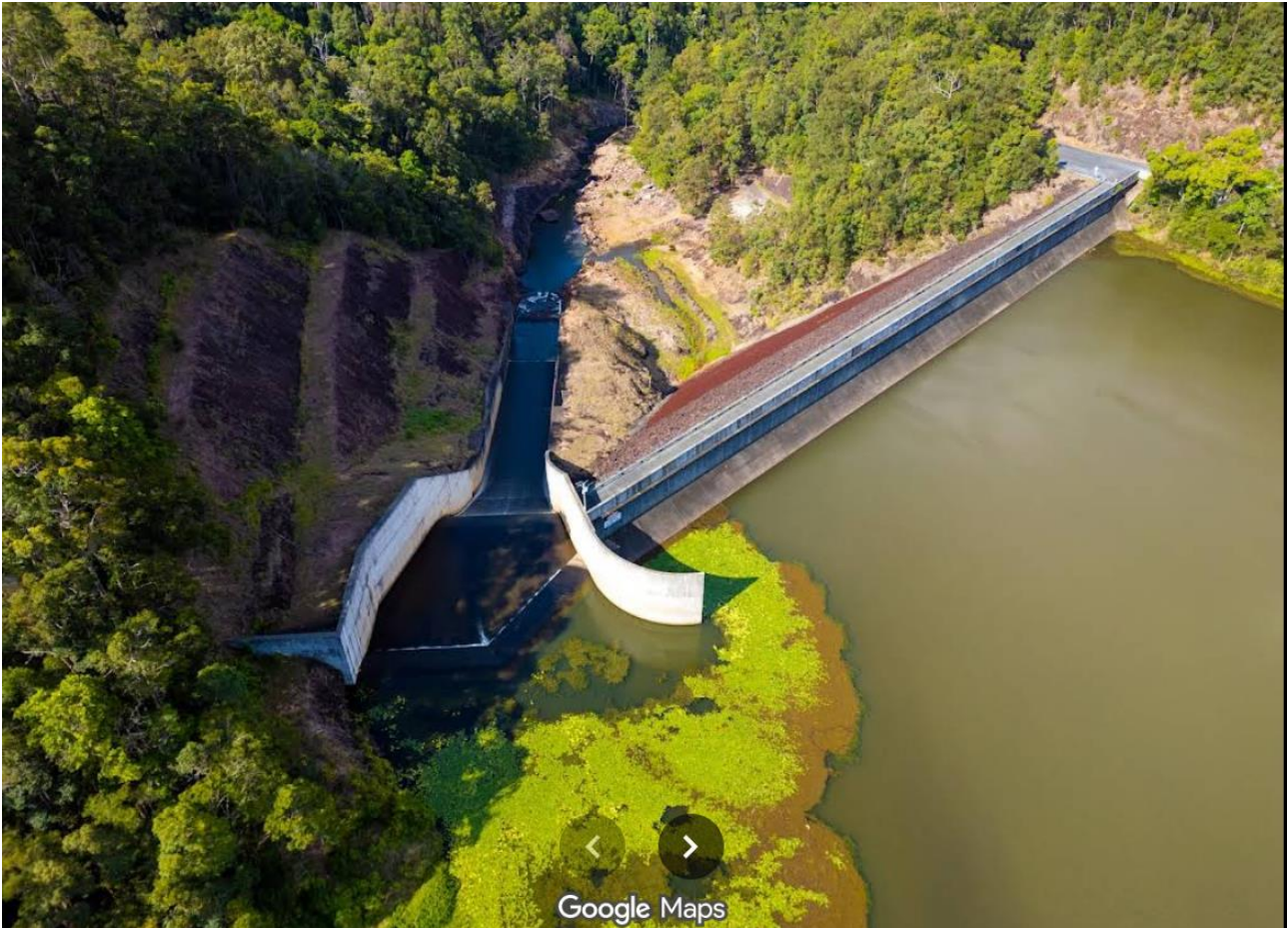
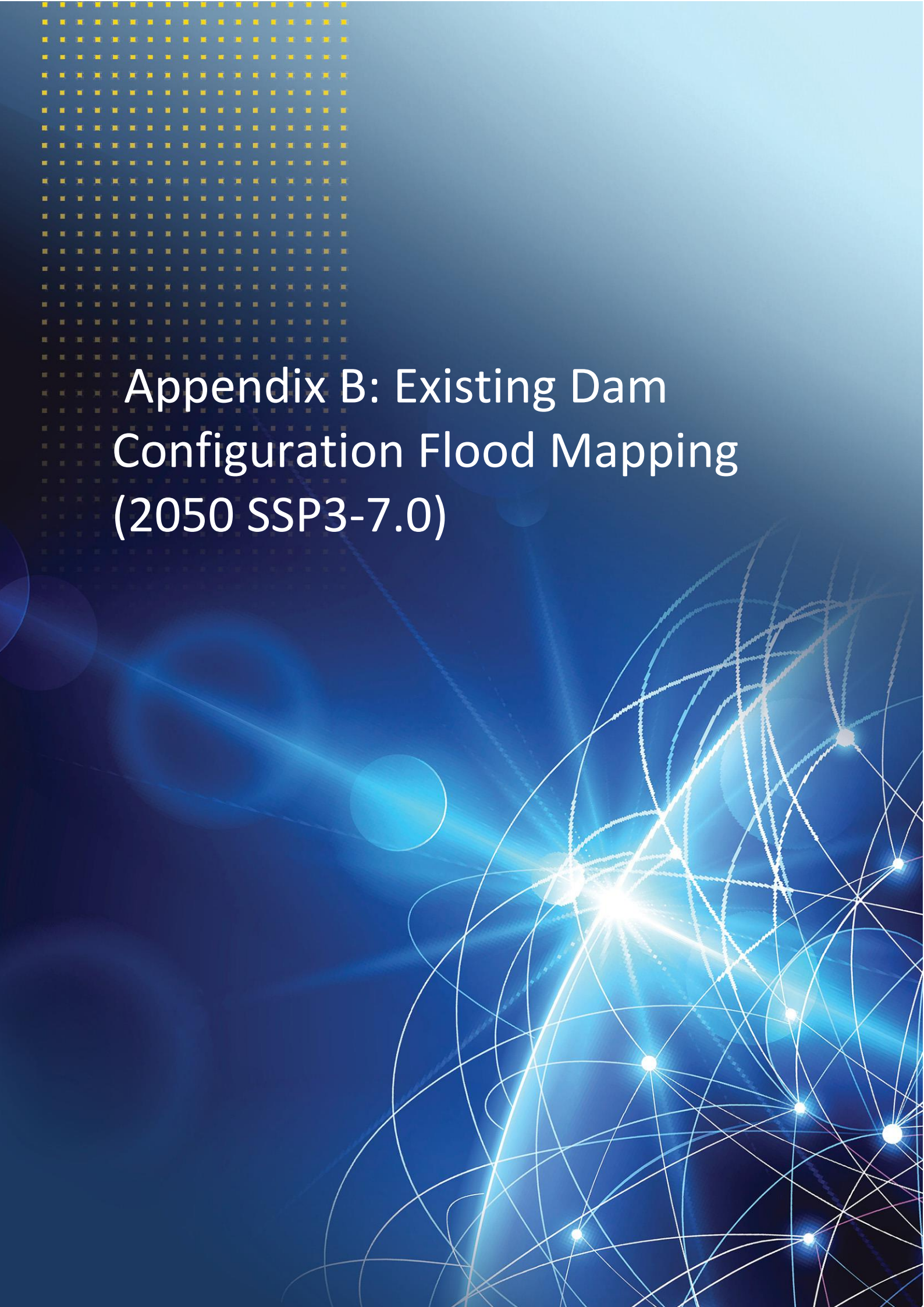


Photo showing the existing spillway and dam in 2024 (Source: Google Maps)



Appendix B: Existing Dam Configuration Flood Mapping (2050 SSP3-7.0)

LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

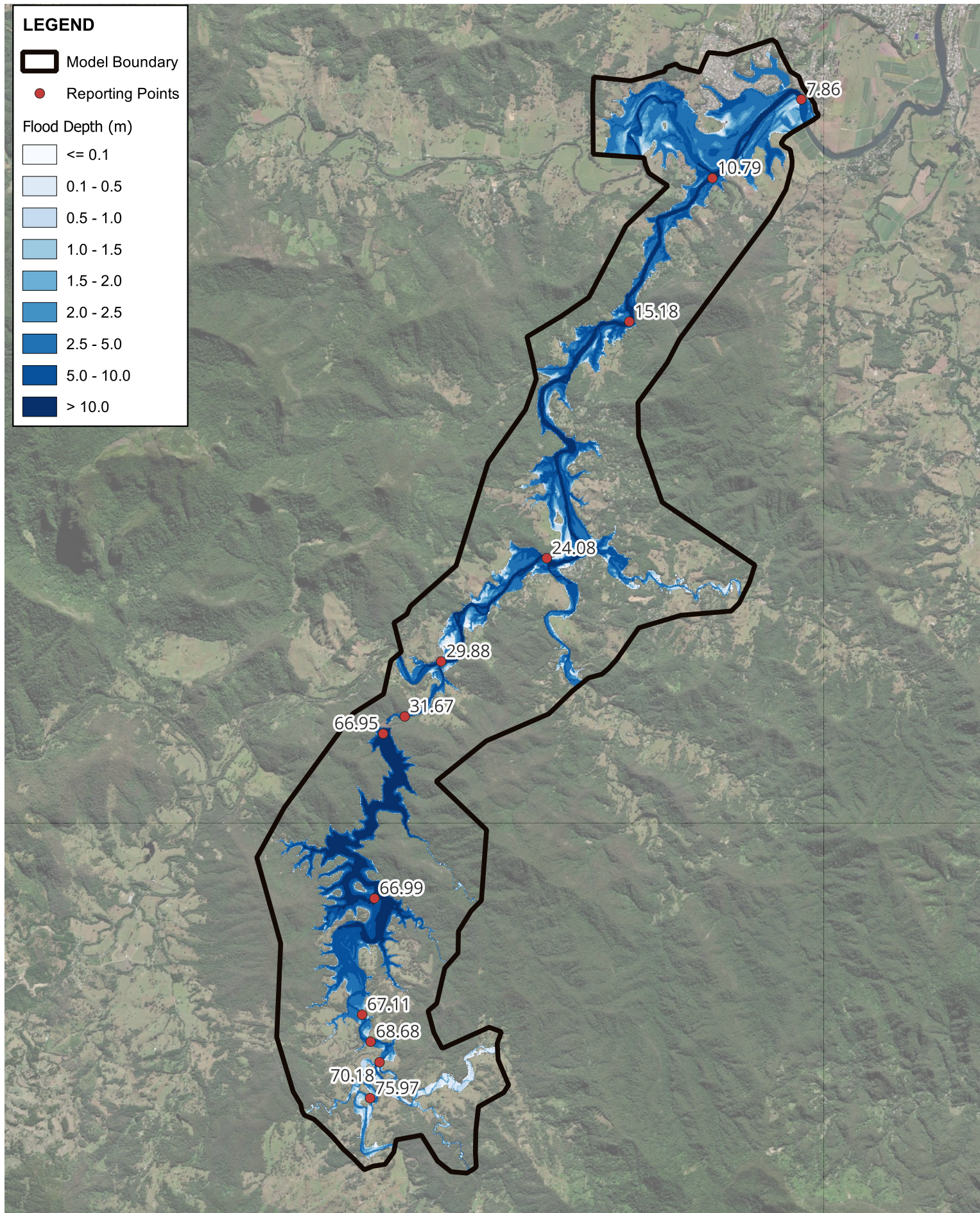
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Peak Flood Depth and Level - Existing Case
(2050 SSP3-7.0) 1% AEP Design Event

Figure:

B1

Rev:

0

Scale at A4
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1:80000.00008160024

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000

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LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

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 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

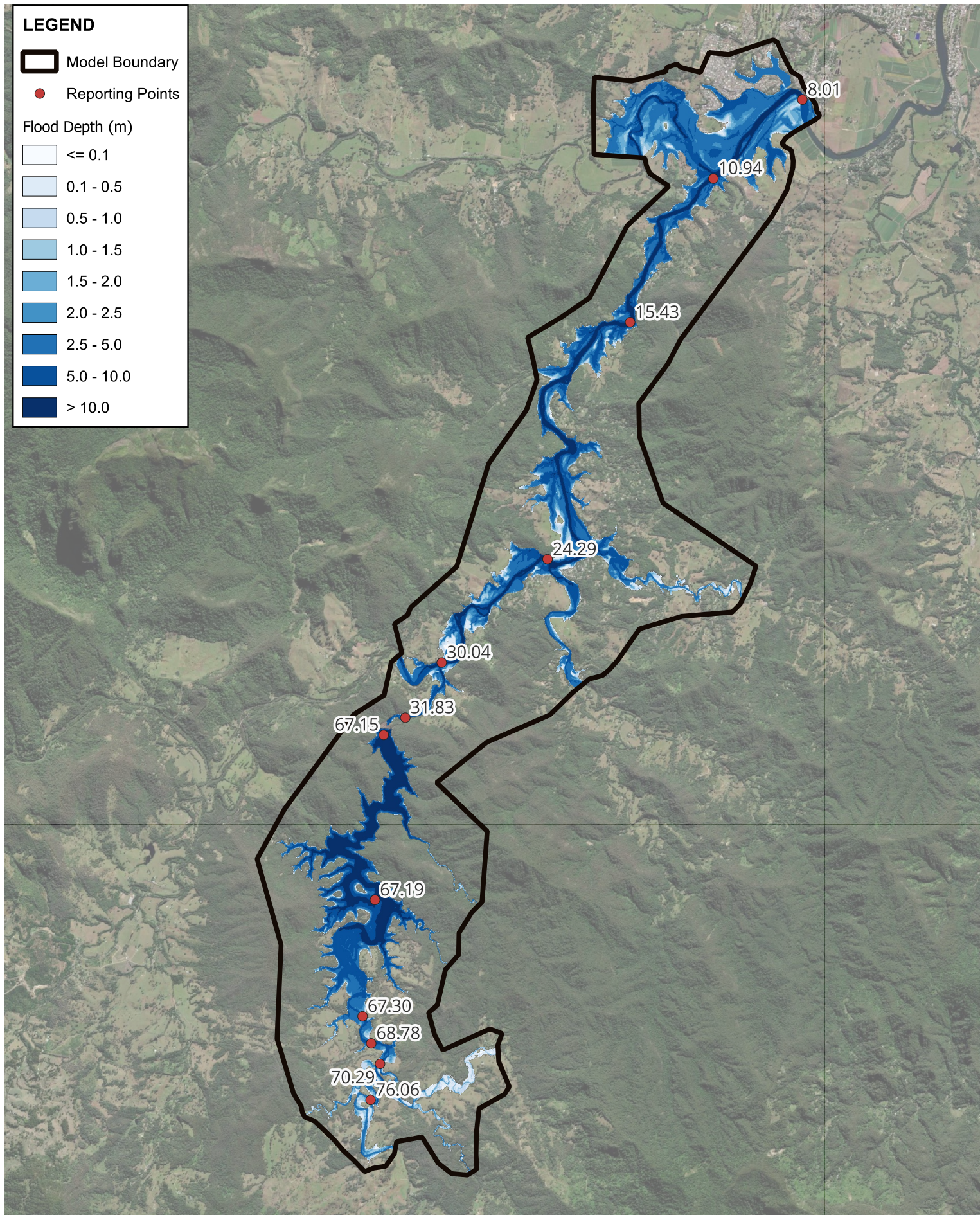
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Peak Flood Depth and Level - Existing Case
(2050 SSP3-7.0) 0.5% AEP Design Event

Figure: **B2**

Rev: **0**

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

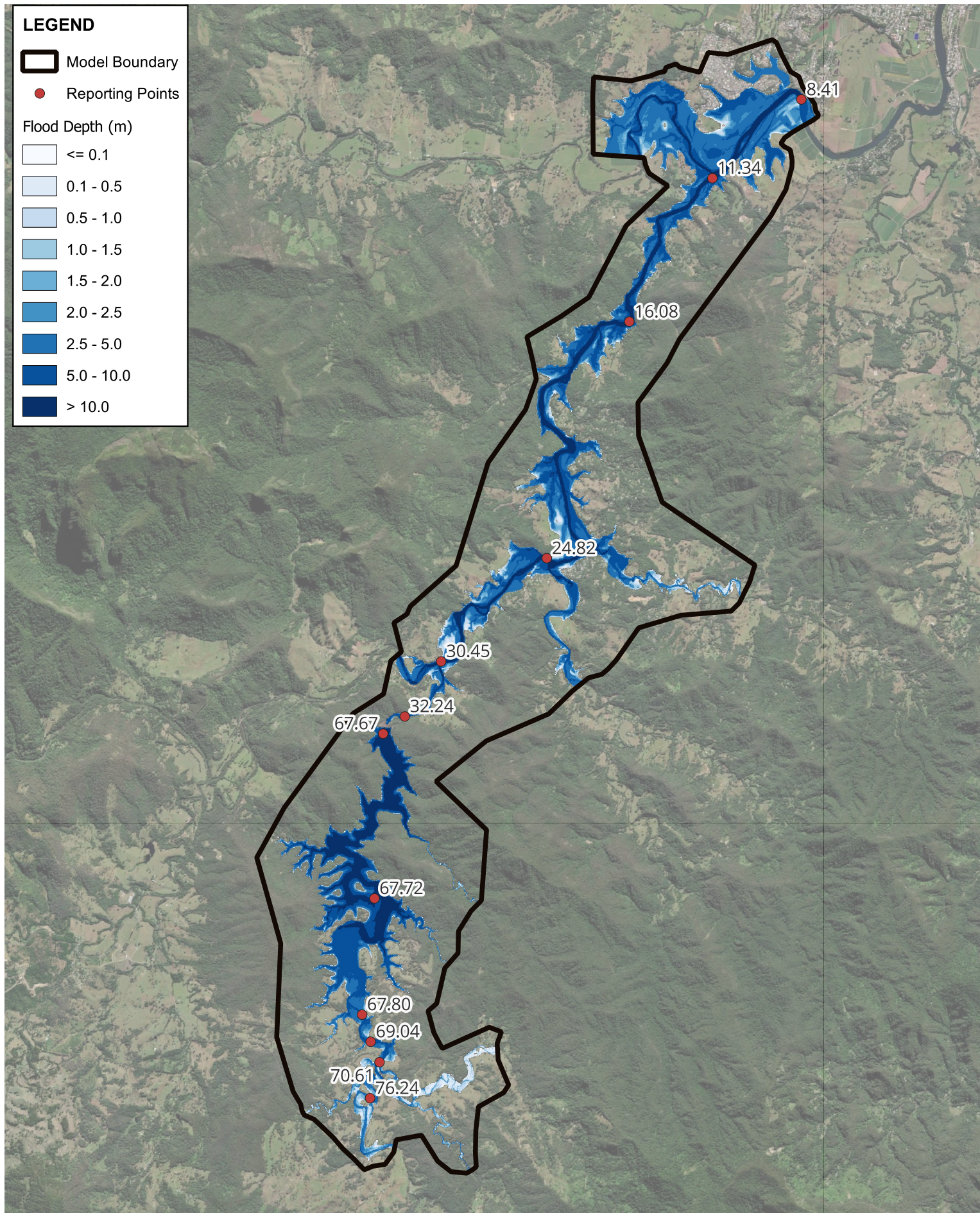
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Peak Flood Depth and Level - Existing Case
(2050 SSP3-7.0) 0.2% AEP Design Event

Figure: **B3**

Rev: **0**

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

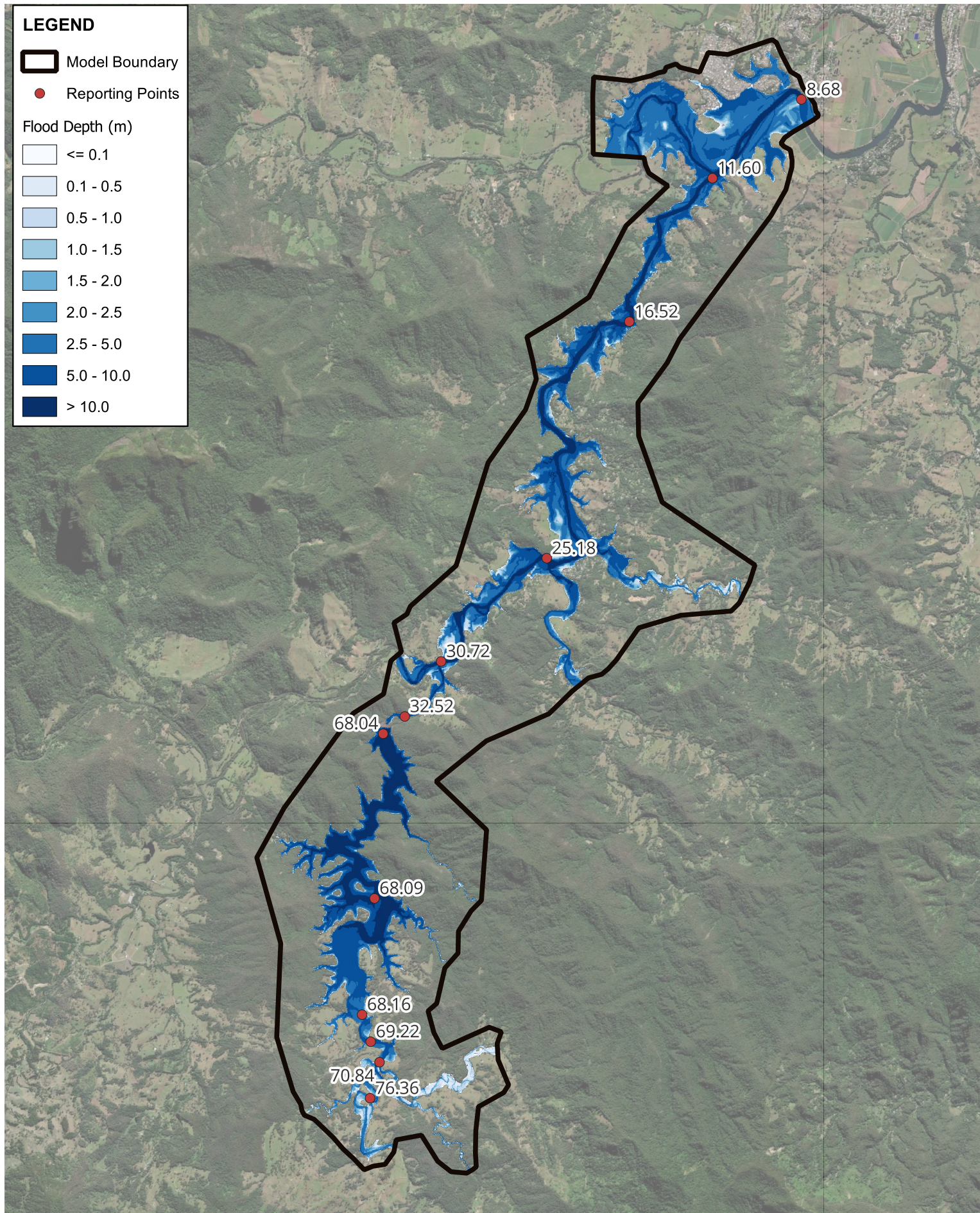
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Peak Flood Depth and Level - Existing Case
(2050 SSP3-7.0) 0.1% AEP Design Event

Figure: **B4**

Rev: **0**

Scale at A4
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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

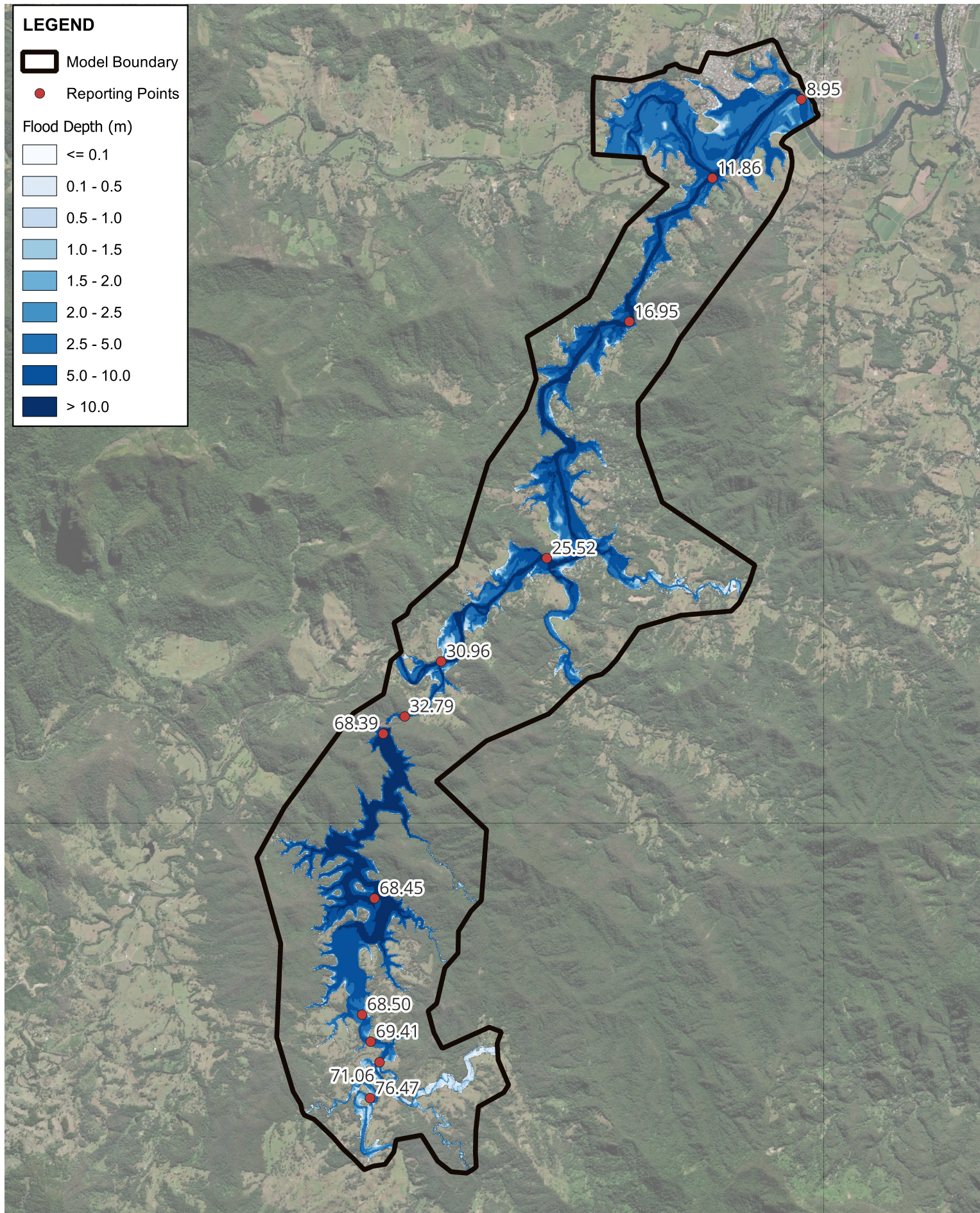
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



**Peak Flood Depth and Level - Existing Case
(2050 SSP3-7.0) 0.02% AEP Design Event**

Figure: **B5**

Rev: **0**

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

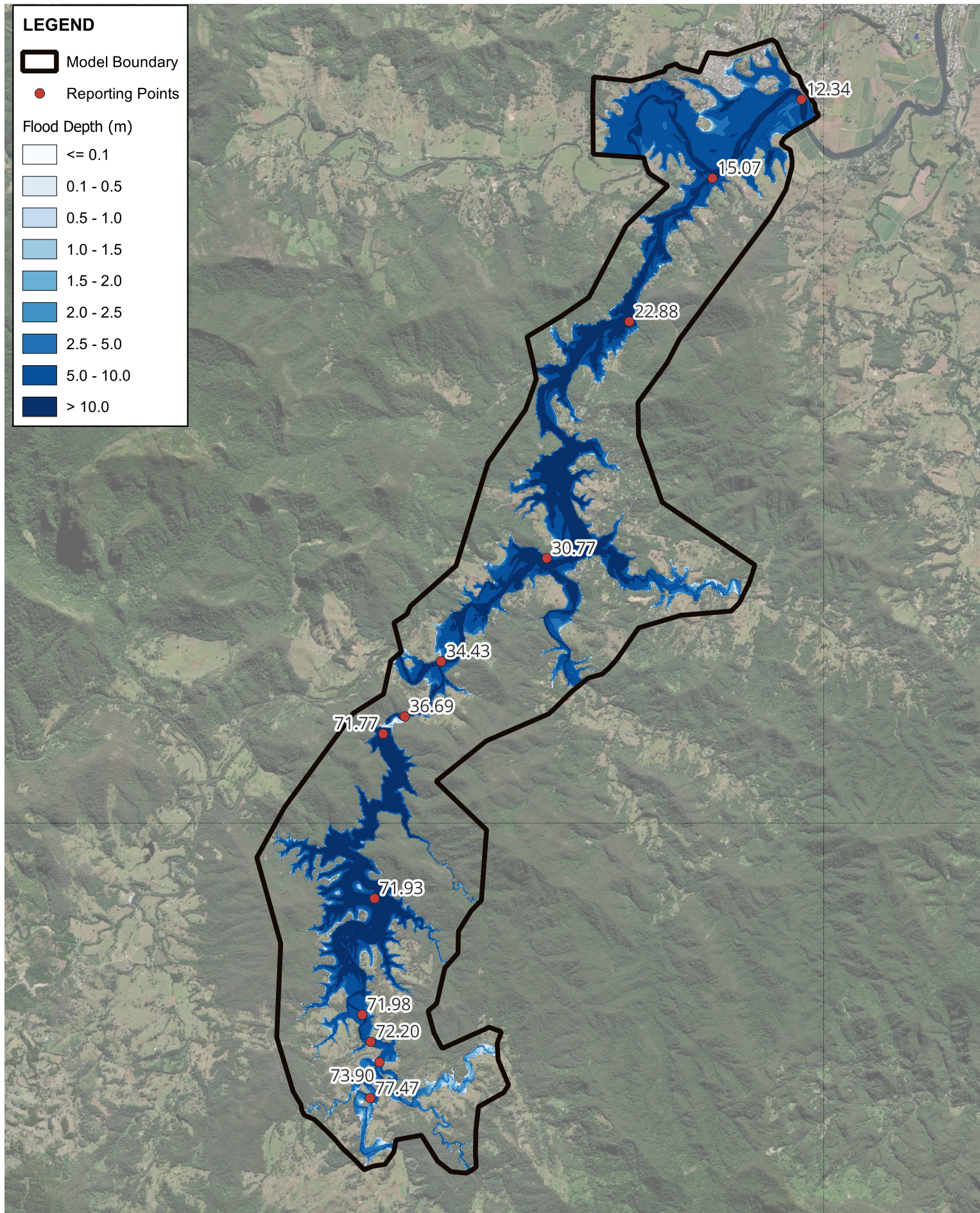
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 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Title: **Peak Flood Depth and Level - Existing Case (2050 SSP3-7.0) PMF Design Event**

Figure: **B6**

Rev: **0**

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

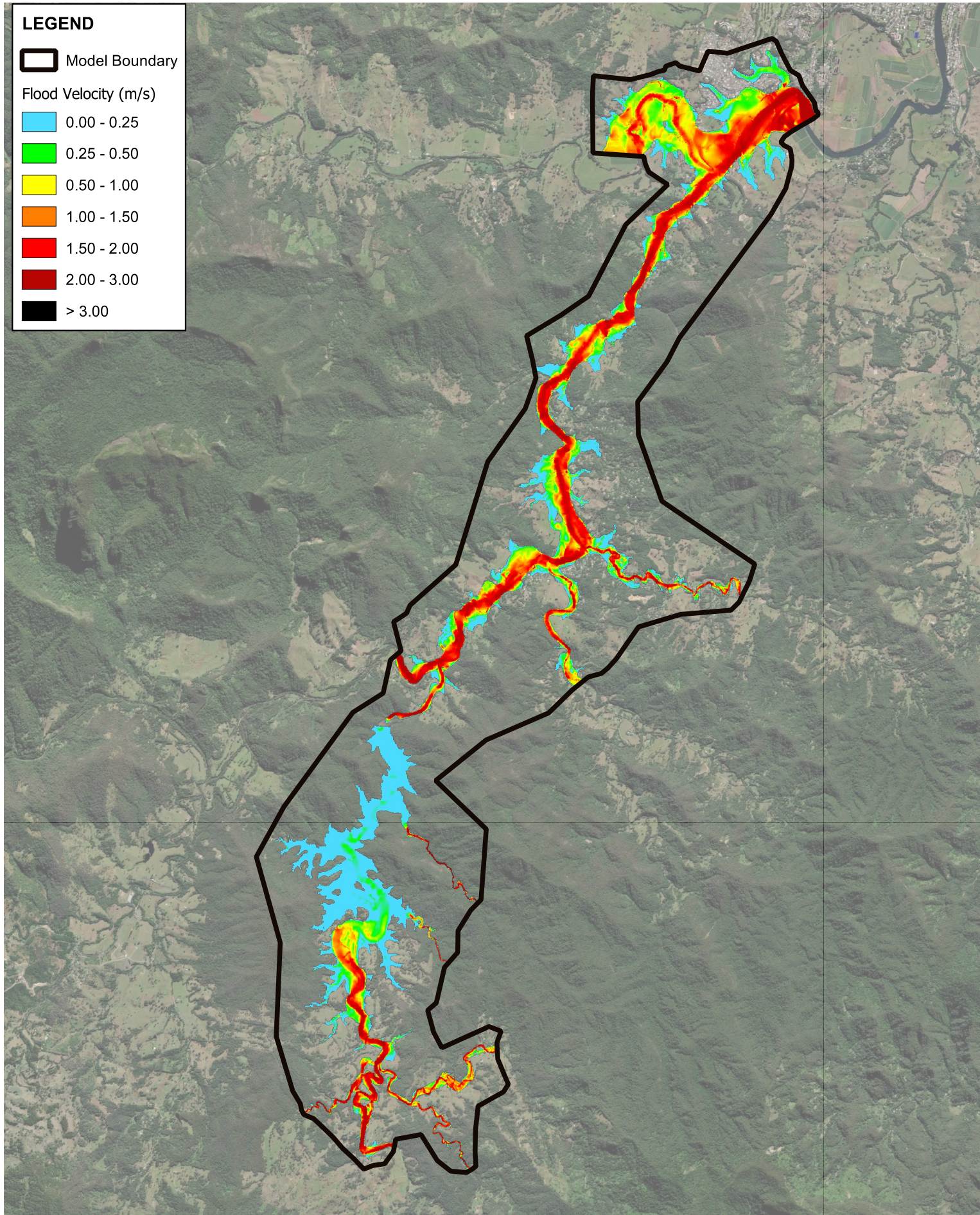
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Peak Velocity - Existing Case (2050 SSP3-7.0) 1% AEP Design Event

Figure: **B7**

Rev: **0**

Scale at A4
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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

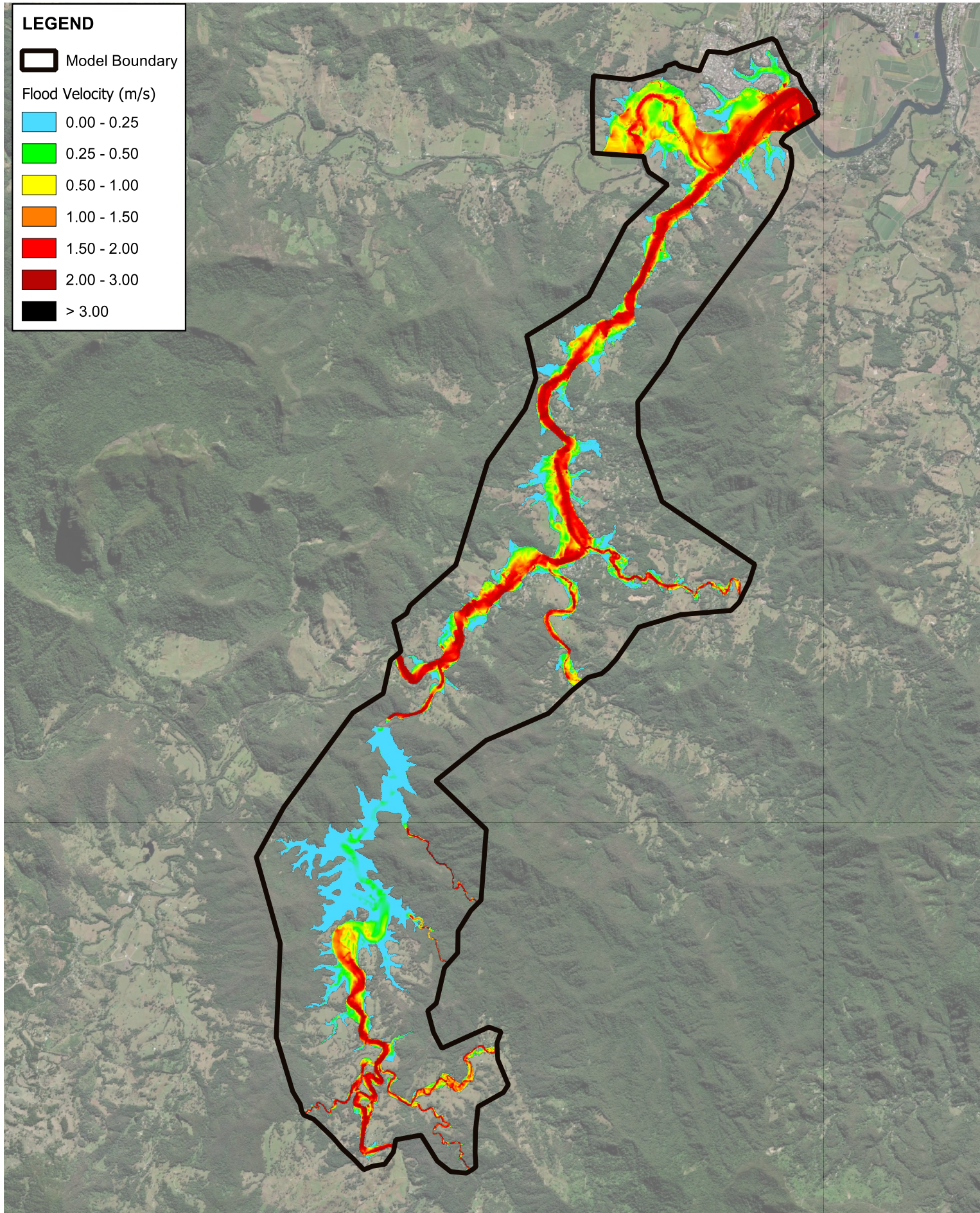
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 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title:
**Peak Velocity - Existing Case
(2050 SSP3-7.0) 0.5% AEP Design Event**

Figure:
B8

Rev:
0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

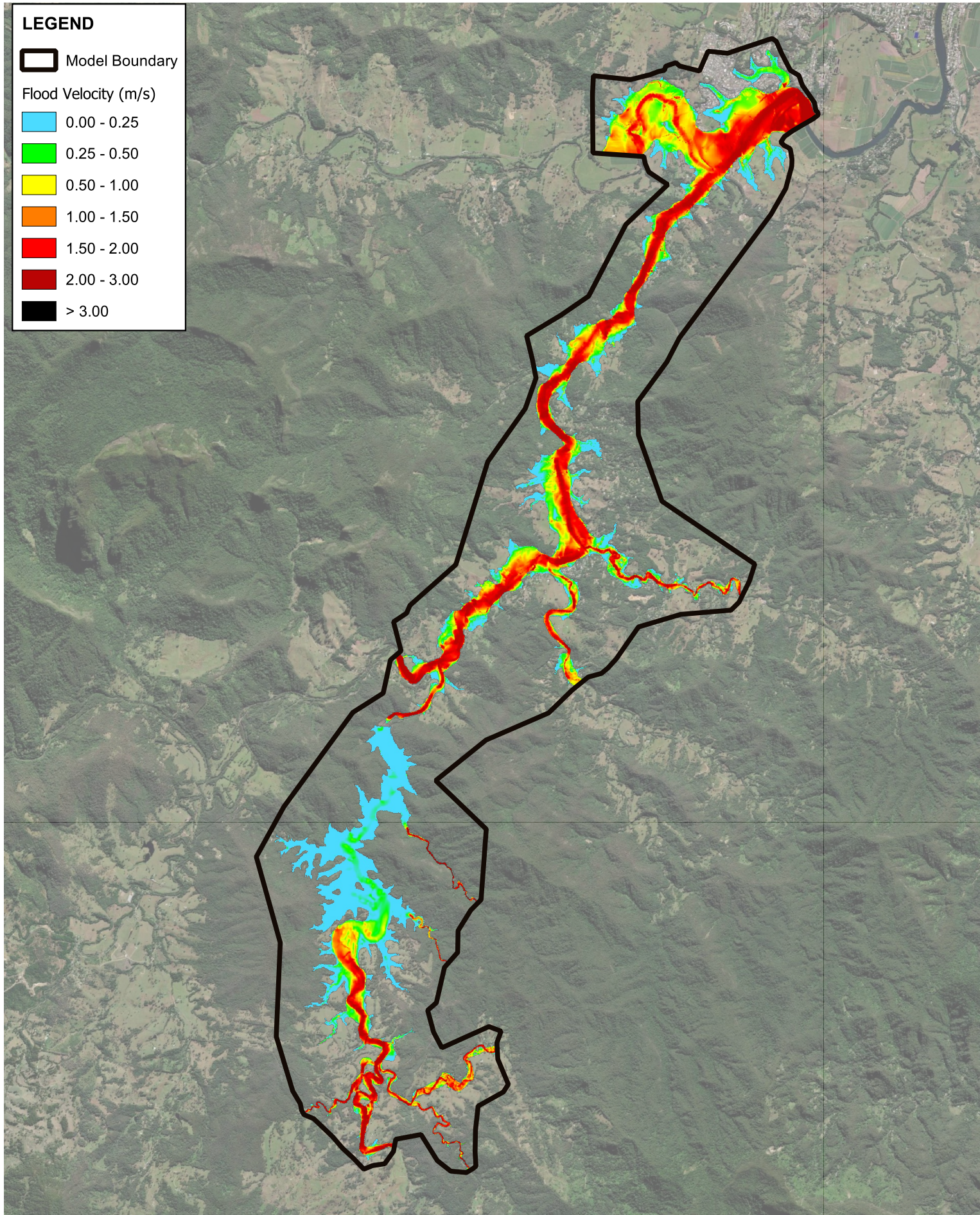
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 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Peak Velocity - Existing Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure:

B9

Rev:

0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

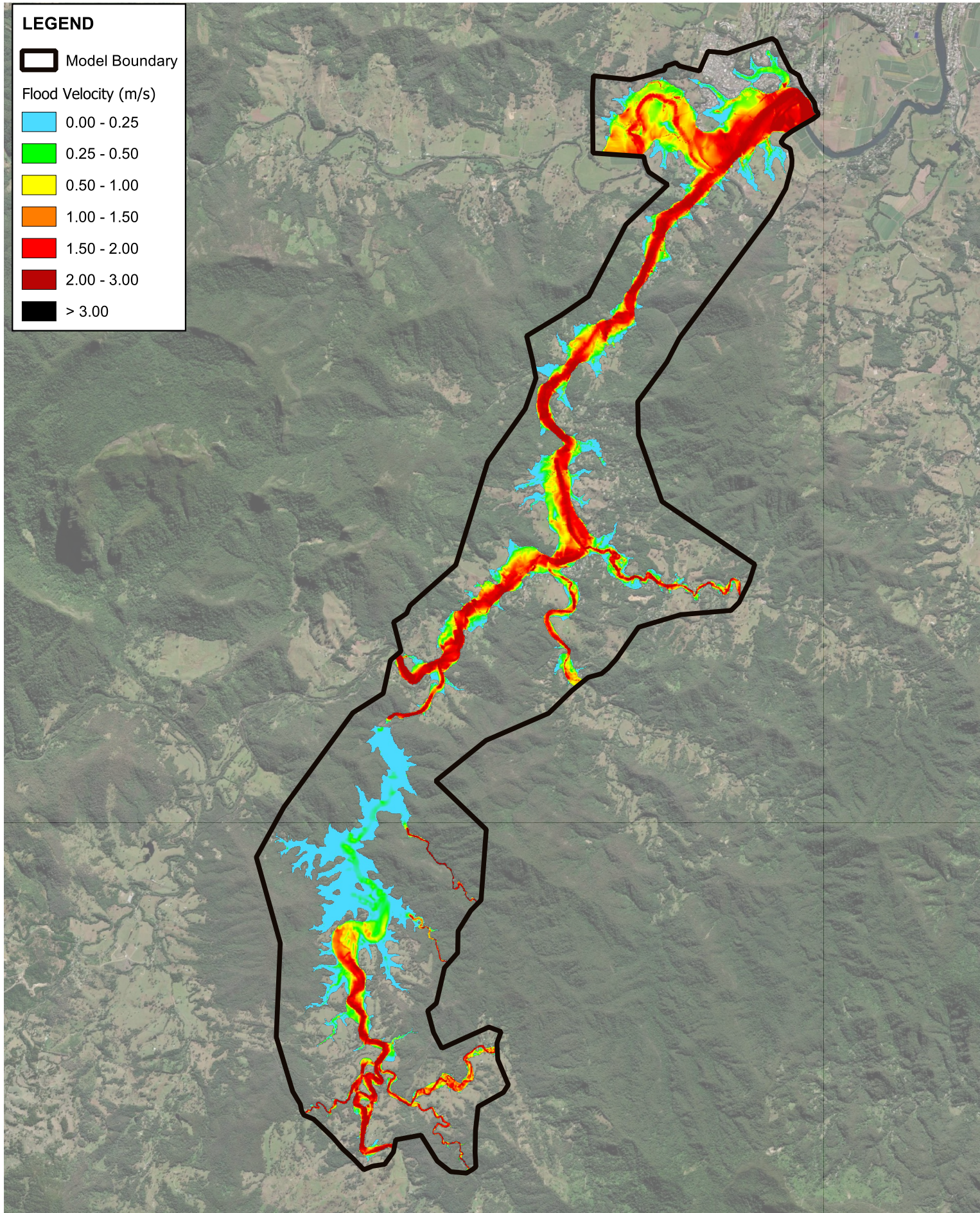
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 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title:
**Peak Velocity - Existing Case
(2050 SSP3-7.0) 0.1% AEP Design Event**

Figure:
B10

Rev:
0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

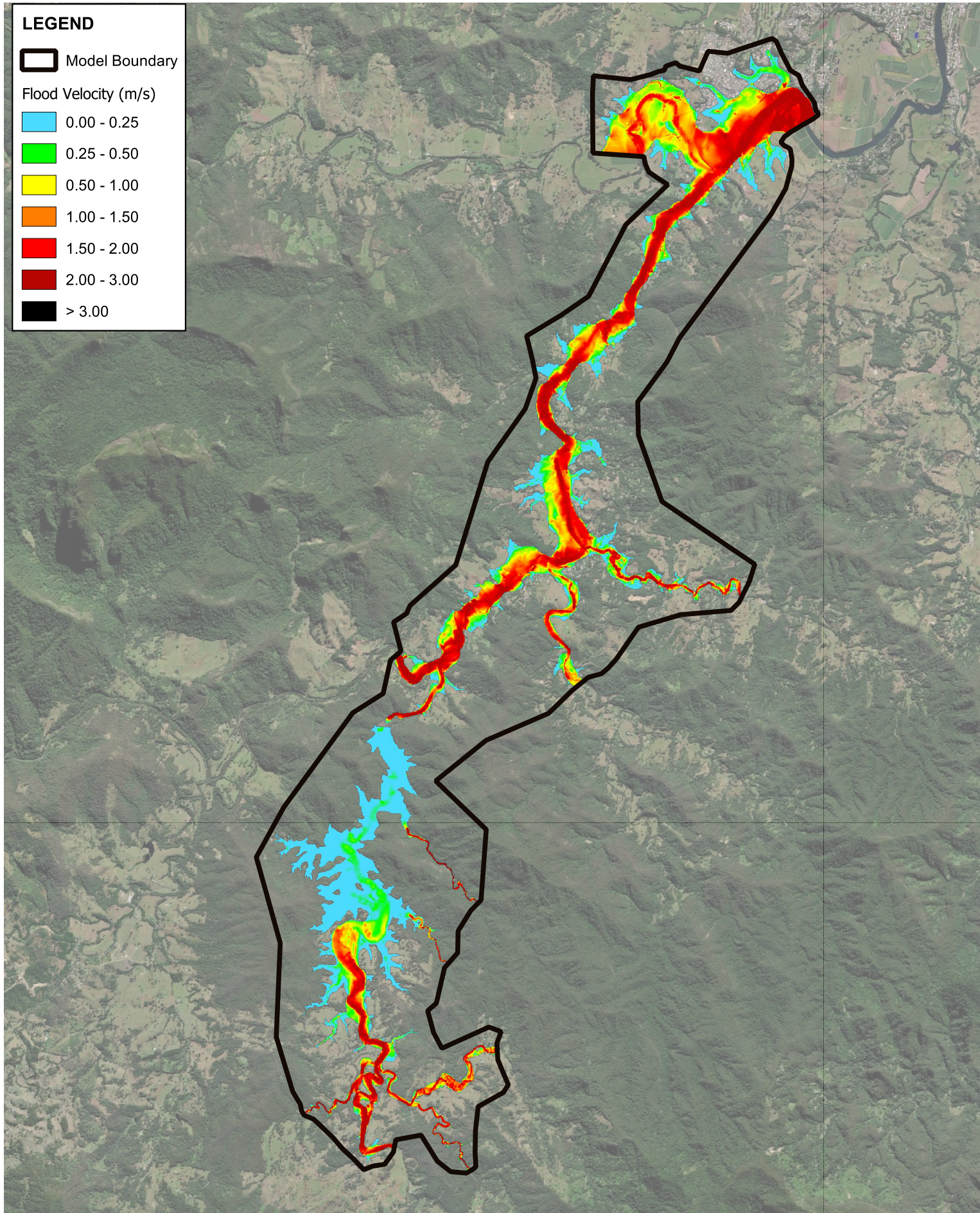
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 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Peak Velocity - Existing Case (2050 SSP3-7.0) 0.05% AEP Design Event

Figure:

B11

Rev:

0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

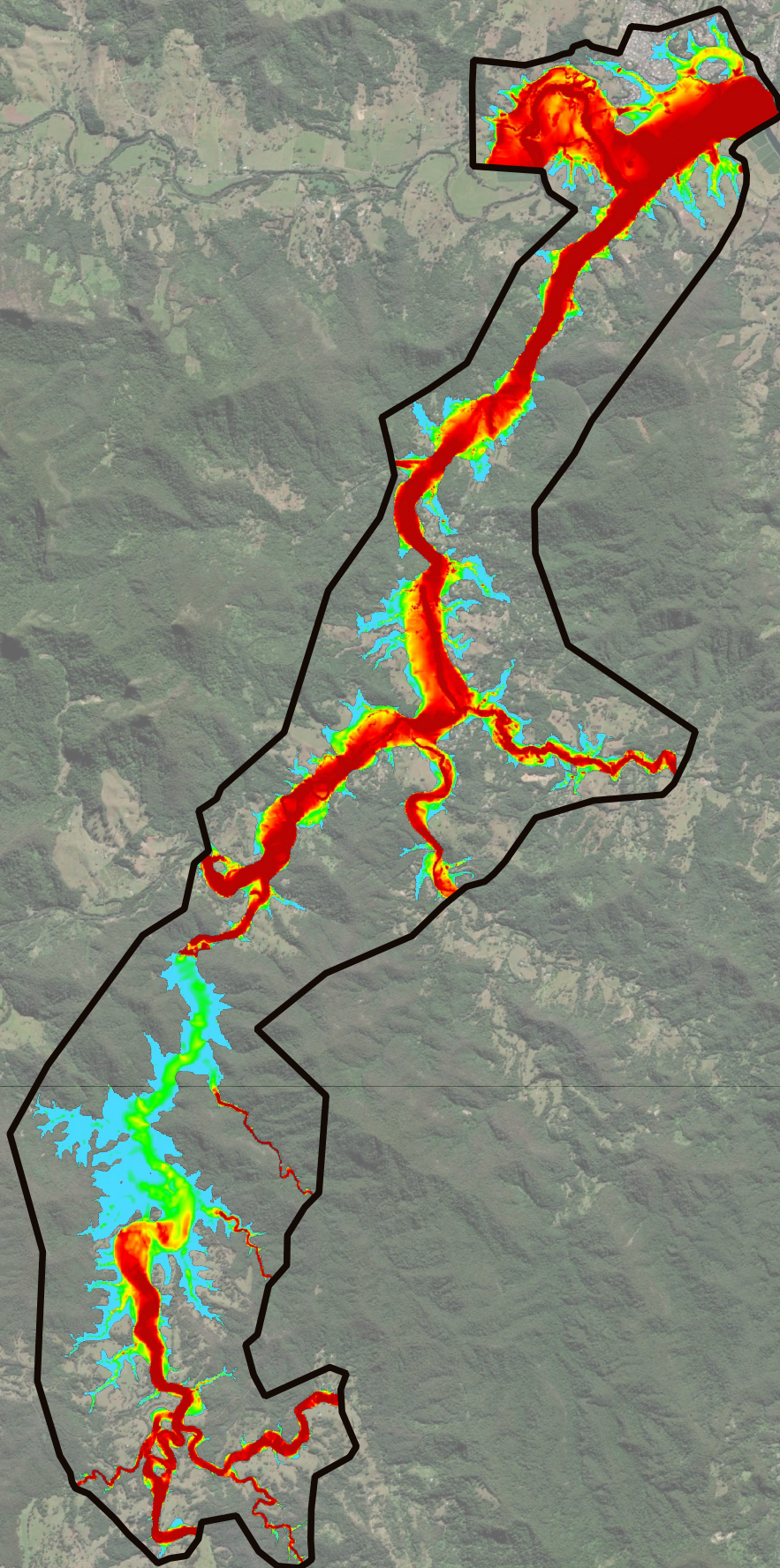
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 1.00 - 1.50

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 2.00 - 3.00

 > 3.00



Peak Velocity - Existing Case (2050 SSP3-7.0) PMF Design Event

Figure:

B12

Rev:

0

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Scale:

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1:80,000



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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

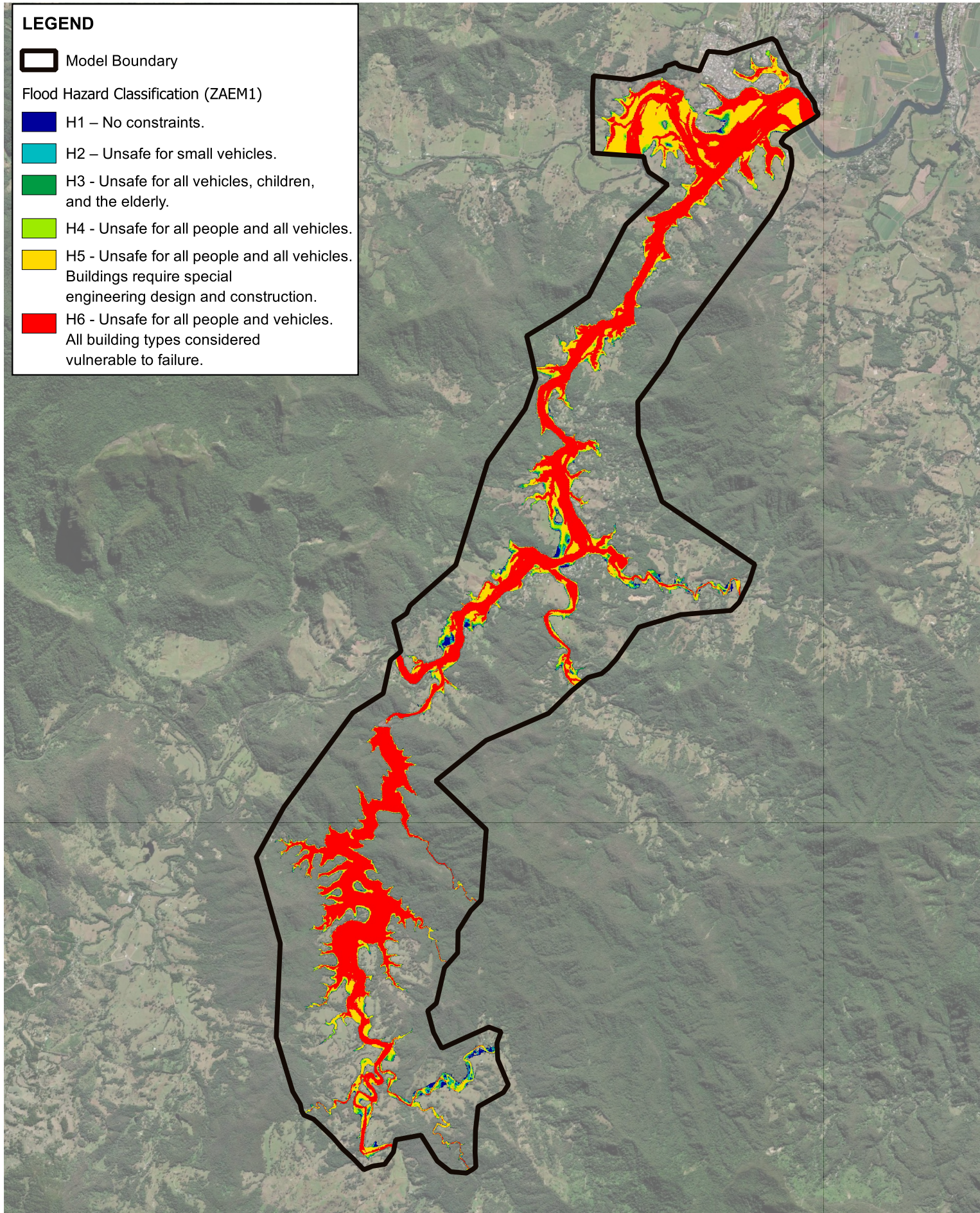
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Existing Case (2050 SSP3-7.0) 1% AEP Design Event

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000

Figure:

B13

Rev:

0



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

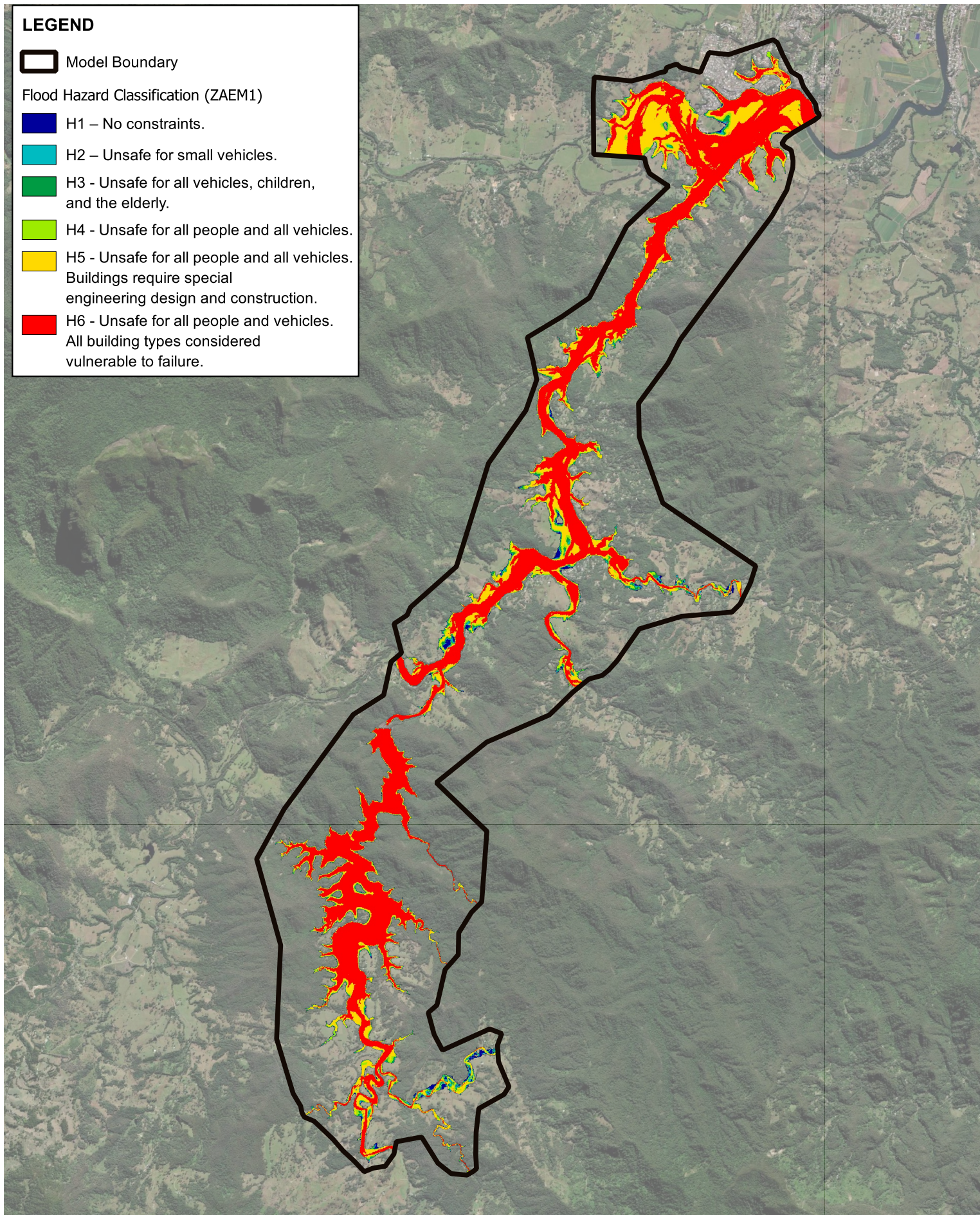
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Existing Case (2050 SSP3-7.0) 0.5% AEP Design Event

Figure:

B14

Rev:

0

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1:80000.00008160024

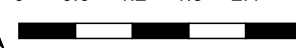
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

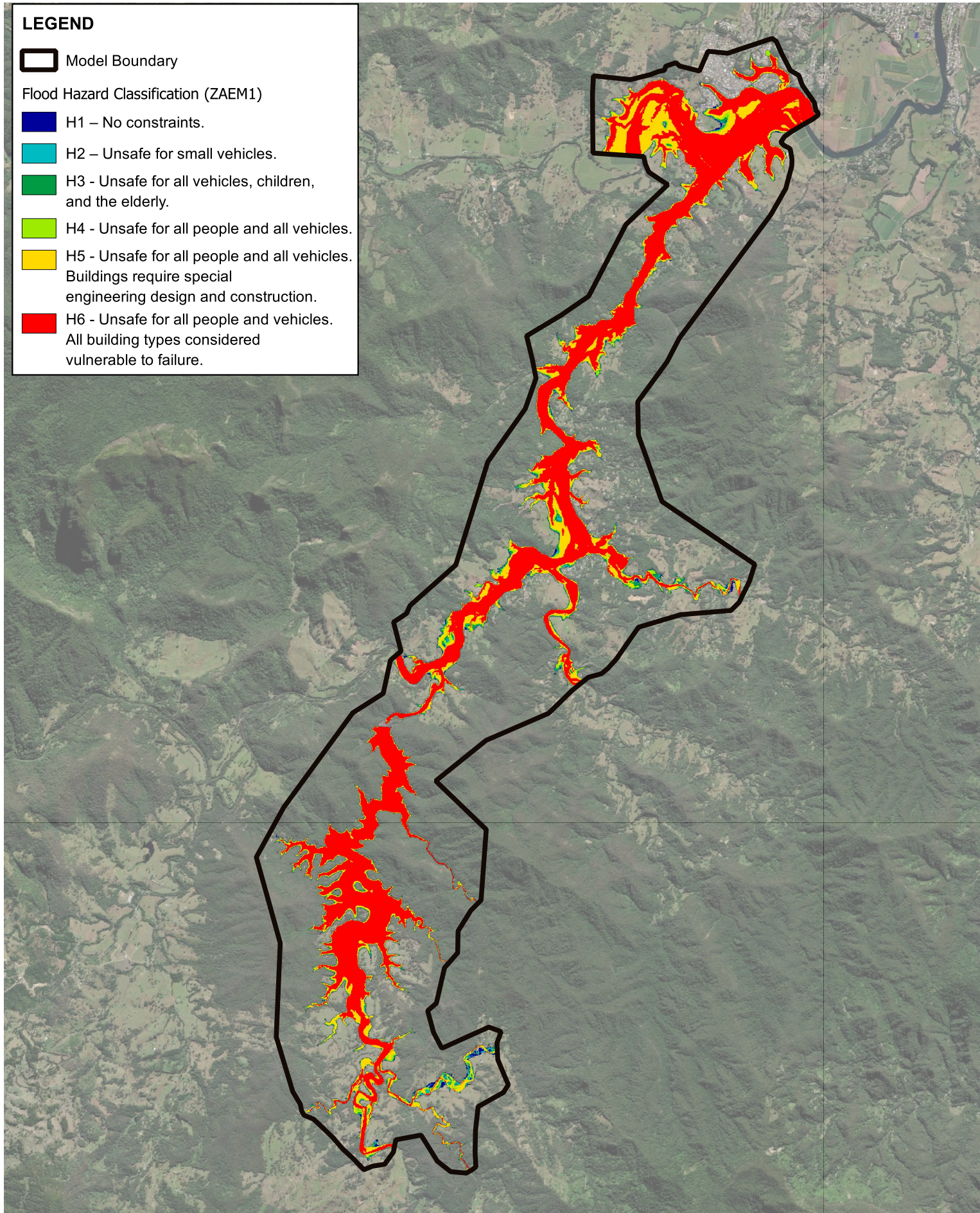
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Existing Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure: **B15**

Rev: **0**

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

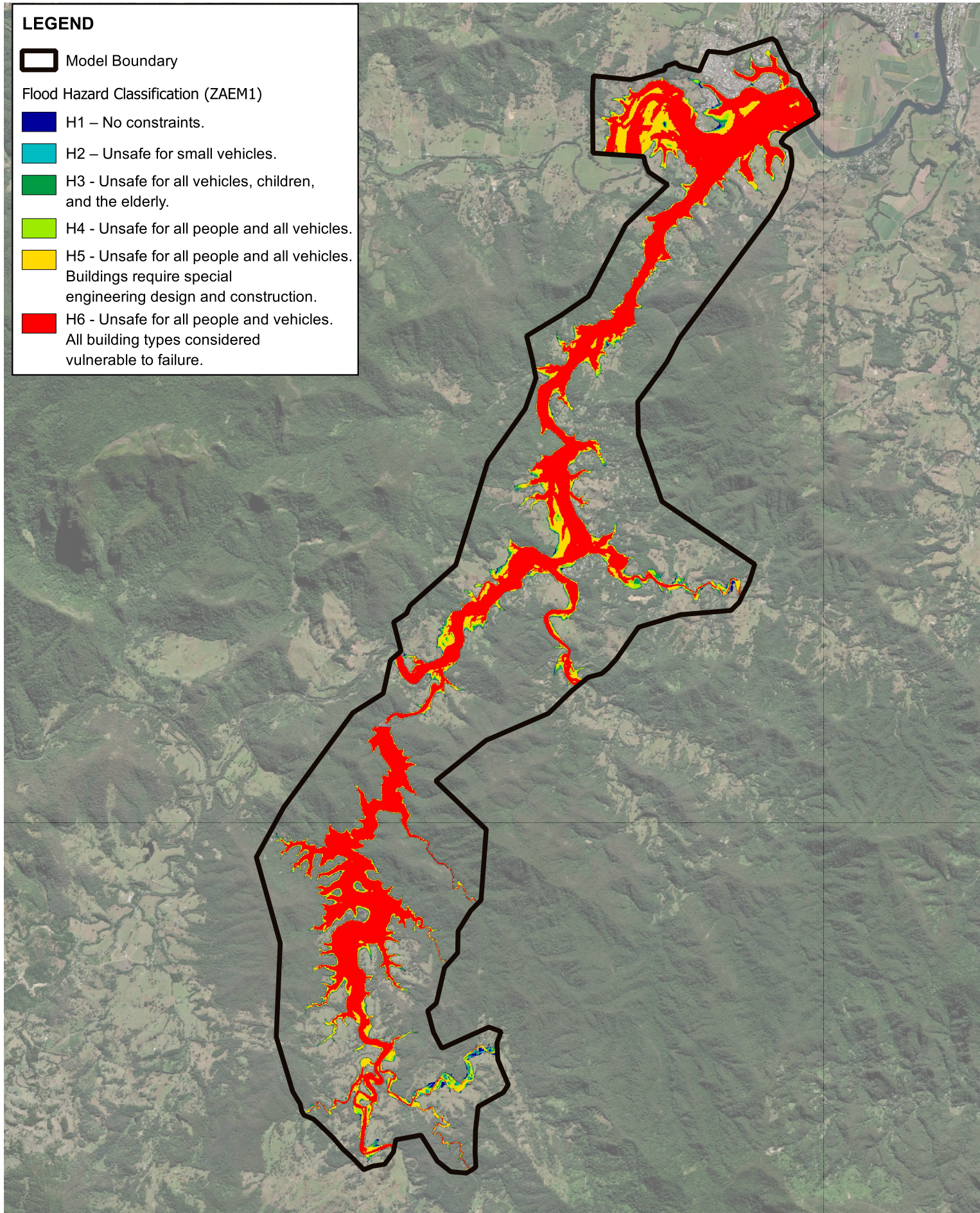
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Title: Flood Hazard - Existing Case (2050 SSP3-7.0) 0.1% AEP Design Event

Figure:
B16

Rev:
0

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

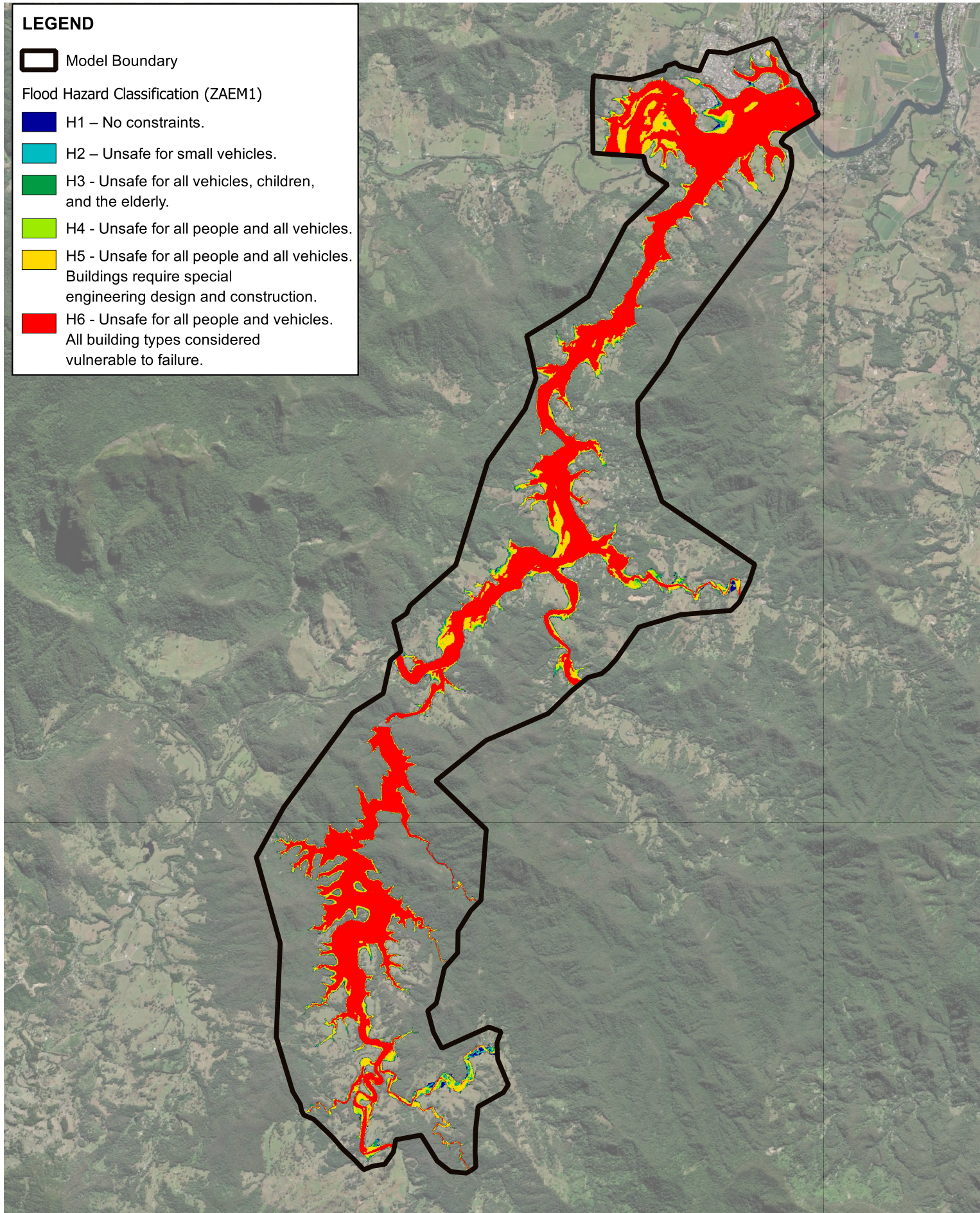
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Title: Flood Hazard - Existing Case (2050 SSP3-7.0) 0.05% AEP Design Event

Figure:

B17

Rev:

0

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

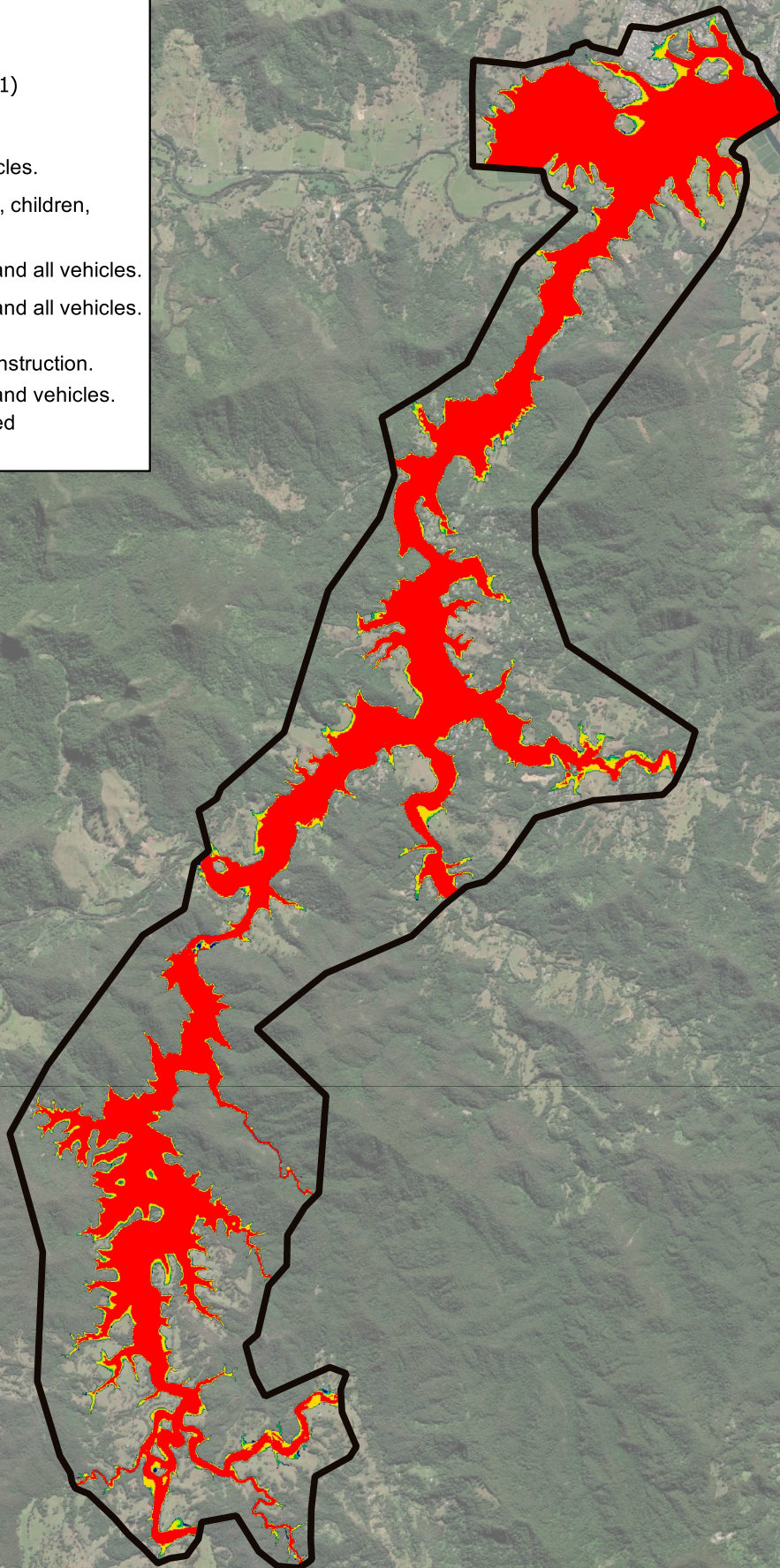
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Existing Case (2050 SSP3-7.0) PMF Design Event

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000

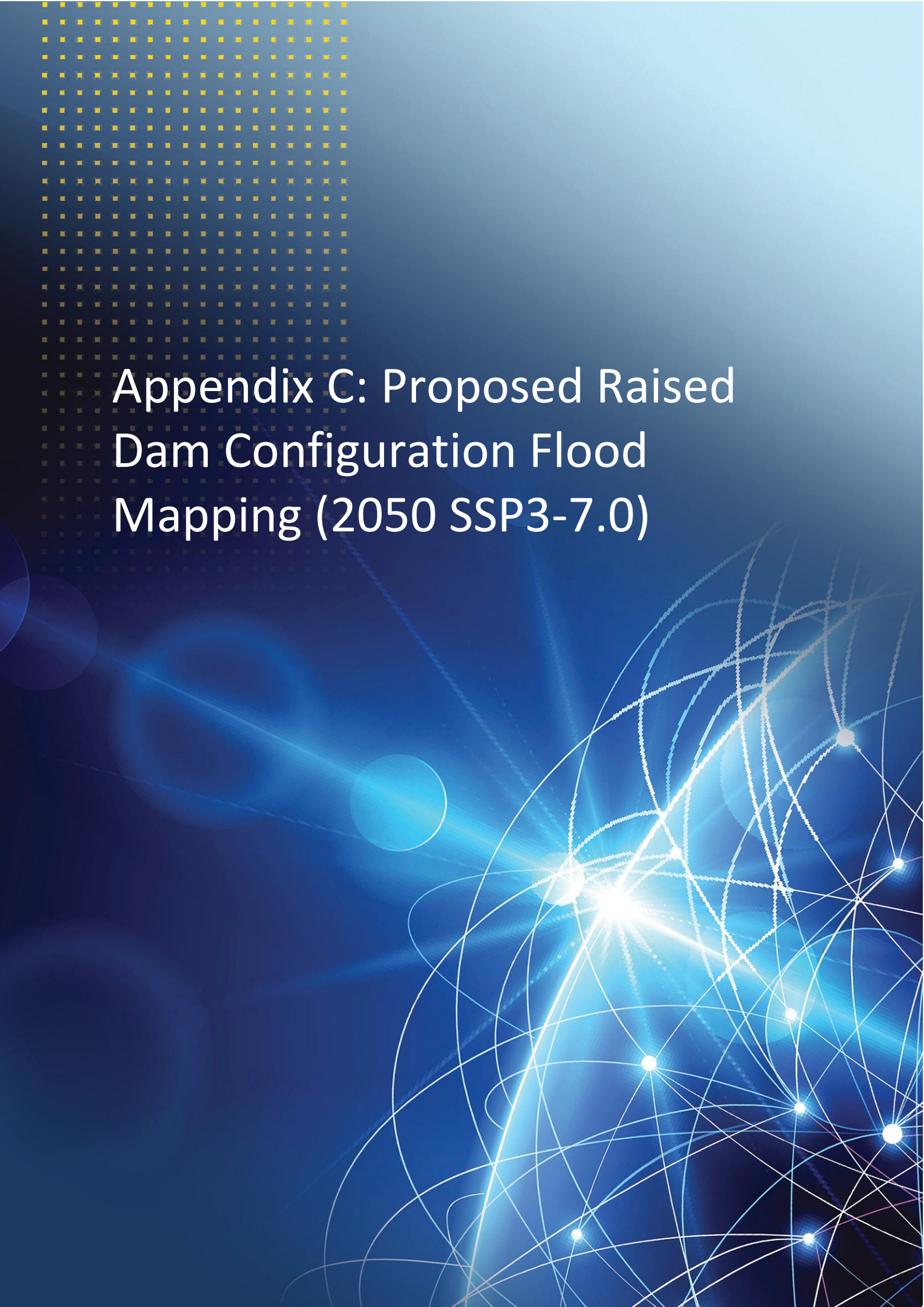
Figure:

B18

Rev:

0





Appendix C: Proposed Raised Dam Configuration Flood Mapping (2050 SSP3-7.0)

LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 ≤ 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

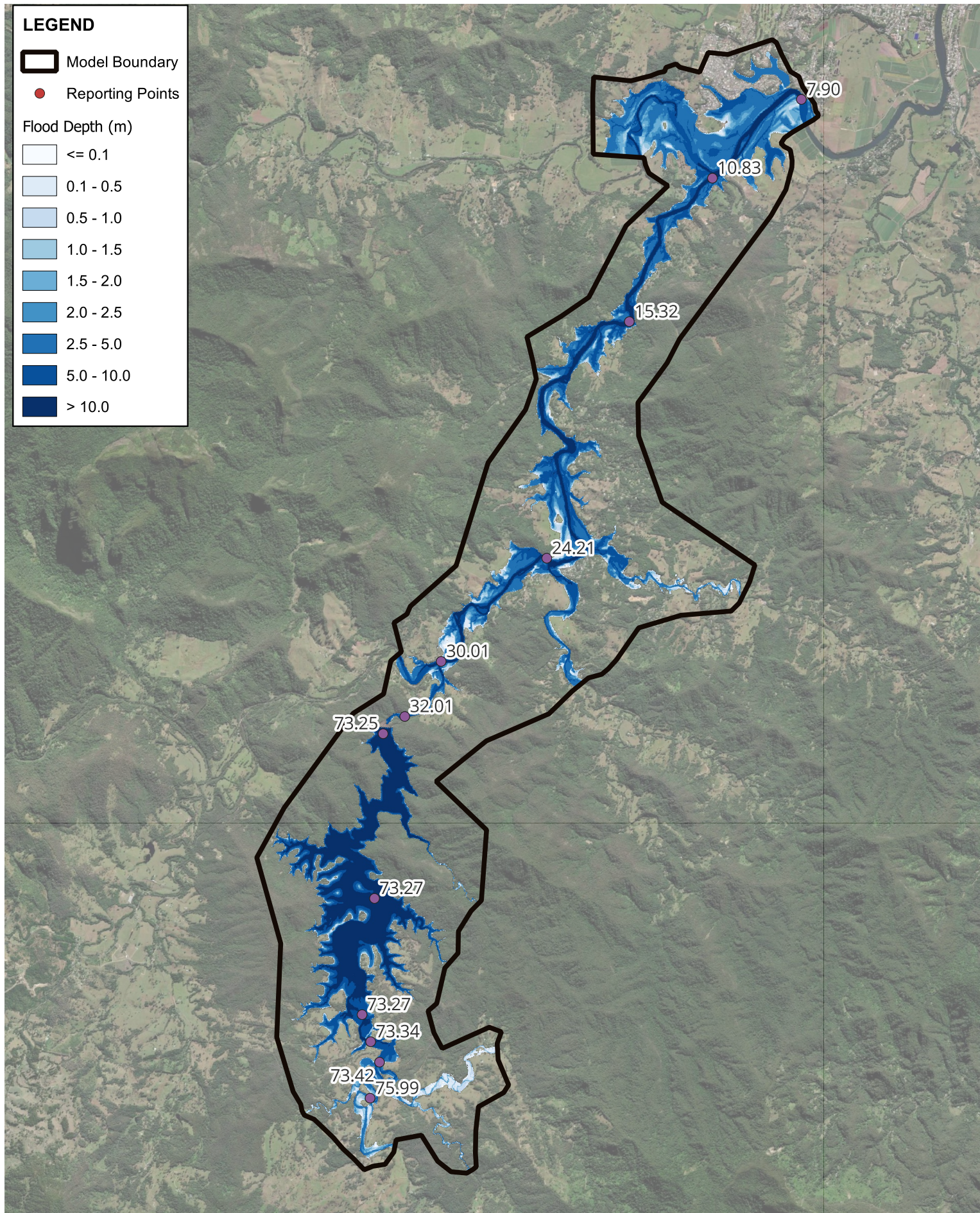
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Title:
**Peak Flood Depth and Level - Proposed Case
(2050 SSP3-7.0) 1% AEP Design Event**

Figure:

C1

Rev:

0

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

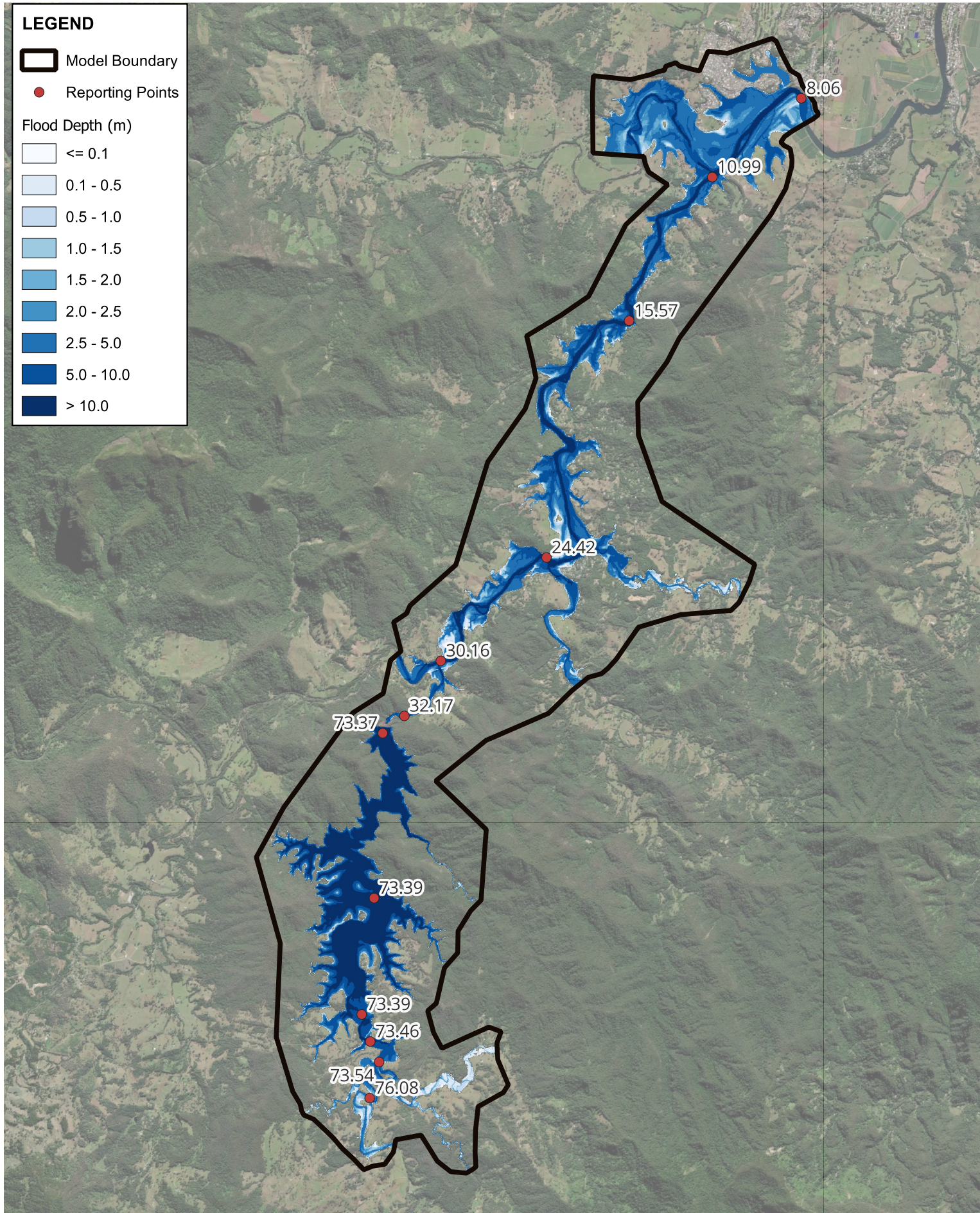
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Title: Peak Flood Depth and Level - Proposed Case (2050 SSP3-7.0) 0.5% AEP Design Event

Figure:

C2

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 ≤ 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

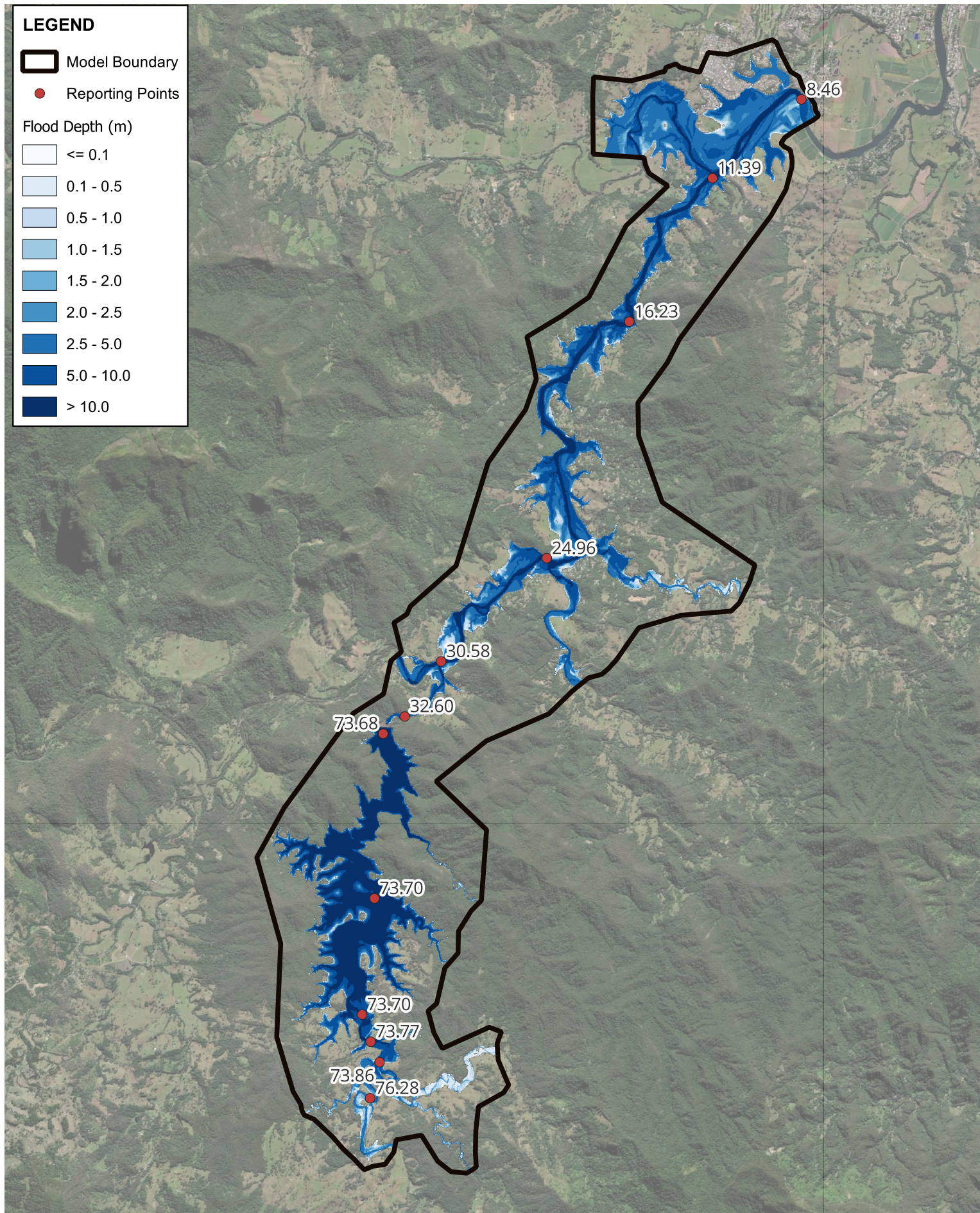
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Peak Flood Depth and Level - Proposed Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure:

C3

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

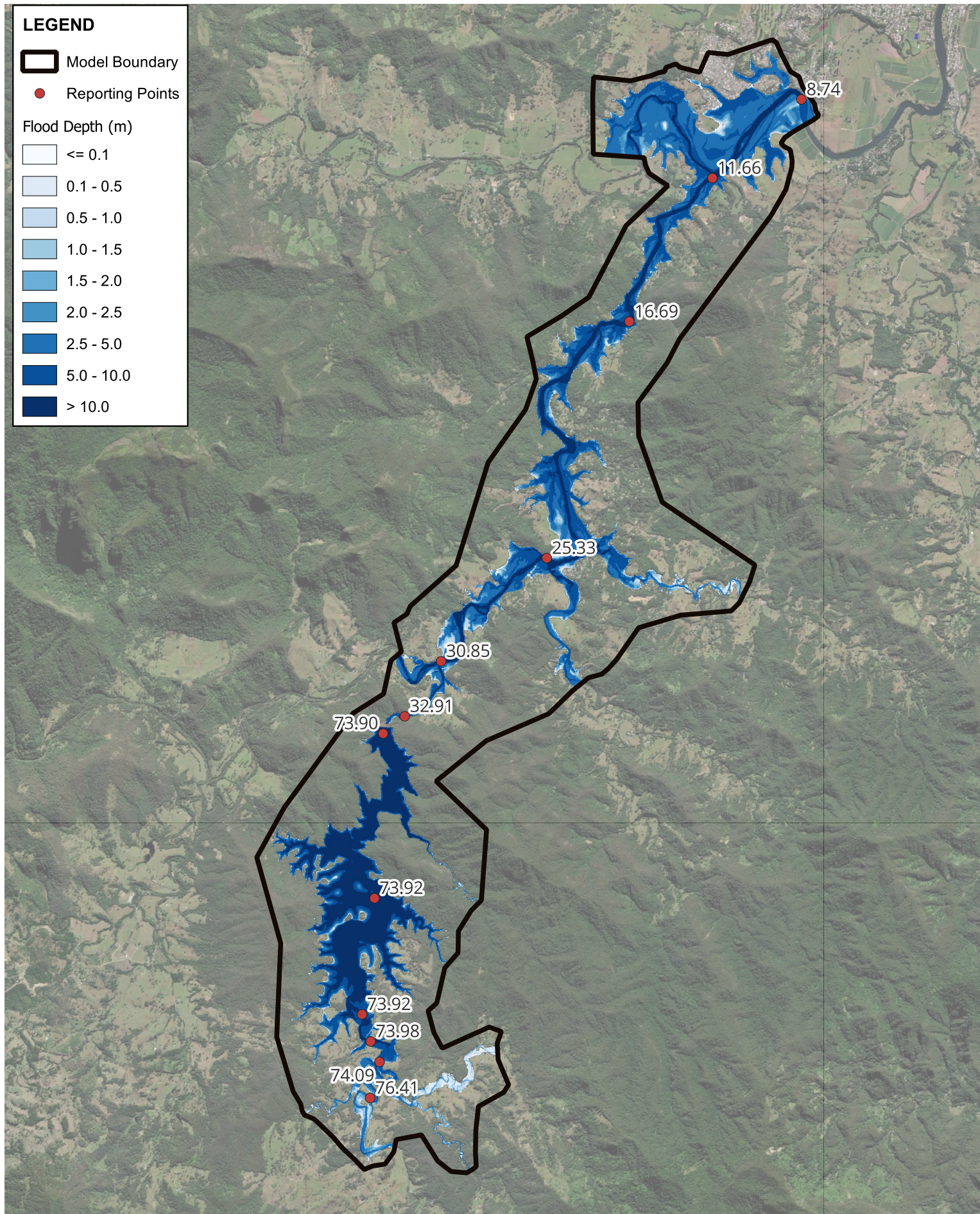
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Title: Peak Flood Depth and Level - Proposed Case (2050 SSP3-7.0) 0.1% AEP Design Event

Figure:

C4

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 <= 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

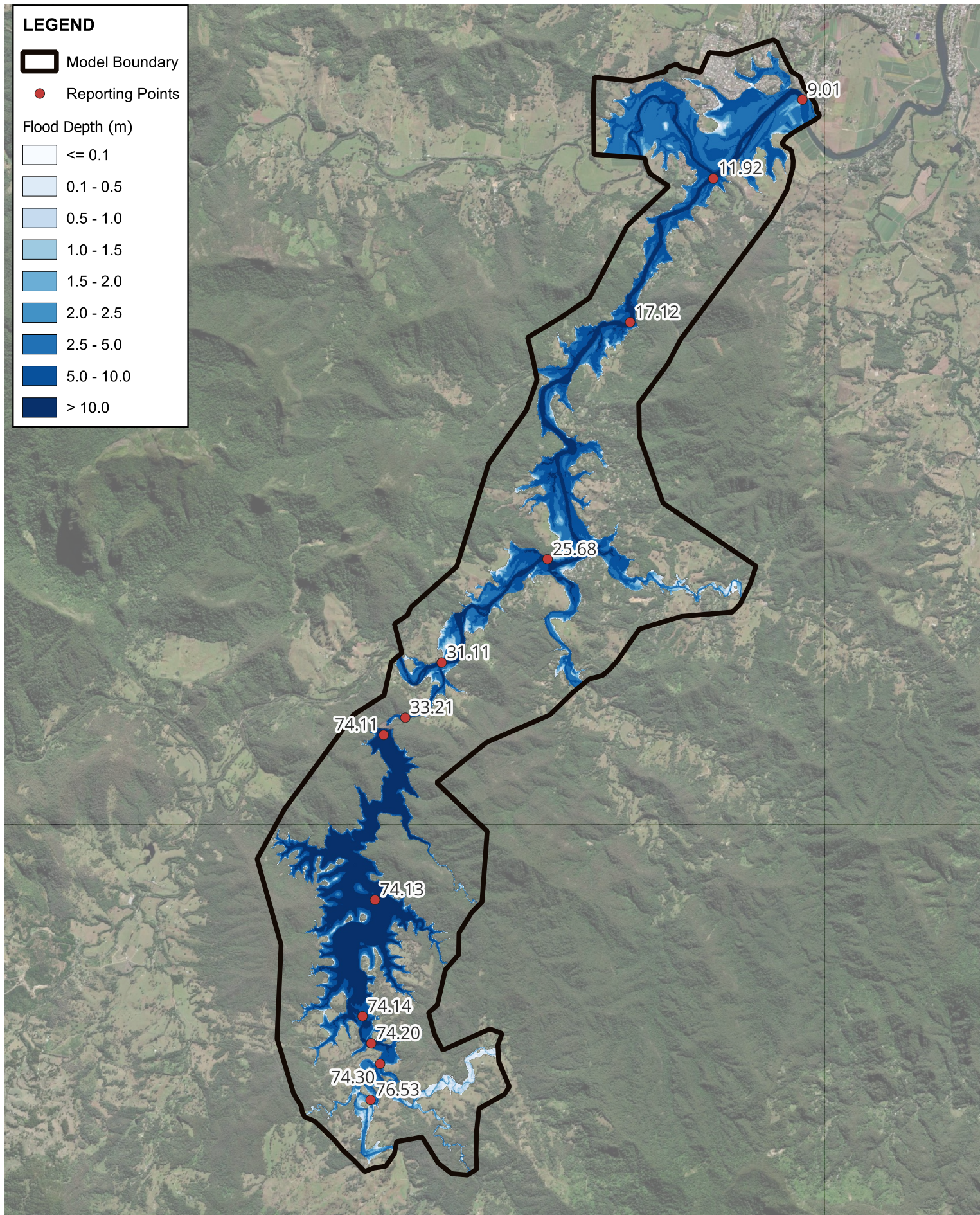
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Title:
**Peak Flood Depth and Level - Proposed Case
(2050 SSP3-7.0) 0.05% AEP Design Event**

Figure:
C5

Rev:
0

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

 Reporting Points

Flood Depth (m)

 ≤ 0.1

 0.1 - 0.5

 0.5 - 1.0

 1.0 - 1.5

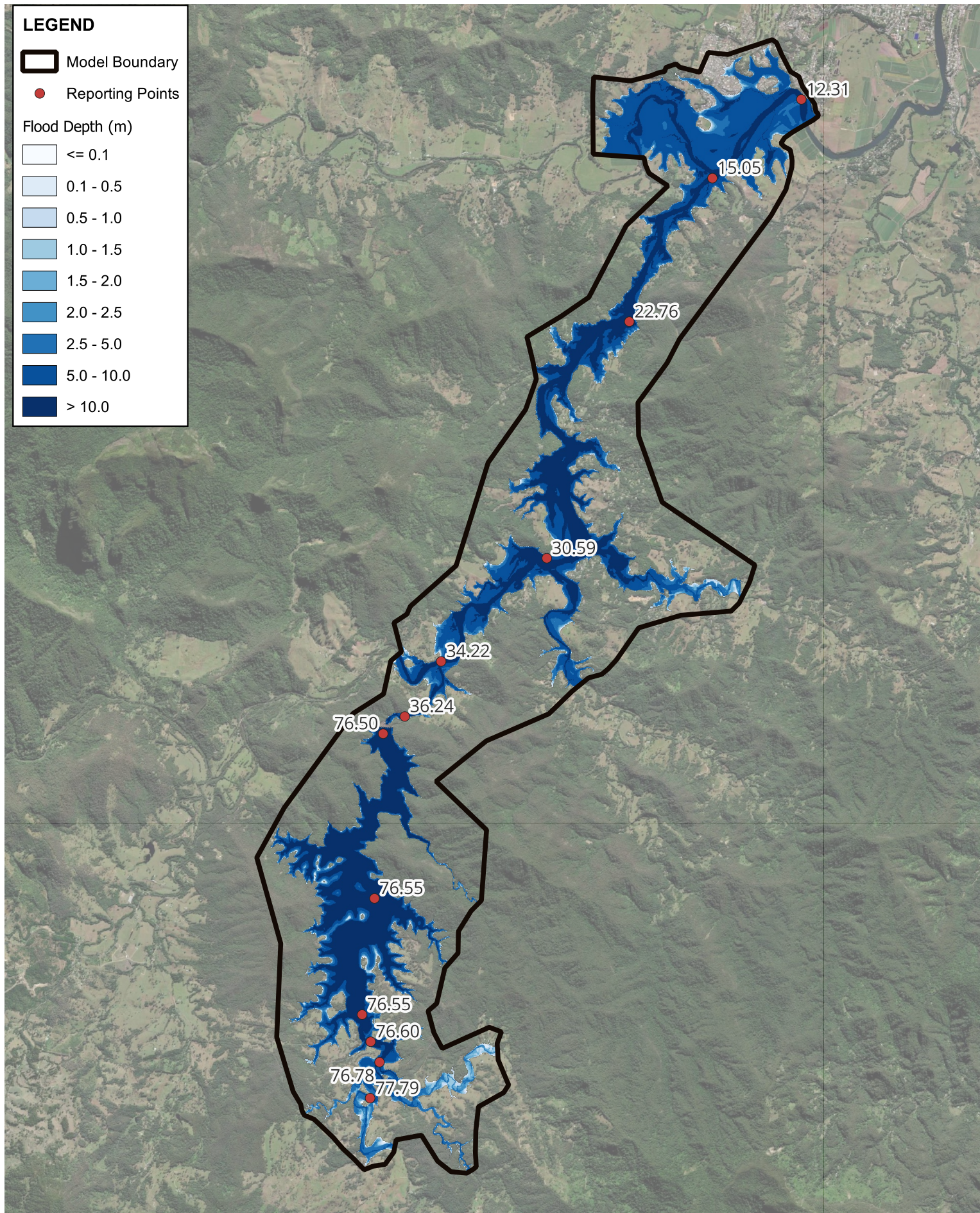
 1.5 - 2.0

 2.0 - 2.5

 2.5 - 5.0

 5.0 - 10.0

 > 10.0



Title: **Peak Flood Depth and Level - Proposed Case (2050 SSP3-7.0) PMF Design Event**

Figure: **C6**

Rev: **0**

Scale: at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

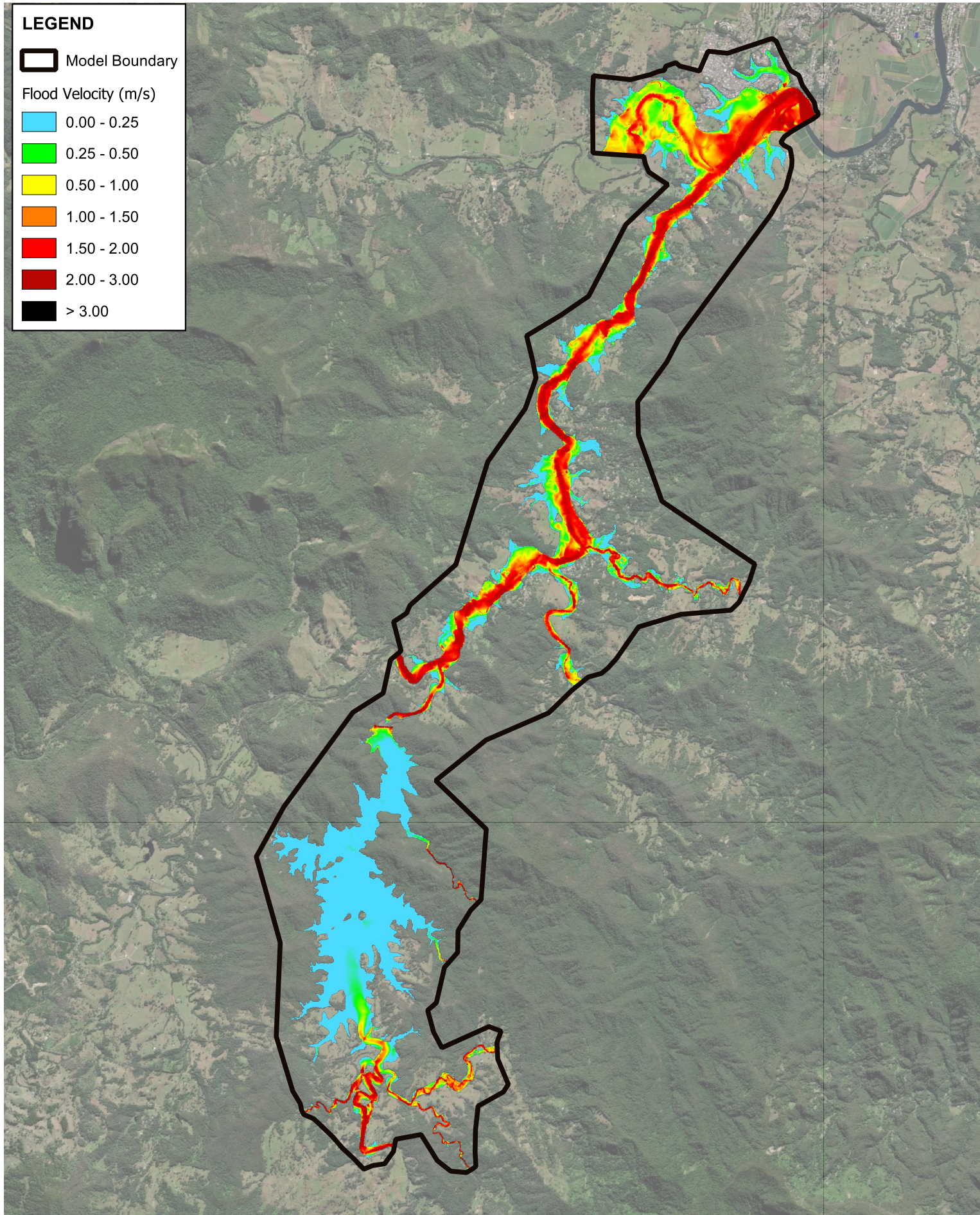
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title: Peak Velocity - Proposed Case (2050 SSP3-7.0) 1% AEP Design Event

Figure:

C7

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

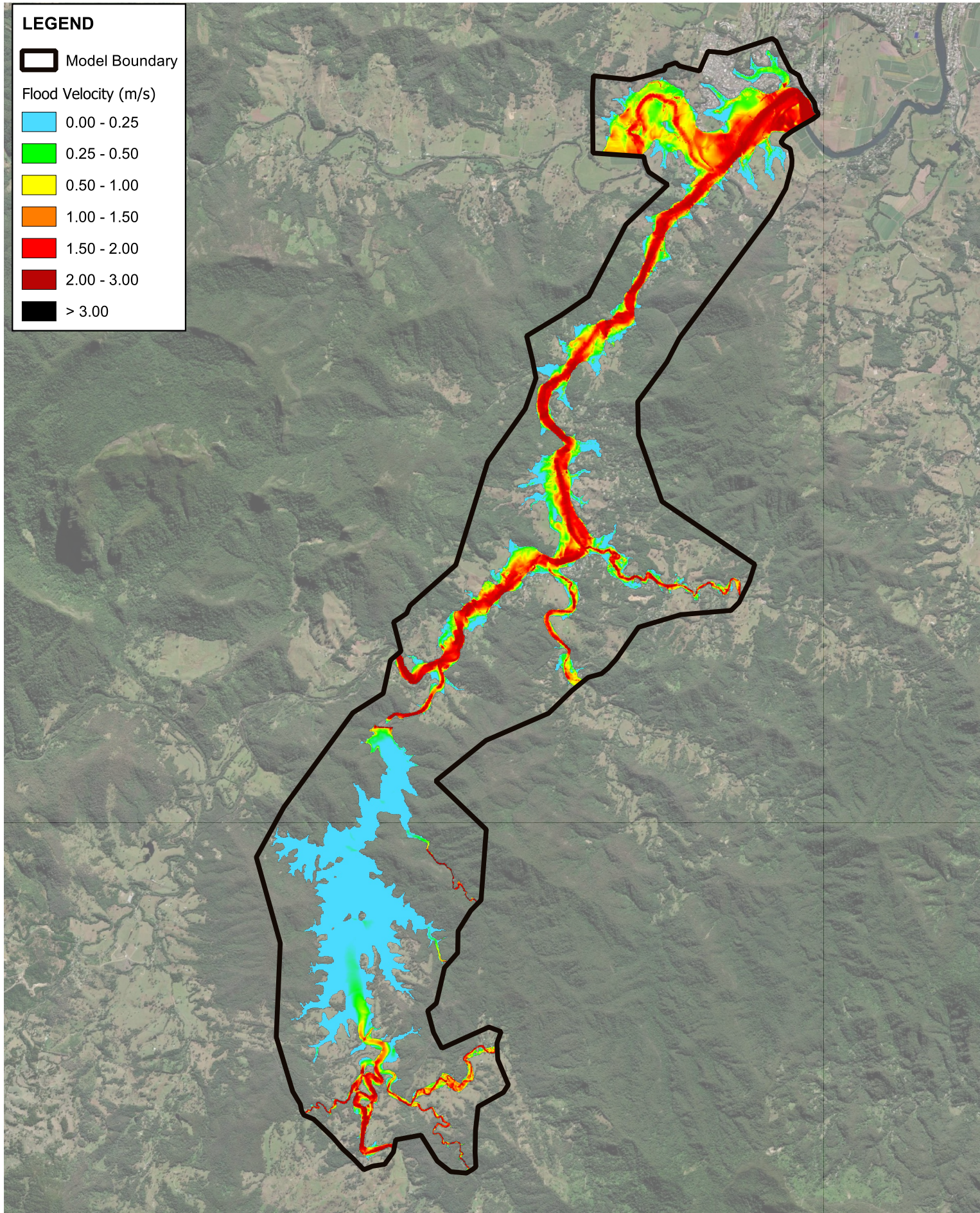
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title: Peak Velocity - Proposed Case (2050 SSP3-7.0) 0.5% AEP Design Event

Figure:
C8

Rev:
0

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

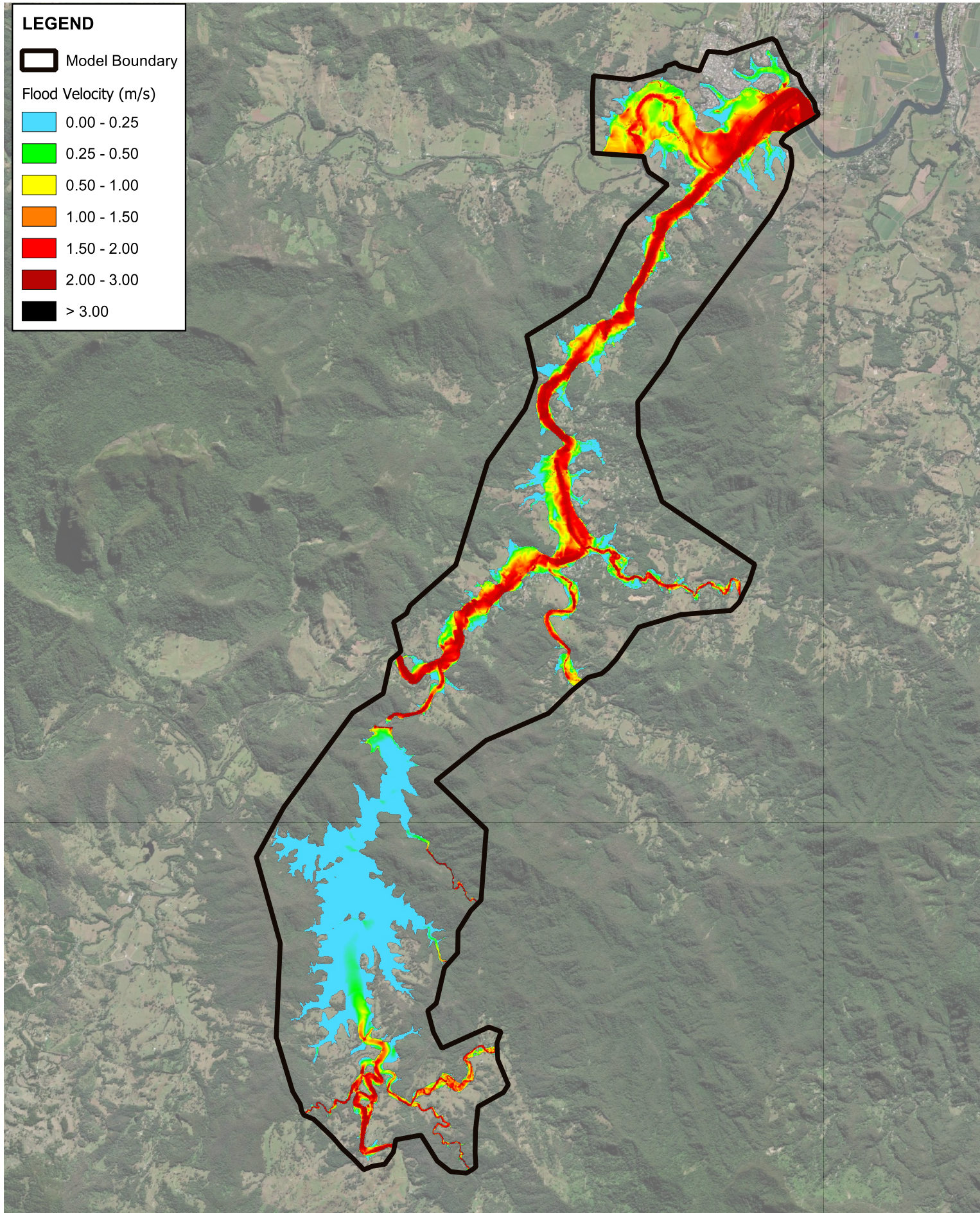
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title:
**Peak Velocity - Proposed Case
(2050 SSP3-7.0) 0.2% AEP Design Event**

Figure:
C9

Rev:
0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

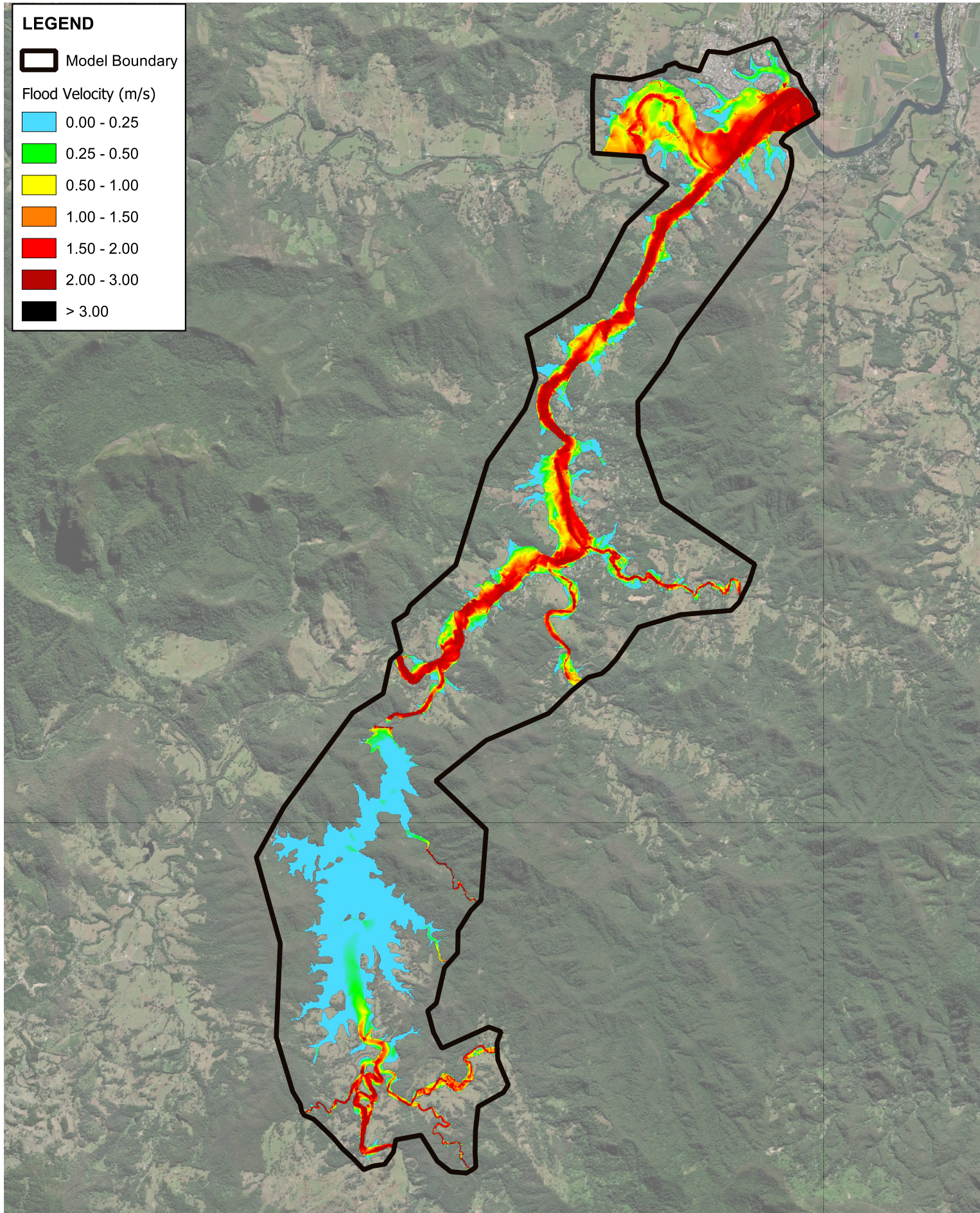
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title:
**Peak Velocity - Proposed Case
(2050 SSP3-7.0) 0.1% AEP Design Event**

Figure:

C10

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

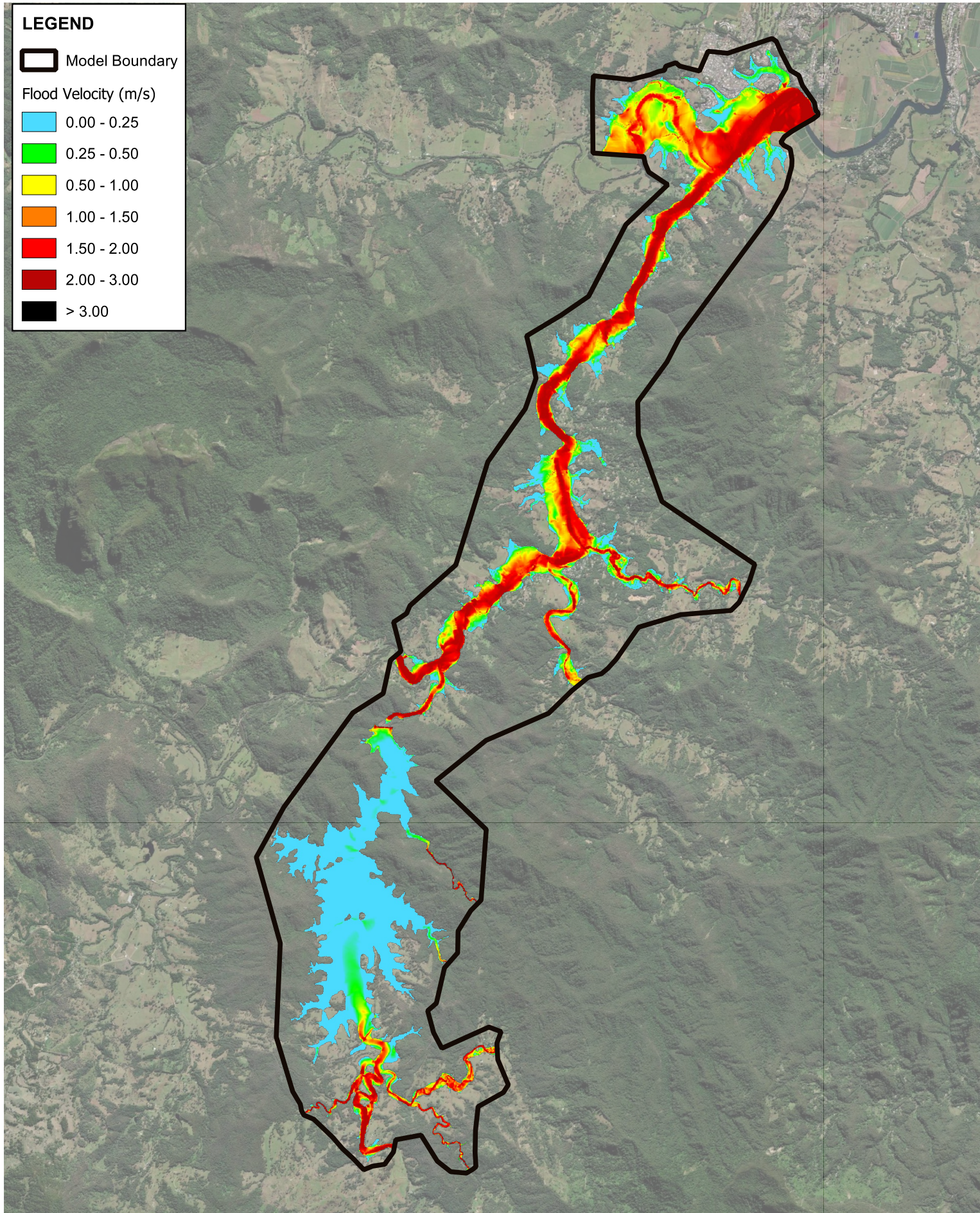
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title: Peak Velocity - Proposed Case (2050 SSP3-7.0) 0.05% AEP Design Event

Figure:

C11

Rev:

0

Scale at A4
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1:80000.00008160024

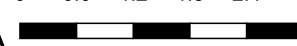
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Velocity (m/s)

 0.00 - 0.25

 0.25 - 0.50

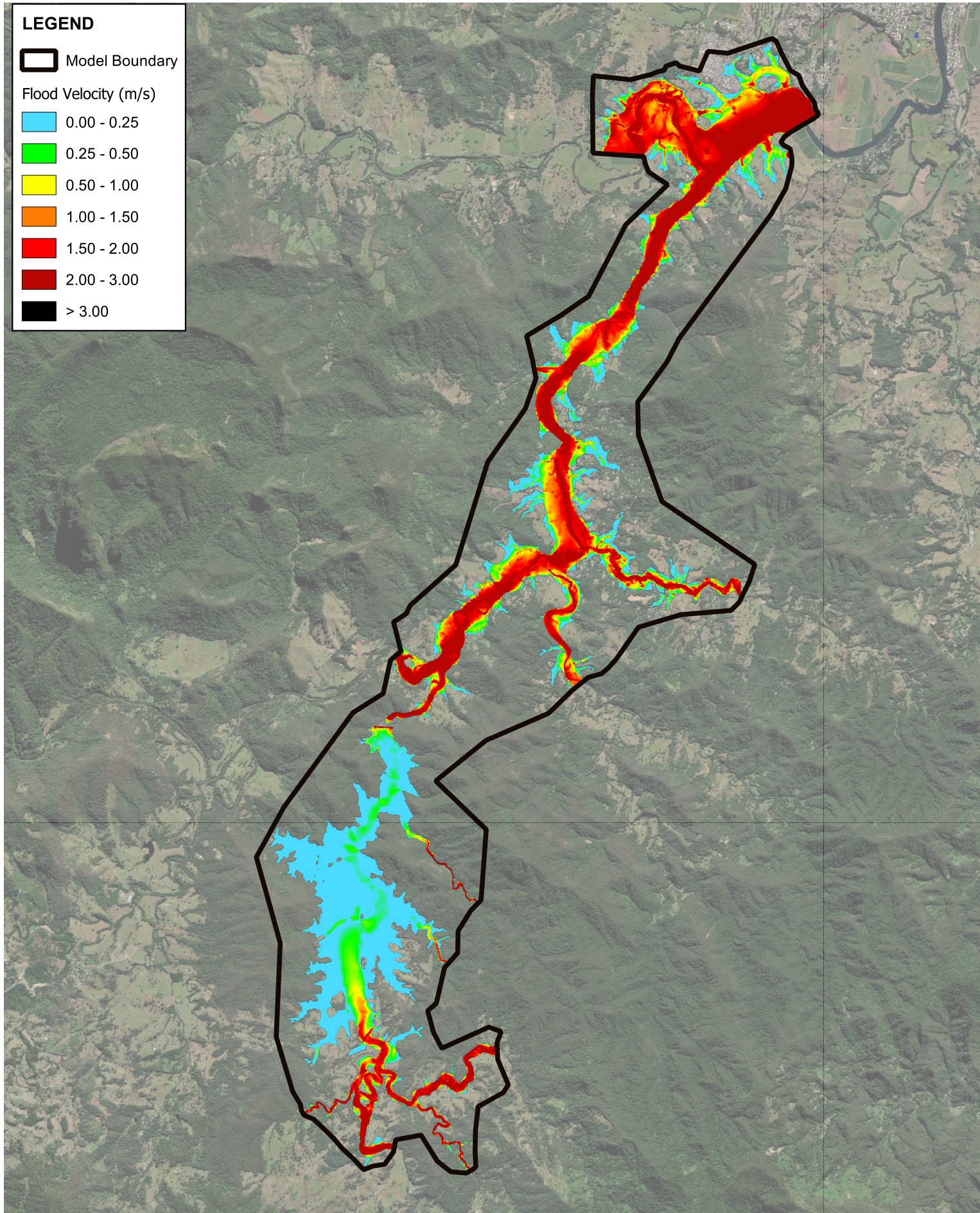
 0.50 - 1.00

 1.00 - 1.50

 1.50 - 2.00

 2.00 - 3.00

 > 3.00



Title: Peak Velocity - Proposed Case (2050 SSP3-7.0) PMF Design Event

Figure:

C12

Rev:

0

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints

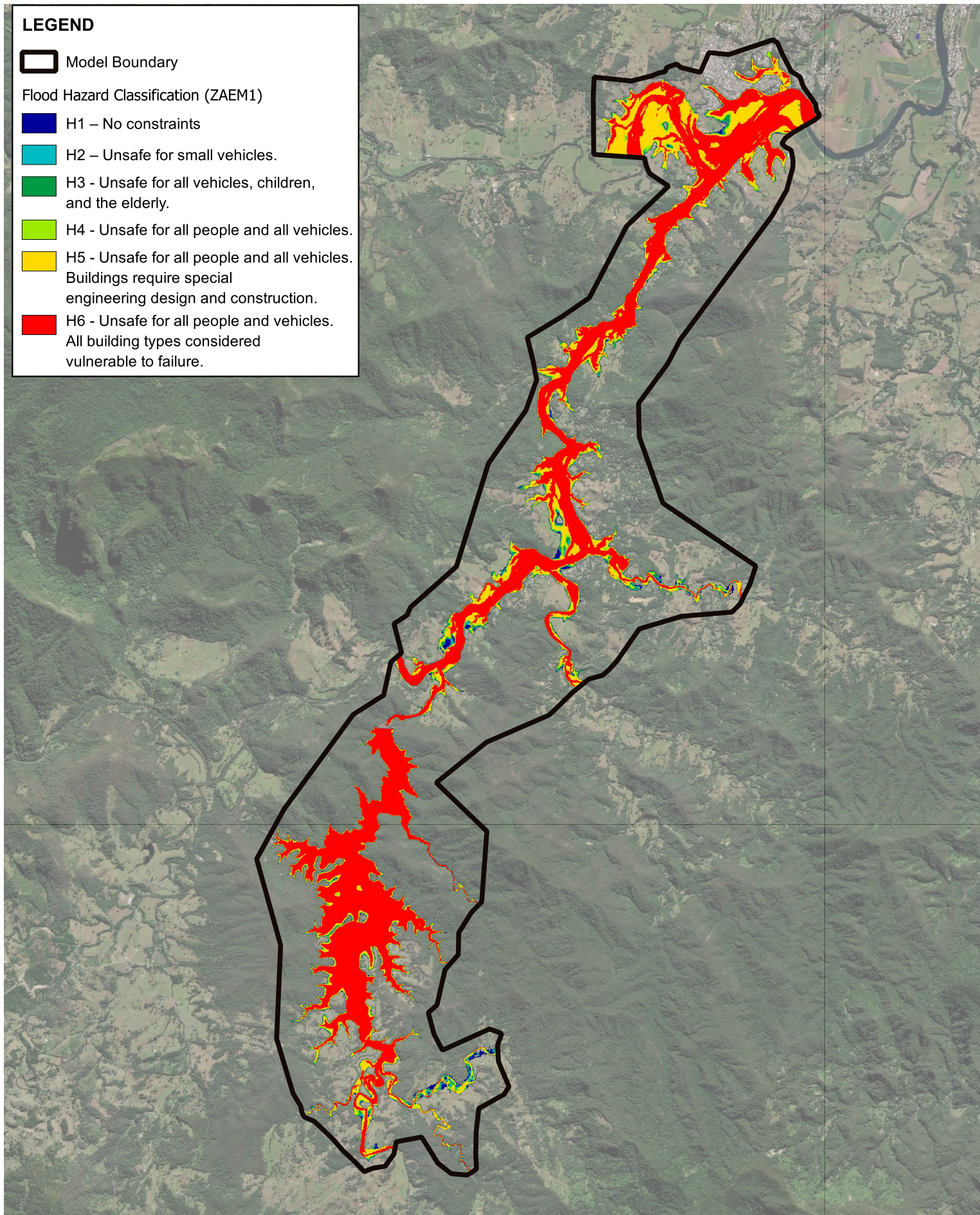
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Proposed Case (2050 SSP3-7.0) 1% AEP Design Event

Figure: **C13**

Rev: **0**

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints

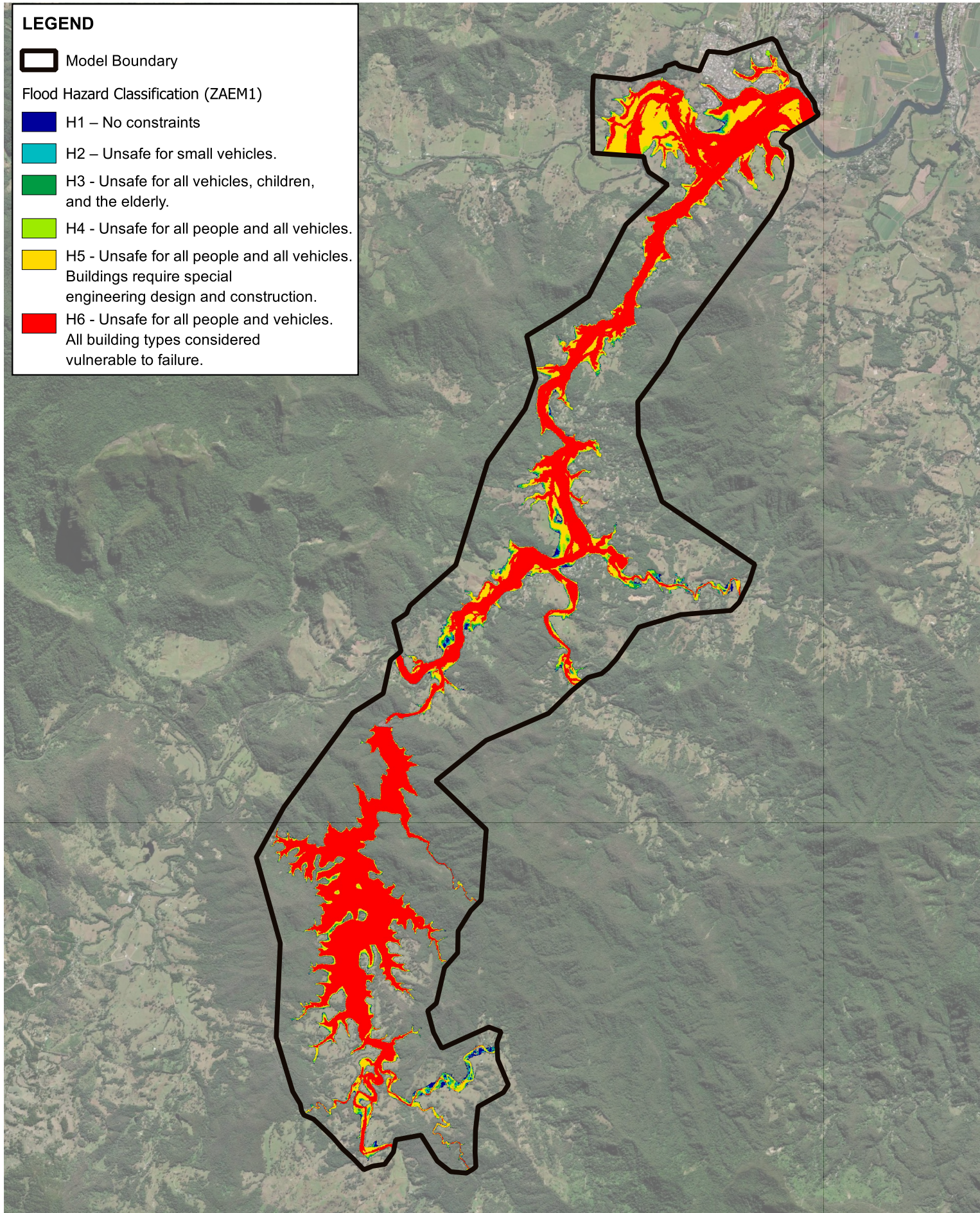
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Proposed Case (2050 SSP3-7.0) 0.5% AEP Design Event

Figure:

C14

Rev:

0

Scale at A4
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1:80000.00008160024

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints

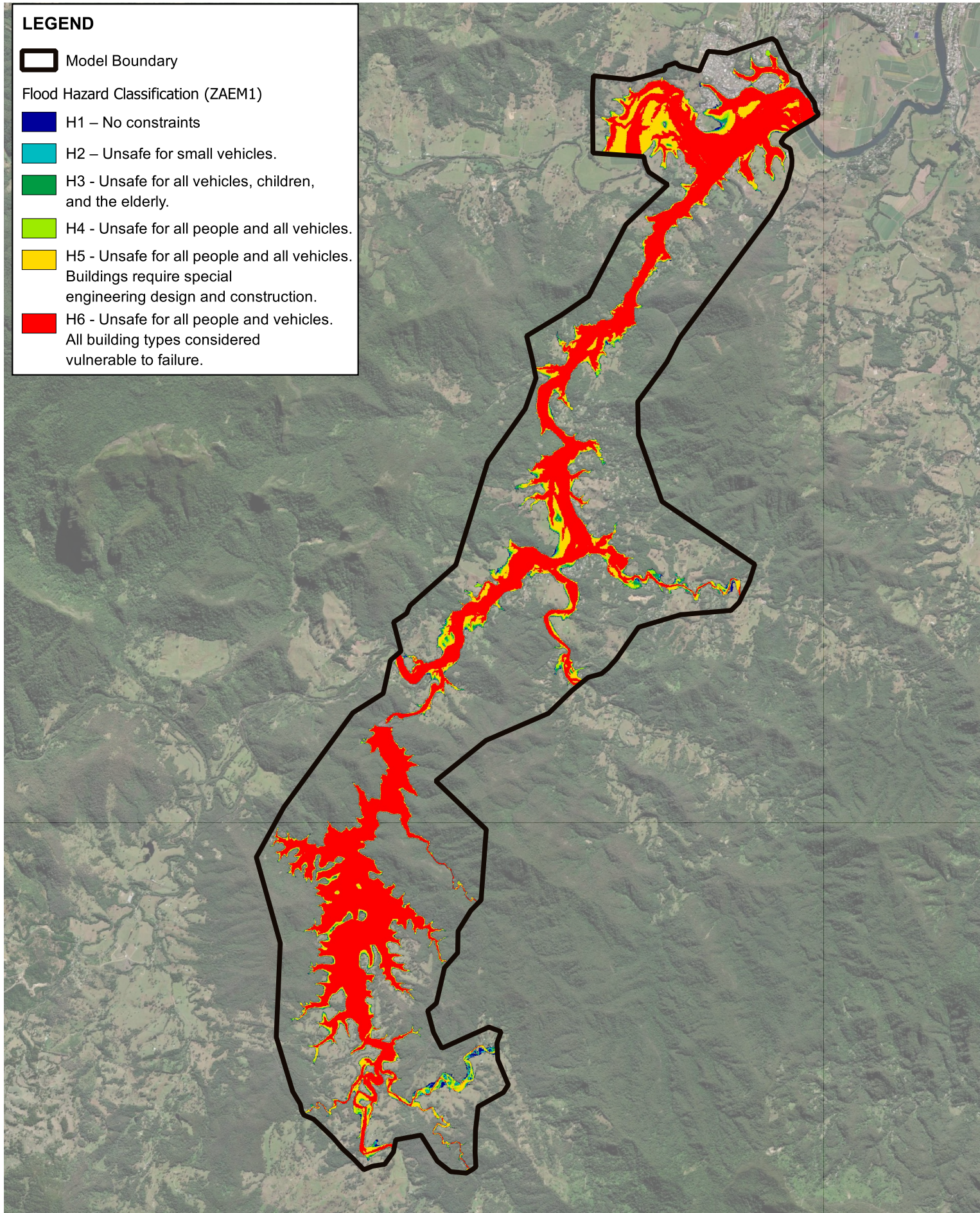
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Title: Flood Hazard - Proposed Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure:
C15

Rev:
0

Scale at A4
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1:80000.00008160024

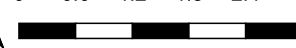
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints

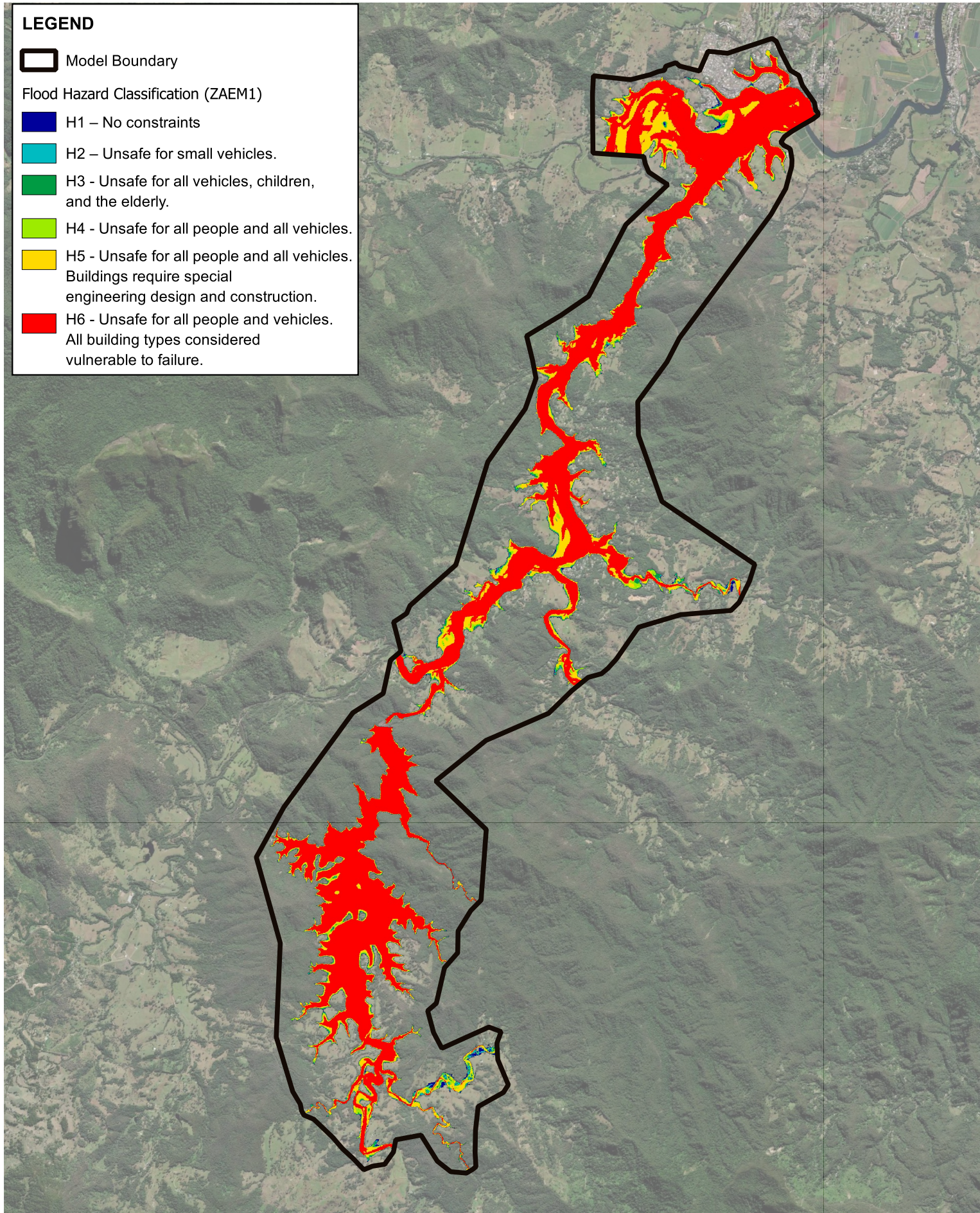
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Title: Flood Hazard - Proposed Case (2050 SSP3-7.0) 0.1% AEP Design Event

Figure:
C16

Rev:
0

Scale at A4
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1:80000.00008160024

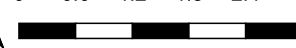
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints

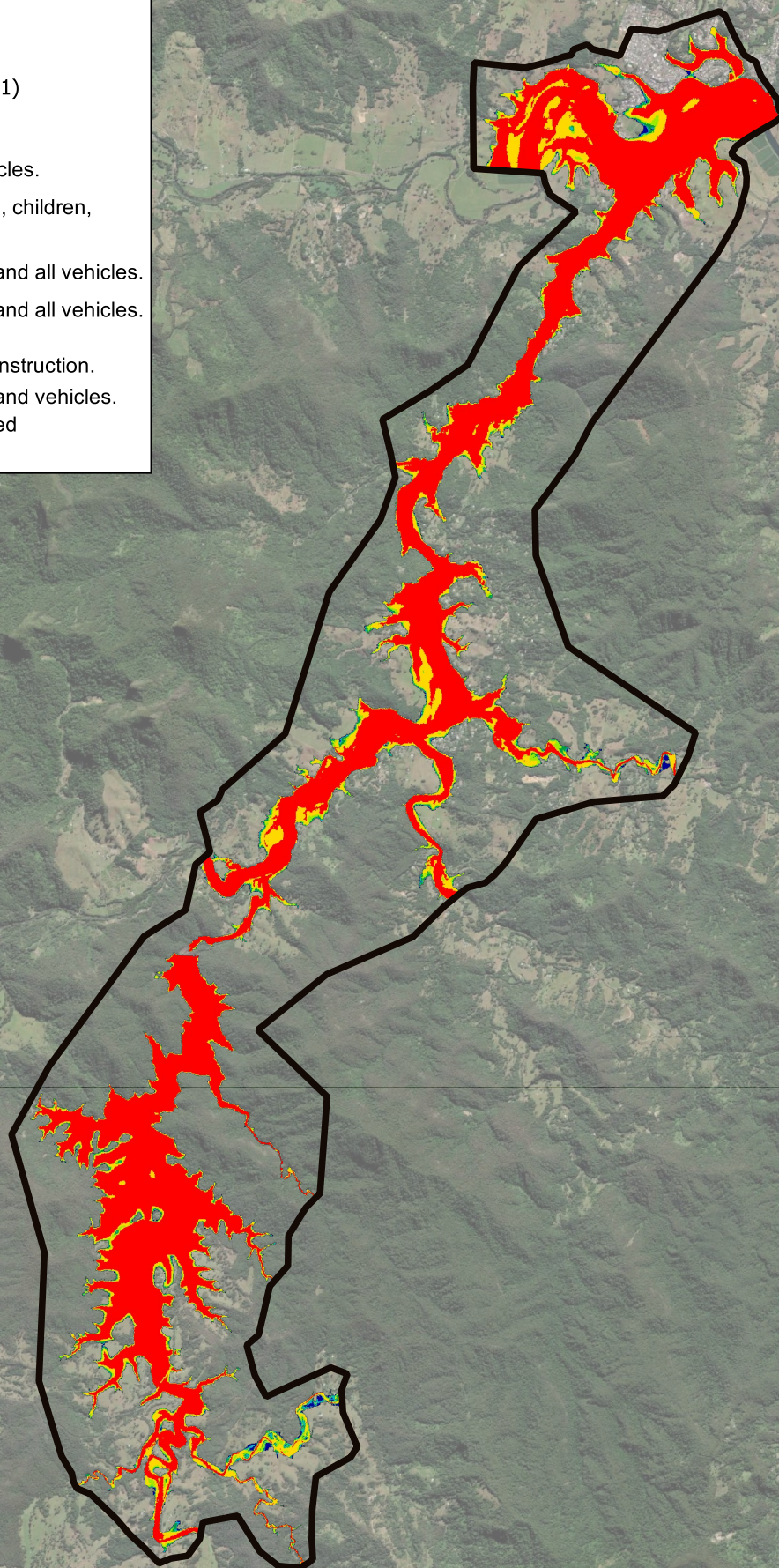
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Proposed Case (2050 SSP3-7.0) 0.05% AEP Design Event

Figure:

C17

Rev:

0

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Flood Hazard Classification (ZAEM1)

 H1 – No constraints.

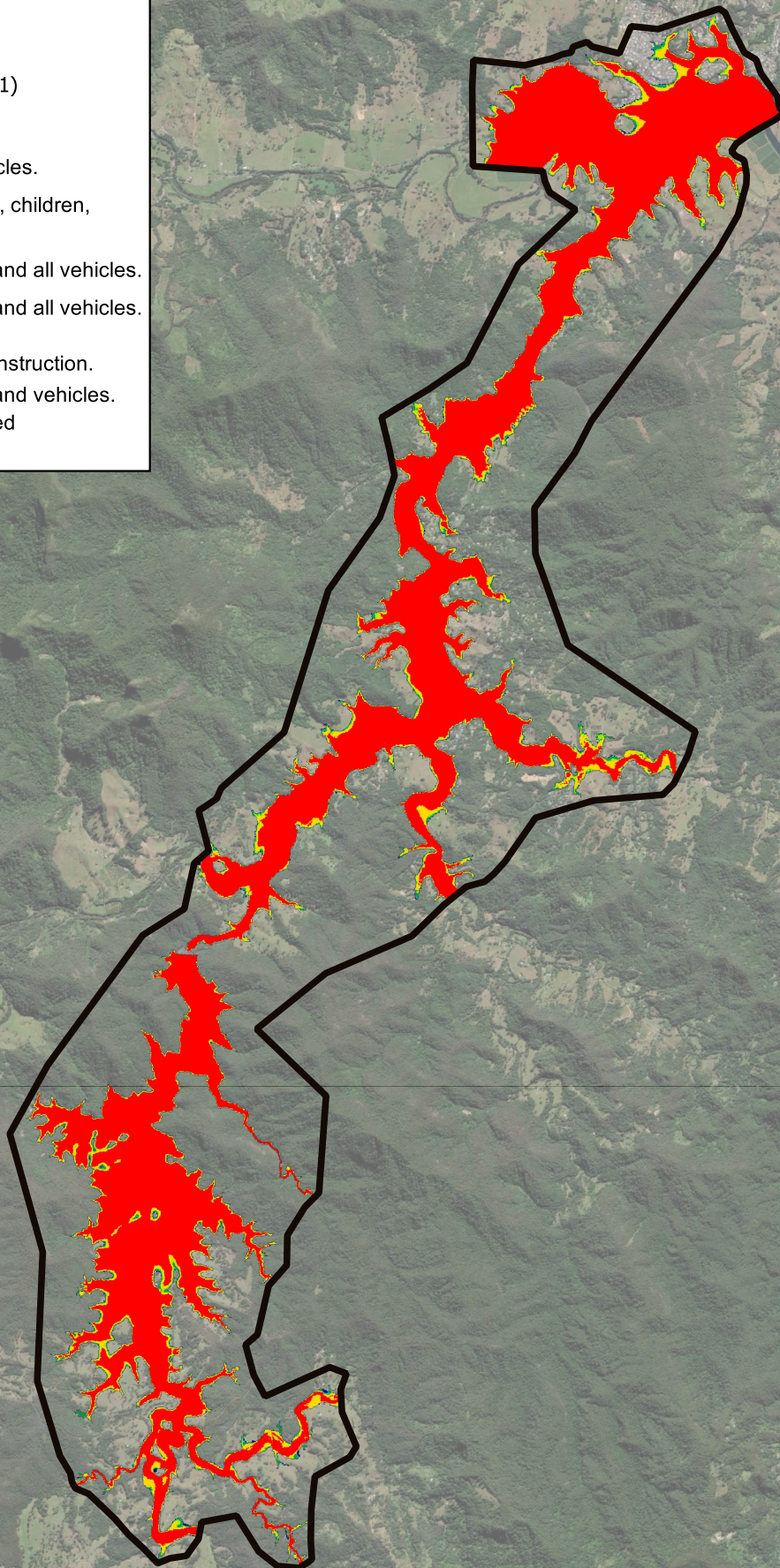
 H2 – Unsafe for small vehicles.

 H3 - Unsafe for all vehicles, children, and the elderly.

 H4 - Unsafe for all people and all vehicles.

 H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction.

 H6 - Unsafe for all people and vehicles. All building types considered vulnerable to failure.



Flood Hazard - Proposed Case (2050 SSP3-7.0) PMF Design Event

Figure: **C18**

Rev: **0**

Scale: at A4
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1:80000.00008160024

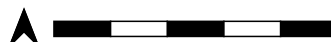
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

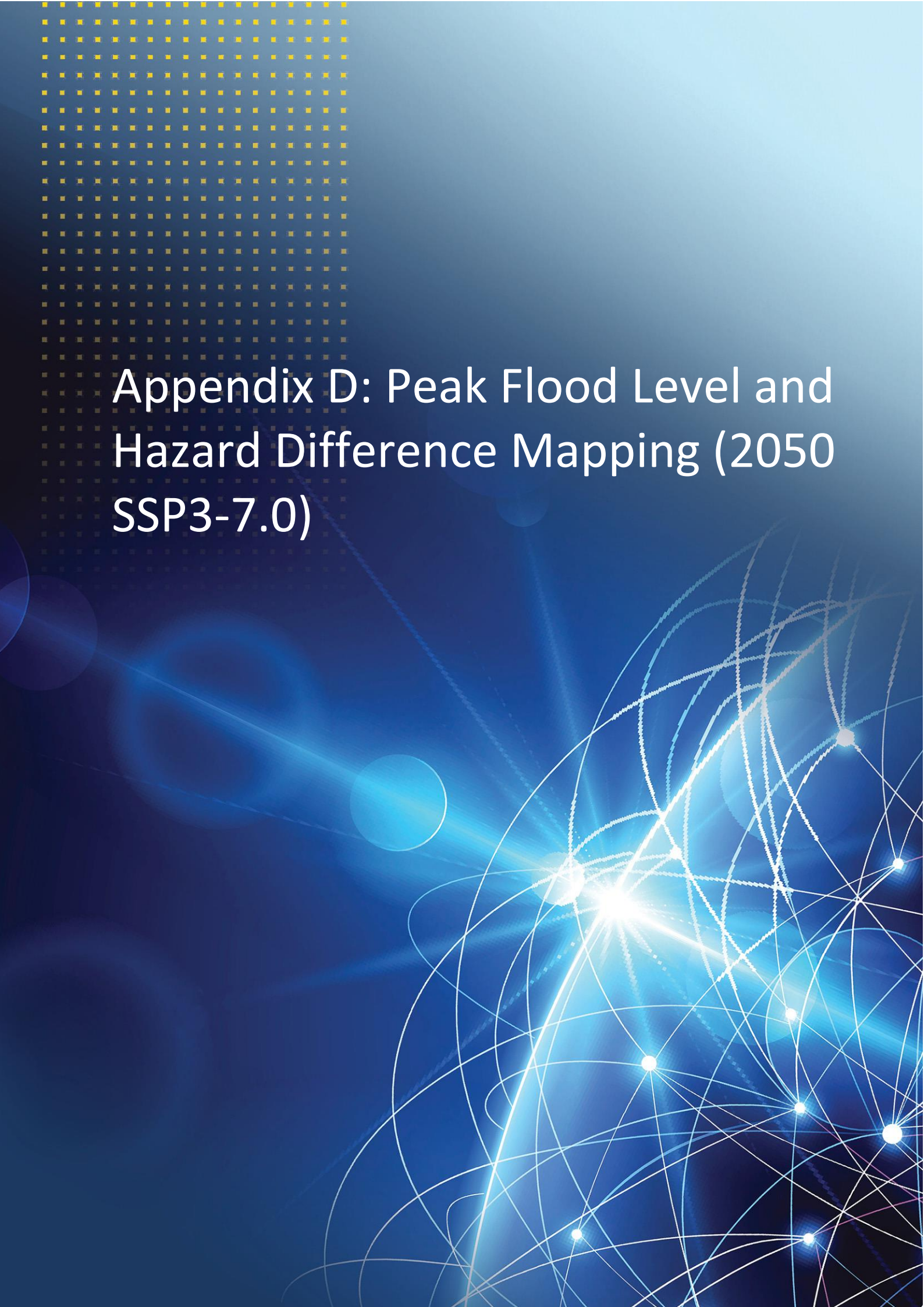
Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000





Appendix D: Peak Flood Level and Hazard Difference Mapping (2050 SSP3-7.0)

LEGEND

 Model Boundary

Differences in Flood level (m)

 ≤ -0.5m

 -0.50m - -0.25m

 -0.25m - -0.10m

 -0.10m - -0.01m

 ±0.01m

 0.01m - 0.50m

 0.50m - 1.0m

 1.0m - 2.5m

 2.5m - 5.0m

 5.0m - 7.5m

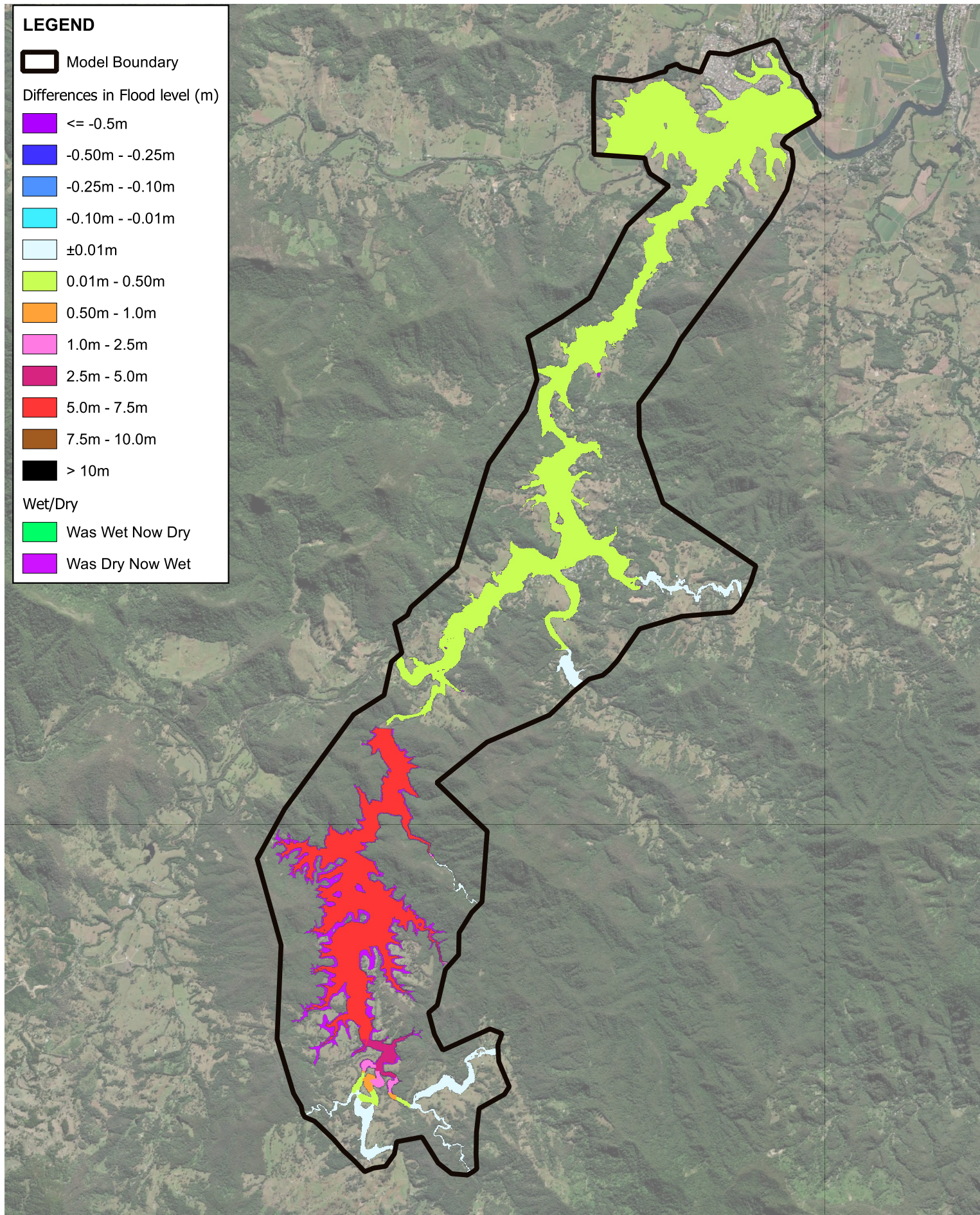
 7.5m - 10.0m

 > 10m

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Level - Proposed Case minus Existing Case (2050 SSP3-7.0) 1% AEP Design Event

Figure:

D1

Rev:

0

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood level (m)

 ≤ -0.5m

 -0.50m - -0.25m

 -0.25m - -0.10m

 -0.10m - -0.01m

 ±0.01m

 0.01m - 0.50m

 0.50m - 1.0m

 1.0m - 2.5m

 2.5m - 5.0m

 5.0m - 7.5m

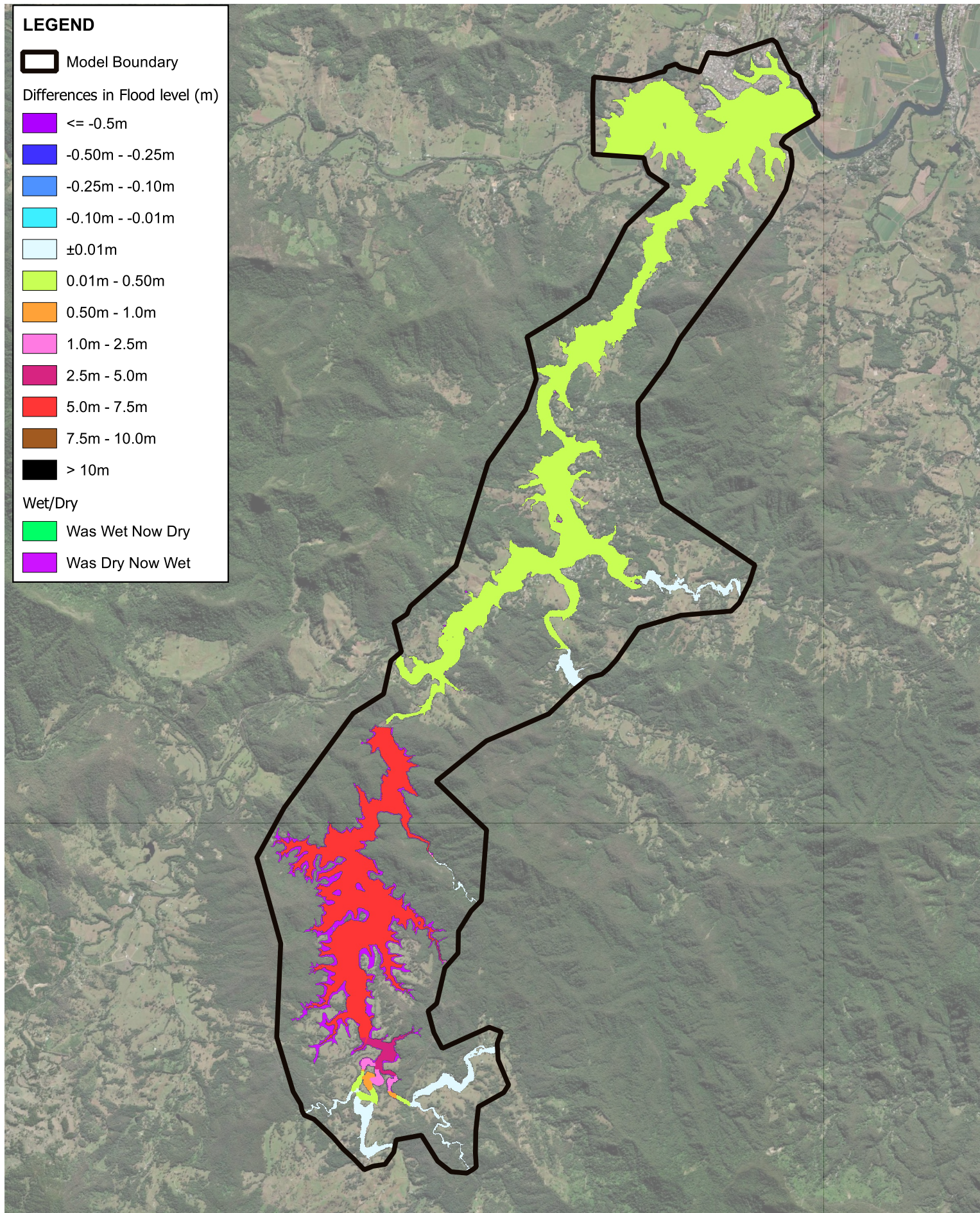
 7.5m - 10.0m

 > 10m

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Level - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.5% AEP Design Event

Figure:

D2

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood level (m)

 ≤ -0.5m

 -0.50m - -0.25m

 -0.25m - -0.10m

 -0.10m - -0.01m

 ±0.01m

 0.01m - 0.50m

 0.50m - 1.0m

 1.0m - 2.5m

 2.5m - 5.0m

 5.0m - 7.5m

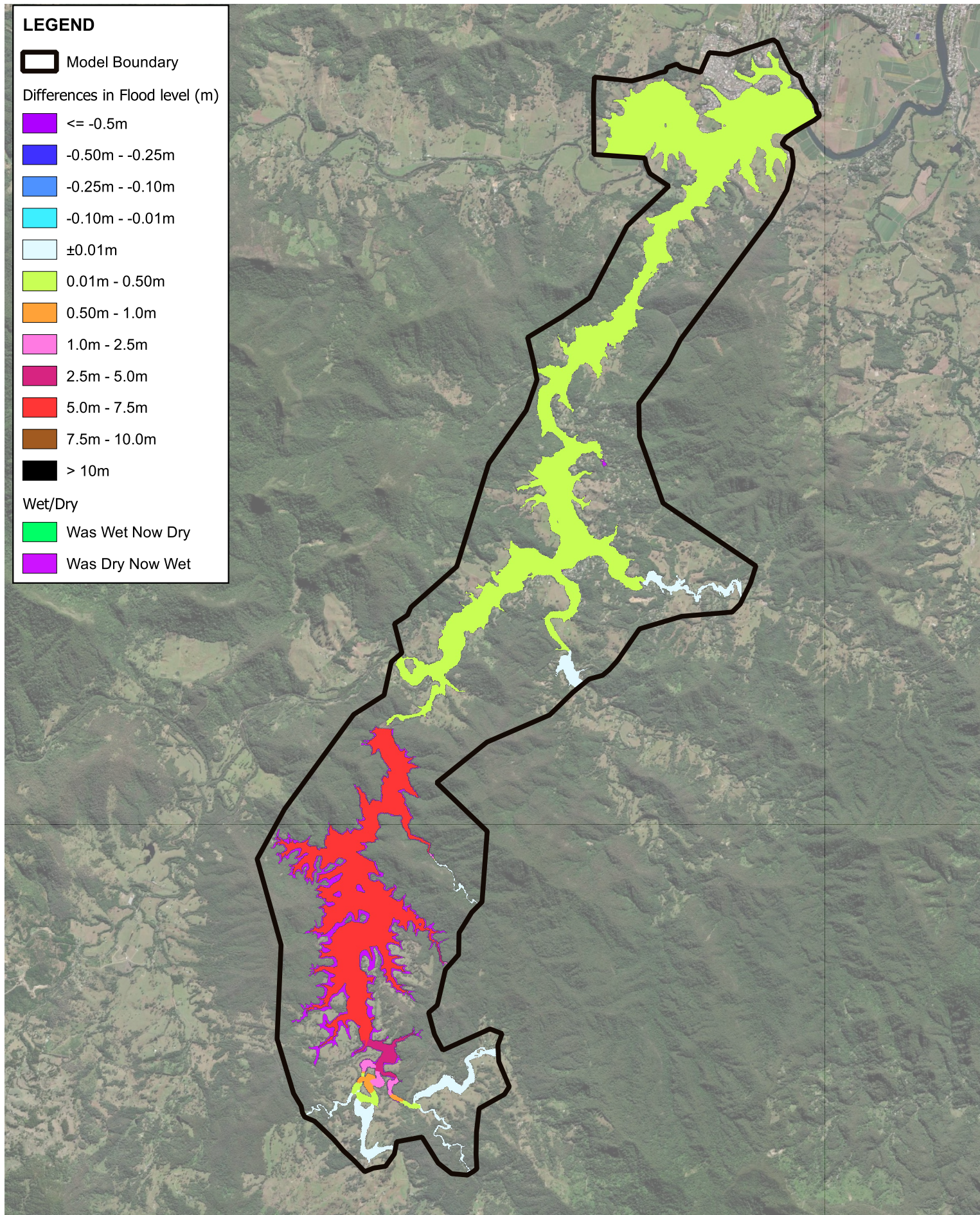
 7.5m - 10.0m

 > 10m

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Level - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure:

D3

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood level (m)

 ≤ -0.5m

 -0.50m - -0.25m

 -0.25m - -0.10m

 -0.10m - -0.01m

 ±0.01m

 0.01m - 0.50m

 0.50m - 1.0m

 1.0m - 2.5m

 2.5m - 5.0m

 5.0m - 7.5m

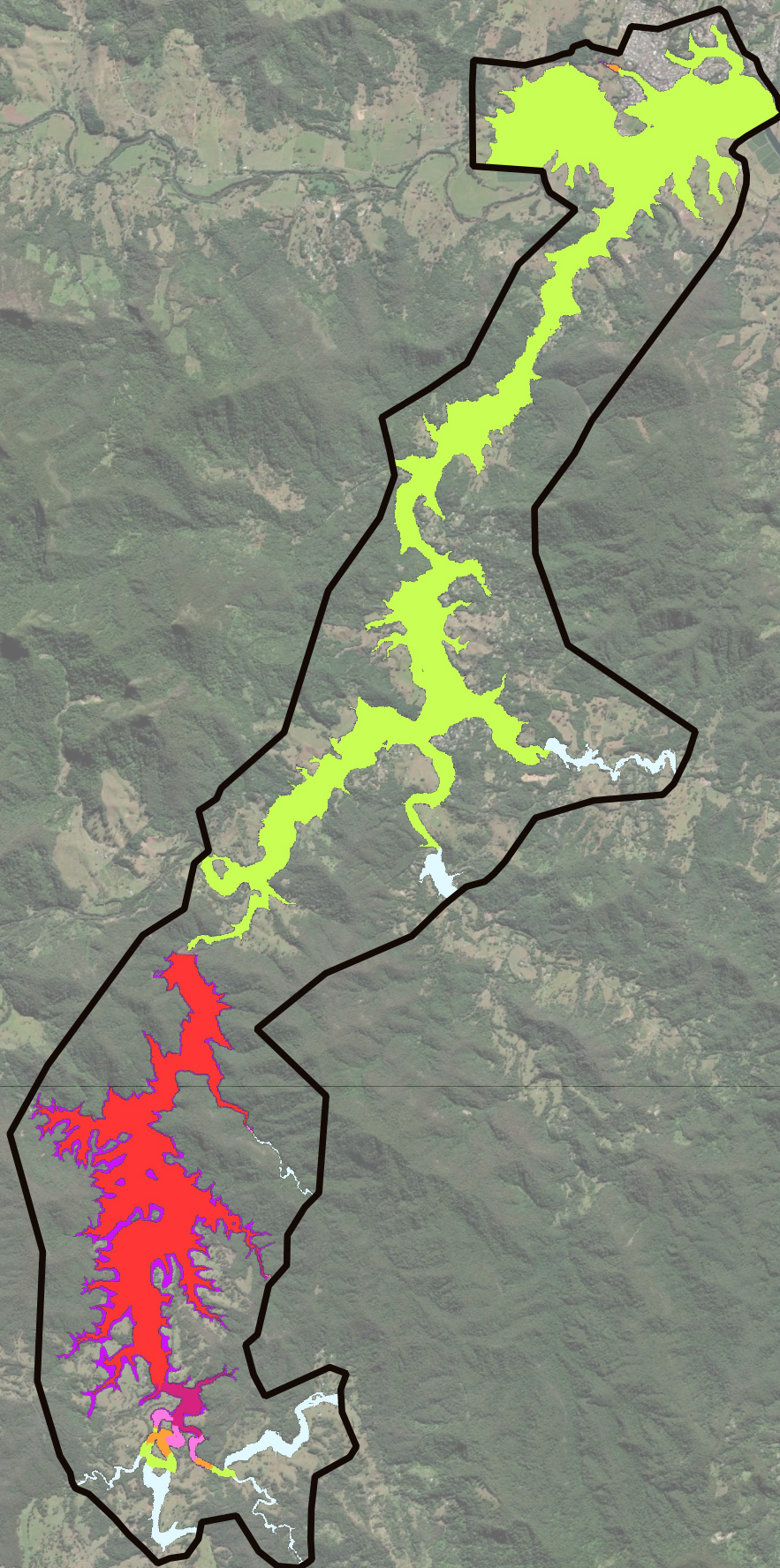
 7.5m - 10.0m

 > 10m

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Level - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.1% AEP Design Event

Figure:

D4

Rev:

0

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood level (m)

 ≤ -0.5m

 -0.50m - -0.25m

 -0.25m - -0.10m

 -0.10m - -0.01m

 ±0.01m

 0.01m - 0.50m

 0.50m - 1.0m

 1.0m - 2.5m

 2.5m - 5.0m

 5.0m - 7.5m

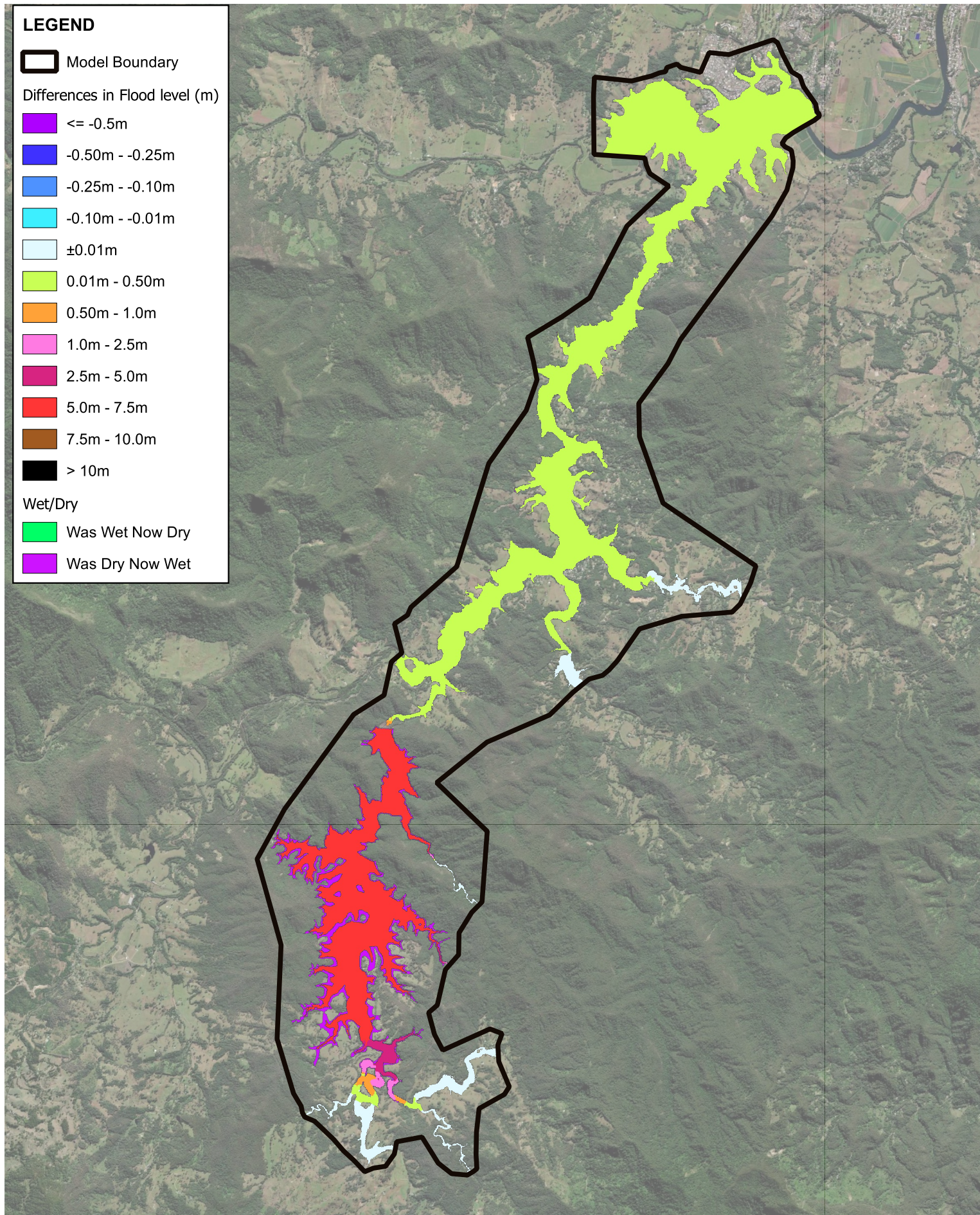
 7.5m - 10.0m

 > 10m

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Title:
Differences in Flood Level - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.05% AEP Design Event

Figure:

D5

Rev:

0

Scale at A4
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood level (m)

 ≤ -0.5m

 -0.50m - -0.25m

 -0.25m - -0.10m

 -0.10m - -0.01m

 ±0.01m

 0.01m - 0.50m

 0.50m - 1.0m

 1.0m - 2.5m

 2.5m - 5.0m

 5.0m - 7.5m

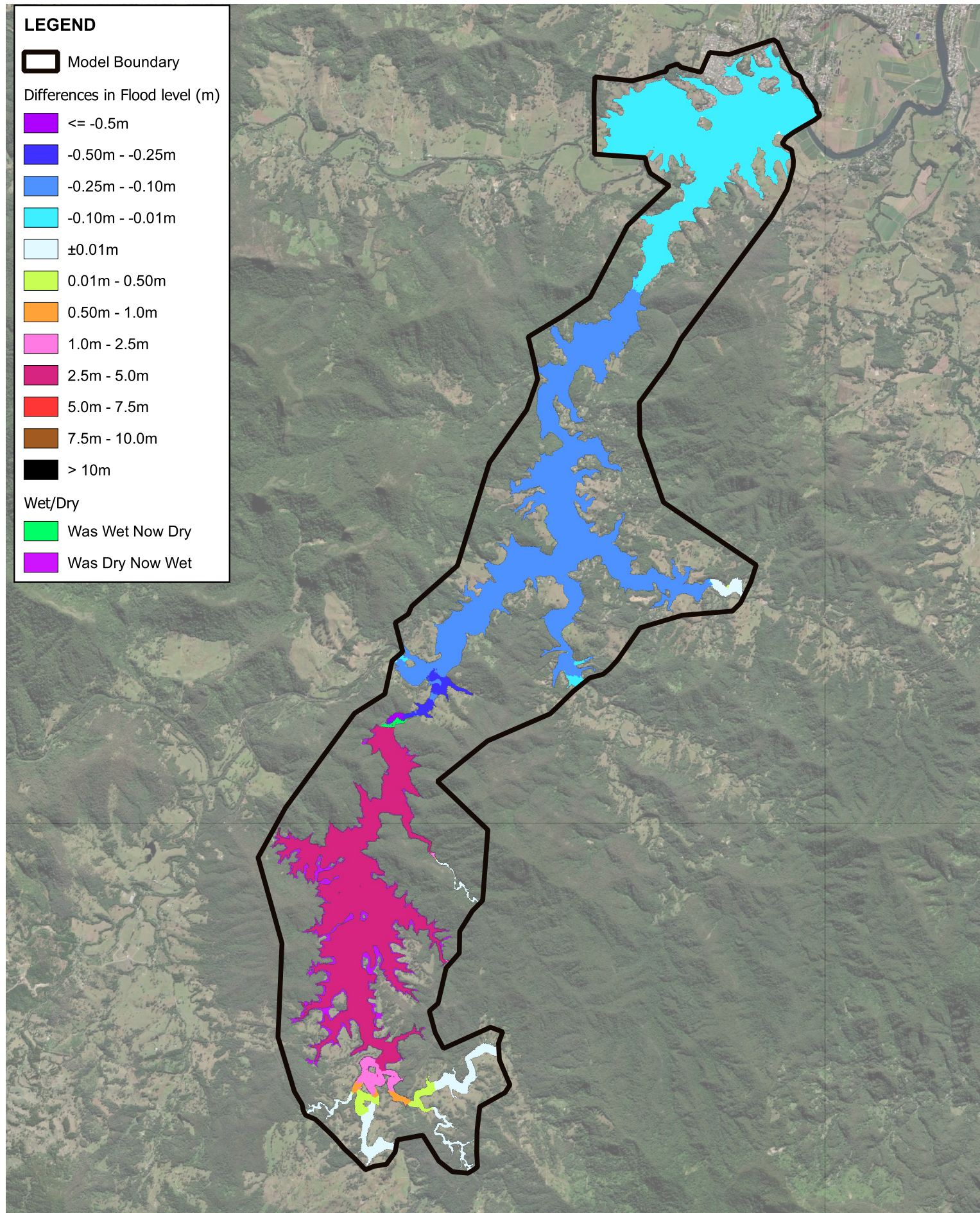
 7.5m - 10.0m

 > 10m

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Level - Proposed Case minus Existing Case (2050 SSP3-7.0) PMF Design Event

Figure: **D6**

Rev: **0**

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood Velocity (m/s)

 ≤ -0.50

 -0.50 - -0.25

 -0.25 - -0.10

 -0.10 - -0.01

 -0.01 - 0.01

 0.01 - 0.5

 0.5 - 1.0

 1.0 - 2.5

 2.5 - 5.0

 5.0 - 7.5

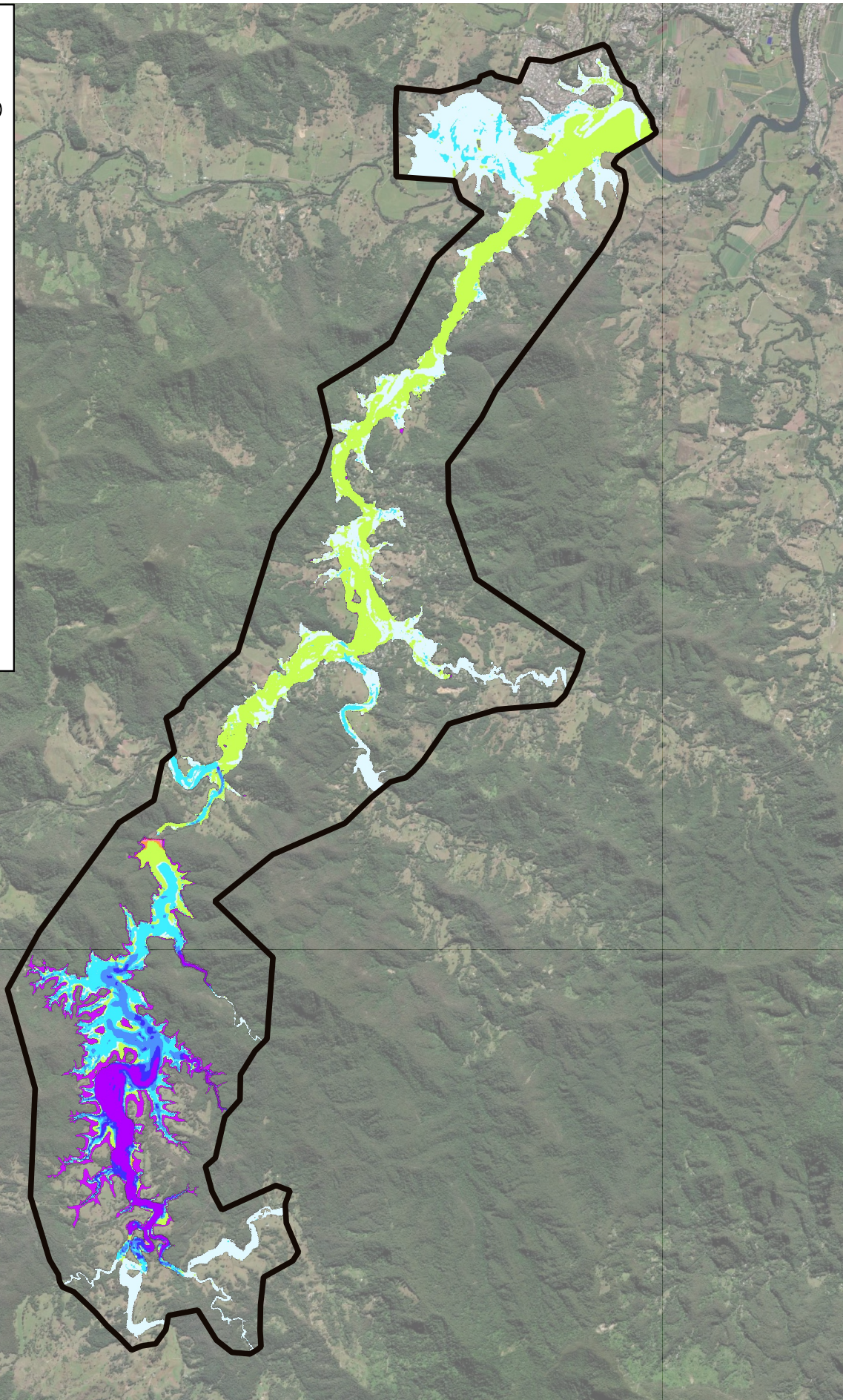
 7.5 - 10.0

 > 10

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Title: **Differences in Flood Velocity - Proposed Case minus Existing Case (2050 SSP3-7.0) 1% AEP Design Event**

Figure:

D7

Rev:

0

Scale at A4
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1:80000.00008160024

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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood Velocity (m/s)

 ≤ -0.50

 -0.50 - -0.25

 -0.25 - -0.10

 -0.10 - -0.01

 -0.01 - 0.01

 0.01 - 0.5

 0.5 - 1.0

 1.0 - 2.5

 2.5 - 5.0

 5.0 - 7.5

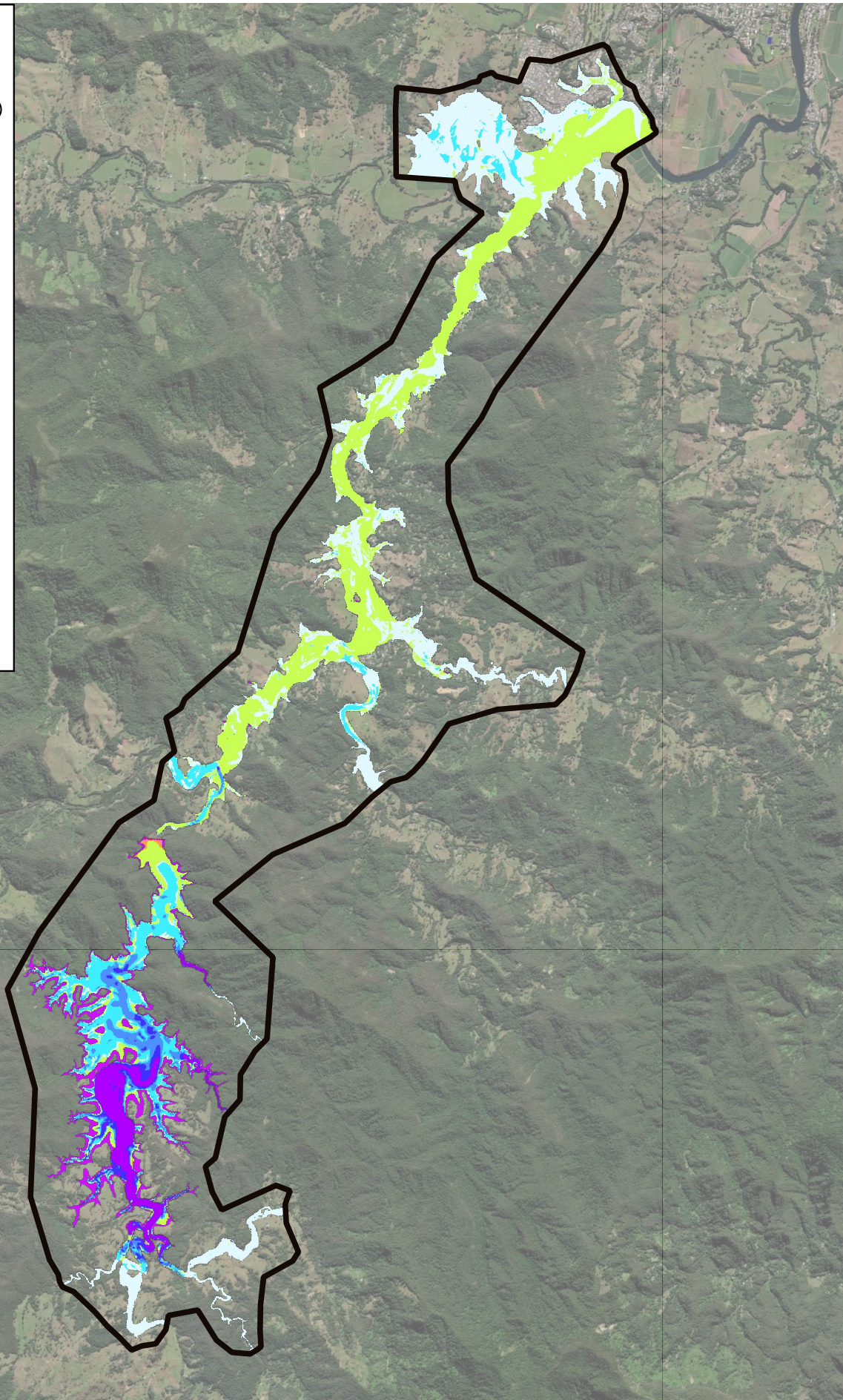
 7.5 - 10.0

 > 10

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Title: **Differences in Flood Velocity - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.5% AEP Design Event**

Figure: **D8**

Rev: **0**

Scale: at A4
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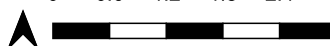
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File: Y:\Water_Resources\Projects\SEN351 - ClarrieHallDamRaisingEIS\G - GIS\Workspaces\ClarrieHall_Dam_FIGURES_REPORT_TRG_REV1.qgz

Scale: 0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood Velocity (m/s)

 ≤ -0.50

 -0.50 - -0.25

 -0.25 - -0.10

 -0.10 - -0.01

 -0.01 - 0.01

 0.01 - 0.5

 0.5 - 1.0

 1.0 - 2.5

 2.5 - 5.0

 5.0 - 7.5

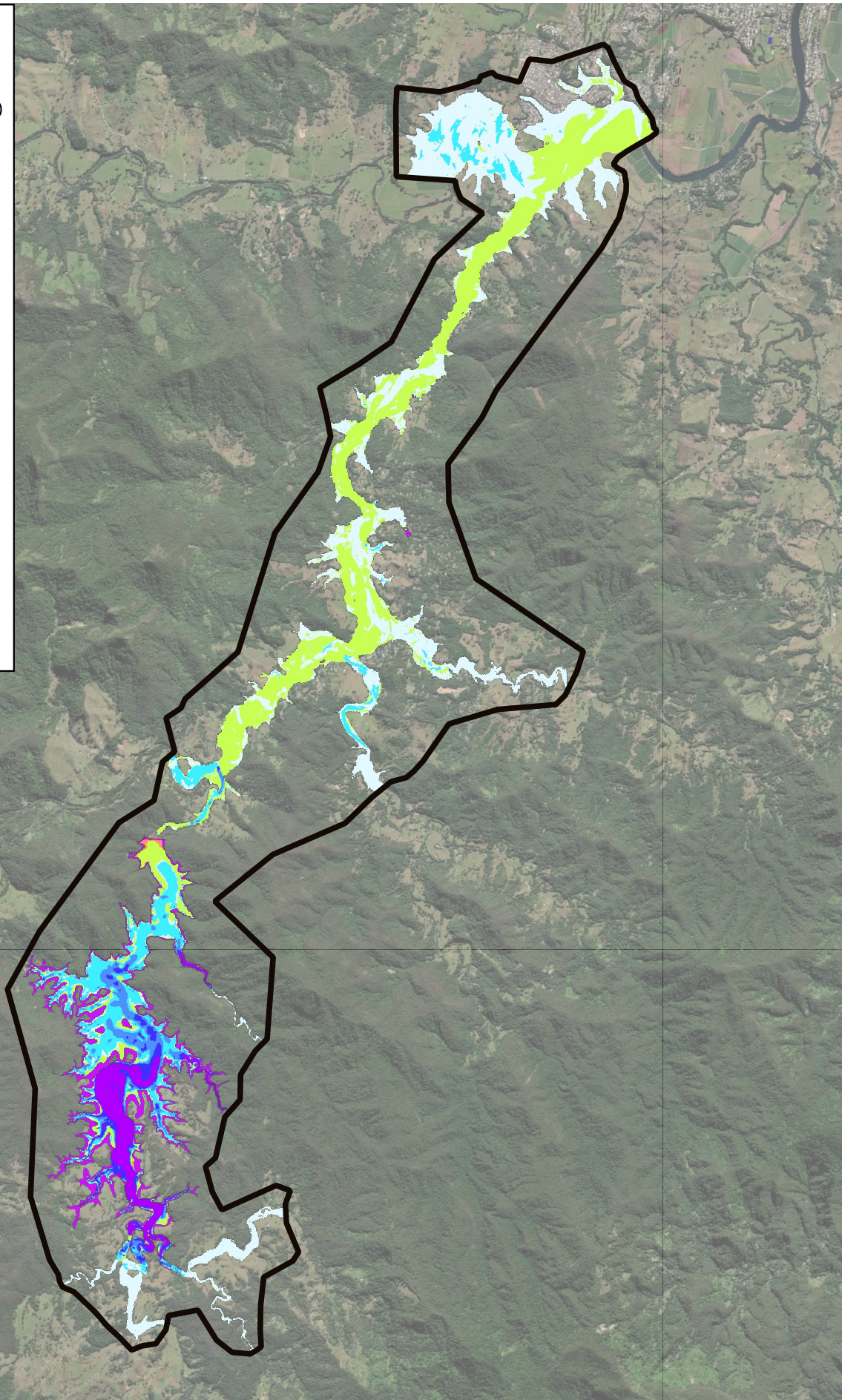
 7.5 - 10.0

 > 10

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Velocity - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure:

D9

Rev:

0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood Velocity (m/s)

 ≤ -0.50

 $-0.50 - -0.25$

 $-0.25 - -0.10$

 $-0.10 - -0.01$

 $-0.01 - 0.01$

 $0.01 - 0.5$

 $0.5 - 1.0$

 $1.0 - 2.5$

 $2.5 - 5.0$

 $5.0 - 7.5$

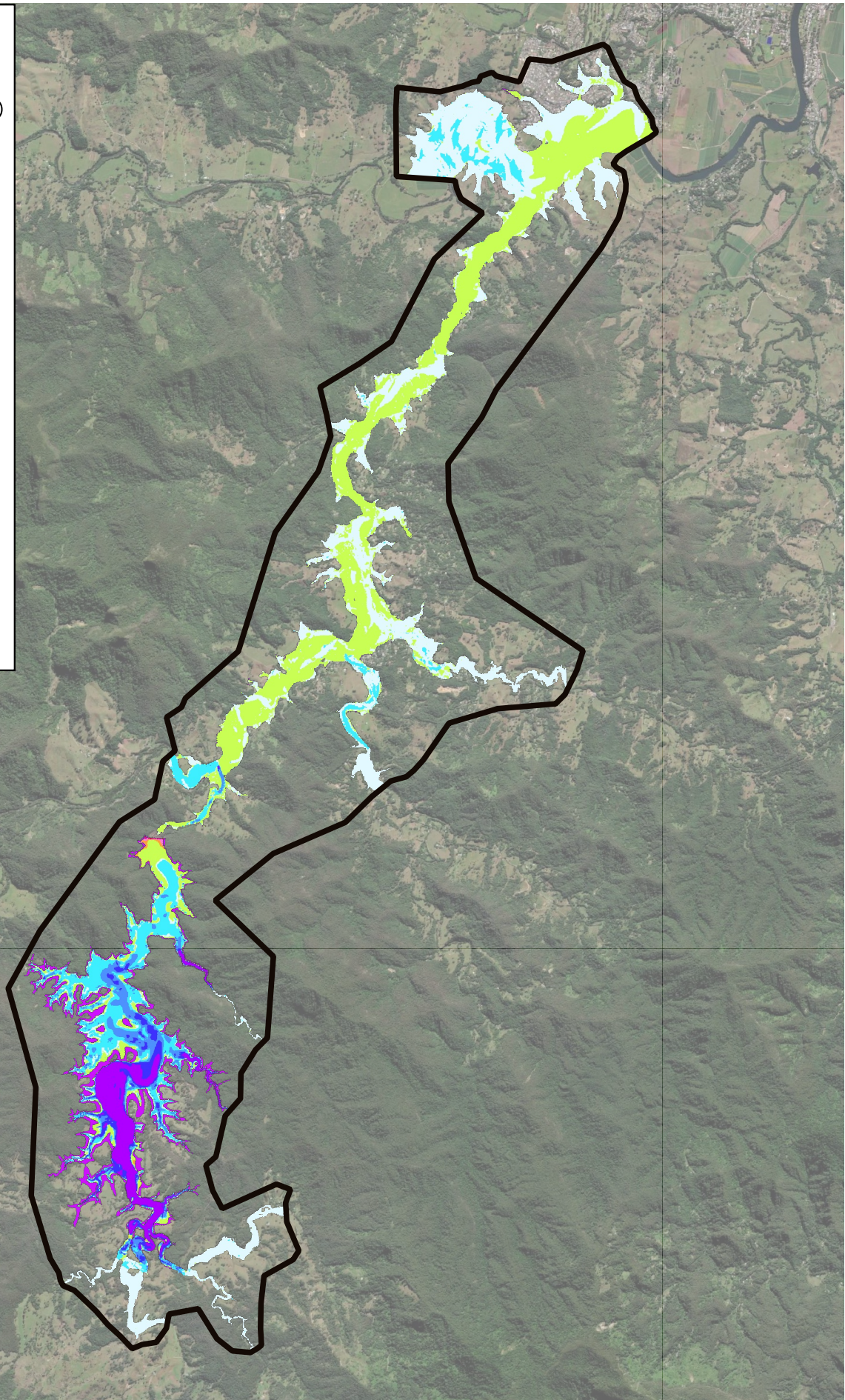
 $7.5 - 10.0$

 > 10

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Title: **Differences in Flood Velocity - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.1% AEP Design Event**

Figure:

D10

Rev:

0

Scale at A4
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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood Velocity (m/s)

 ≤ -0.50

 -0.50 - -0.25

 -0.25 - -0.10

 -0.10 - -0.01

 -0.01 - 0.01

 0.01 - 0.5

 0.5 - 1.0

 1.0 - 2.5

 2.5 - 5.0

 5.0 - 7.5

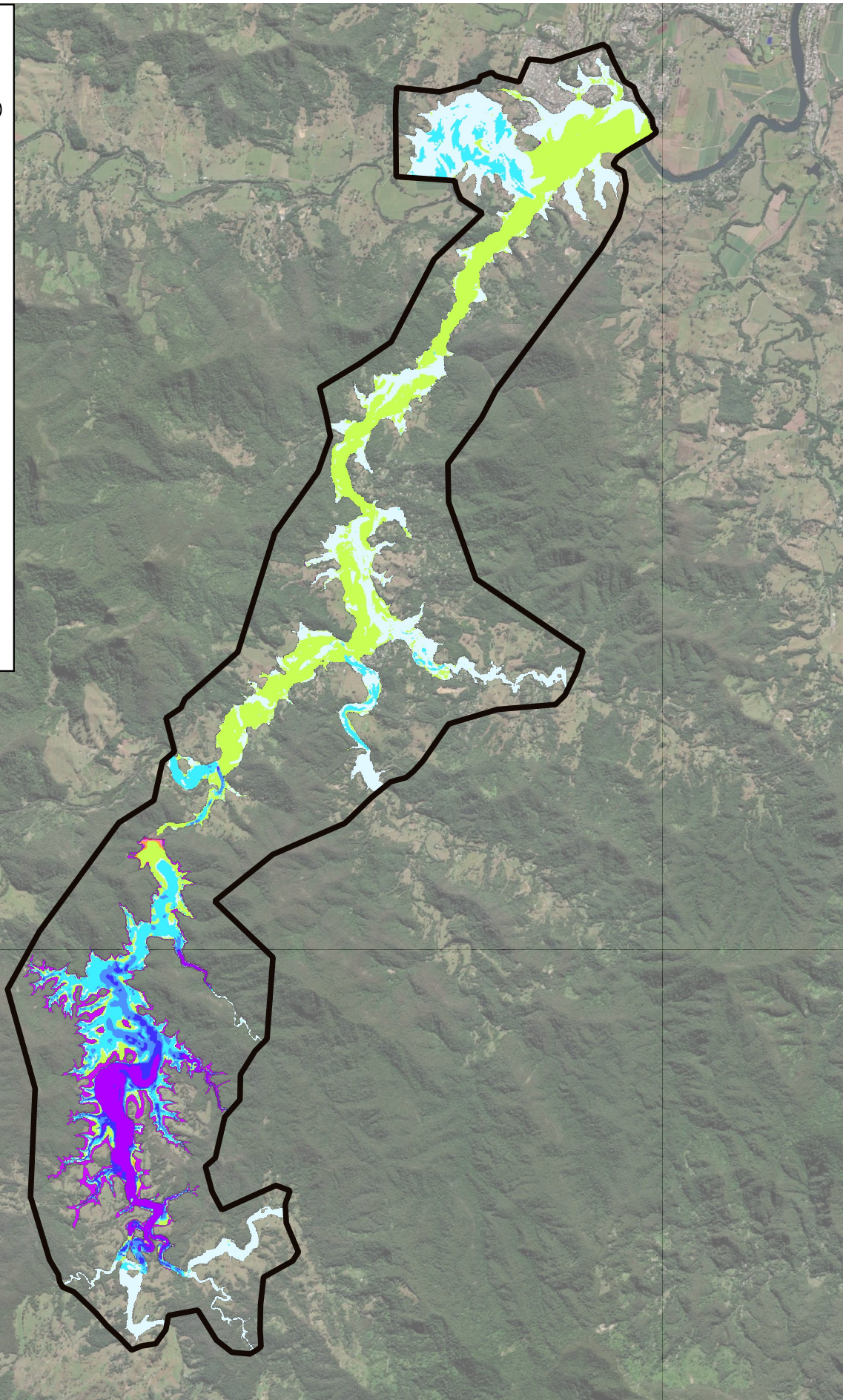
 7.5 - 10.0

 > 10

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Velocity - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.05% AEP Design Event

Figure:

D11

Rev:

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Flood Velocity (m/s)

 ≤ -0.50

 -0.50 - -0.25

 -0.25 - -0.10

 -0.10 - -0.01

 -0.01 - 0.01

 0.01 - 0.5

 0.5 - 1.0

 1.0 - 2.5

 2.5 - 5.0

 5.0 - 7.5

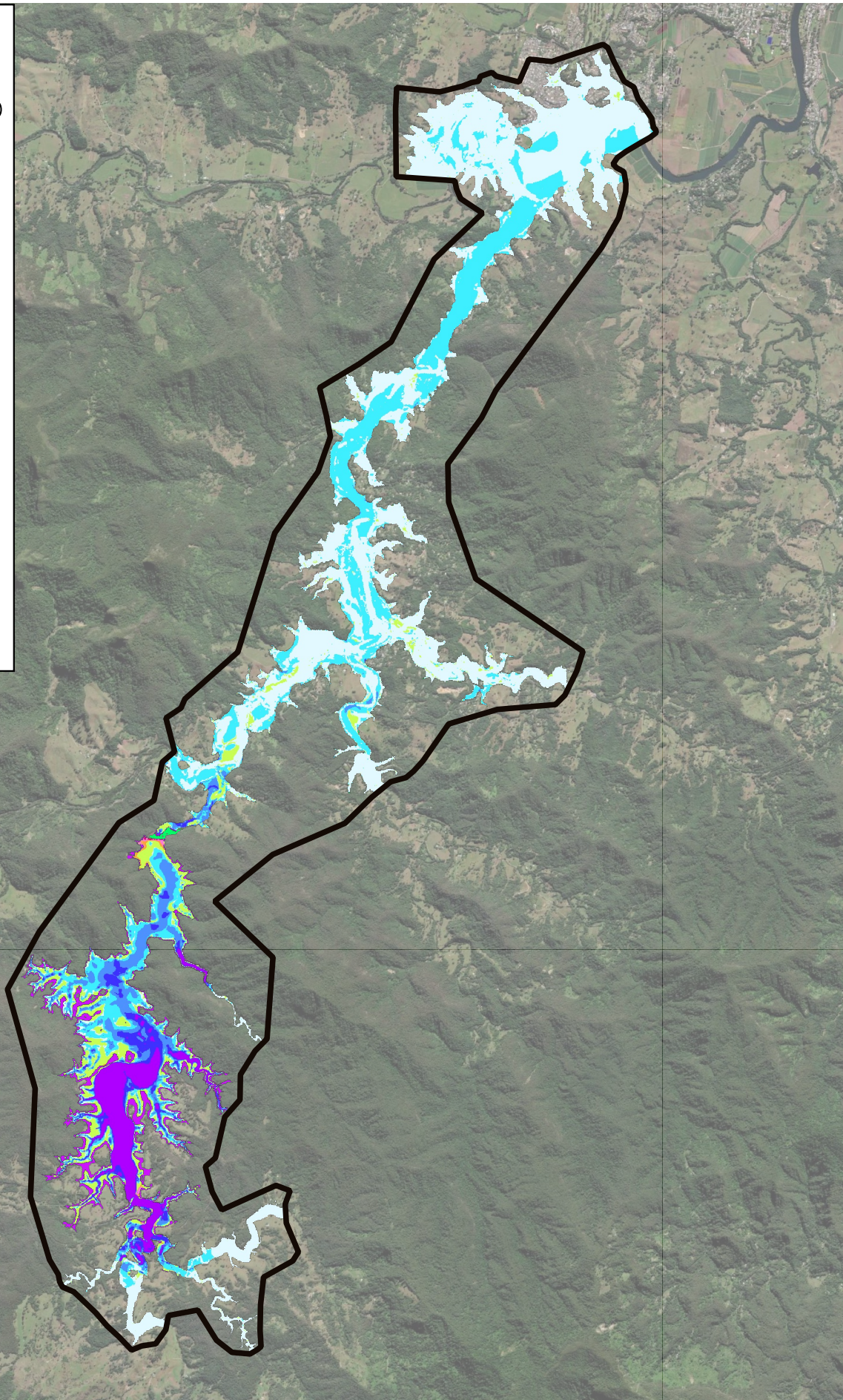
 7.5 - 10.0

 > 10

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Title: **Differences in Flood Velocity - Proposed Case minus Existing Case (2050 SSP3-7.0) PMF Design Event**

Figure:

D12

Rev:

0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



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LEGEND

 Model Boundary

Differences in Hazard Classification

 4 Classifications lower

 3 Classifications lower

 2 Classifications lower

 1 Classification lower

 No Difference

 1 Classification higher

 2 Classifications higher

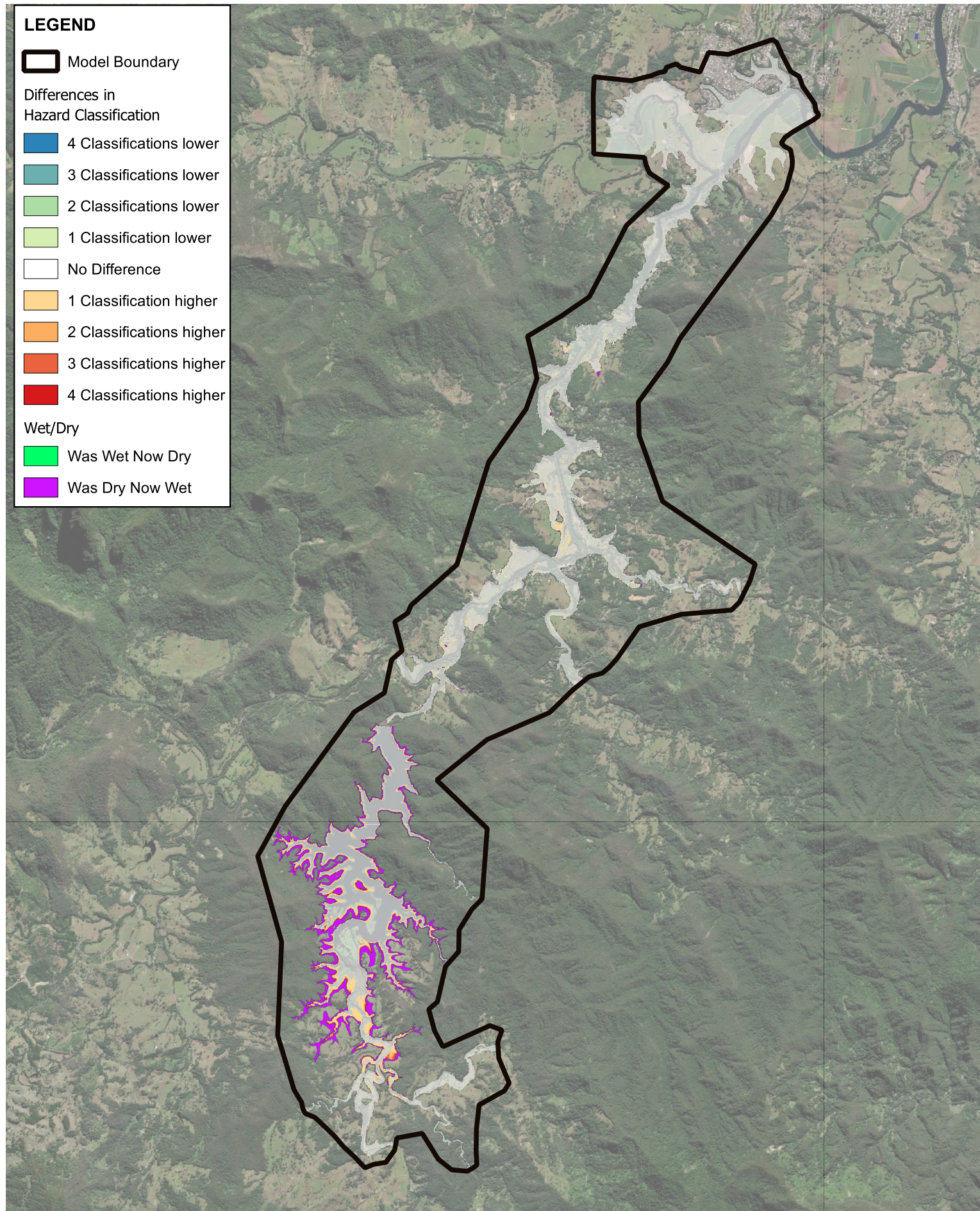
 3 Classifications higher

 4 Classifications higher

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Hazard Classification - Proposed Case minus Existing Case (2050 SSP3-7.0) 1% AEP Design Event

Figure:

D13

Rev:

0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Hazard Classification

 4 Classifications lower

 3 Classifications lower

 2 Classifications lower

 1 Classification lower

 No Difference

 1 Classification higher

 2 Classifications higher

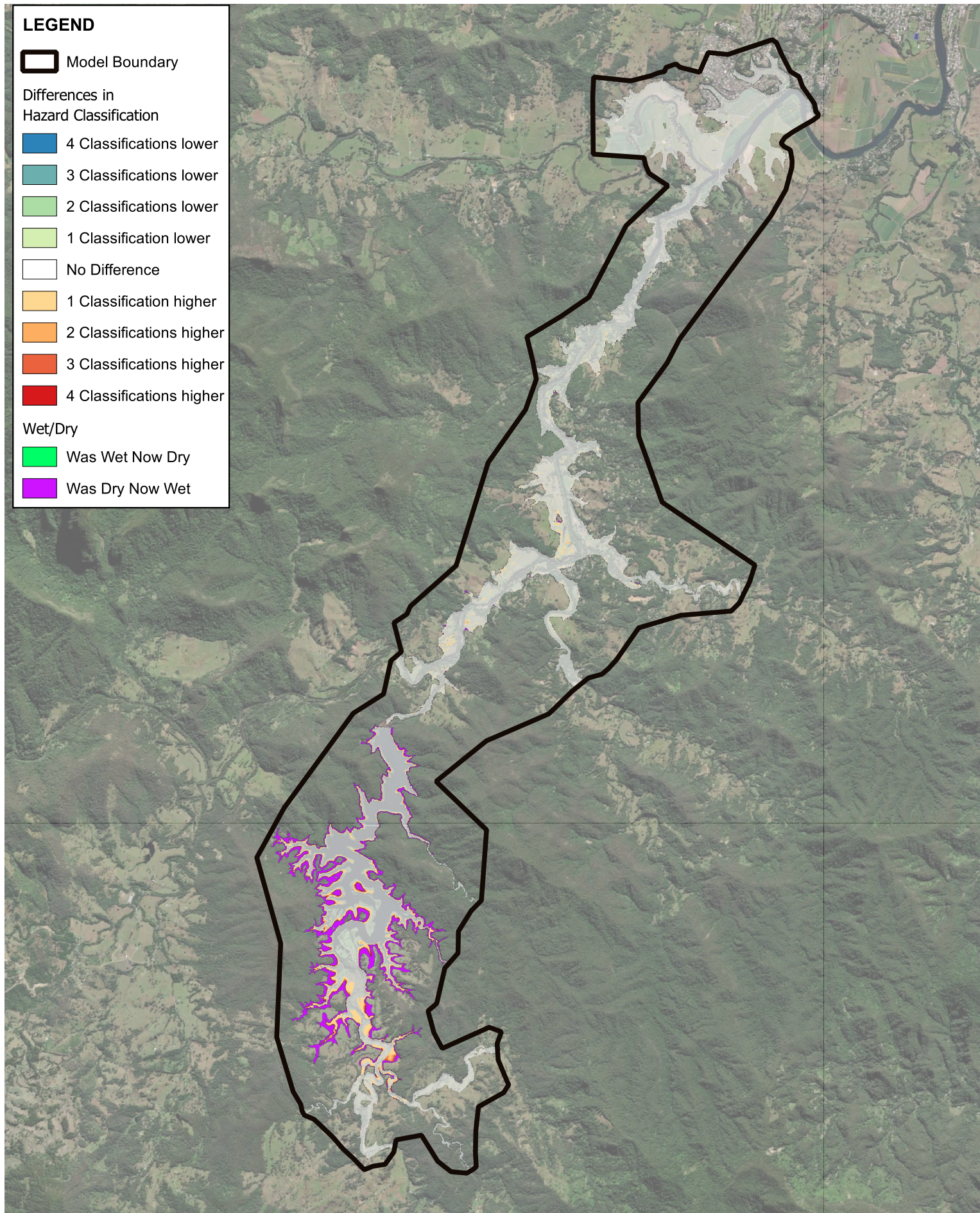
 3 Classifications higher

 4 Classifications higher

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Hazard Classification - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.5% AEP Design Event

Figure:

D14

Rev:

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Hazard Classification

 4 Classifications lower

 3 Classifications lower

 2 Classifications lower

 1 Classification lower

 No Difference

 1 Classification higher

 2 Classifications higher

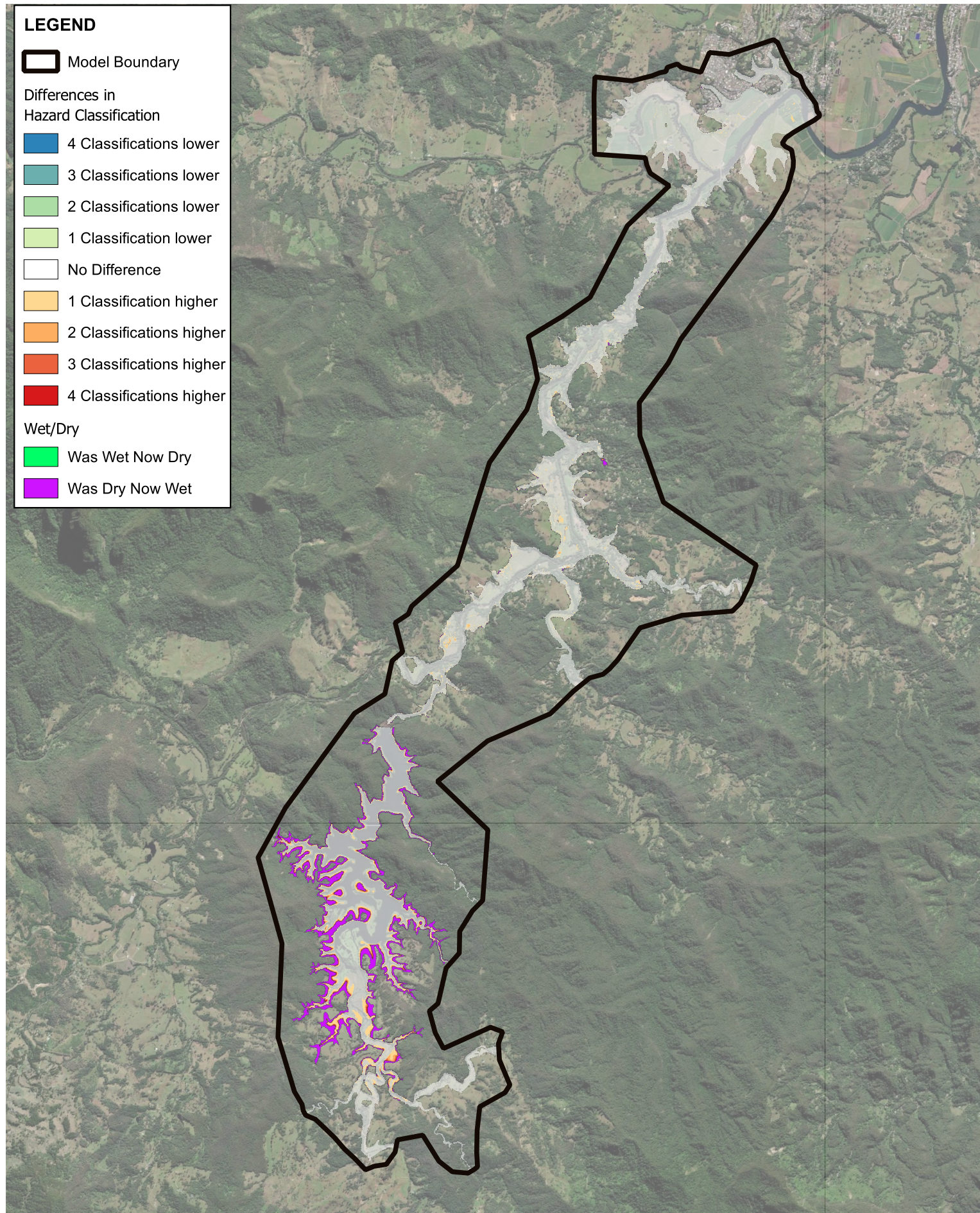
 3 Classifications higher

 4 Classifications higher

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Hazard Classification - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.2% AEP Design Event

Figure:

D15

Rev:

0

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Scale:

0 0.6 1.2 1.8 2.4 3 km



1:80,000



LEGEND

 Model Boundary

Differences in Hazard Classification

 4 Classifications lower

 3 Classifications lower

 2 Classifications lower

 1 Classification lower

 No Difference

 1 Classification higher

 2 Classifications higher

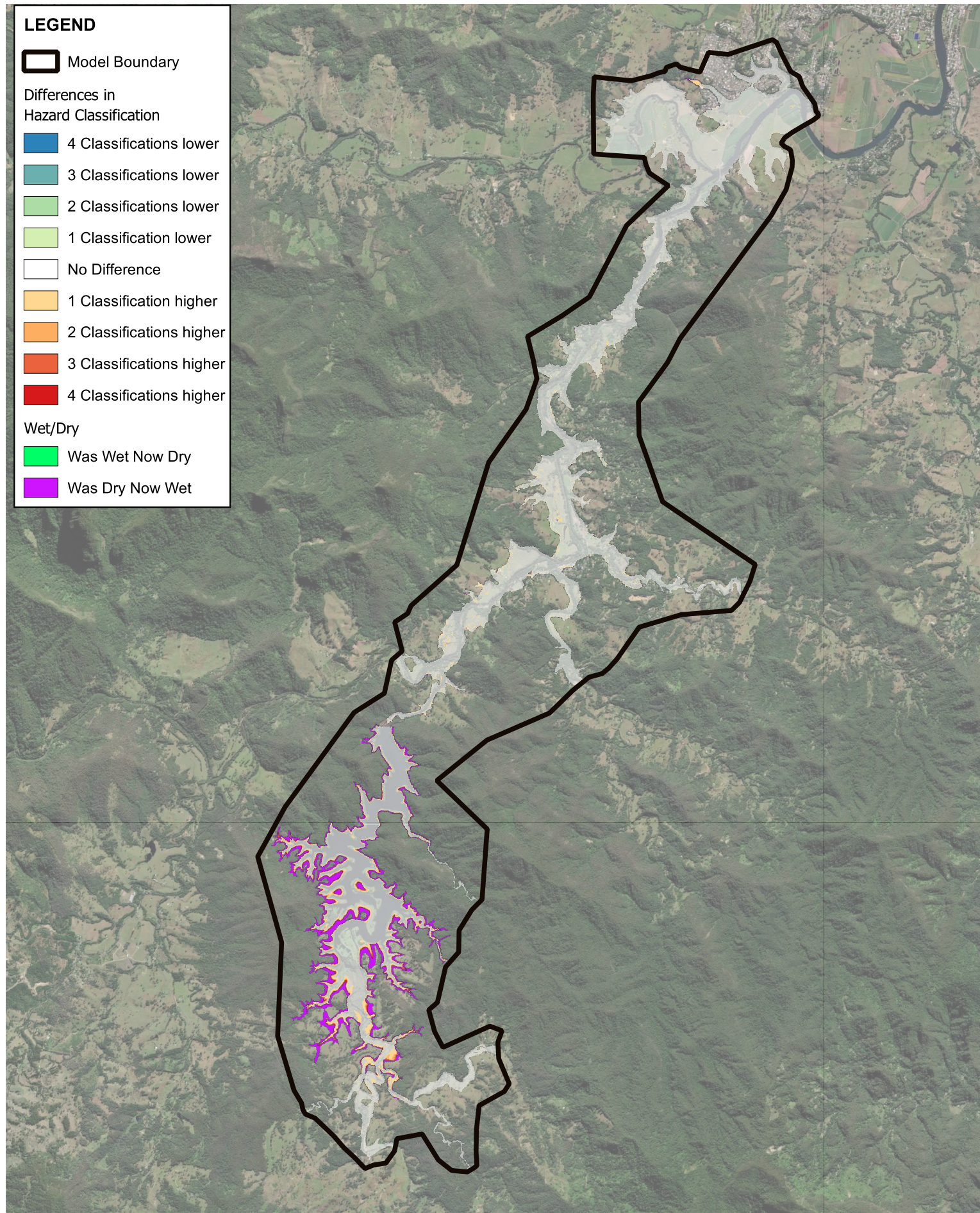
 3 Classifications higher

 4 Classifications higher

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Hazard Classification - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.1% AEP Design Event

Figure:

D16

Rev:

0

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0 0.6 1.2 1.8 2.4 3 km



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LEGEND

 Model Boundary

Differences in Hazard Classification

 4 Classifications lower

 3 Classifications lower

 2 Classifications lower

 1 Classification lower

 No Difference

 1 Classification higher

 2 Classifications higher

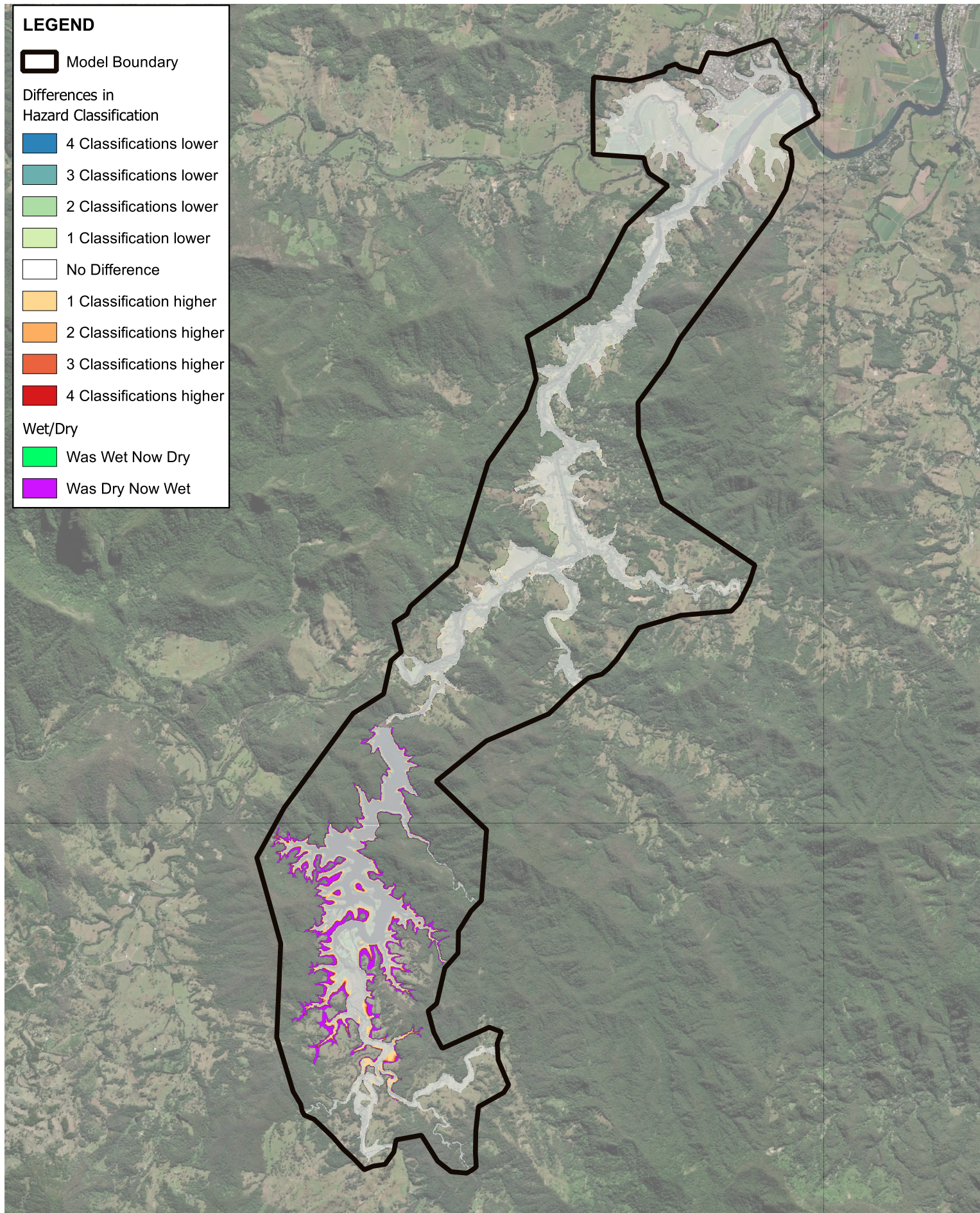
 3 Classifications higher

 4 Classifications higher

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Hazard Classification - Proposed Case minus Existing Case (2050 SSP3-7.0) 0.05% AEP Design

Event

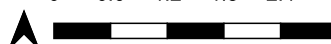
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Scale: 0 0.6 1.2 1.8 2.4 3 km



1:80,000

Figure:

D17

Rev:

0



LEGEND

 Model Boundary

Differences in Hazard Classification

 4 Classifications lower

 3 Classifications lower

 2 Classifications lower

 1 Classification lower

 No Difference

 1 Classification higher

 2 Classifications higher

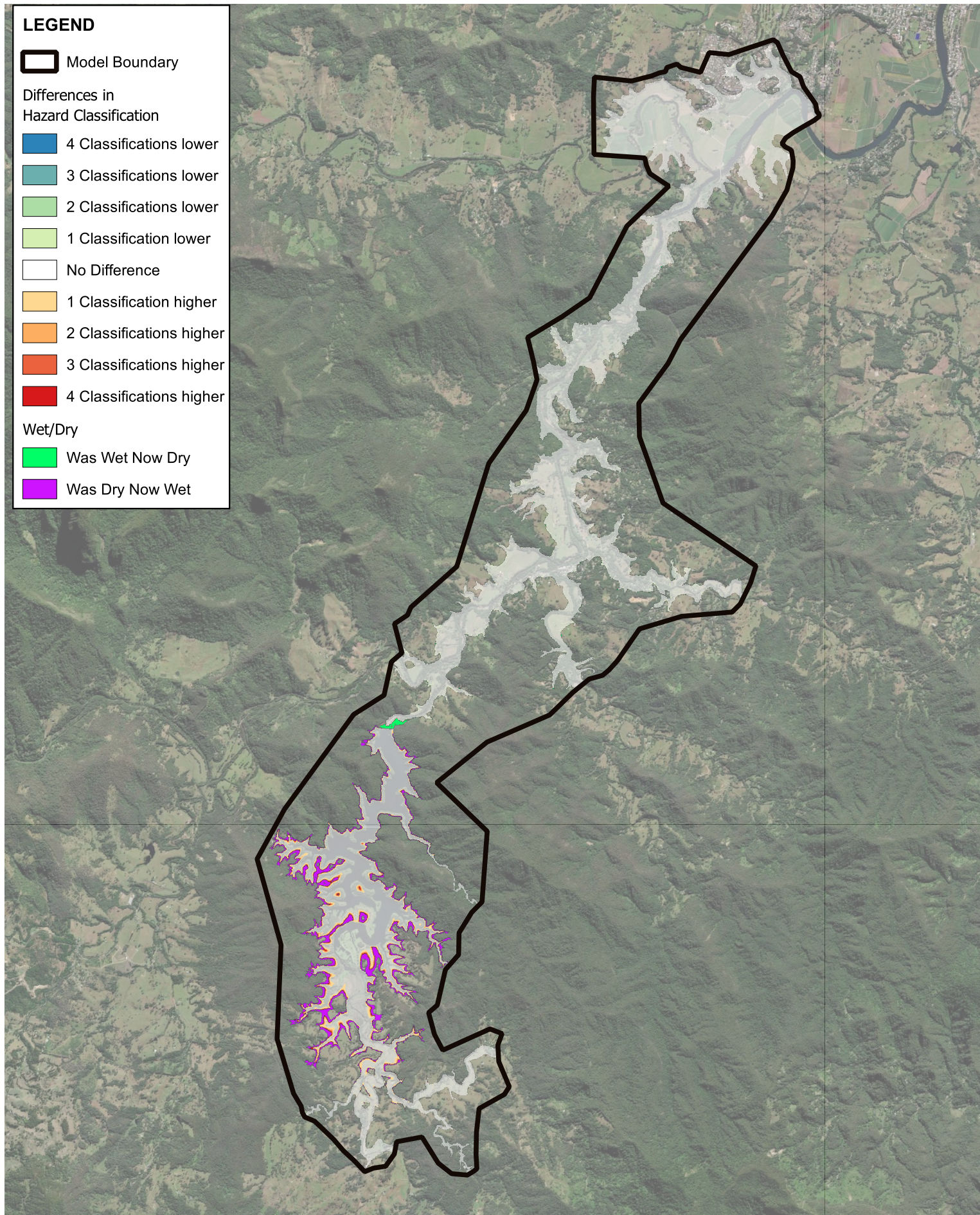
 3 Classifications higher

 4 Classifications higher

Wet/Dry

 Was Wet Now Dry

 Was Dry Now Wet



Differences in Flood Hazard Classification - Proposed Case minus Existing Case (2050 SSP3-7.0) PMF Design Event

Figure:

D18

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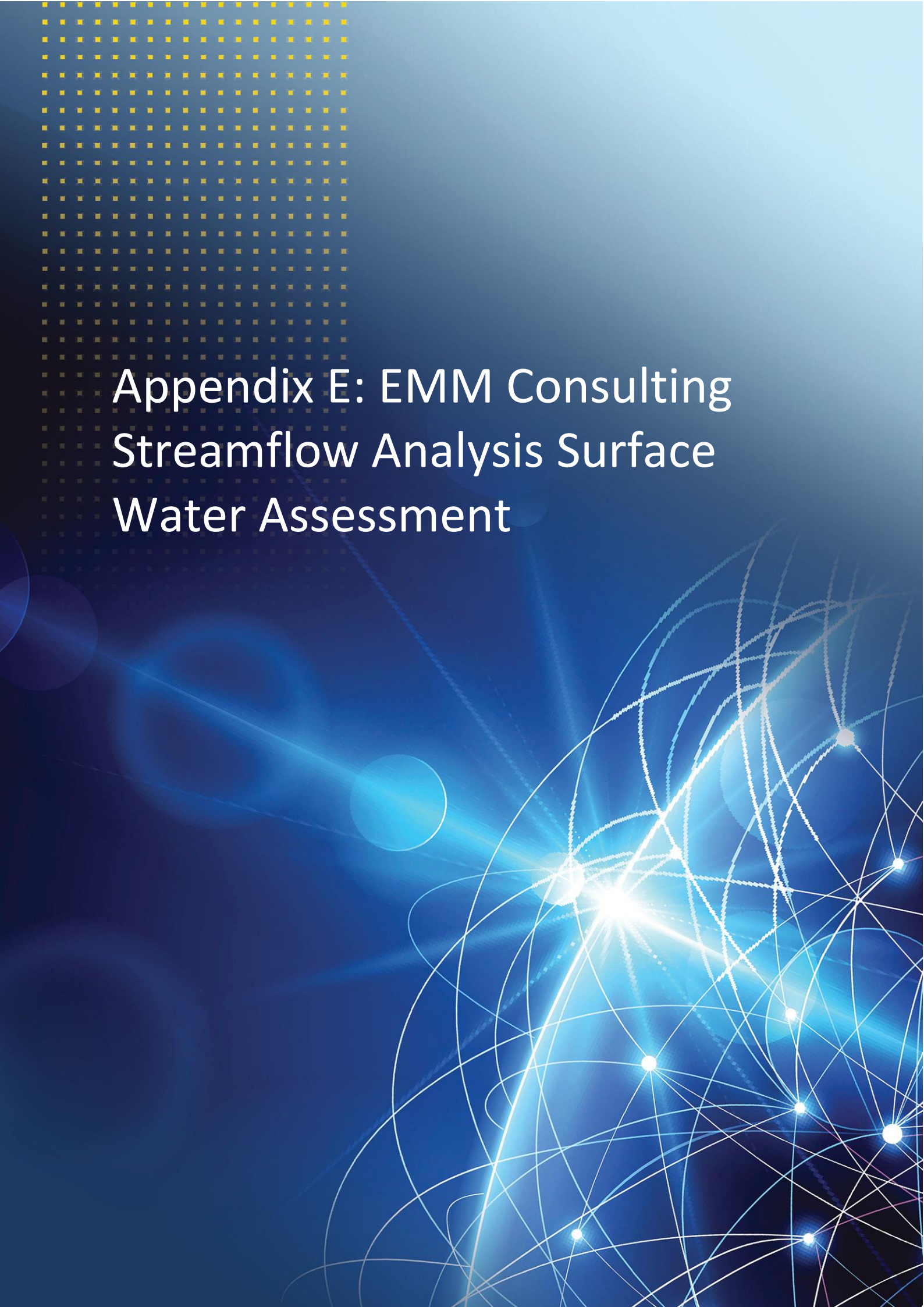
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Appendix E: EMM Consulting Streamflow Analysis Surface Water Assessment

Streamflow analysis

Surface water assessment

Prepared for Tweed Shire Council

November 2025

Streamflow analysis

Surface water assessment

Tweed Shire Council

E230039 Annexure A

November 2025

Version	Date	Prepared by	Reviewed by	Comments
1	8 August 2024	A Jones-Gill	J Muller N Bartho	Issue for publication
2	6 November 2025	A Jones-Gill	J Muller	With revised spillway (80 m)

Level 4 74 Pirie Street
Adelaide SA 5000
ABN: 28 141 736 558

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Executive Summary

ES1 Context

This document describes the result of streamflow regime modelling undertaken for the Clarrie Hall Dam EIS. Version 1 of the document was prepared as an annexure to the EIS Surface Water Assessment, and submitted as part of the EIS in 2024.

ES2 Revisions

This Version 2 was prepared during the Response to Submissions phase of the project, and includes the following changes:

- The proposed spillway curve has been revised, allowing it to pass higher flows (Figure ES1)

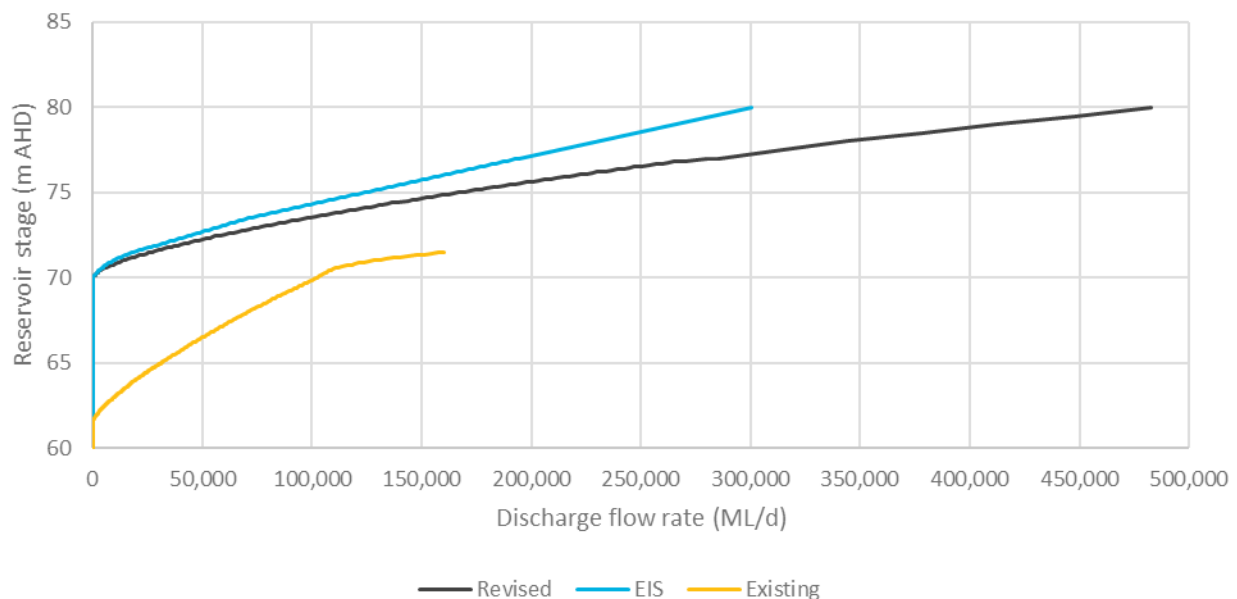


Figure ES1 Spillway curves

ES3 Effects of spillway revision

Previously, the flow regime modelling had concluded that the spillway on the raised dam would partially restrict outflows such that peak flows downstream during floods would be lower, and the recession of floods would be drawn out a little longer, due to water being held within the reservoir.

The latest modelling shows that the wider spillway will in general release flood waters as quickly the existing spillway such that future peak flow and duration of high flow events will be very similar to current. A comparison between the EIS submission and the revised modelling for the wider spillway is provided below for the historical climate period 1976. The previous plot presents the effects of the project as reduced peaks and extended recession as discussed, while the modelling of the revised spillway show very little difference between the current and future hydrographs.

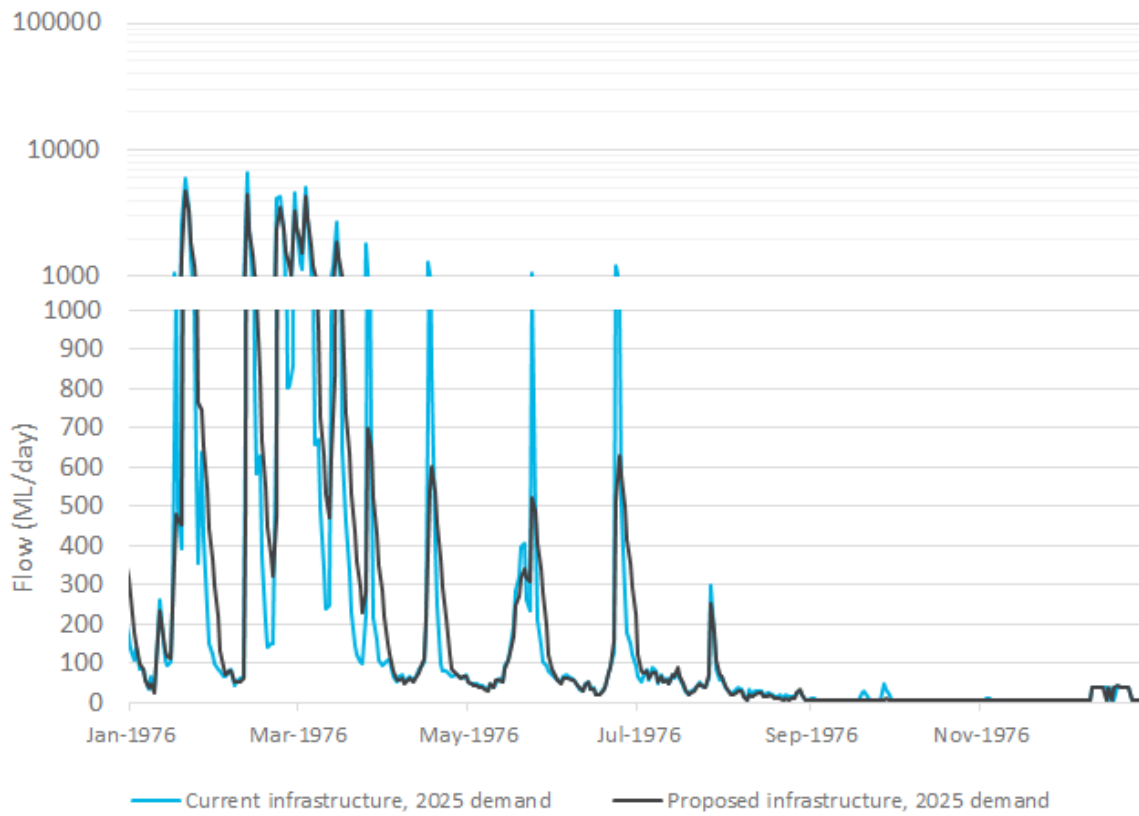


Figure ES2 EIS model results: Modelled flow in Doon Doon Creek

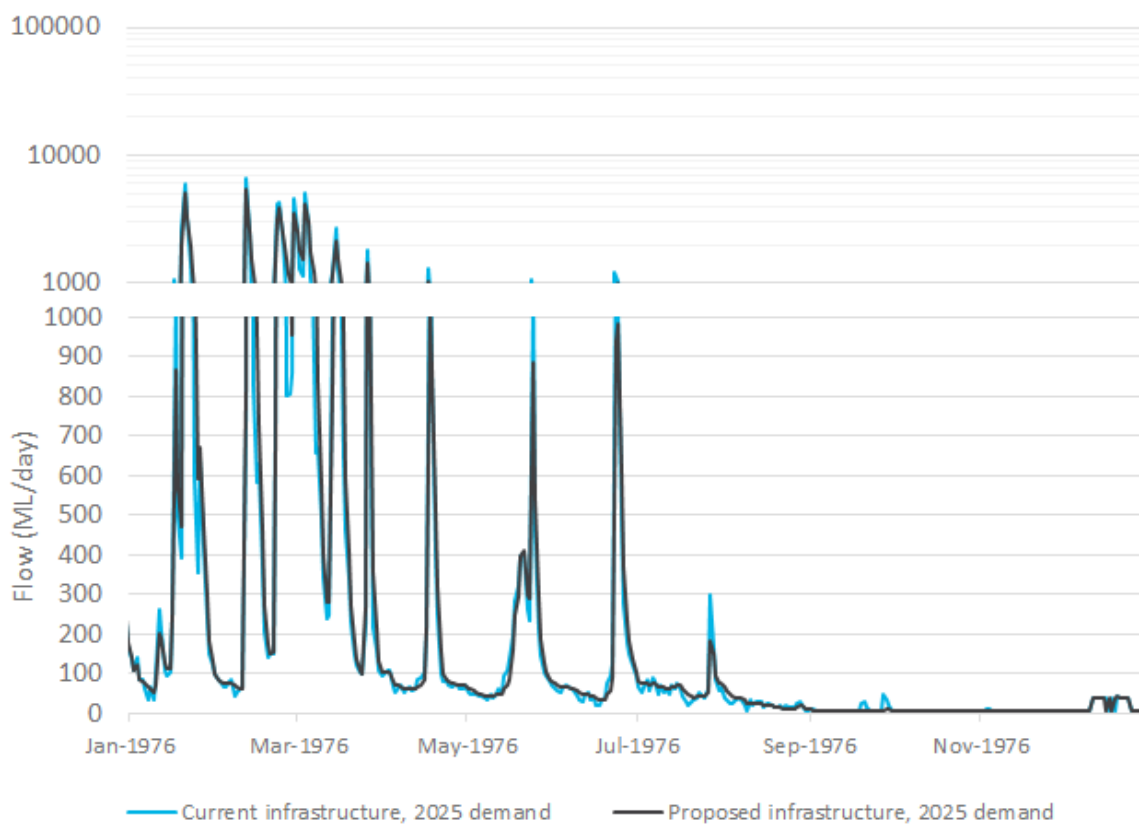


Figure ES3 Revised spillway: Modelled flow in Doon Doon Creek

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Glossary

Key terminology is briefly defined as follows to assist in interpretation of this technical annexure.

Allocation	
Water Allocation	The volumetric quantity of water that can actually be taken during any year, consequent to Water Allocation Announcement(s).
Allocation Announcement	The basis upon which Water Allocation is calculated from time to time. It may take the form of an Initial Announcement at the beginning of the Water Year or a Supplementary Announcement during the Water Year. It is expressed as a percentage of Entitlement.
d/s	Downstream.
Entitlement	The volumetric quantity of water specified on the licence as being the maximum that can be taken during any year, subject to Allocation Announcement(s).
Flow regime	A description of the quantity and timing of streamflows, including the seasonal frequency of events such as no flow and flood flows.
Historical	In the context of this report, 'historical' refers to: - records of observed climate - the SILO interpolation of observed climate records - results of model simulations which used either of the above climate data sources.
IPCC	Intergovernmental Panel on Climate Change
Regulated river	A river for which a licensed entitlement regime exists with centralised allocation, and from which orders may be placed for upstream release of a licensed allocation. A necessary, but not sufficient, condition for a river to be regulated is that it is located downstream of a surface water storage.
Source (model)	eWater Source. Australia's National Hydrological Modelling Platform (NHMP). A software model platform designed to simulate all aspects of water resource systems to support integrated planning, operations and governance from urban, catchment to river basin scales including human and ecological influences.
TWS	Town water supply.
u/s	Upstream.
WSP	Water Sharing Plan. A statutory document that establishes the rules for sharing water between the environment and water users, and between competing water users. The relevant WSP for the Clarrie Hall Dam raising project is the 'Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023'. Note that this plan commenced on 1 July 2023 and replaces the previous plan: 'Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources Order 2010'.
WRP	Water Resource Plan.

1 Introduction

1.1 Project description

Tweed Shire Council (Council) has resolved to undertake the planning and land acquisitions for the Clarrie Hall Dam Raising (CHDR) (the Proposal) as the preferred option to secure water supply for the Tweed Shire until approximately 2065. The Proposal is to raise the wall of Clarrie Hall Dam by 8.5 metres to a height of 70 metres Australian Height Datum (AHD RL70), thereby increasing the capacity of the dam from 16,720 megalitres (ML) to 42,300 ML for the purpose of water supply augmentation.

This streamflow analysis report is a technical annexure to the Surface Water Assessment and outlines the results of the river system modelling that was undertaken to inform the Environmental Impact Statement (EIS) for the Proposal. Modelling was carried out by EMM utilising the existing NSW Department of Planning and Environment – Water (DPE-Water) eWater Source model of the Tweed River System.

1.2 Revised spillway

Following submission of the EIS, DPHI requested additional information regarding:

- the (larger) dimensions of a spillway which would safely pass floods in 2050, acknowledging that climate change is expected to increase rainfall intensity in the Tweed River catchment
- the hydrological effects of constructing the wider spillway

The spillway dimensions required were determined by others. The spillway discharge curve for the revised spillway is illustrated in Figure 1.1

This version of this report contains hydrology information describing the effects of constructing the (larger) revised spillway.

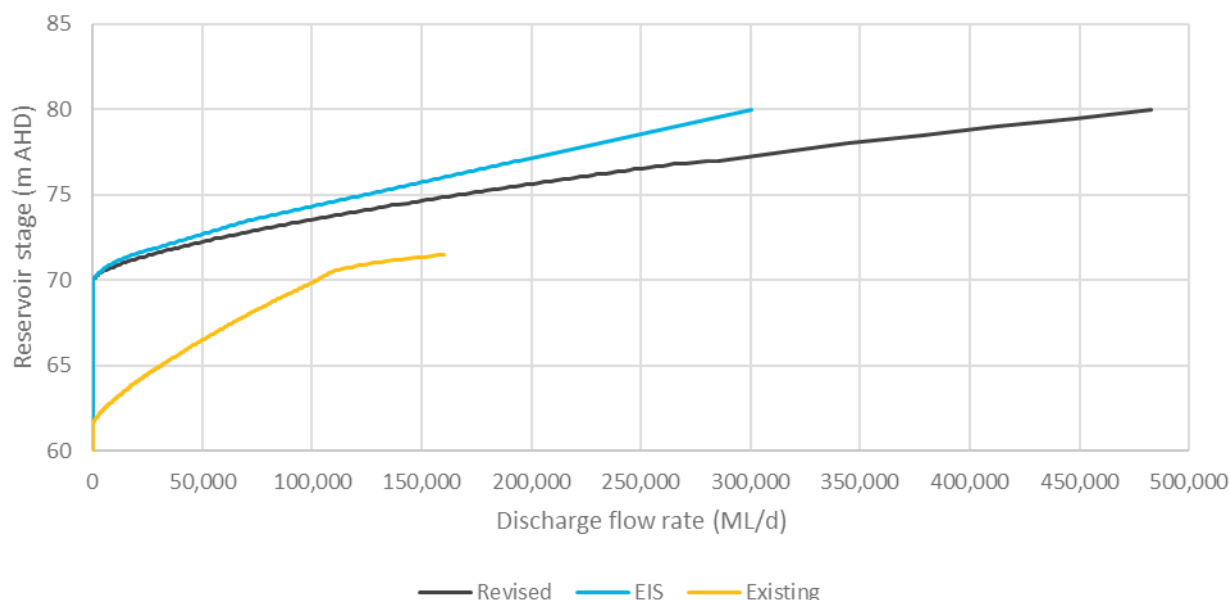


Figure 1.1 Spillway curves

1.3 Project location

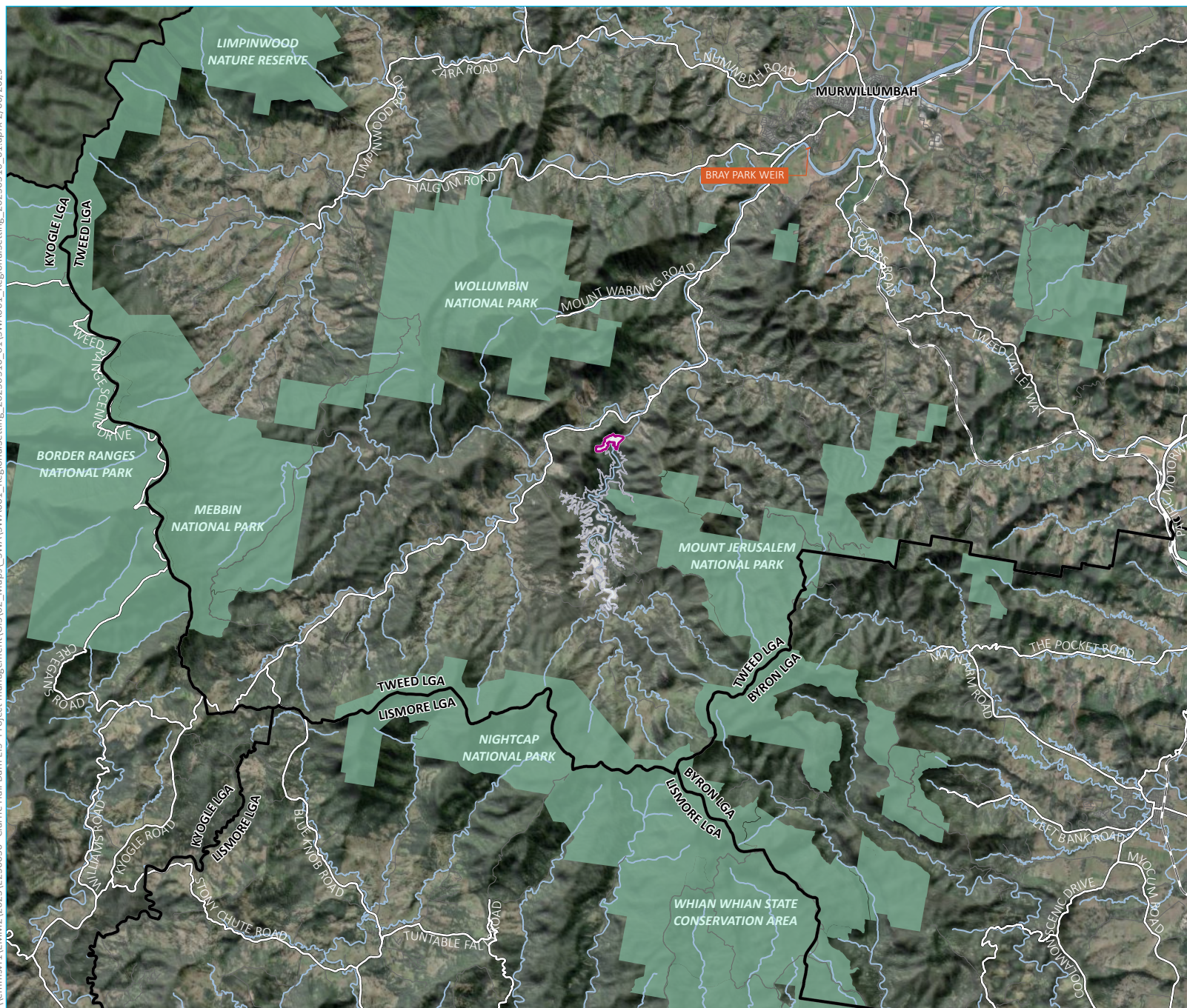
Clarrie Hall Dam is located on Doon Doon Creek in the small rural locality of Doon Doon, approximately 15 km south-west of Murwillumbah in the Far North Coast region of NSW. Doon Doon Creek is a tributary of the Tweed River, located within the Tweed Shire Local Government Area (LGA). The Tweed River provides water for irrigation and is the primary source of water supply for the Tweed Shire LGA. Clarrie Hall Dam is operated by Council to provide storage, and during drier months water is released from the dam to augment flows in the Tweed River.

The Tweed district water supply is a run of the river supply augmented by releases from Clarrie Hall Dam. Bray Park Weir, located 5 km upstream of Murwillumbah, is the point of abstraction for the district water supply and effectively acts as a tidal barrage. By raising the upstream water level, the weir maintains a pool in the river supplied by the combined flow of the Tweed and Oxley rivers. Raw water is extracted for public water supply from the pool upstream of the weir, and during low-flow periods releases from Clarrie Hall Dam are used to top-up the weir pool. Tweed Shire Council also maintain small water supply networks located at Uki and Tyalgum.

The Tweed River has a total catchment area of approximately 1,326 square kilometres (km²) and drains the majority of the Tweed Shire LGA (1,340 km²). The Tweed Shire LGA has a population approaching 100,000 people and borders the NSW shires of Byron, Lismore and Kyogle. Murwillumbah is a town situated in the middle of the Tweed River catchment, with a population of around 9,500. The major urban area of Tweed Heads surrounds the Tweed River estuary and is home to around half of the Shire population.

The Tweed River catchment is bounded by the McPherson Range to the north on the NSW-Queensland border, the Nightcap and Burringbar Ranges to the south and south-east, and the Tweed Range to the west. These elevated areas form the southern extent of the Scenic Rim of the Great Dividing Range and parts of these areas are designated as national parks and world heritage areas. The mountains and ranges of the Tweed Valley are remnants of the Tweed Volcano, forming a large erosion caldera that encircles the volcanic plug of Mount Warning. The regional setting of the Proposal is shown in Figure 1.2 and Figure 1.3 shows the major waterways and relevant streamflow gauges in the vicinity of the Proposal.

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Source: EMM (2023); ABS (2021); DCSSS (2023); ESRI (2023); GA (2009)



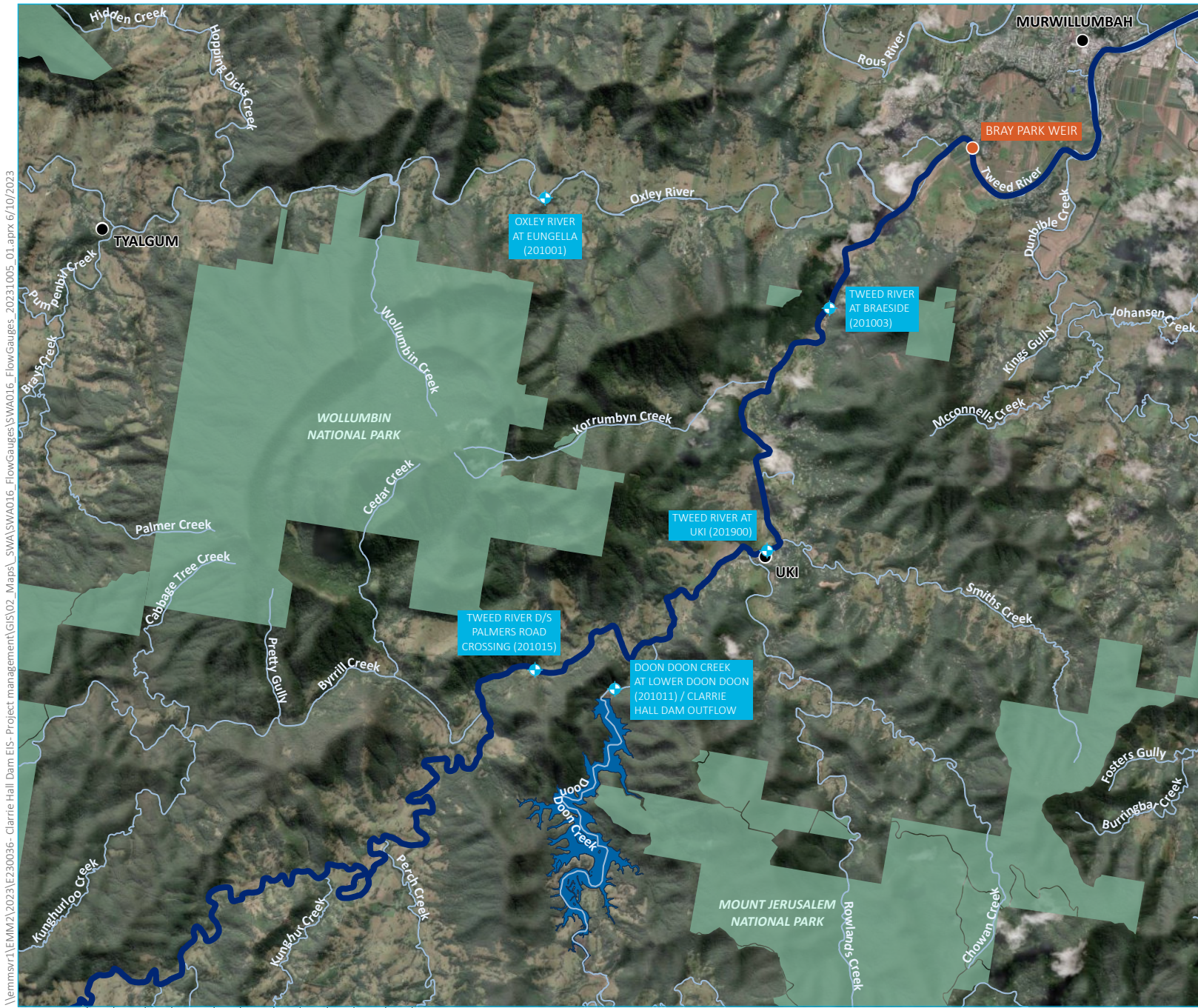
- KEY**
- Construction disturbance footprint
 - Development site
 - Bray Park weir
 - Rail line
 - Major road
 - Minor road
 - Named watercourse
 - Named waterbody
 - NPWS reserve
 - Local government area
- INSET KEY**
- NPWS reserve
 - State forest
 - Brunswick catchment
 - Tweed catchment

Regional setting

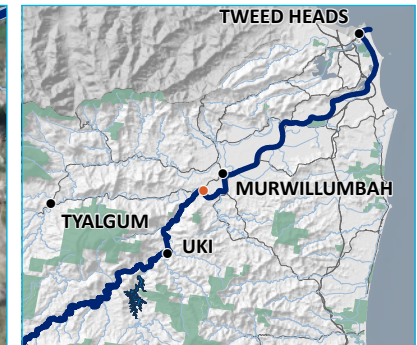
Clarrie Hall Dam EIS
Surface Water Assessment
Figure 1.1



\\lemmsvr1\EMM2\2023\E230036-Clarrie Hall Dam EIS-Project management\GIS\02_Maps_SWA\SWA016_FlowGauges\SWA016_FlowGauges_20231005_01.aprx 6/10/2023



Source: EMM (2023); ABS (2021); DCSSS (2023); ESRI (2023); GA (2009); KBR (2023)



- KEY
- Stream flow gauge used for analysis
 - Urban centre
 - Bray Park weir
 - Clarrie Hall Dam at current FSL
 - Tweed River
 - Waterway
 - Named waterbody
 - NPWS reserve
- INSET KEY
- Major road
 - NPWS reserve

Waterways and relevant flow gauges in the vicinity of the project

Clarrie Hall Dam EIS
Streamflow Analysis
Annexure A to the Surface Water Assessment
Figure 1.2



1.4 Annexure structure

This annexure is structured as follows:

- Chapter 2 describes the historical streamflow regime of Doon Doon Creek and the Tweed River, based on analysis of historical gauge records.
- Chapter 3 gives an overview of:
 - the NSW DPE eWater Source model of the Tweed River system which was utilised for this assessment
 - project-specific changes that were made to the model
- Chapter 4 details:
 - the input data used for analysis
 - changes made to the Source model
 - the scenarios modelled
- Chapter 5 presents results that describe the possible future streamflow regime (i.e. once the raised Clarrie Hall Dam is operational), including:
 - seasonal flow duration curves
 - tables of average annual flows and dam releases
 - statistics describing the dam storage volumes
- Chapter 6 describes the possible future streamflow regime following population growth and climate change

2 Historical flow regime

2.1 Overview

Data from a number of gauging stations was used to assess the existing flow regime of Doon Doon Creek, the Tweed River and within the Tweed Valley more broadly. Data was obtained via the Bureau of Meteorology (BoM) and from the NSW Water Data Online portal.

Streamflow in Doon Doon Creek was recorded for a 12-year period prior to the opening of Clarrie Hall Dam. Additionally, there is a record of Clarrie Hall Dam outflows (i.e. streamflow in Doon Doon Creek downstream of Clarrie Hall Dam) available from 2008 (total outflow is the sum of releases and flow over the spillway). Streamflow records for the Tweed River and the Oxley River are typically longer, with some records starting in the 1950s.

Figure 2.1 lists the streamflow gauges that were used and shows their period of record.

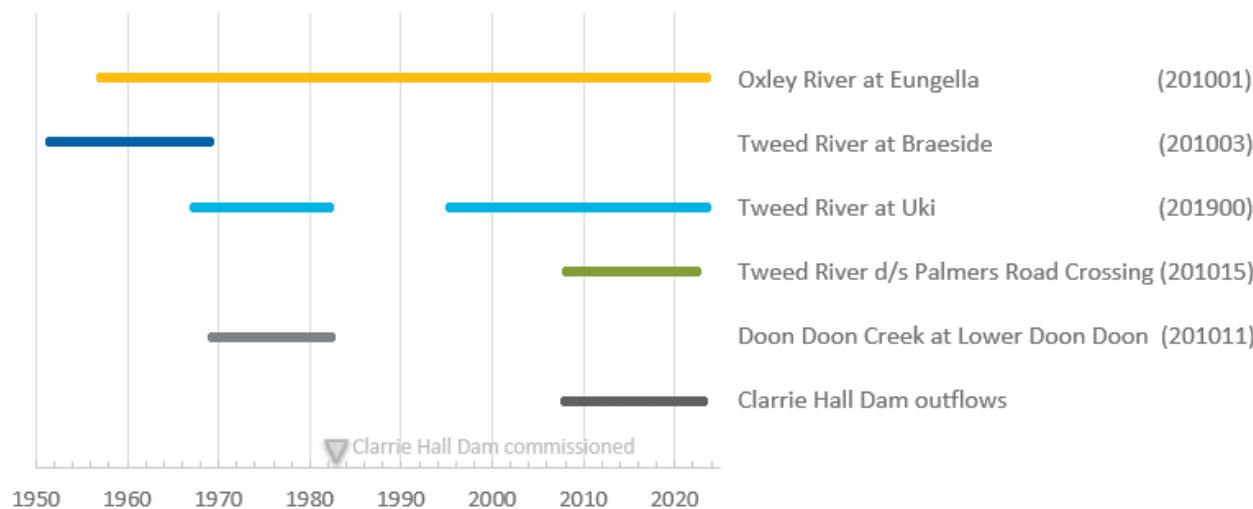


Figure 2.1 Streamflow gauge record duration

Flow regimes in the Tweed Valley follow a broadly similar pattern and are primarily driven by seasonal variation in rainfall and evaporation (Figure 2.2). Generally, streamflow is highest in Autumn, when rainfall is high and evaporation is low, and in Summer. Lower flows occur in Spring and Winter, coinciding with lower rainfall.

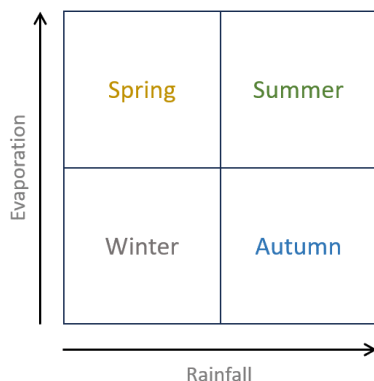


Figure 2.2 Seasonal variation in rainfall and evaporation in the Tweed Valley

Using the reference period 2009 to 2021, when there is overlap between streamflow records, Figure 2.3 shows overall and seasonal flow statistics for key streamflow gauges, along with a map showing the location of the

gauges. By using a reference period for this analysis, the varying influence of wet and dry periods on the streamflow records is removed and comparison can be made. This figure shows that:

- flows are highest in summer and autumn across all gauges
- across the total record and all seasons, median flow is below mean flow indicating that the dataset is skewed. The mean is increased by a relatively few number of days with high or very high flow, while the median reflects many days of lower flows. This is most pronounced in summer, likely due to the combination of more extreme rainfall events and drier overall conditions producing low flows.
- gauges with a larger contributing catchment area have higher flows across all statistics and seasons:
 - Oxley River at Eungella (201001), which is located on the Oxley River upstream of the confluence with the Tweed River and has a contributing catchment area of approximately 215 km²
 - Tweed River at Uki (201900), which is located on the Tweed River upstream of the confluence with the Oxley River and has a contributing catchment area of approximately 275 km²
- Clarrie Hall Dam outflows are the lowest flows across all statistics and seasons, corresponding to a contributing catchment area of approximately 60 km² for Clarrie Hall Dam.
- Clarrie Hall Dam outflows exhibit less variation in flow across the seasons compared with Tweed River d/s Palmers Croad Crossing (201015), which is located on the Tweed River upstream of the confluence with Doon Doon Creek and also has a smaller contributing catchment area of 155 km². This is likely due to the regulating effect of the dam on the natural streamflow regime (i.e. capturing and attenuating higher flows and meeting minimum flow release requirements).

The following sections present additional detail for these gauge locations.

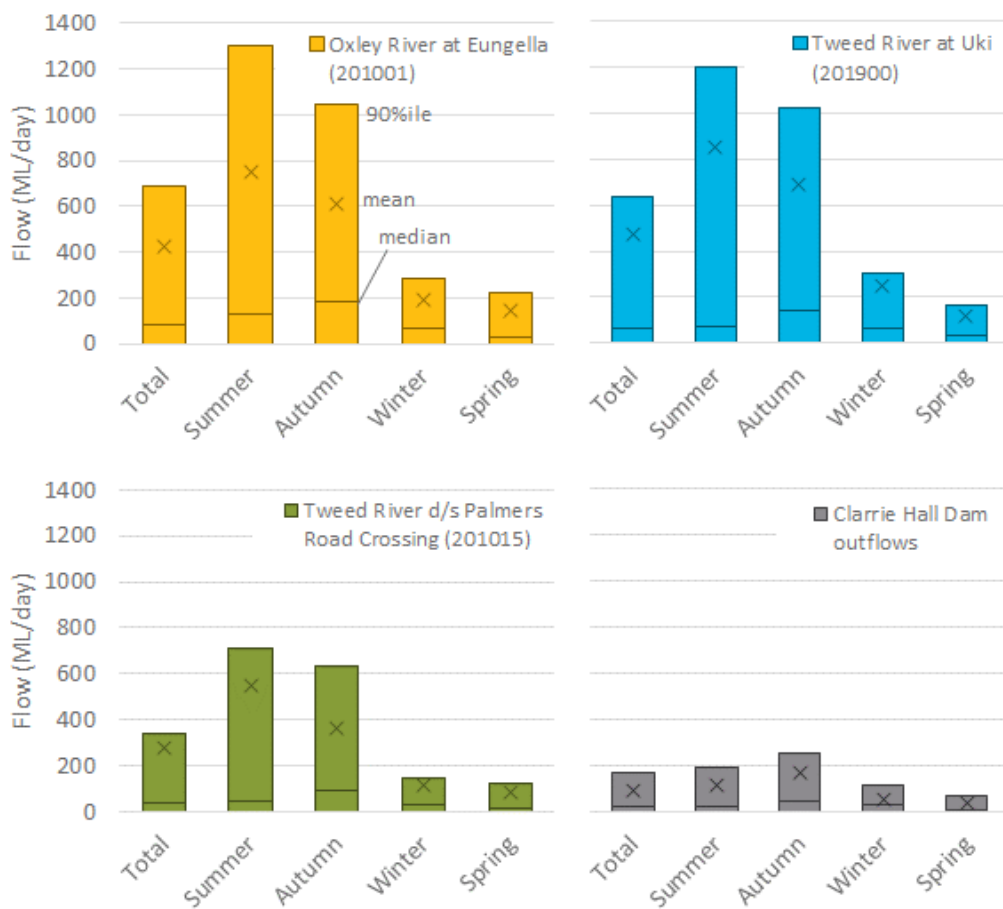
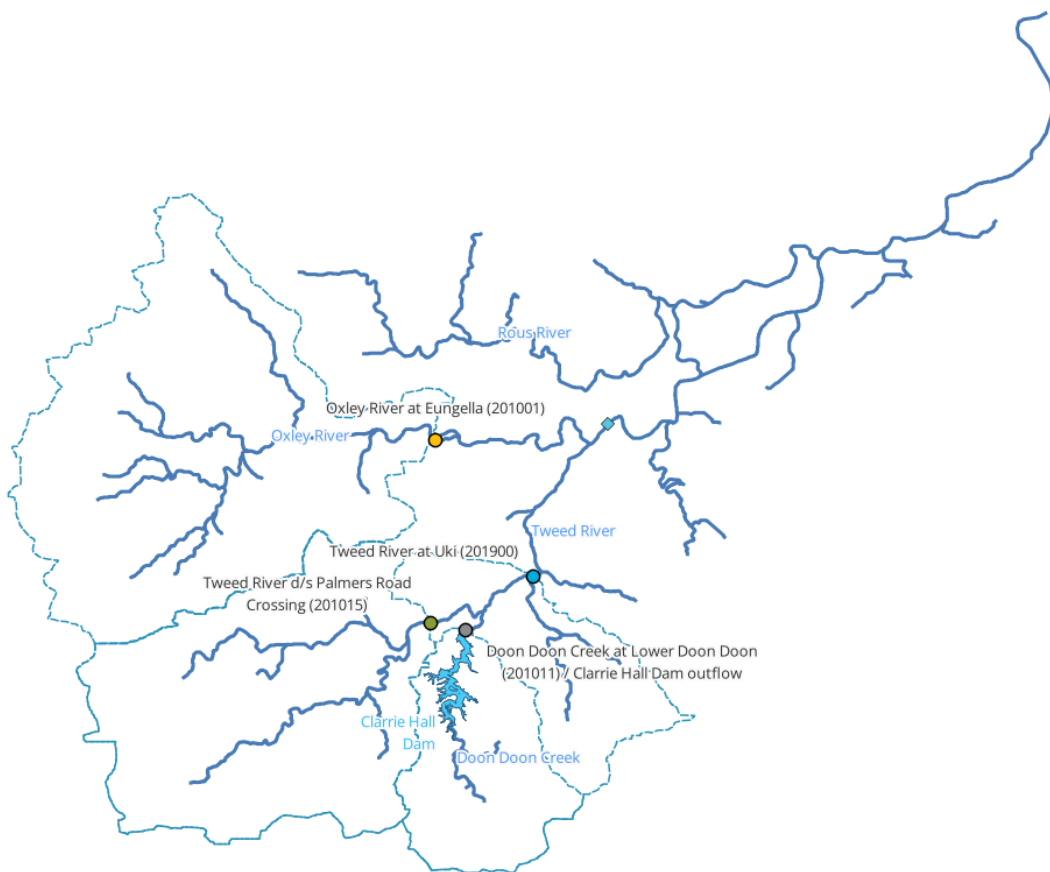


Figure 2.3 Overall and seasonal flow percentiles for key streamflow gauges (2009–2021)

Figure 2.4 shows the Tweed River streamflow record from January 2019 to May 2020, alongside storage levels in Clarrie Hall Dam and Clarrie Hall Dam outflows. This period includes low flow conditions in 2019 (including environmental flow release from Clarrie Hall Dam), and higher flow conditions from the start of 2020.

Following drawdown in Clarrie Hall Dam in early 2019 and again in early 2020, there is a period in the streamflow record when higher flow is recorded at the Tweed River at Uki (201900) and d/s Palmers Road Crossing (201015) and only a very small release is made from Clarrie Hall Dam as storage levels recover (see 'A1' and 'A2'). This is due to runoff from the catchment area upstream of Clarrie Hall Dam being retained in the reservoir. Flow is higher at Uki due to inflows from additional catchment area.

Between September 2019 and January 2020, records show significant drawdown of Clarrie Hall Dam coinciding with very low flow recorded in the Tweed River d/s Palmers Road Crossing (201015). Flow recorded at Uki during this period is likely due to releases made from Clarrie Hall Dam for water supply purposes (see 'B') and may be lower than dam releases due to losses along the creek.

From February 2020, the streamflow record shows higher flow in the Tweed River for all gauges. Storage levels in Clarrie Hall Dam were full (i.e. > 61.5 m AHD), and during this period the streamflow recorded at Uki is greater than that recorded at the gauge d/s Palmers Road Crossing and released from Clarrie Hall Dam (see 'C').

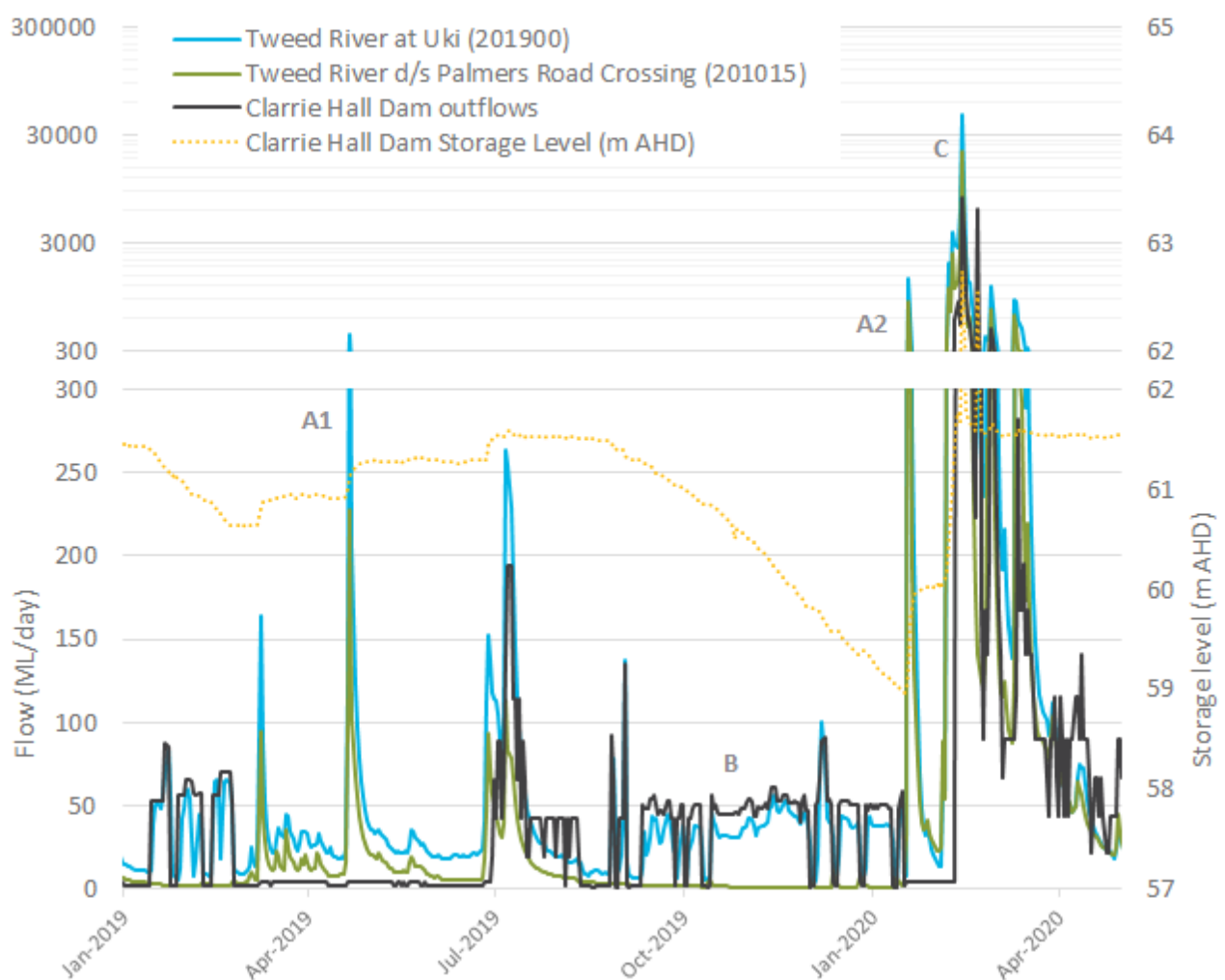


Figure 2.4 Tweed River streamflow records, Clarrie Hall Dam outflow and storage level January 2019 to May 2020

2.2 Doon Doon Creek seasonal flow duration curves

Flow duration curves illustrating the statistical representation of the frequency of various flow rates were produced for the Doon Doon Creek using the historical streamflow record.

The streamflow gauge on Doon Doon Creek at Lower Doon Doon (201011) was operational prior to Clarrie Hall Dam being open and therefore does not represent the current flow regime in Doon Doon Creek. However, with a contributing catchment area of approximately 55 km², it was located close to the current Clarrie Hall Dam and is therefore indicative of the flow regime both for inflows to Clarrie Hall Dam and for other smaller catchments within the Tweed Valley.

Flow duration curves for Doon Doon Creek at Lower Doon Doon (201011) (Figure 2.5) show that:

- in the absence of the dam, the creek is almost perennial, with no-flow on ~4% of days, with a slightly higher probability of no-flow days occurring during summer
- the flow duration curve for summer is steeper than for other seasons. Peak flows are higher in summer (i.e. with < 20% probability of exceedance), likely caused by a higher frequency of extreme rainfall events, and low flows are lower in summer (i.e. with > 80% probability of exceedance), likely due to drier catchment conditions following spring
- although flow is generally lower during winter than in summer and autumn, flow is perennial. This is likely due to wetter catchment conditions following autumn
- flows are lowest in spring

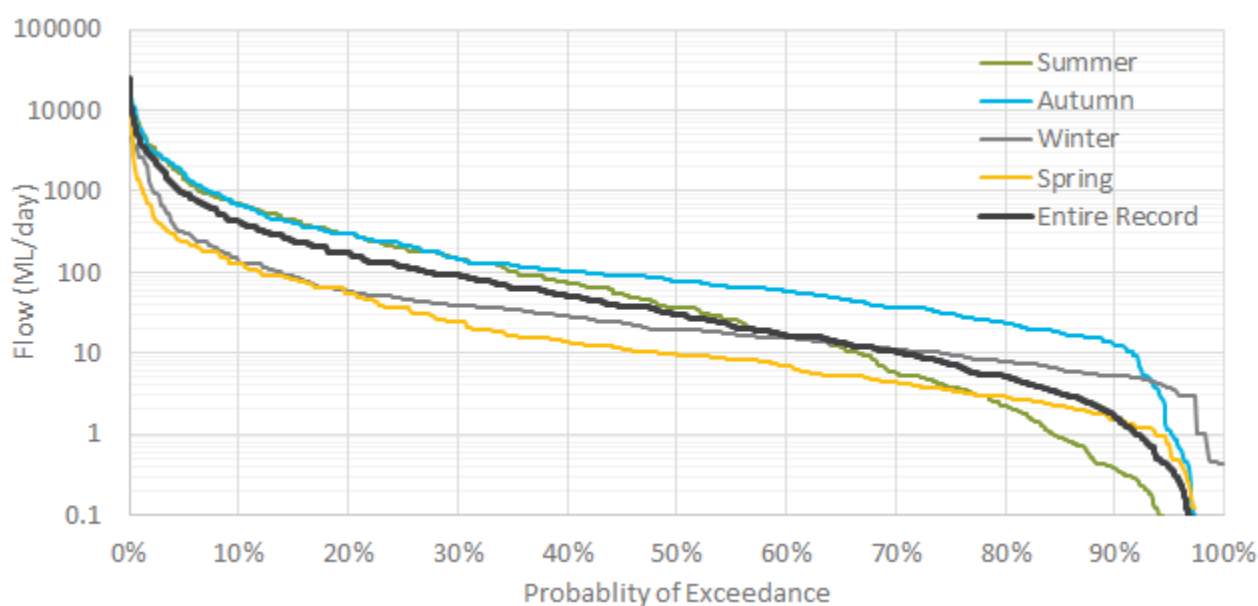


Figure 2.5 Doon Doon Creek at Lower Doon Doon (201011) seasonal flow duration curve (12 years gauge record) [Note: prior to Clarrie Hall Dam coming online]

Records for other gauges indicate that flow in the Tweed Valley is generally perennial, other than headwater catchments.

2.3 Tweed River seasonal flow duration curves

The Palmers Road Crossing (201015) gauging station is located on the Tweed River upstream of the confluence with Doon Doon Creek, and therefore is not influenced by releases from Clarrie Hall Dam. The contributing catchment area is approximately 155 km².

The gauging station on the Tweed River at Uki (201900) is located downstream of the Doon Doon Creek confluence and receives releases from Clarrie Hall Dam. The contributing catchment area is approximately 275 km².

The gauging station at Braeside (201003) is located on the Tweed River approximately 5 km downstream of the gauge at Uki. The contributing catchment area is approximately 320 km². It is no longer operational.

Gauges on the Tweed River demonstrate a relatively consistent flow regime through the seasons (Figure 2.6 to Figure 2.8) with:

- higher peak flows in summer than in other seasons (i.e. with < 20% probability of exceedance), likely driven by higher frequency extreme rainfall events
- higher flows in autumn than in other seasons (20%–80% probability flows) driven by higher overall rainfall and lower evaporation
- lower flows during spring than in other seasons (20%–90% probability flows), driven by lower rainfall and higher evaporation

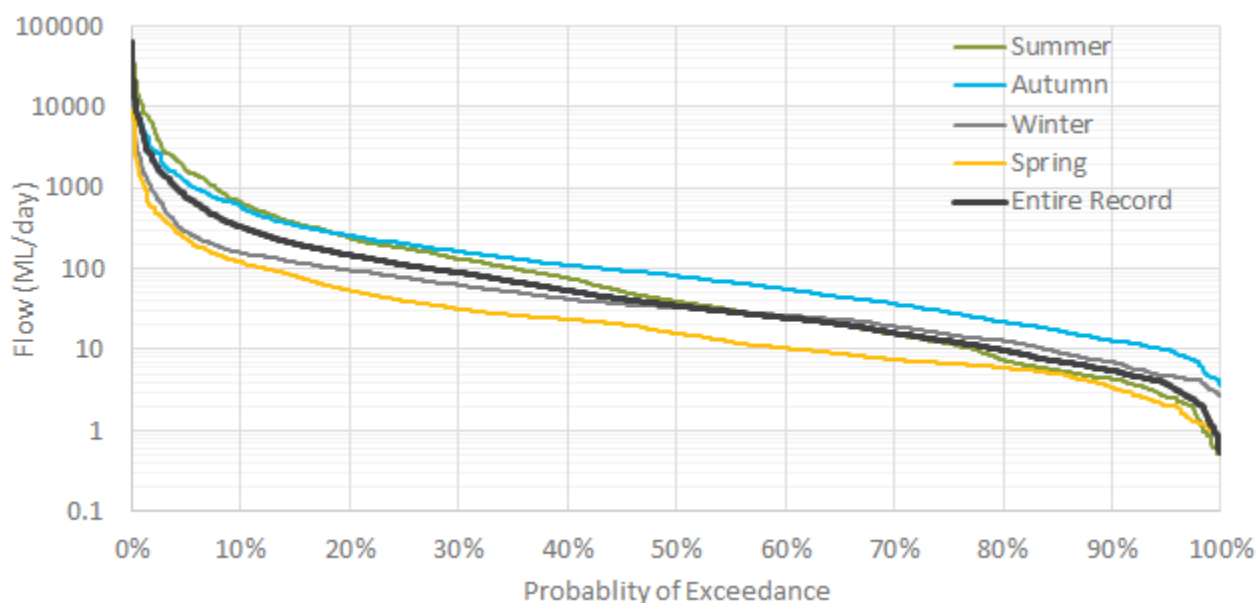


Figure 2.6 Tweed River d/s Palmers Rd Crossing (201015) seasonal flow duration curve (14 years of record)

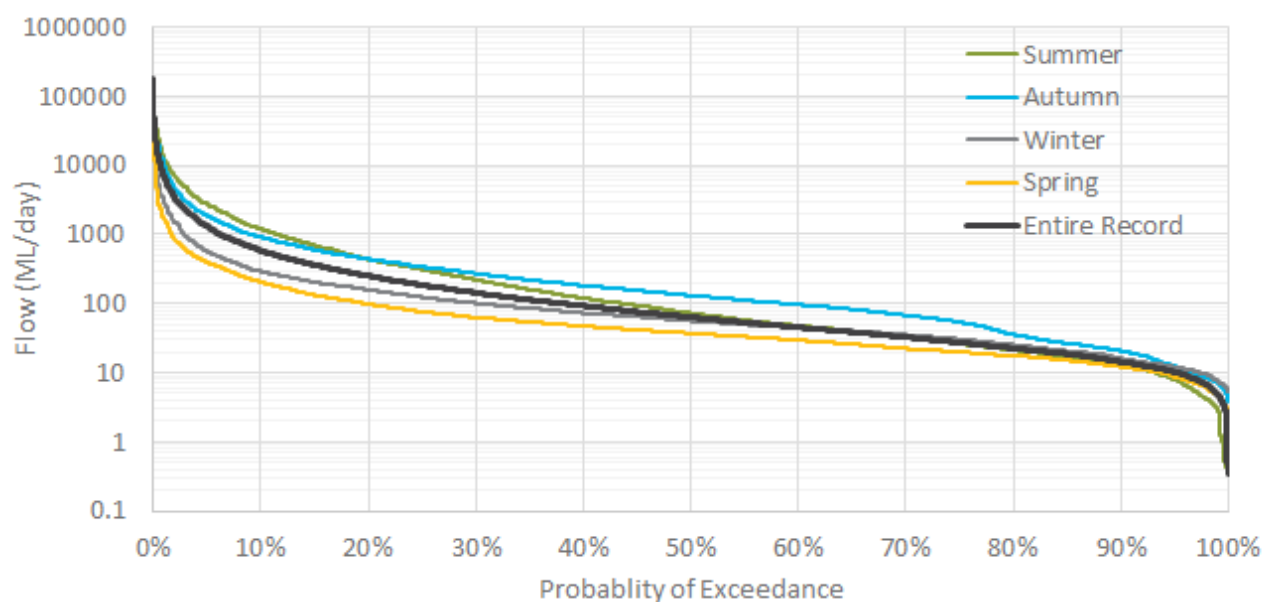


Figure 2.7 Tweed River at Uki (201900) seasonal flow duration curve (43 years gauge record)

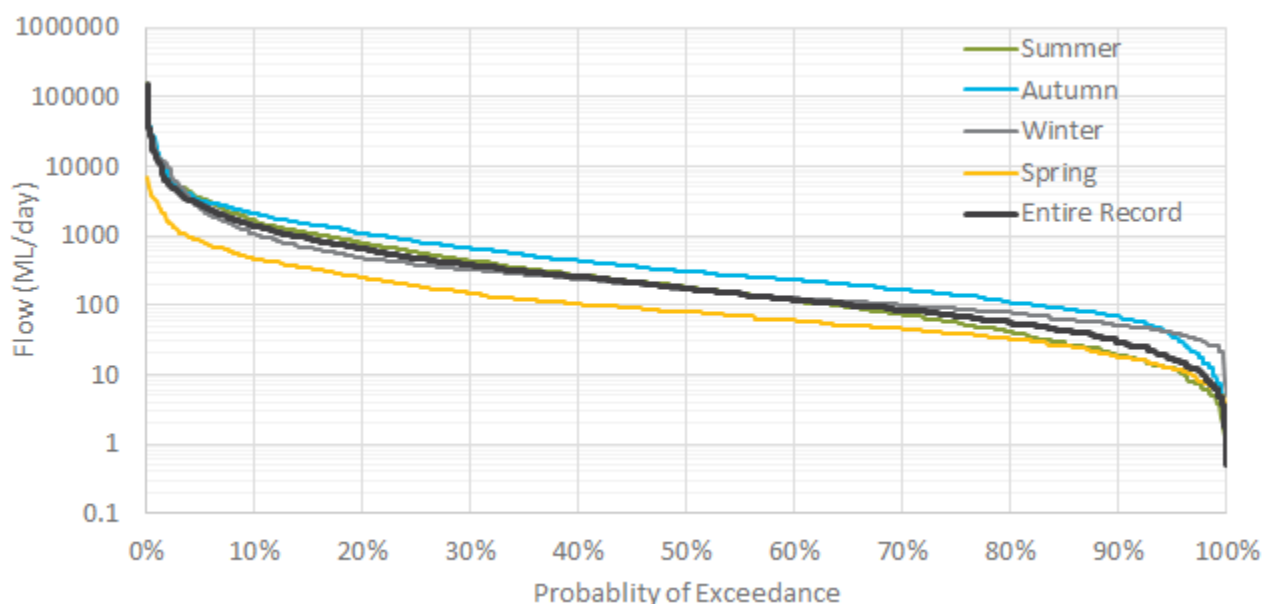


Figure 2.8 Tweed River at Braeside (201003) seasonal flow duration curve (17 years of record)

2.4 Oxley River seasonal flow duration curves

The Eungella (201001) gauging station on the Oxley River has a catchment area of approximately 215 km². It has the longest streamflow record in the Tweed Valley.

The Oxley River joins the Tweed River just upstream of Bray Park Weir and is unaffected by releases from Clarrie Hall Dam. Flow duration curves for the Oxley River (Figure 2.9), demonstrate a flow regime that is consistent with what is described for the Tweed River above.

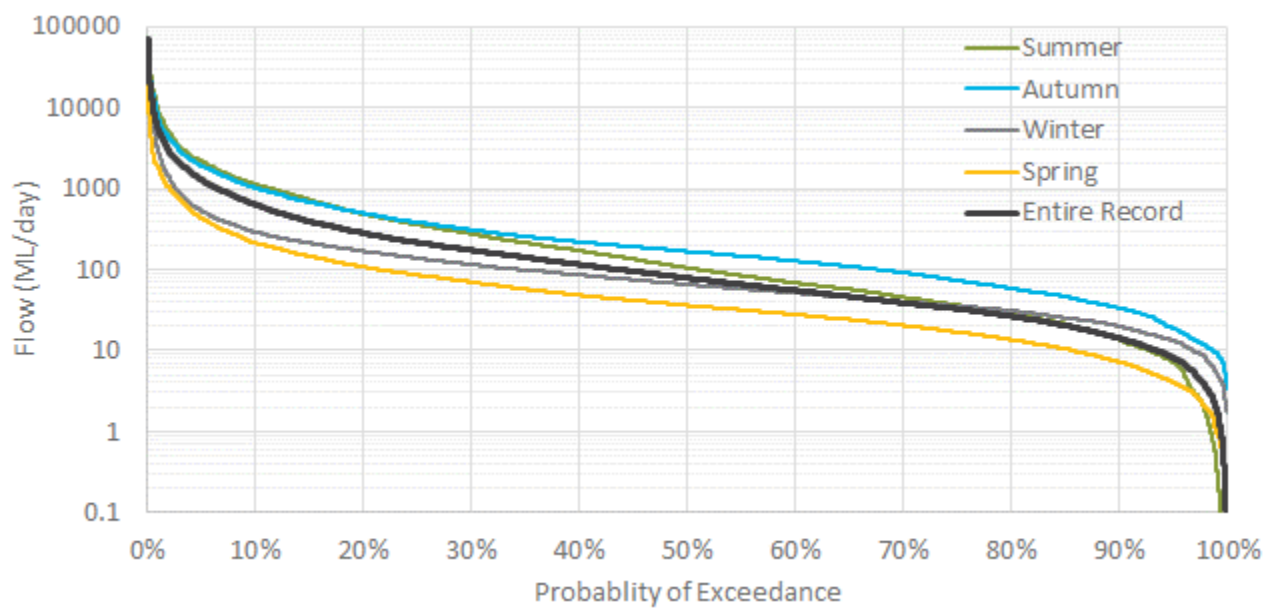


Figure 2.9 Oxley River at Eungella (201001) seasonal flow duration curve (52 years of record)

3 Hydrology model setup and assumptions

The existing and potential future flow regime following development of the Proposal was modelled using the existing DPE-Water Tweed River Valley Source model. This model was developed by DPE-Water in 2019–2020 using the national hydrological modelling platform eWater Source and replaced the previous Tweed River IQQM Model, which was originally developed in around 2006 (NSW DPE-Water, 2020a). Source is a hydrological modelling platform originally developed by the eWater Cooperative Research Centre (CRC) until June 2012, with development post June 2012 undertaken by eWater Limited. It is focussed on modelling both catchment hydrologic responses to climate conditions, and river operations.

DPE-Water provided EMM with the Tweed River Valley Source model as well as input climate and hydrological data, calibrated rainfall-runoff model parameters, and available documentation. While the DPE-Water Tweed River Valley Source model, parameters and input datasets were used to model the effects of the proposed dam raising and produce results for analysis and inclusion in this report and the EIS, DPE-Water is not responsible for any data or results generated by EMM.

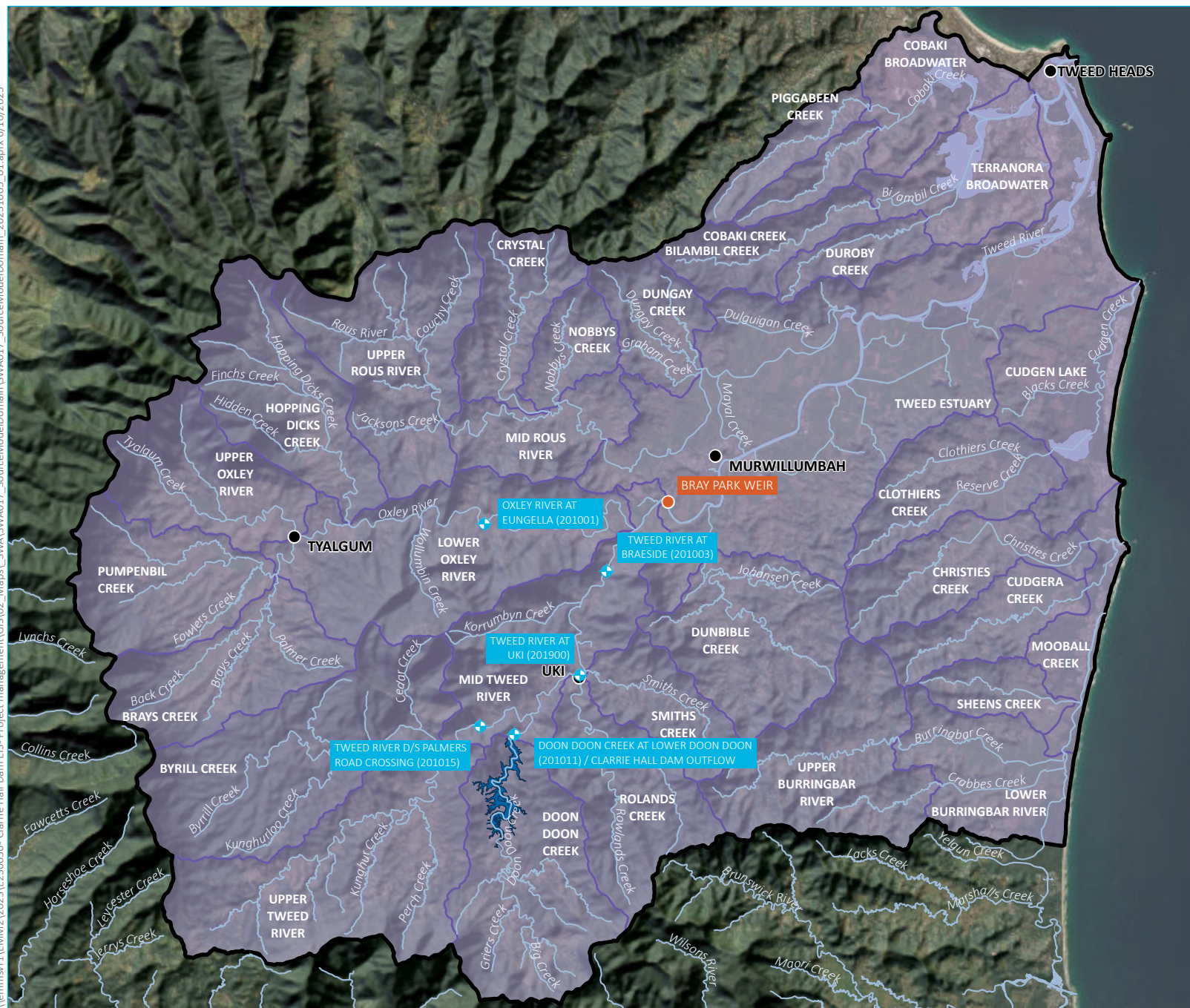
It is noted that because the relevant Water Sharing Plan (WSP) was updated subsequent to initial model development, EMM has updated the model in consultation with DCCEEW to reflect the current WSP. Changes to the model to reflect the current WSP are described in Section 3.3.

3.1 DPE-Water Tweed River Valley Source model

The DPE-Water Tweed River Valley Source model encompasses the catchment area of the Tweed River and its tributaries, as well as a number of smaller coastal catchments (Figure 3.1). It is a river system model which runs using a daily timestep and simulates:

- hydrological processes of river and storage inflows, evaporative losses (from rivers and storages), and river losses (note that groundwater is not explicitly modelled, and river losses are estimates only)
- storage releases and spills (Clarrie Hall Dam and Bray Park Weir), based on rainfall, water supply ordering and environmental release requirements
- water demand across various water users as outlined in the Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023 (2023 WSP), including: basic landholder rights, stock and domestic users, unregulated river access (i.e. irrigation users), aquifer demands, and local water utility access for urban water demand. Irrigation demand and urban water demand are simulated as variable daily demands based on recent climate variables through the use of crop modelling and irrigation deficit modelling. The model does not include the application of water restrictions and associated reductions in urban water demands.
- seasonal and daily irrigation requirements for various crop types
- the water sharing and resource allocation processes
- the daily river and bulk water supply system operation as implemented by Council (simplified for modelling purposes)

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- KEY**
- Model domain
 - Clarrie Hall Dam at current FSL
 - Catchment
 - + Stream flow gauge used for analysis
 - Urban centre
 - Bray Park weir
 - Waterway
 - Named waterbody

DPE-Water Tweed River Valley
source model domain

Clarrie Hall Dam EIS
Streamflow Analysis
Annexure A to the Surface Water Assessment
Figure 3.1

Tributaries of the Tweed River include (refer to Figure 3.1):

- the Oxley River, which flows into the Tweed River upstream of Bray Park Weir, above the tidal limit
- a number of creeks systems, including Doon Doon Creek
- the Rous River, which enters the Tweed River below Bray Park Weir

Streamflow input data for the Source model are generated via a separate modelling process, utilising either historical or stochastic climate data (rainfall and evaporation) and rainfall-runoff models (Sacramento Model) developed and calibrated by DPE-Water for each subcatchment. Climate data inputs are also required in the Source model directly to simulate rainfall and evaporation from river and storages water surfaces and to estimate irrigation and urban water demands. More information about the climate data used is given in Section 0. The relationship of these elements to the Source model is given by Figure 3.2.

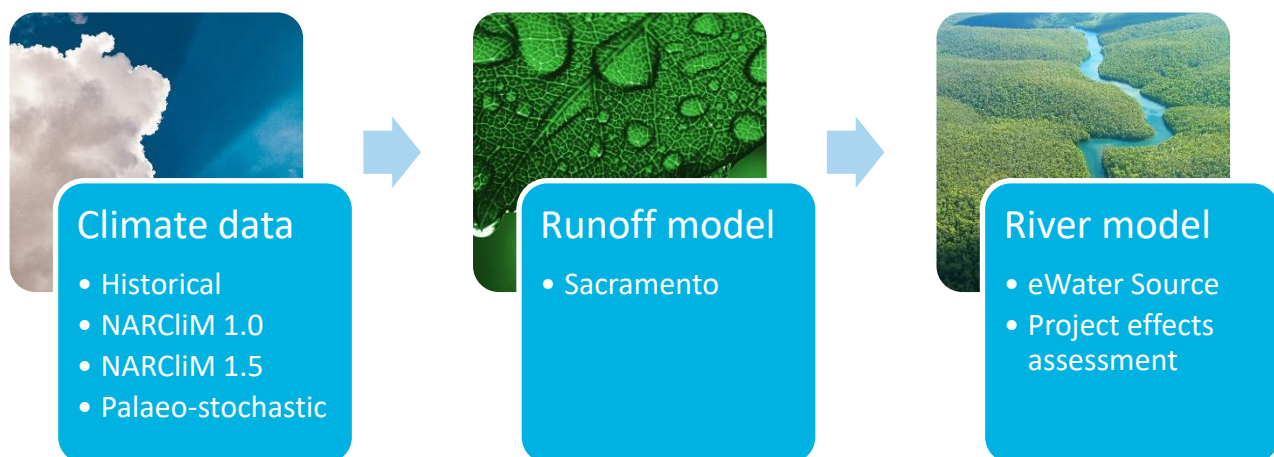


Figure 3.2 Model element relationships

The model includes water supply to Tweed Shire Council Town Water Supply (i.e. Tweed Heads and Murwillumbah) and to the smaller villages of Uki and Tyalgum. More information about demands in the model is given in Section 4.3. Clarrie Hall Dam and Bray Park Weir storages are included in the model and these work together to service the Town Water Supply.

3.2 Model adequacy

DPE provided EMM with the calibration report for the Tweed River Valley Source model (NSW DPE-Water, 2020b), which notes that the model was developed using available data and current accepted standard methodologies, and concludes that overall, it models the behaviour of the catchment under current WSP rules (i.e. current WSP at the time of model calibration) and operational rules and gives a fair approximation of observed operational behaviour. Calibration statistics for streamflow gauges within the model ranged from “satisfactory” to “very good”, based on performance evaluation criteria provided in (Moriasi, Gitau, Pai, & Daggupati, 2015) for the hydrologic model statistical performance measures used.

A second DPE-Water report detailing the conceptualisation of the Tweed River Valley Source model explicitly confirms that the current model schematisation is suitable for use in assessing the proposed raising of Clarrie Hall Dam, meaning that there is no need to change the node/link configuration of the model for this assessment, and that the current calibration is valid (NSW DPE-Water, 2020a).

EMM undertook model checking and validation to ensure the adequacy of the model and input files received from DPE-Water, including water balance checks, comparisons of modelled results with those presented in the calibration report, and modelling of the historical climate record to ensuring that major events were appropriately

represented. The model performed as expected (e.g. illustrated low flow during the Federation Drought, Millennium Drought and the 2019 drought, and significant flood flows in 1974 and 2022).

Operation of Clarrie Hall Dam within the model was also broadly checked against the '*Clarrie Hall Dam Operations and Maintenance Plan Revision 4.2*' (Tweed Shire Council, 2022) to ensure the most up-to-date information about current dam operations was adequately reflected by operating rules within the model.

3.3 Update of model for Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2023

The water use, water sharing and resource allocation processes in the model provided by DPE-Water were based on the Water Sharing Plan for the Tweed River Area Unregulated and Alluvial Water Sources 2010 (2010 WSP). During the preparation of the EIS, the 2010 WSP was superseded by the 2023 WSP, which came into effect on the 23rd of June 2023.

In consultation with DPE-Water, EMM updated the Tweed River Valley Source model to reflect the updates in the 2023 WSP, by changing the following:

- a rule was introduced whereby no pumping from Doon Doon Creek or Mid Tweed Water Sources is allowed when the flow at Tweed River d/s Palmers Road Crossing (201015) is between 45–147 ML/day
- the amount of water required to satisfy basic landholder rights and the share components specified for access licences have changed slightly. Overall, there is a reduction
- rules for extraction in the Mid Tweed Water Sources is now based on flow at Tweed River d/s Palmers Road Crossing (201015), whereas previously they were based on flow at Oxley River at Eungella (201001)
- minor changes to the flow rates defining flow classes at reference sites which underpin rules for extraction
- entitlement volumes and pumping capacities for licenced water users represented in the model were updated using the latest information from the NSW Water Register, as provided to EMM by DPE-Water

There were no changes to the environmental water release requirements relating to Clarrie Hall Dam.

3.4 Proposal assessment

To simulate the effects of the Proposal, EMM implemented changes to the DPE-Water Tweed River Valley Source model. A high-level summary of the changes made is outlined below, with details of model changes and input data given in Chapter 4.

3.4.1 Source model version

The Source model and plugins were brought into the version of Source current at the time of modelling (Source version 5.20.0.12549 and SourcePlugin.AllocationAndUtilities version 5.5.0.4 respectively).

3.4.2 Input data (rainfall, evaporation, and streamflow)

The Source model was updated to accommodate the input climate and hydrological data required to assess the Proposal (described in Section 0), specifically:

- historical rainfall and evaporation data sequences were extended to the 31st of December 2022
- palaeo-stochastic data was obtained for the relevant climate input stations

- climate change projections were used to generate data for the relevant climate input stations
- the 'scenario input set' functionality in Source was utilised to define the input data for each modelled scenario to best accommodate the large file sizes of stochastic climate data
- the Sacramento parameters provided by DPE-Water were used to develop a runoff model within the Source platform, to convert climate data into river inflow data

3.4.3 Demand

Water supply to Tweed Shire Council Town Water Supply (i.e. Tweed Heads and Murwillumbah) and to the smaller villages of Uki and Tyalgum, were updated to reflect current demand (at 2025, when the Proposal will be operational) and future projected demand (at 2065) (described in Section 4.3).

3.4.4 Clarrie Hall Dam storage node

The storage node for Clarrie Hall Dam was updated to reflect recent Computational Fluid Dynamics (CFD) modelling of the existing spillway (GHD, 2023).

For scenarios where the dam wall is raised, the storage node for Clarrie Hall Dam was updated to include (described in Section 4.1):

- the proposed spillway
- the proposed new full supply level (FSL) and volume
- updated storage curves (i.e. depth-volume-surface area data) above the current FSL, based on recent LiDAR data from 2017
- updated outlet discharge relationships which reflect proposed changes to the FSL and outlet tower

4 Model scenarios and input data

Table 4.1 gives a summary of the scenarios that were modelled. The input data and assumptions for these modelling scenarios are detailed in this Chapter.

Table 4.1 Summary of scenarios modelled

Scenario	Infrastructure			Climate			Demand	
	Current	Proposed (EIS)	Revised (this document)	Historical	Palaeo-stochastic	Climate change projections	Current (2025)	Future (2065)
Scenarios presented in the EIS								
1	X			X			X	
2	X			X				X
3	X				X		X	
4	X				X			X
5	X					X		X
6		X		X			X	
7		X		X				X
8		X			X		X	
9		X			X			X
10		X				X		X
Scenarios presented in this document								
11			X	X			X	
12			X		X		X	
13			X		X			X
14			X			X		X

4.1 Infrastructure scenarios

There were two infrastructure scenarios considered in the EIS modelling (Table 4.2):

- Current infrastructure – existing system with Clarrie Hall Dam at a FSL of 61.5 m AHD, storage capacity of 16 GL, and current configuration. This is the base case.
- Proposed infrastructure – Clarrie Hall Dam raised by 8.5 metres to a height of 70 m AHD, thereby increasing the storage capacity of the dam to 42.3 GL for the purpose of water supply augmentation.

Table 4.2 **Model scenarios - infrastructure**

	Current	Proposed (EIS)	Revised (this document)
Volume	16 GL	42.3 GL	42.3 GL
Full supply level (FSL)	61.5 m AHD	70 m AHD	70 m AHD
Spillway	Existing spillway	New spillway (Option 1B)	80 m wide spillway
Intake tower	Existing intake tower and water inlet ports	Intake tower raised by 8.5 m with three additional water inlet ports	Intake tower raised by 8.5 m with three additional water inlet ports
Outlets	400 mm diameter fixed cone dispersion (FCD) valve 900 mm diameter FCD valve	400 mm diameter FCD valve 900 mm diameter FCD valve	400 mm diameter FCD valve 900 mm diameter FCD valve

4.1.1 CHD spillway

CFD modelling of the existing spillway was undertaken in 2023, and a new rating curve was generated. EMM has updated the DPE-Water Tweed River Valley Source model with the new rating curve for the current infrastructure scenarios.

CFD modelled was undertaken for the revised spillway (Worley Consulting, 2025) and the resulting spillway curve for the new spillway was implemented in the Source model for proposed infrastructure scenarios.

Figure 4.1 shows the rating curves for current spillway at Clarrie Hall Dam and for the new spillway once Clarrie Hall Dam is raised.

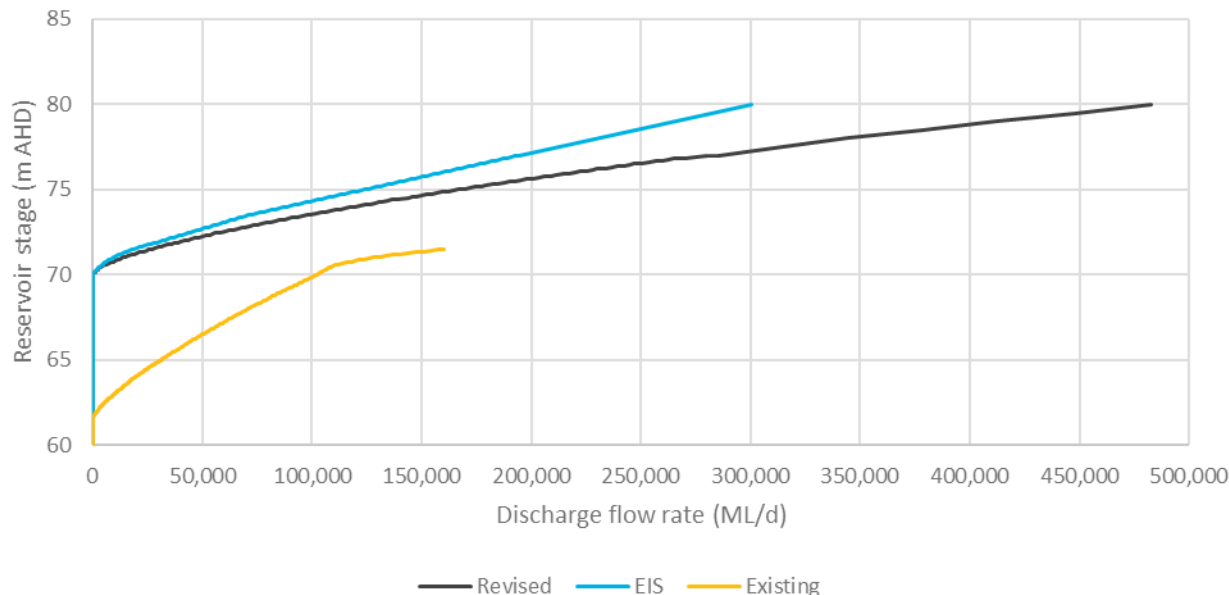


Figure 4.1 **Spillway rating curves for the Clarrie Hall Dam based on CFD modelling (GHD, 2023) (Worley Consulting, 2025)**

4.1.2 CHD storage relationships

A comparison of storage relationships for Clarrie Hall Dam was undertaken as part of the concept design for the Proposal (Tweed Shire Council, 2018). LiDAR data collected in 2017 was used to generate an improved storage curve for Clarrie Hall Dam between 61.5 m AHD and 77 m AHD – shown in Figure 4.2.

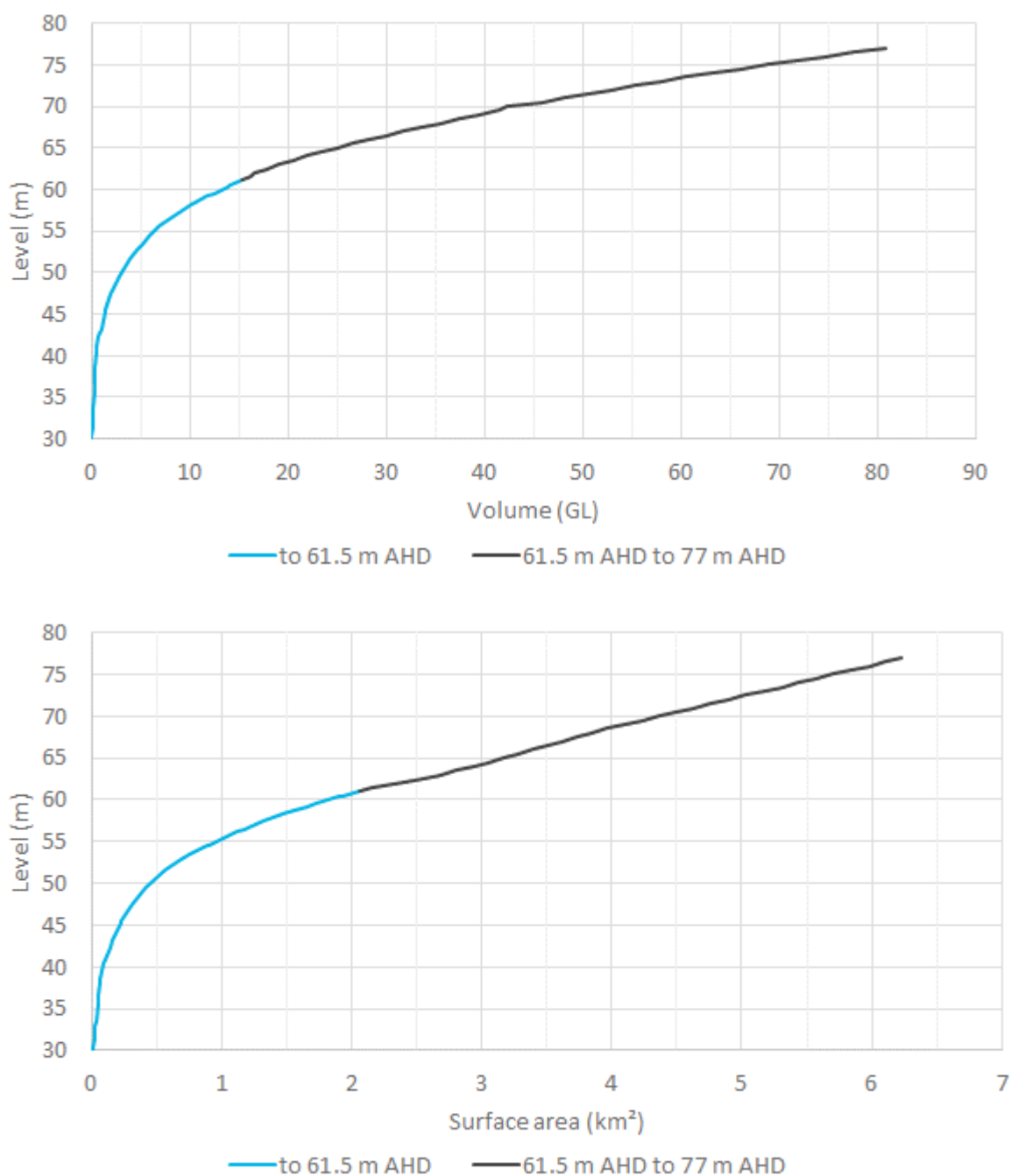


Figure 4.2 Clarrie Hall Dam storage and volume curves (Tweed Shire Council, 2018)

4.1.3 CHD outlets

Currently, managed releases from Clarrie Hall Dam are regulated via two fixed cone dispersion (FCD) valves of 400 mm diameter and 900 mm diameter. Under the proposed infrastructure scenario, the inlet tower will be raised by 8.5 m and will have an additional three water inlet ports. The outlet pipework and outlet valves will remain as they are.

The Source model includes outlet discharge curves for each of the FCD valves, which represent maximum discharge rate vs dam storage level. The discharge capacity of FCD valves reduces with storage level and maximum discharge rate can be represented via the relationship: $Q = C_d A \sqrt{2gH}$, where Q is discharge, C_d is the discharge coefficient of the valve, A is cross-sectional area, g is gravitational constant, and H is the upstream head.

EMM updated the outlet discharge curves for the two FCD valves to include the higher FSL of Clarrie Hall Dam once it is raised. Maximum discharge rates were calculated using: outlet discharge curves in the existing Source model; the discharge relationship for FCD valves (given above); detailed information about proposed changes to the intake tower (Tweed Shire Council, 2018); standard hydraulic relationships for head loss; and detailed information about the outlet works at Clarrie Hall Dam from the operations and maintenance Plan (Tweed Shire Council, 2022).

4.2 Climate sequences

The DPE-Water Tweed River Valley Source model and associated rainfall-runoff models were calibrated using climate data from 17 climate stations across the Tweed region.

Within the Source model, daily rainfall and evaporation data is used to simulate rainfall onto and evaporation from rivers and storages and is a factor in determining daily demand. The catchment rainfall runoff models (Sacramento Model) use daily rainfall and evaporation data to generate streamflow inputs for the Source model.

The following three climate sequences were modelled:

1. Historical climate – observed climate records for the period 1889 to 2022 (134 years)
2. Current climate – palaeo-stochastic climate data generated by the University of Adelaide in association with DPE-Water for use in developing the NSW regional water strategies (10,000 years)
3. Future climate – the palaeo-stochastic climate data described in 2. perturbed by NARCLiM climate change projections to create plausible future climate data (10,000 years).

4.2.1 Historical climate: observed climate data

The 134-year period from the 1st of January 1889 to the 31st of December 2022 was modelled using the observed historical climate record with data from the SILO database (<https://www.longpaddock.qld.gov.au/silo/>).

The SILO database catalogues Australian climate data from 1889 to the present. It provides daily meteorological datasets for a range of climate variables in ready-to-use formats suitable for biophysical modelling, research and climate applications (The State of Queensland, 2023). Point rainfall and evaporation data for the 17 climate stations required for modelling was extracted from the SILO database in March of 2023. Most rainfall stations within the vicinity of the Proposal have records from the 1950s onwards, however a couple have records dating back to the 1890s.

Model results using the historical climate data were used to present historical flow sequences for illustration.

4.2.2 Current climate: palaeo-stochastic climate data

Stochastic modelling processes use the statistical characteristics of actual climate data to generate long-term, extended synthetic datasets (stochastic data). This type of data is particularly useful for understanding climate-based risks because it includes: greater climate variability, a range of different / plausible climate sequencing not seen in the actual climate record, and periods of low or high flow with varying persistence (e.g. long-term droughts and significant floods).

The New South Wales Government, in conjunction with the University of Newcastle and the University of Adelaide, has developed 10,000 year daily stochastic climate datasets for use in river system modelling to inform Regional Water Strategies. The stochastic datasets were developed based on:

- the 130-year observed historical climate record
- understanding of prevailing climate drivers (e.g. Interdecadal Pacific Oscillation, east coast lows)

- 500 years of reconstructed palaeo-climate data (e.g. tree rings, river sediments and ice cores)

The approach used to develop these stochastic datasets is outlined in Figure 4.3 and described in the report “*New climate analysis informs NSW’s regional water strategies*” (State of New South Wales, 2020) and in Attachment A.

The stochastic climate datasets are available for a large number of climate stations across NSW and are grouped by region. The 17 climate stations required for modelling are within the “Far North Coast” region. The data was downloaded from the NSW seed portal (<https://www.seed.nsw.gov.au/>): “*Water Modelling-Stochastic Climate Data: Far North Coast*”. This dataset was used in river system modelling using the DPE-Water Tweed River Valley Source model to inform the Far North Coast Regional Water Strategy (NSW DPE-Water, 2023).

Model results using the palaeo-stochastic climate data were used to develop the description of project effects with “current climate” in Chapter 5.

4.2.3 Future climate: climate data perturbed using climate change projections

i Background

Internationally, data for use in climate change assessments is managed and distributed by the Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for assessing science related to climate change (IPCC, 2023). The objective of the IPCC is to provide regular assessment reports of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation, and to provide governments at all levels with scientific information that they can use to develop climate policies. At a global level, climate data is actively curated by the IPCC to ensure traceability, stability, availability and transparency of data and scenarios related to the assessment reports of the IPCC. To date, the IPCC has released 6 assessment reports, each describing a suite of Global Climate Models (GCMs) and emissions scenarios.

Table 4.3 gives a high-level summary of recommendations for three most recent IPCC Assessment Reports, which are relevant to data that is available for use in this project.

Table 4.3 Summary of relevant IPCC assessment reports

Assessment Report	GCMs CMIP ¹ (suite of GCMs)	Emissions scenarios
Fourth Assessment Report (AR4)	CMIP3	SRES ² scenarios: B1, A1T, B2, A1B, A2, A1FI
Fifth Assessment Report (AR5)	CMIP5	RCPs ³ : RCP2.6, RCP4.5, RCP6.0, RCP8.5
Sixth Assessment Report (AR6)	CMIP6	SSPs ⁴ : SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5

1. Coupled Model Intercomparison Project – suite of GCMs that underpin the Assessment Report

2. Special Report on Emissions Scenarios (SRES)

3. Representative Concentration Pathways (RCPs)

4. Shared Socioeconomic Pathways (SSPs)

In general, GCMs are more accurate at describing changes to temperature and evaporation than rainfall, which has greater inherent variability. Additionally, GCMs are unable to predict detailed future climate conditions at a regional scale. Therefore, at a national and state level, government agencies are responsible for determining and providing guidance on data use for climate change assessments in Australia, including which GCMs are suitable for different locations, and methods for downscaling global data for regional use. Of most relevance to this project, advice is provided by:

- CSIRO and Bureau of Meteorology, via the Climate Change in Australia website (CSIRO and Bureau of Meteorology, 2023)
- the NSW government, via the AdaptNSW website (and related portals, reports) (NSW Government, 2023).

The NSW and Australian Regional Climate Modelling (NARCLiM) is a collaboration led by the NSW Government with the ACT and South Australian governments and input from the University of New South Wales's Climate Change Research Centre (UNSW CCRC). It was established to produce regional climate projections and data for studies into the impacts of climate change in south-east Australia, including the Proposal area. [Note: NARCLiM was formerly known as the NSW and ACT Regional Climate Modelling project prior to inclusion of South Australia]. At the time of assessment, there have been two NARCLiM releases, while a third is in development but not available at the time of modelling; these are summarised in Table 4.4.

Table 4.4 **Summary of NARCLiM releases and their basis**

NARCLiM release	Release Date	IPPC assessment report used	GCMs	Emissions scenarios
NARCLiM 1.0	2014	AR4, CMIP3	MPI-M ECHAM5, JAMSTEC MIROC, CSIRO QCCCE, CSIRO-MK3, CCCma CGCM 3.1	SRES A2
NARCLiM 1.5	2020	AR5, CMIP5	CSIRO BOM ACCESS1.3, CSIRO BOM ACCESS 1.0, CCCma CanESM2	RCP4.5, RCP8.5
NARCLiM 2.0	in development	AR6, CMIP6	n/a	n/a

ii Available dataset

Utilising the stochastic datasets described in Section 4.2.2, the NSW government produced 10,000-year daily climate datasets for the Regional Water Strategies, which incorporate climate change projections. The following steps were used to produce these “climate perturbed” datasets (see Attachment A, Figure 4.3):

1. The driest global climate model (GCM) for the high emissions scenario at 2060-79 was selected for NSW from the NARCLiM1.0 suite of climate projections. This was a deliberate decision intended to represent a ‘worst case’ scenario to identify vulnerabilities in meeting water related outcomes.
2. Daily stochastic data was scaled using monthly climate factors developed from the climate projection.

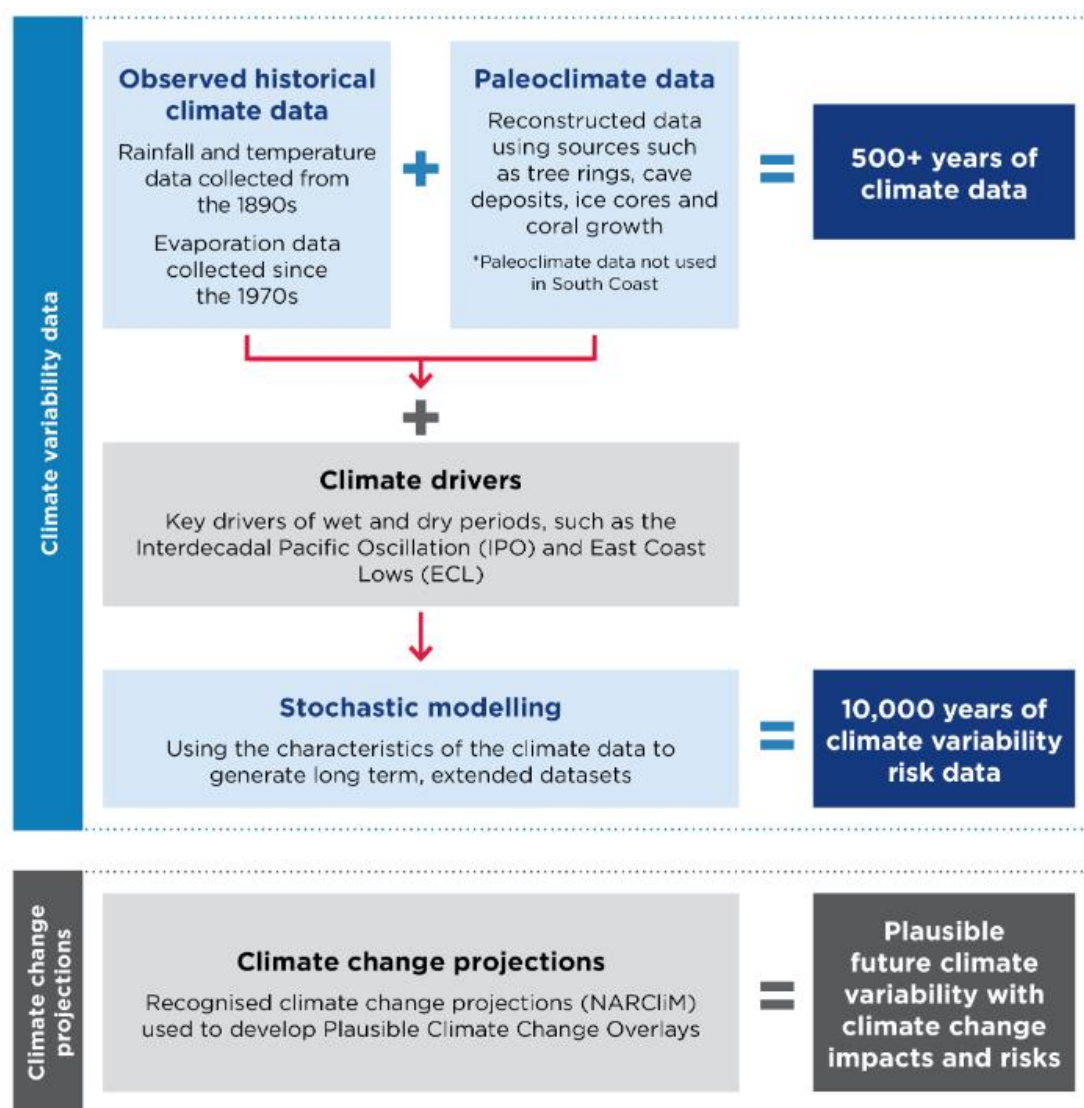


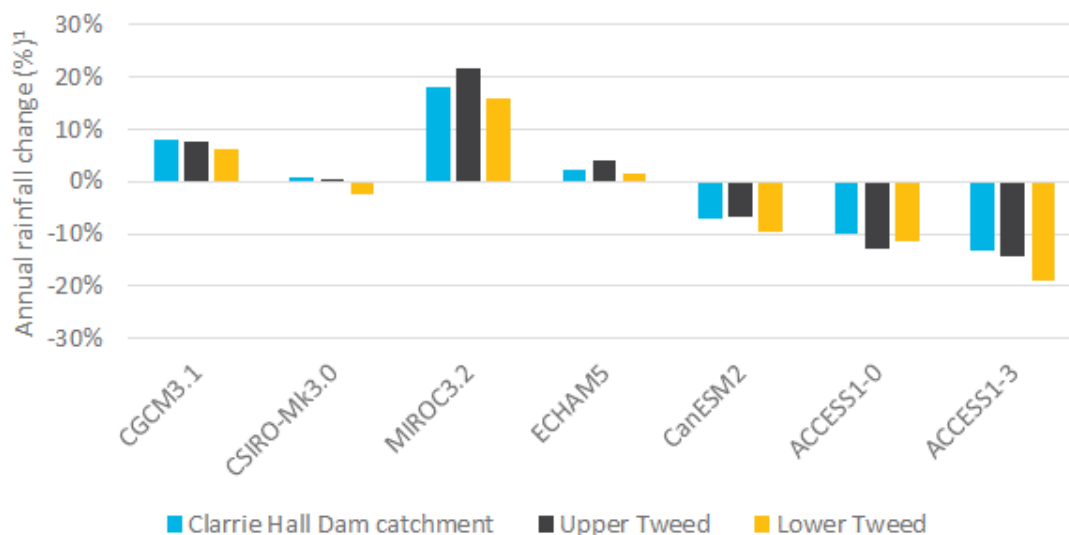
Figure 4.3 Climate data used in the Far North Coast regional water strategy (NSW DPE-Water, 2020)

The method used to produce this data was reviewed and endorsed by an independent panel of experts, coordinated by the Office of the Chief Scientist and Engineer. However, the panel noted that this science is still developing and recommended ongoing work to continuously improve the method and keep up to date with the latest scientific findings (State of New South Wales, 2020).

A new climate perturbed climate dataset was generated for use in this project because:

- the climate change projection used for the Regional Water Strategies did not appropriately represent the future climate drying potential at the Proposal location in the Tweed River Valley, as described Climate Change in Australia (CCA) website (<https://www.climatechangeinaustralia.gov.au/en/projections-tools/summary-data-explorer>)
- the climate change projection used for the Regional Water Strategies was generated before the NARCLIM1.5 datasets were available
- as mentioned above, continuous improvement and application of up-to-date climate data is recommended

NARCLiM1.0 and NARCLiM1.5 gridded data was downloaded from the NSW government climate data portal (<https://climatedata-beta.environment.nsw.gov.au>). Using monthly gridded precipitation data, the driest GCM for the high emissions scenario at 2060–2079 was found to be “CSIRO BOM ACCESS1.3” for the Tweed region (Figure 4.4), based on comparison with the historical reference period (1990–2009). CSIRO BOM ACCESS1.3 is a GCM from the CMIP5 suite and was downscaled for NSW as part of NARCLiM1.5.

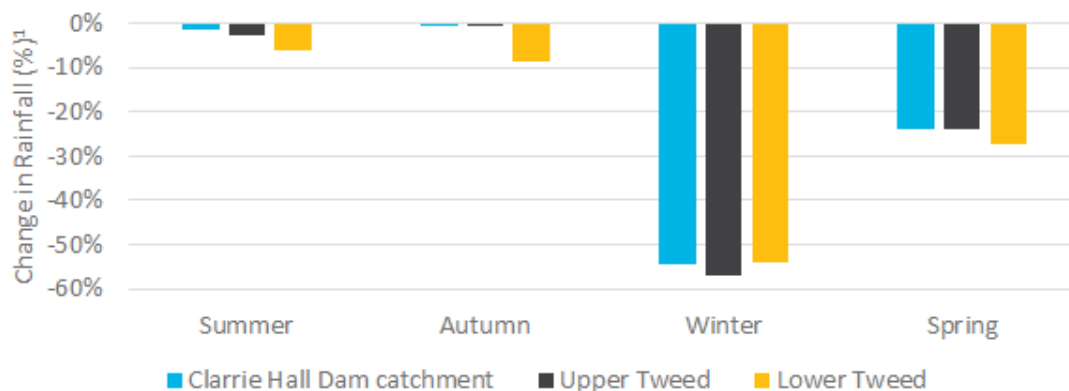


1. 2060–2079 period compared with 1990–2009 reference period, based on NARCLiM climate change modelling (NSW Government, 2023)

Figure 4.4 Comparison of GCM rainfall projections (2065)

Monthly scaling factors were calculated for rainfall and evaporation at each of the 17 climate stations required for modelling using the monthly gridded data. Overall, there was:

- a decrease in rainfall of approximately 20%
 - large decreases in rainfall in winter and spring (Figure 4.5)
 - little change to rainfall in summer and autumn.
- an increase in evaporation of approximately 10%



1. 2060–2079 period compared with 1990–2009 reference period, based on NARCLiM climate change modelling (NSW Government, 2023)

Figure 4.5 ACCESS1-3 seasonal rainfall projections (2065)

Monthly scaling factors were applied to the palaeo-stochastic datasets described in Section 4.2.2 to create 10,000 year daily “climate perturbed” climate datasets for modelling.

Model results using the climate perturbed climate data were used to develop the description of project effects with “future climate”. This is presented in Chapter 6, along with an overview of the methodology used to assess these model results.

As described in Section 6.1, DPE-Water have developed a climate change assessment methodology for water storage projects, which is included as Attachment A. Following this methodology, the rainfall decreases presented in Figure 4.4 and Figure 4.5 were not applied in the model directly, but rather, periods of data with rainfall statistics matching those provided on the CCA website for the Tweed Region were extracted from the climate perturbed dataset for analysis. The reason for selecting a model with dry predictions (i.e. ACCESS1.3) was so that there would be sufficient periods of 126 years that matched the CCA statistics and met the definitions for wet and dry conditions set out in the DPE-Water methodology. Other GCMs with higher rainfall did not allow production of climate sequences with rainfall reduced enough to meet the dry climate definition.

4.3 Demand growth

4.3.1 Urban demand

The DPE-Water Tweed River Valley Source model includes water supply to Tweed Shire Council Town Water Supply (i.e. Tweed Heads and Murwillumbah) and to the smaller villages of Uki and Tyalgum.

Two demand cases were considered in the Source model:

1. Current demand – demand at 2025, when the Proposal is expected to be operational
2. Future demand – demand at 2065, taken to coincide with the future climate data

Annual usage within the Source model was updated for these two demand cases based on the study into future water demand which was commissioned by Council (Hydrosphere, 2020a). Forecast demands for the Tweed District, Uki and Tyalgum are shown in Figure 4.6, with the years 2025 and 2065 highlighted.

Urban water demand is simulated as variable daily demands based on recent climate variables using an irrigation deficit model. The Source model does not currently include the application of water restrictions and associated reductions in urban water demand.

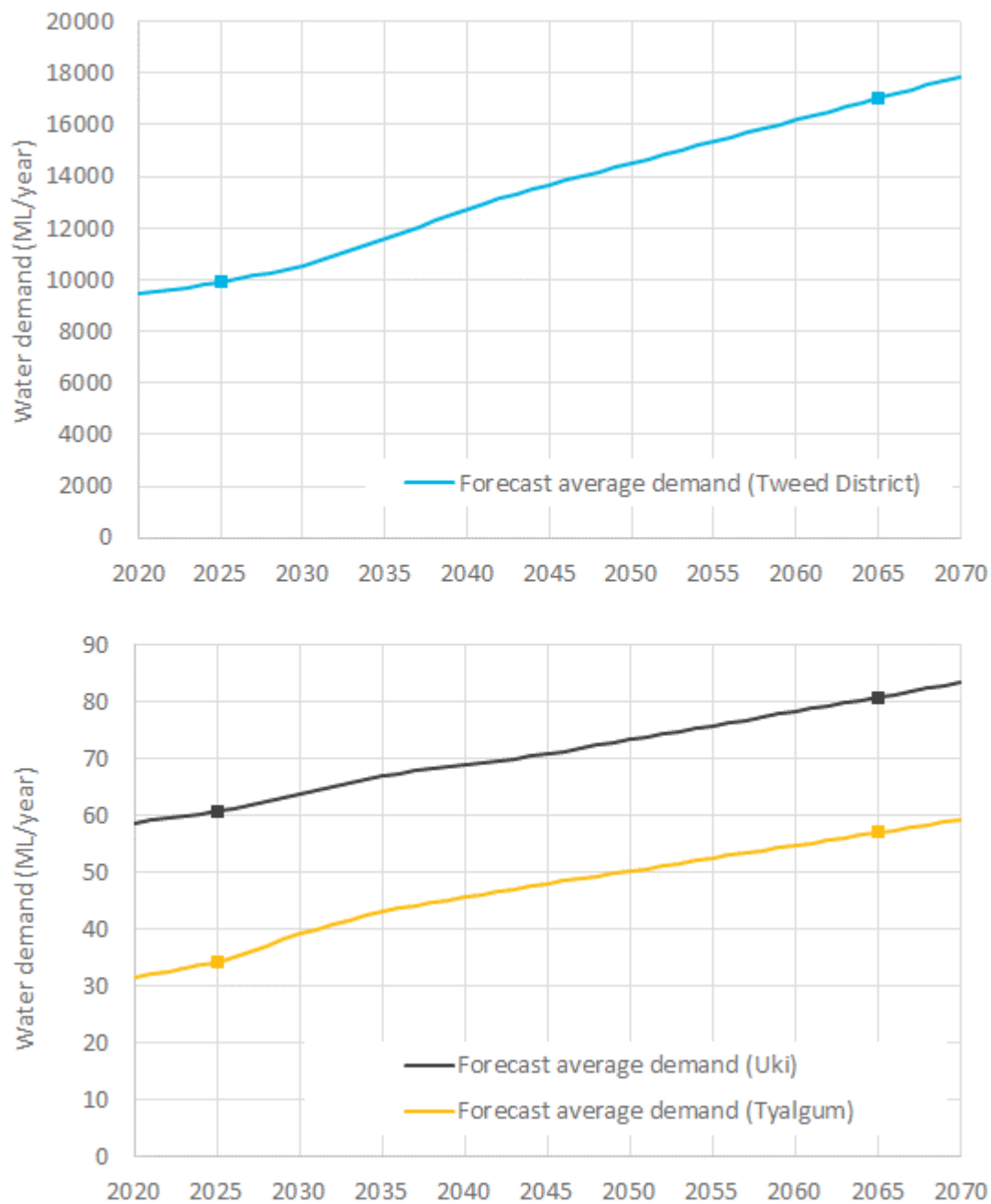


Figure 4.6 Forecast average demands for the Tweed District (top), Uki and Tyalgum (bottom) (Hydrosphere, 2020a)

4.3.2 Other demands

In addition to urban water demand, the Source model simulates demand for: basic landholder rights, stock and domestic users, unregulated river access (i.e. irrigation users), and aquifer demands. The model estimates seasonal and daily irrigation requirements for various crop based on recent climate variables using crop modelling.

Across the demand cases modelled, demand other than urban demand, remains unchanged based on the following assumptions: crop type, irrigated area and crop requirements do not change, the WSP rules do not significantly change.

4.4 Environmental water releases

Key assumptions that are implemented in the Source model and which are relevant to Clarrie Hall Dam, are outlined in Table 4.5.

Currently, the WSP specifies water storage levels for Clarrie Hall Dam as a percentage. It has been assumed in the Source modelling that specified water storage levels translate to volumes that would remain constant once Clarrie Hall Dam is raised (i.e. that a specified water storage of “50%” in the WSP is equivalent to 8 GL, which is equivalent to a water storage of 19% for the raised dam). These volumes are outlined in italics in Table 4.5 under the heading “*Proposed infrastructure*”.

Table 4.5 Water release requirements relating to Clarrie Hall Dam in the WSP (DPIE, 2023)

Releases from Bray Park Weir		
A release at least equal to the target flow rate specified must be made from Bray Park Weir through the fish ladders each day the water storage level of Clarrie Hall Dam is at the level specified.		
Water storage levels—Clarrie Hall Dam		Target flow rate
Current infrastructure	<i>Proposed infrastructure</i>	
Equal to or greater than 75%	<i>Equal to or greater than 12 GL (28% of raised dam volume)</i>	8 ML/day
Greater than 50% and less than 75%	<i>Greater than 8 GL and less than 12 GL</i>	5 ML/day
Less than or equal to 50%	<i>Less than or equal to 8 GL (19% of raised dam volume)</i>	3 ML/day
Releases from Clarrie Hall Dam in the Doon Doon Creek water source		
A release at least equal to the target flow rate specified, including releases for local water utility purposes, must be made from Clarrie Hall Dam each day the flow measured at the flow reference point is at the level specified.		
The flow reference point means the Oxley River at Eungella gauge (201001) in the Lower Oxley River Water Source.		
Flow at flow reference point	Target flow rate	
Equal to or greater than 13 ML/day	4 ML/day	
Greater than 3 ML/day and less than 13 ML/day	2 ML/day	
Less than or equal to 3 ML/day	1 ML/day	

5 Model results with current climate

5.1 Overview

An overview of model results is provided in Table 5.1, which illustrates that:

- mean extraction volumes for town water supply (TWS) would be unchanged by the Proposal
- mean managed releases from Clarrie Hall Dam would not materially change as a result of the Proposal
- the percentage of time when dam storage levels are below 13.6 GL will reduce significantly as a result of the Proposal
 - 13.6 GL is 85% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which level 1 restrictions are imposed, 7.2 GL is 45% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which emergency restrictions are imposed (Tweed Shire Council, 2022).
 - storage levels fall below 13.6 GL (the current threshold volume for water restrictions) approximately 12% of the time with the 2065 demands. With the Proposal, this is reduced to 0.1% of the time
 - storage levels fall below 7.2 GL (the current threshold volume for water restrictions) approximately 1% of the time with the 2065 demands. With the Proposal, this is reduced to 0.1% of the time
- the amount and frequency of potential demand shortfall is reduced as a result of the Proposal. Note: demand management measures which would be implemented to prevent shortfalls, are not modelled in the Source model
 - with the 2065 demands, demand shortfalls occur in 0.8% of years, roughly corresponding to the frequency of very low dam levels. This reduces to 0.1% of years with the Proposal.
- Evaporation will increase by around 3 GL/year due to the larger dam surface area, however this is offset by around 3 GL/year increased rainfall capture over the same area.
- Mean spill volumes from Clarrie Hall dam reduce by around 20 ML/year to 100 ML/year due to the Proposal, which is considered negligible in the context of Tweed River yearly flows of 163,000 ML/year past Uki.
- The Proposal has little effect on mean streamflow in the Tweed River.

Water restrictions and associated reductions in urban water demand are not modelled explicitly in the Source model because the water restrictions policy in the Tweed Valley is still relatively new and the resulting water savings are as yet unclear. If the Proposal results in less time in water restrictions, it is possible that water use over the long term may be slightly higher.

Model results in Chapter 5 were developed using palaeo-stochastic climate generated by DPE-Water (described in Section 4.2.2) other than where explicitly described as using historical climate data.

Table 5.1 Overview of model results with the current climate

Infrastructure scenario:		Current		Revised spillway (80 m wide)	
Demand case:		Current (2025)	Future (2065)	Current (2025)	Future (2065)
Clarrie Hall Dam:					
capacity	ML	16,000	16,000	42,300	42,300
FSL	m AHD	61.5	61.5	70	70
mean managed releases	ML/year	2,170	3,664	2,143	3,723
mean spills	ML/year	52,081	50,612	52,057	50,495
mean evaporation volume	ML/year	3,222	3,115	6,501	6,422
mean rainfall volume	ML/year	3,379	3,297	6,606	6,545
TWS:					
mean extraction at Bray Park Weir	ML/year	9,728	16,543	9,728	16,546
mean demand shortfall	ML/year	0.0	3.5	0	0
% of years with shortfall	%	0.0%	0.8%	0.0%	0.1%
time below 13.6 GL (85% of current infrastructure – equates to Level 1 restrictions ¹)	%	3.6%	11.6%	0.0%	0.1%
time below 7.2 GL (45% of current infrastructure – equates to Emergency level water restrictions ¹)	%	0.1%	1.0%	0.0%	0.1%
River flows:					
mean flow in Doon Doon Creek d/s of Clarrie Hall Dam	ML/year	54,251	54,277	54,200	54,218
mean flow in the Tweed River at Uki	ML/year	163,811	163,735	163,734	163,643
mean flow in the Tweed River at Braeside	ML/year	191,808	191,741	191,685	191,605
mean flow at Bray Park Weir	ML/year	285,604	285,748	285,428	285,534
Project effect at end of system (EOS)	%	-	-	-0.1%	-0.1%

1. (Tweed Shire Council, 2022)

5.2 Flow regime

5.2.1 Historical flow sequences

Flow hydrographs were developed by running the model with historical climate sequences. Two sequences are presented below to illustrate the effect of the Proposal during dry (Figure 5.1 to Figure 5.5) and wet periods (Error! Reference source not found. to Figure 5.9).

Historical climate data were used in the model to prepare Figure 5.1 to Figure 5.9. All other analysis presented in this chapter was prepared using the results of simulations using stochastic climate data.

i Dry sequence (2005 – 2007)

The drier sequence (2005 to 2007) illustrates that:

- the proposed dam would not be drawn down as far as the existing dam during drought (Figure 5.1)
- the proposed dam will take longer to fill and spill following drawdown during dry periods (Figure 5.1 and Figure 5.2)
- water releases to satisfy town water demands will be higher in the future (2065 demand reported) (Figure 5.2)
 - this effect was simulated but is not caused by the Proposal
- increased water demand in the future (2065 demand reported) will increase the time required for the dam to fill and spill following a dry period (Figure 5.1)
 - this effect was simulated but is not caused by the Proposal

Of these effects:

- the increased releases for town water supply affects Tweed River flow from Doon Doon Creek through to Bray Park Weir (Figure 5.3 to Figure 5.5)
- reduced spills following dam drawdown affects Tweed River flow from Doon Doon Creek to Uki (Figure 5.7), but effects become less noticeable at Braeside (Figure 5.8) and Bray Park Weir (Figure 5.9) due to the large unregulated upstream catchments

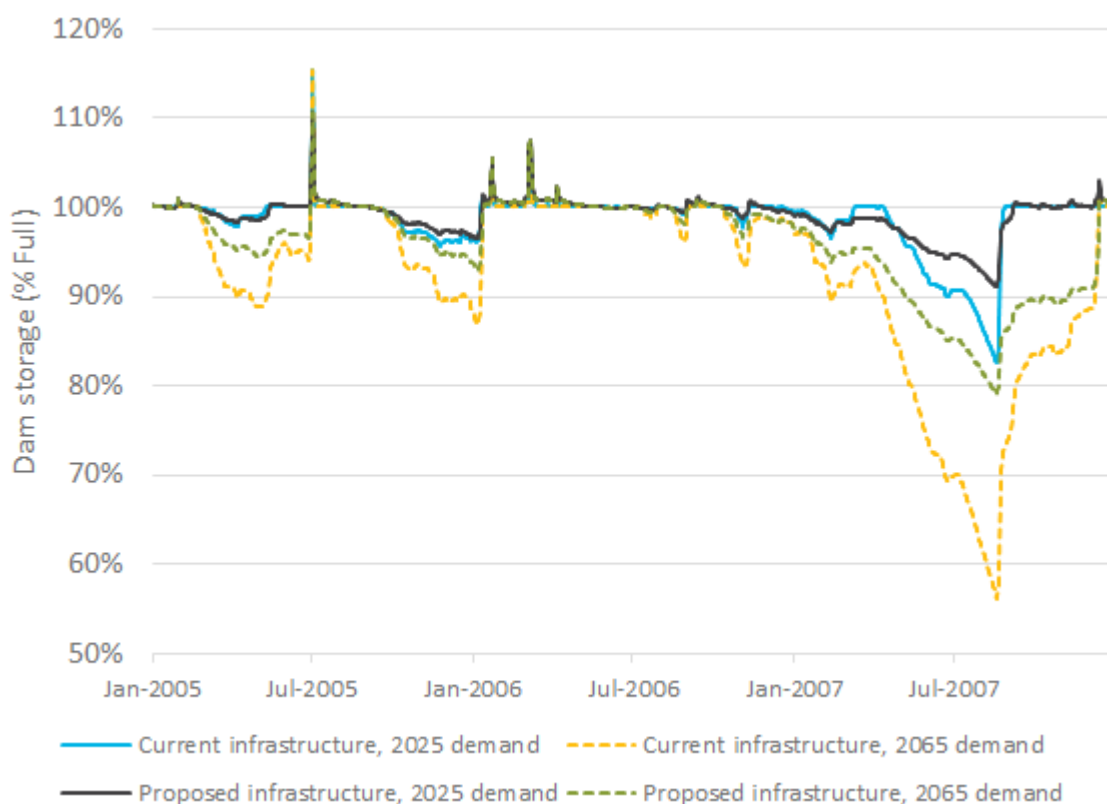


Figure 5.1 Modelled storage levels in Clarrie Hall Dam, historical climate (2005-2007)

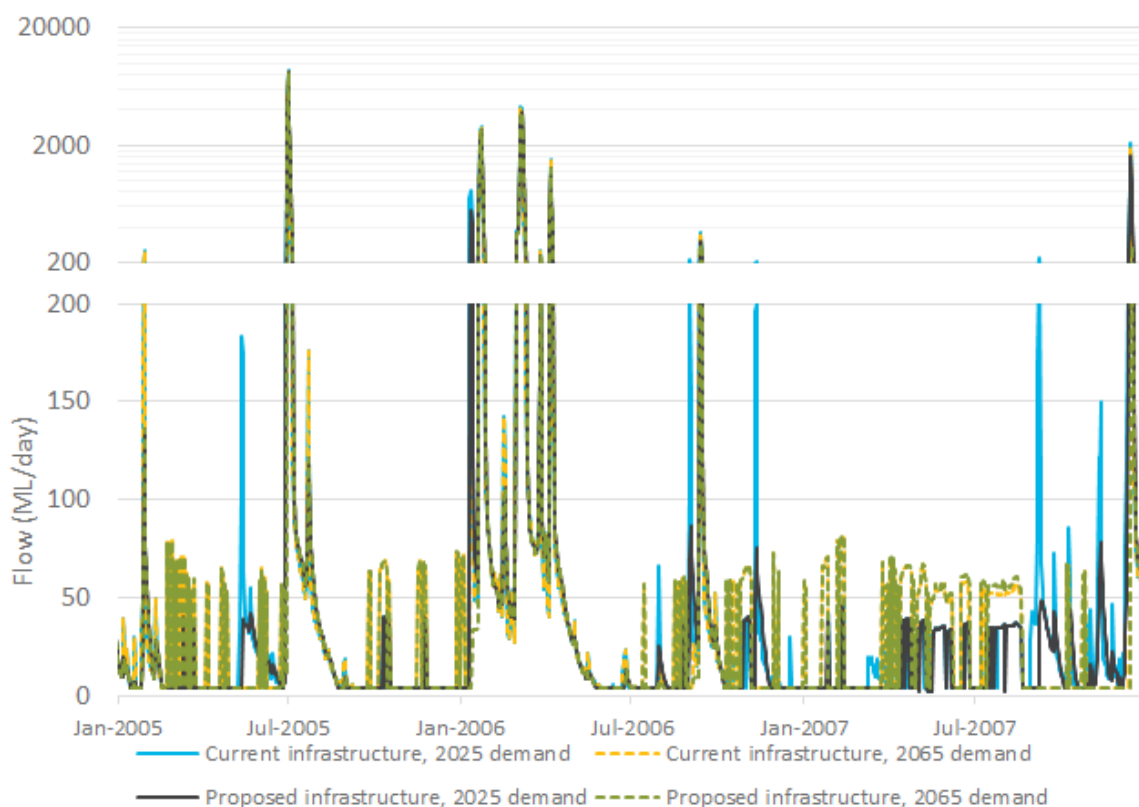


Figure 5.2 **Modelled flow in Doon Doon Creek downstream of Clarrie Hall Dam, historical climate (2005-2007)**

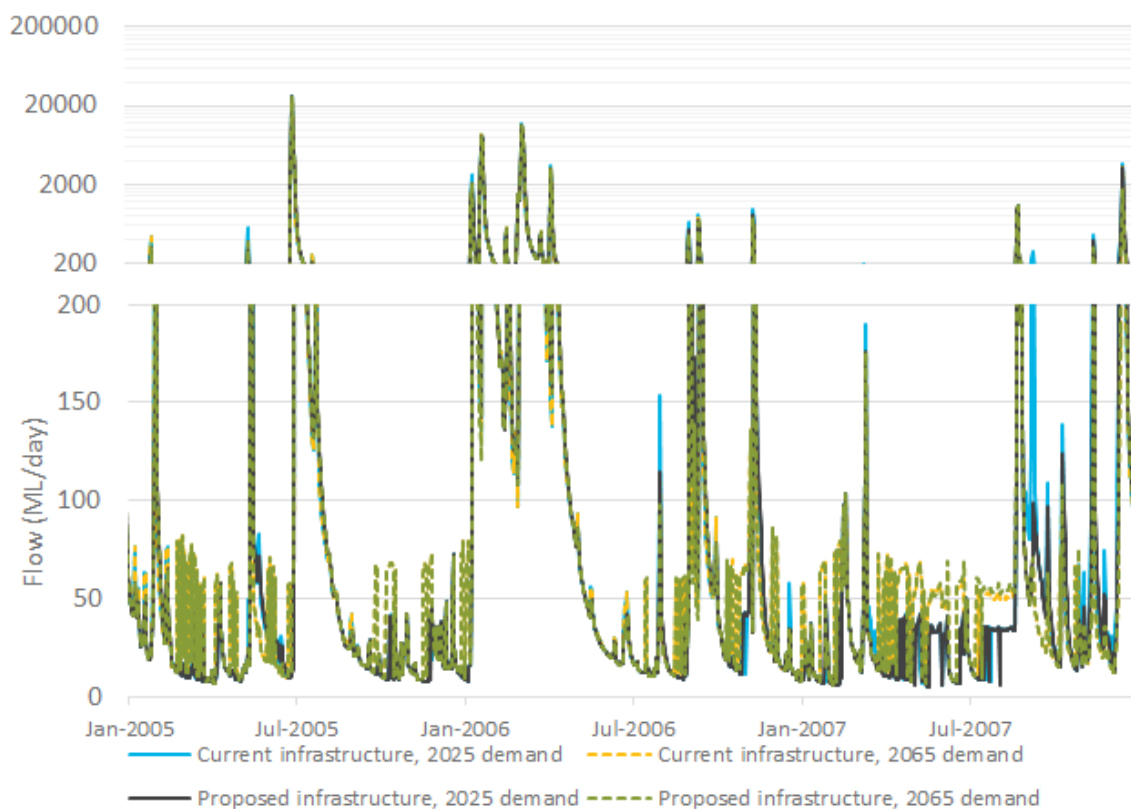


Figure 5.3 **Modelled flow in the Tweed River at Uki (201900), historical climate (2005-2007)**

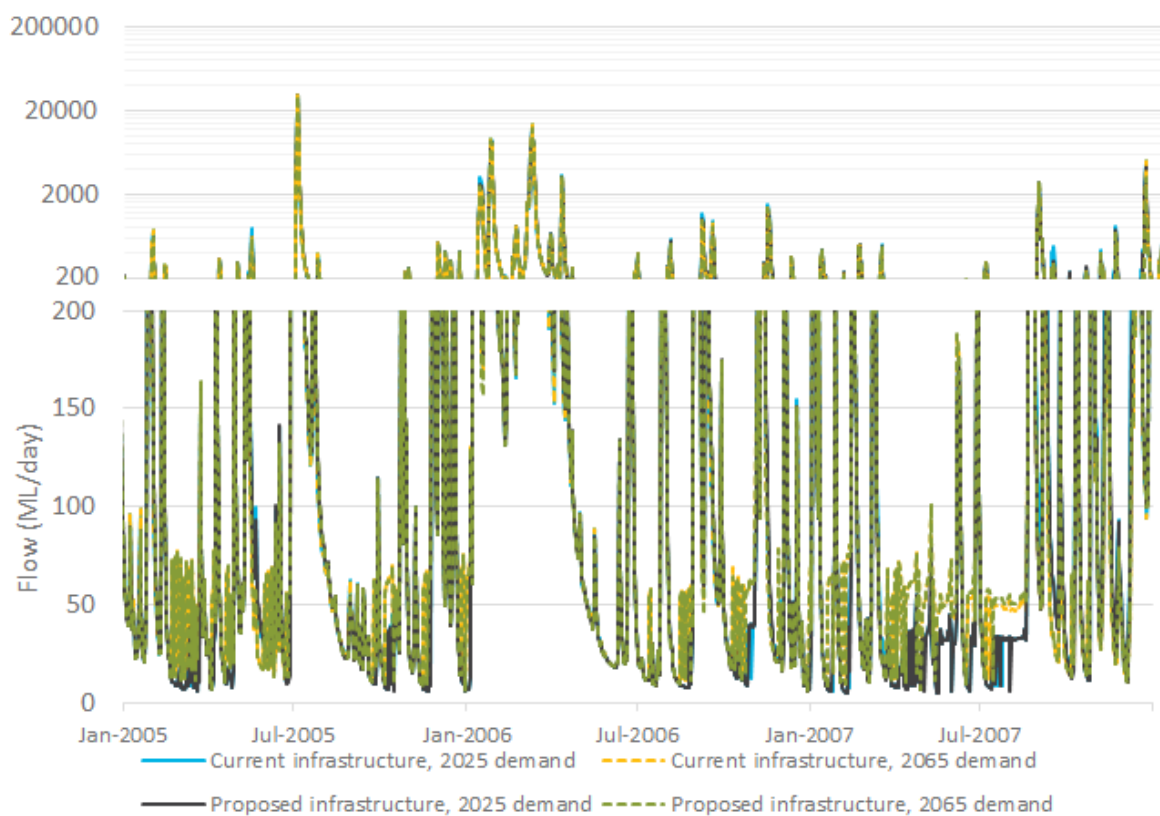


Figure 5.4 Modelled flow in the Tweed River at Braeside (201003), historical climate (2005-2007)

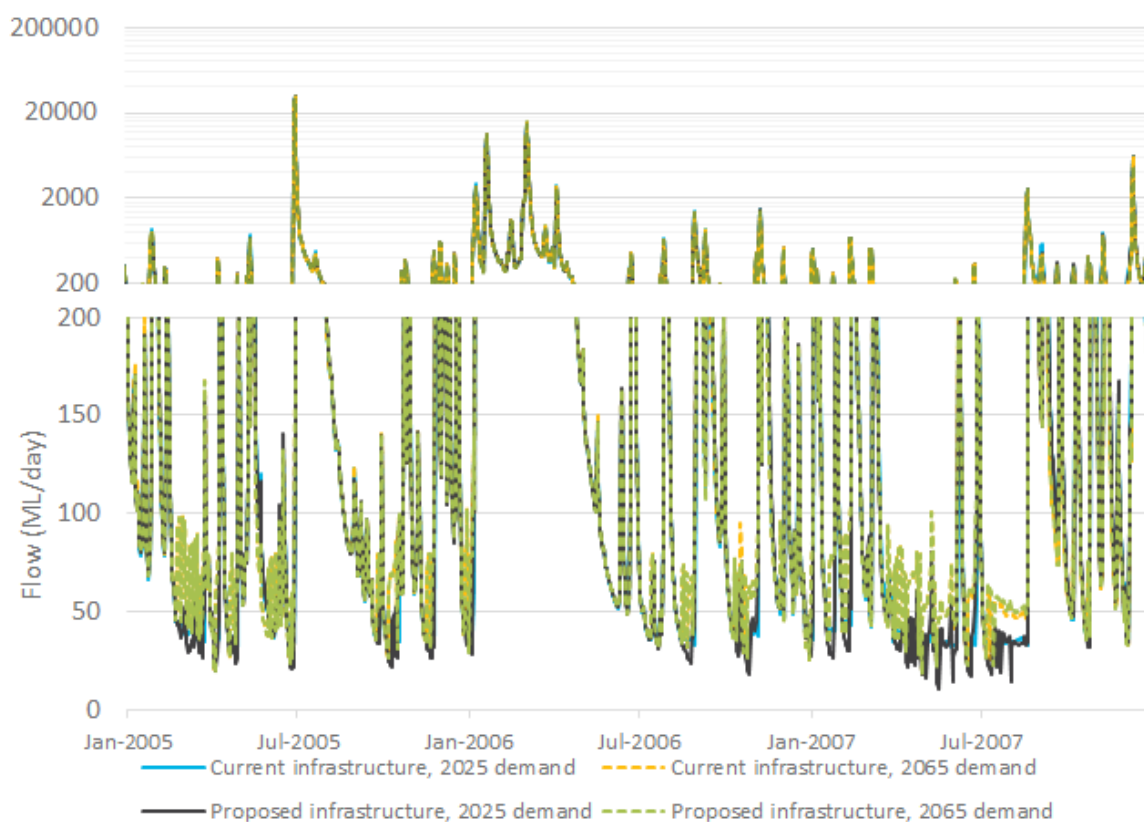


Figure 5.5 Modelled flow downstream of Bray Park Weir, historical climate (2005-2007)

ii Wet sequence (1976)

During wetter sequences (eg 1976) the proposed raised dam with a revised (80 m wide) spillway will result in flow sequences in Doon Doon Creek which are very similar (peaks, recession, and flow duration) to those which would occur with the existing dam (Figure 5.6). Subsequently, the flow regime in the Tweed River would be unaffected by the project (Figure 5.7 to Figure 5.9).

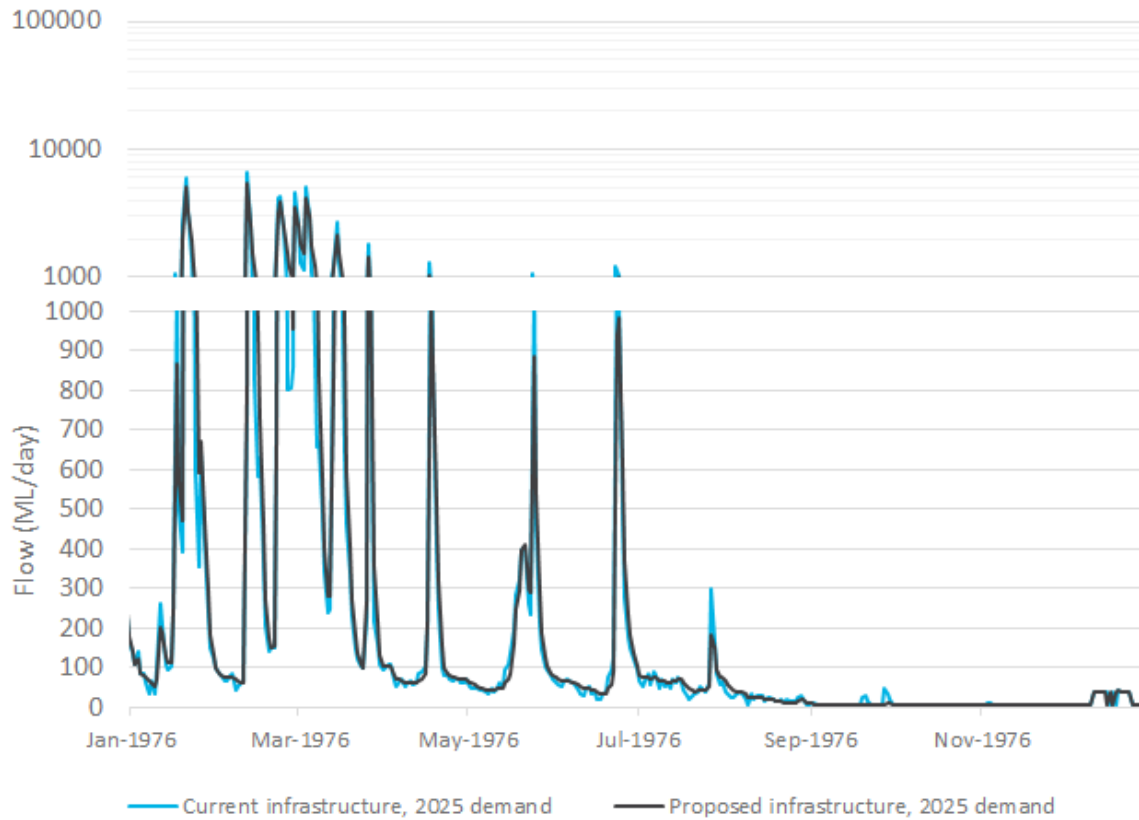


Figure 5.6 Modelled flow in Doon Doon Creek downstream of Clarrie Hall Dam, historical climate (1976)

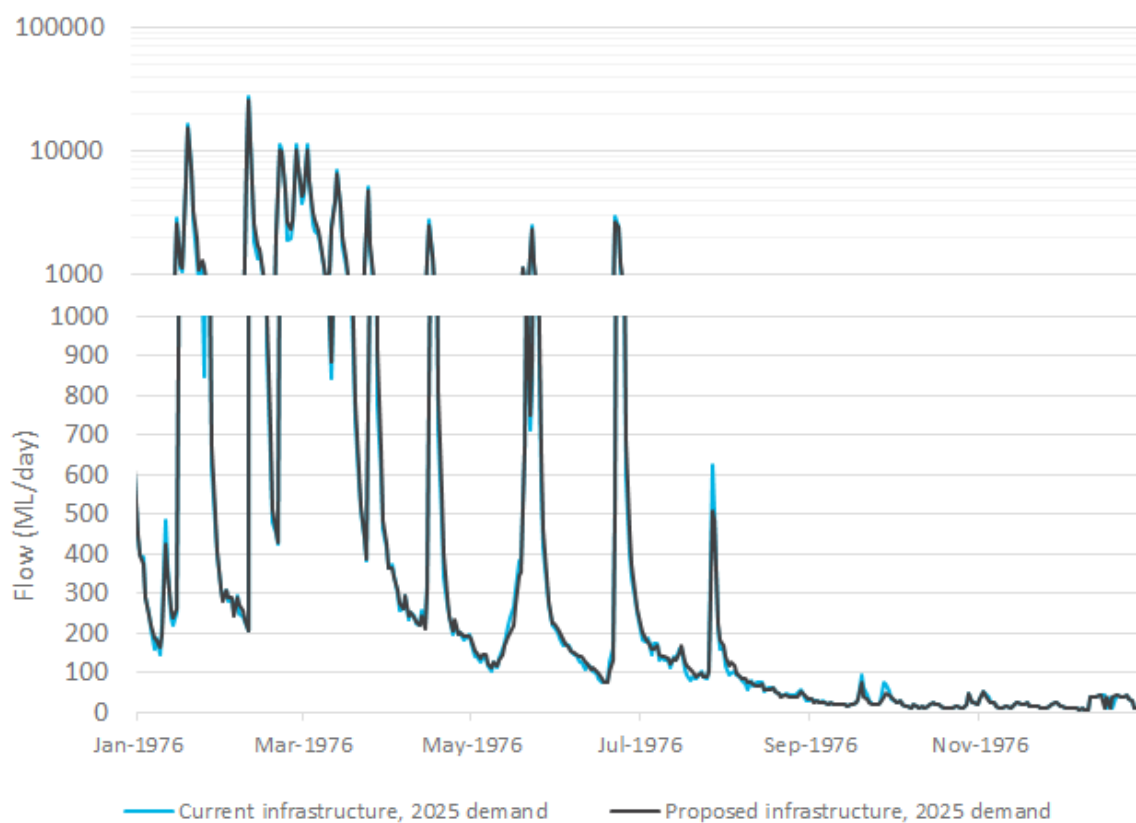


Figure 5.7 **Modelled flow in the Tweed River at Uki (201900), historical climate (1976)**

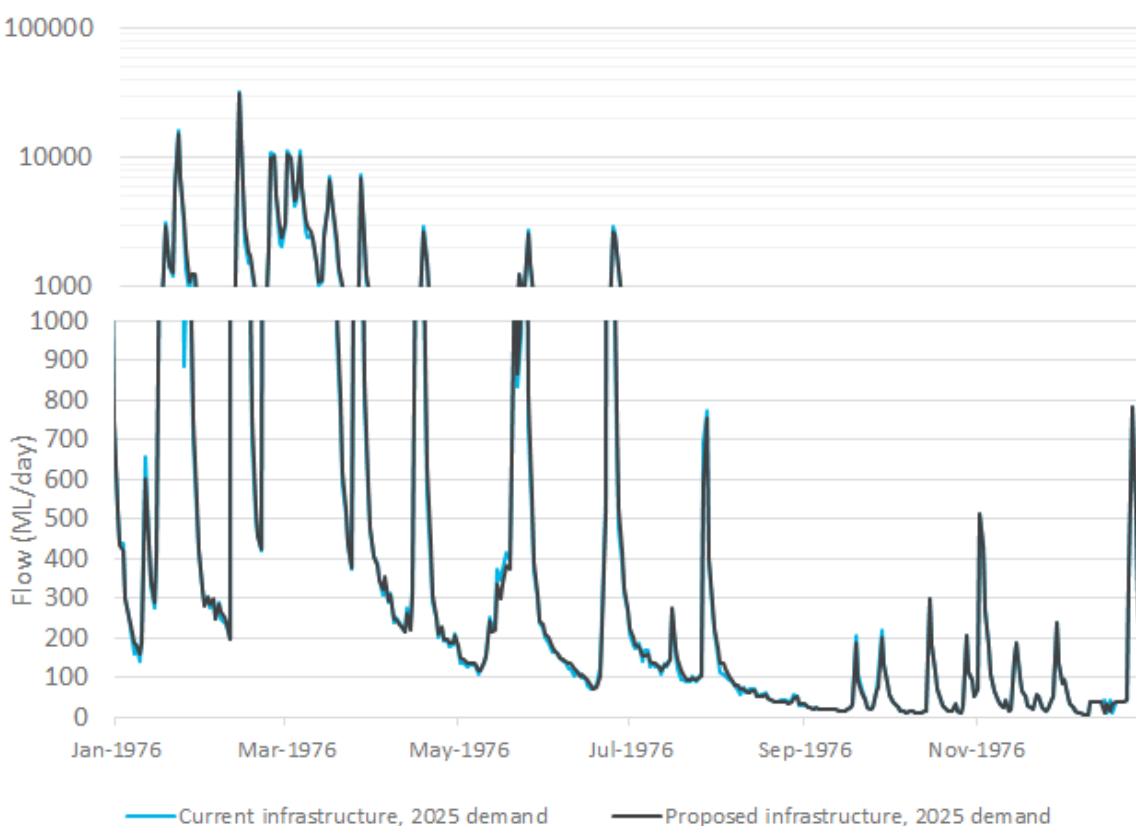


Figure 5.8 **Modelled flow in the Tweed River at Braeside (201003), historical climate (1976)**

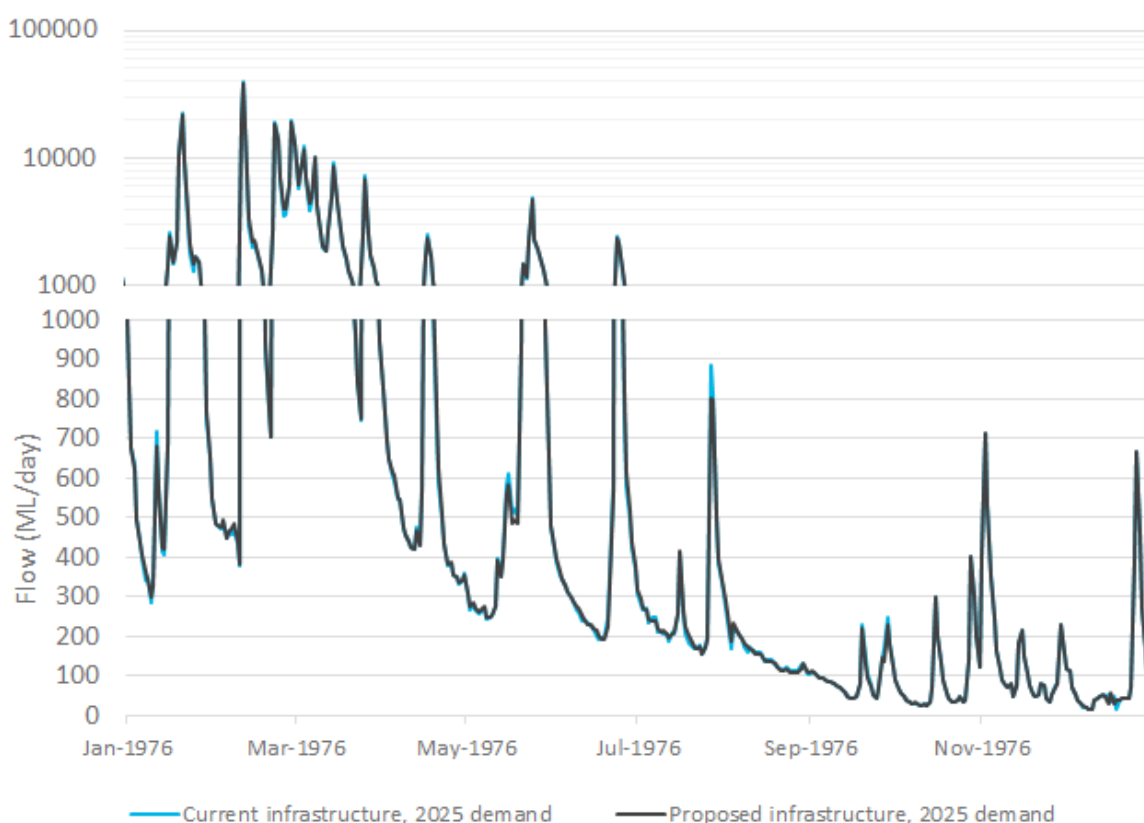


Figure 5.9 Modelled flow downstream of Bray Park Weir, historical climate (1976)

5.2.2 Flow duration curves

Seasonal flow duration curves (Figure 5.10 to Figure 5.12) were developed from the flow results of simulations using palaeo-stochastic climate data.

Flow duration curves for Doon Doon Creek (Figure 5.10) show that:

- the reduction in flood peak flow rate due to the larger dam (Section 5.2.1ii) is associated with the low probability (0% - 2%) section of the curve
- the extended recession period following a high flow event (Section 5.2.1ii) is seen in the 3% - 15% section of the curve, with flows of ~130 – 1,000 ML/day occurring on more days
 - this effect is less pronounced in Spring, when conditions are driest and there are fewer flood events
- through the typical daily operations part of the curve (30% - 65%), future (2065) demand results in increased flows by around 6 ML/day
- minimum releases are expected to currently occur around 30% of the time (from 70% to 100% on the curve), but this would increase to 35% of the time (from 65% to 100% on the curve) with the larger dam
 - this is caused by the increased surface area of the dam resulting in higher volumes evaporated from the dam surface, which in turn results in the dam spilling less often. Manual releases of the minimum flow would then be required.

Within 5 km downstream at Uki (Figure 5.11), most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional

catchment area and unaffected tributaries. The reduction in high flow events and increase in moderate flow events due to the increased flood capture and attenuation capacity of the dam and longer flood recession, are still present but have reduced influence on the flow statistics.

Flow duration curves for the Tweed River at Braeside (Figure 5.12) and Bray Park Weir (Figure 5.13), 7.5 km and 10 km downstream of the dam respectively, show that there is negligible change in the long term Tweed River flow regime due to the proposed infrastructure.

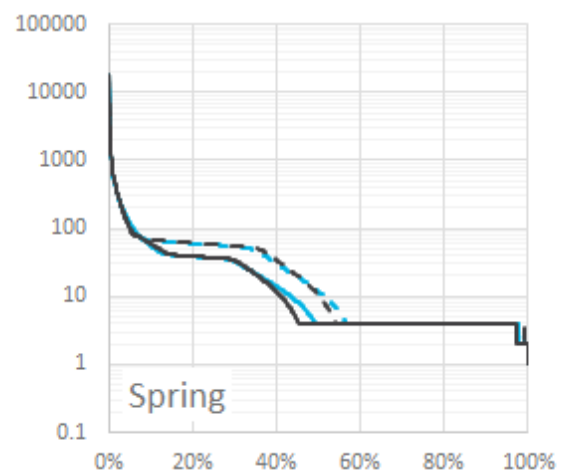
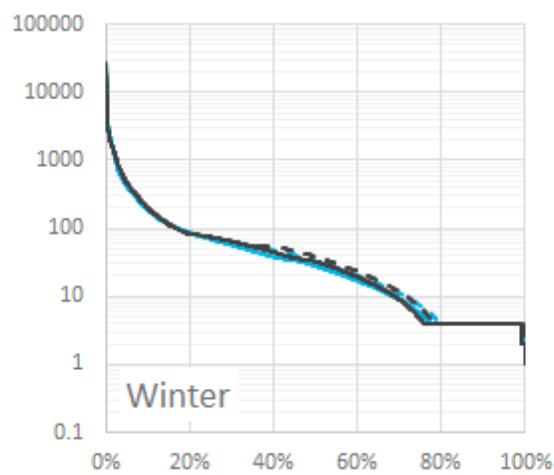
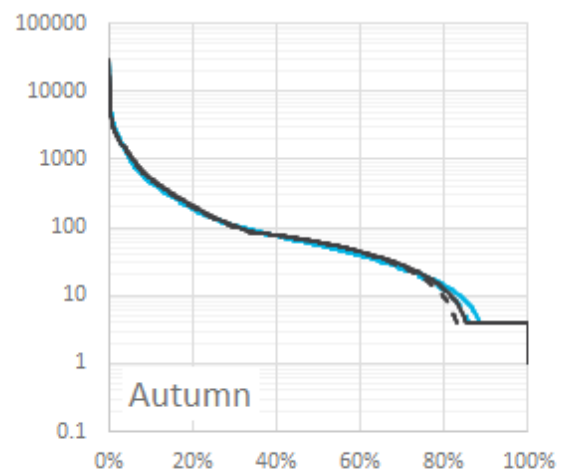
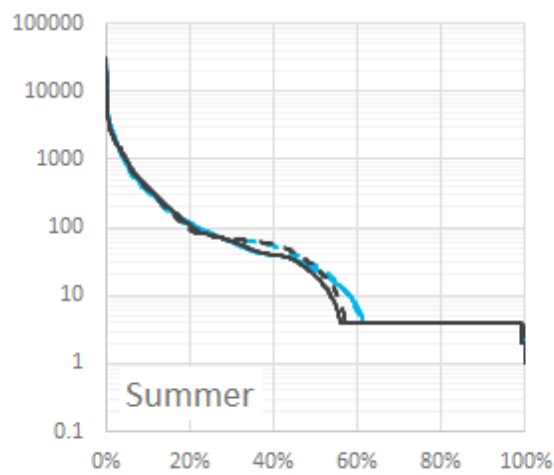
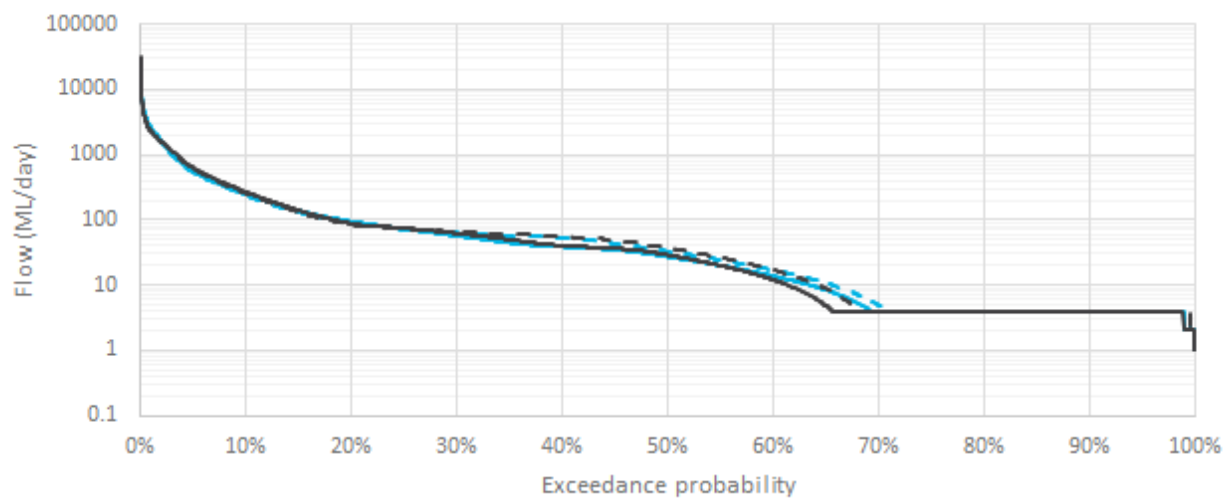


Figure 5.10 Flow duration curve at Doon Doon Creek downstream of Clarrie Hall Dam, current climate

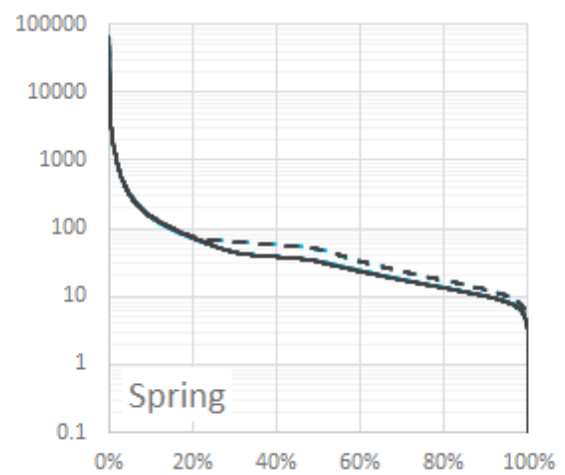
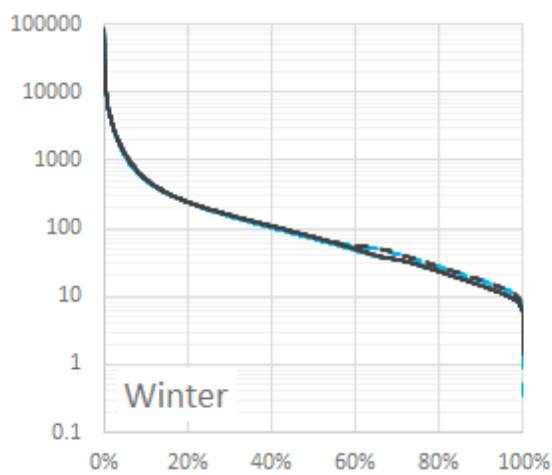
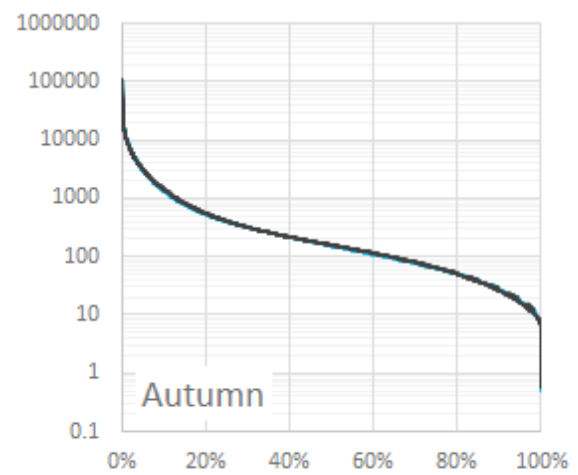
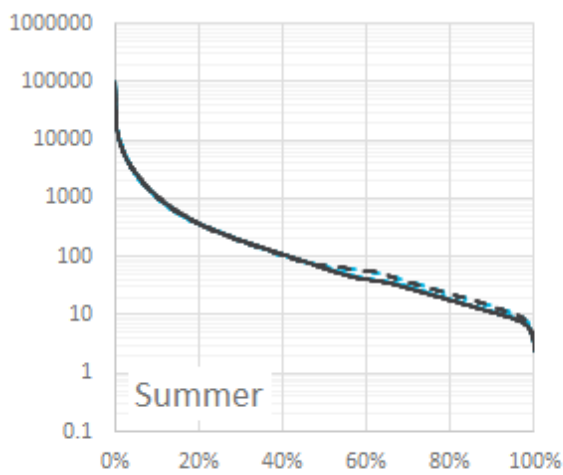
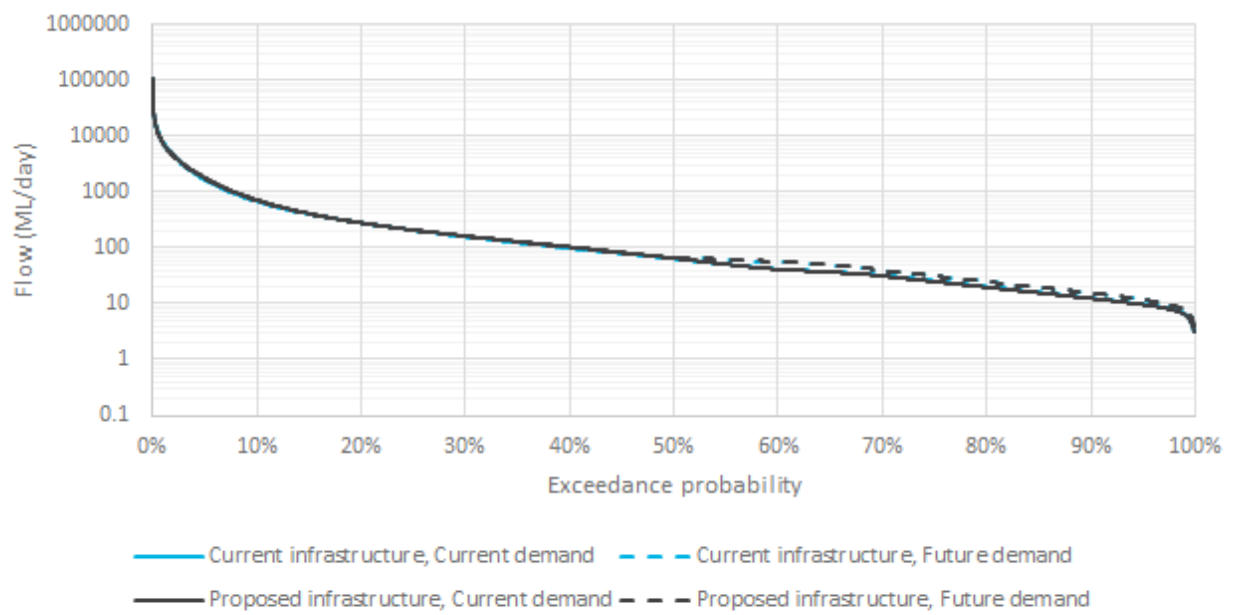


Figure 5.11 Flow duration curve for Tweed River at Uki (201900), current climate

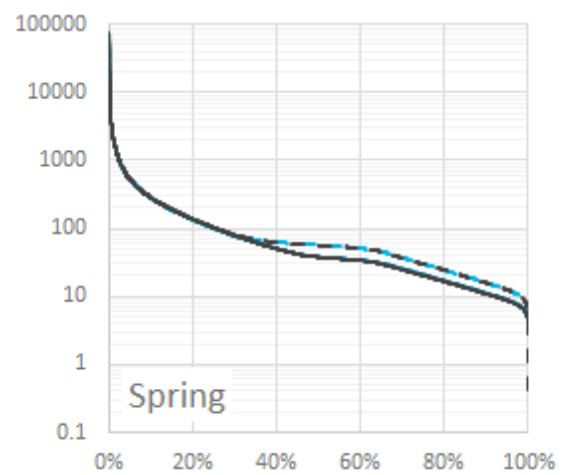
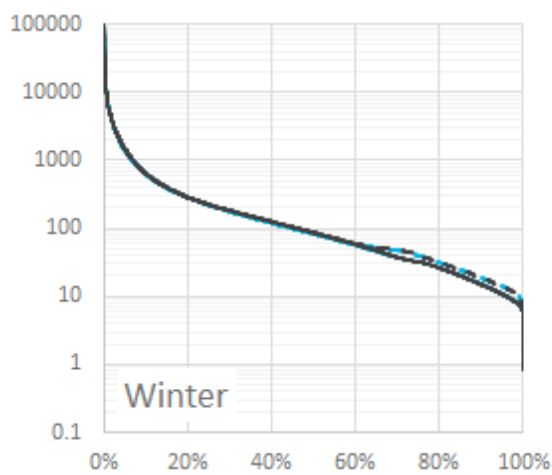
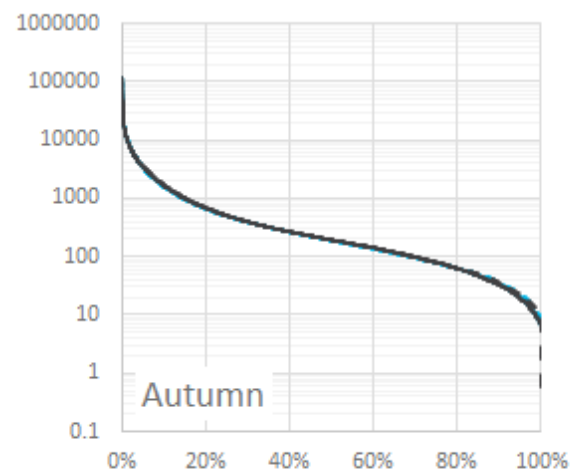
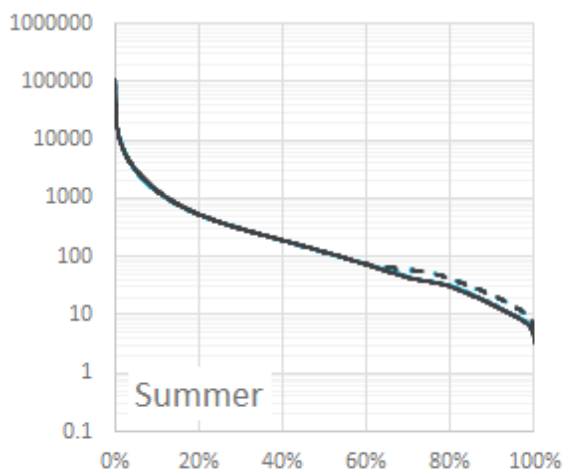
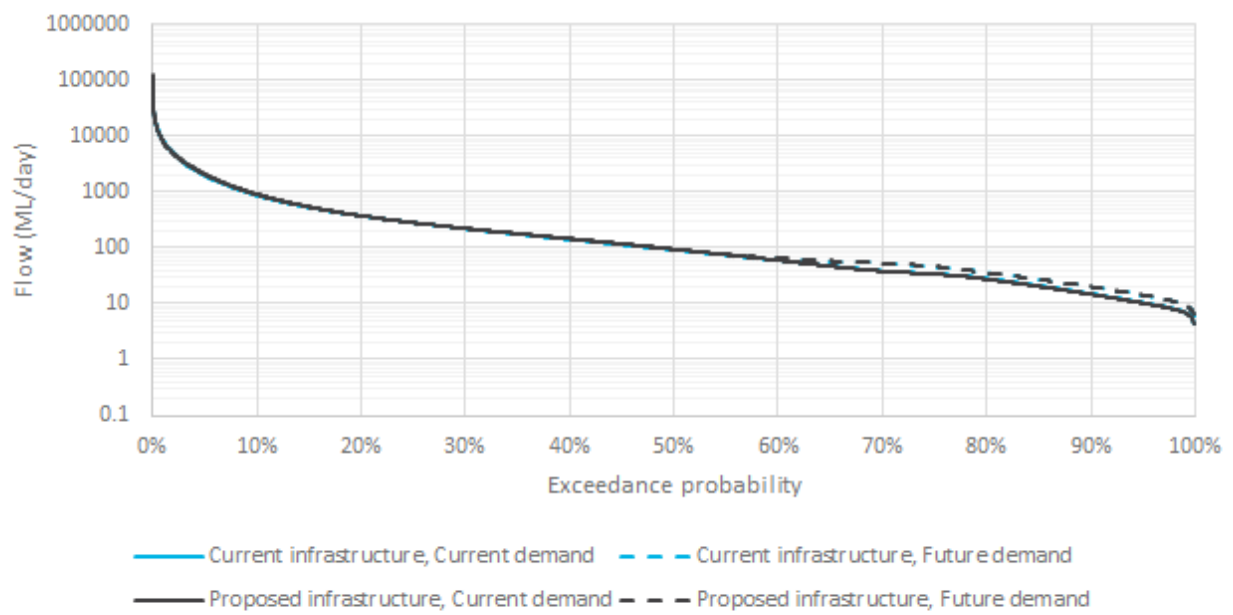


Figure 5.12 Flow duration curve for Tweed River at Braeside (201003), current climate

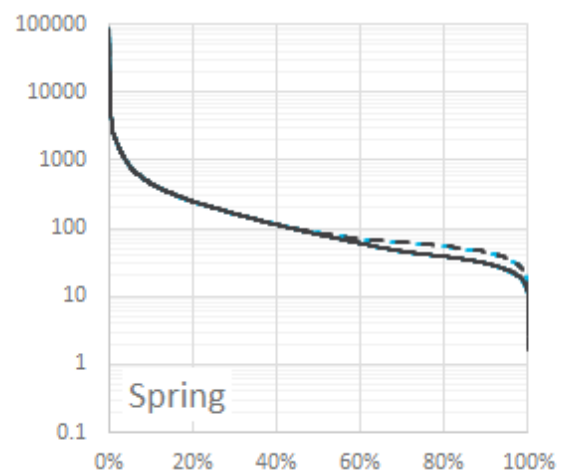
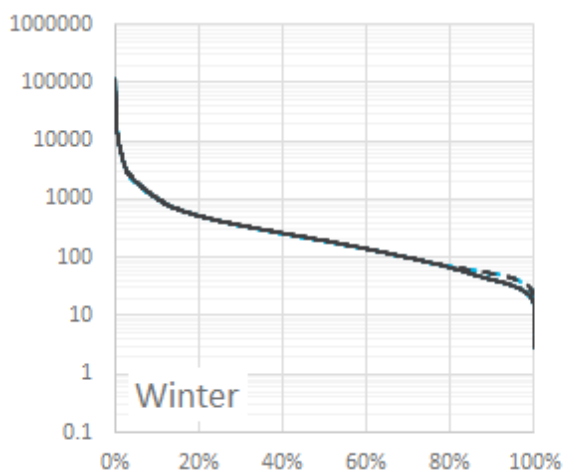
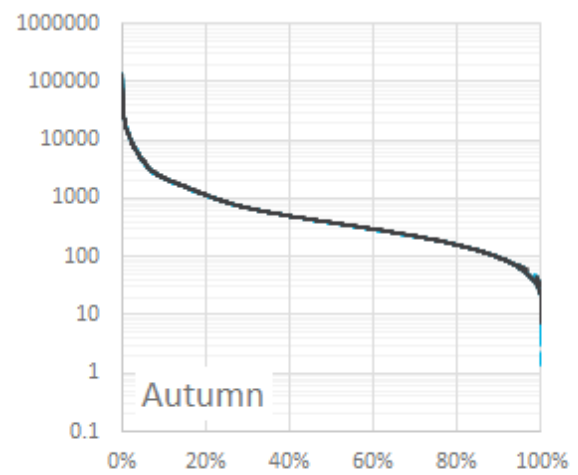
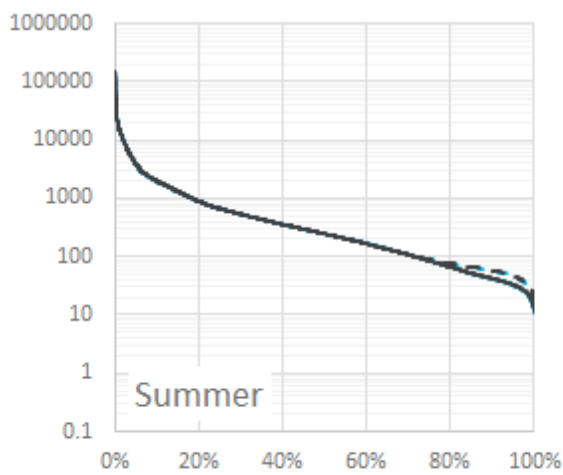
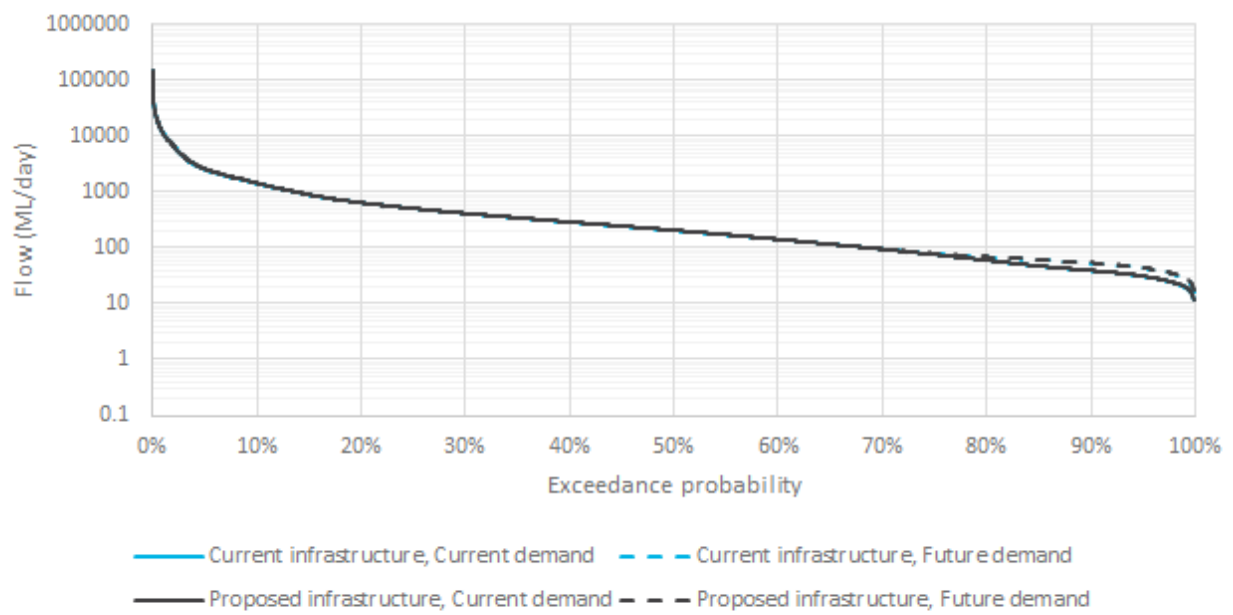


Figure 5.13 Flow duration curve for Tweed River downstream of Bray Park Weir, current climate

5.3 Clarrie Hall Dam storage

Figure 5.14 shows probability of exceedance curves for Clarrie Hall Dam storage levels, developed from the flow results of simulations using palaeo-stochastic climate data.

This figure shows that:

- Under both infrastructure scenarios (i.e. with and without the Proposal):
 - Clarrie Hall Dam would be full approximately 70% of the time under both current and future demand cases
 - storage levels would exceed FSL only very infrequently (0% - 3%)
 - storage levels would be lower under the future demand case, as more releases are made from the dam for water supply purposes
- Without the Proposal, storage levels fall below FSL approximately 25% of the time (between 75% and 100% on the probability of exceedance curve). However, this corresponds to falling below 13.6 GL – which is 85% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which level 1 restrictions are imposed (Tweed Shire Council, 2022) – approximately 4% of the time with current demand and 12% of the time with future demand. This is most likely to occur during summer and spring.
- with the Proposal, storage levels fall below FSL for approximately the same amount of time (i.e. 25% of the time), however storage levels remain above 30 GL (i.e. approximately 70% of proposed capacity), 99% of the time under current and future demand cases

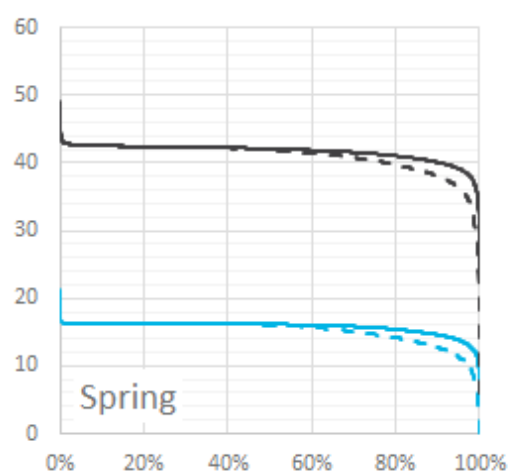
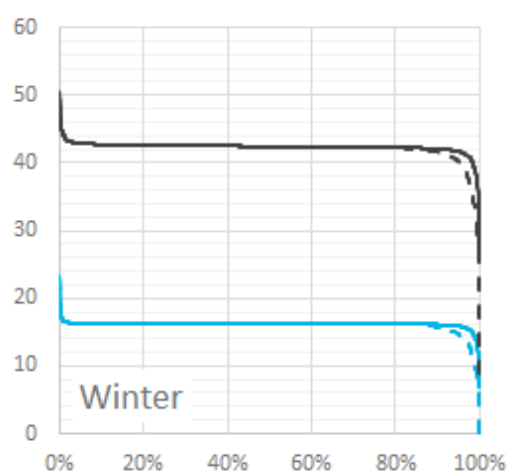
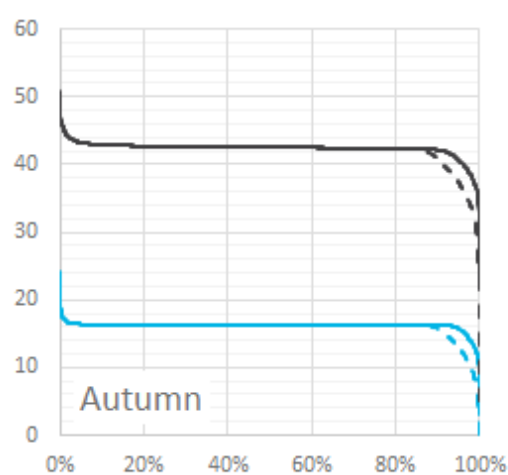
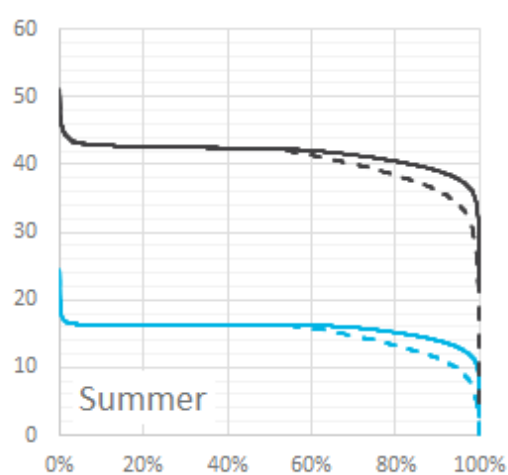
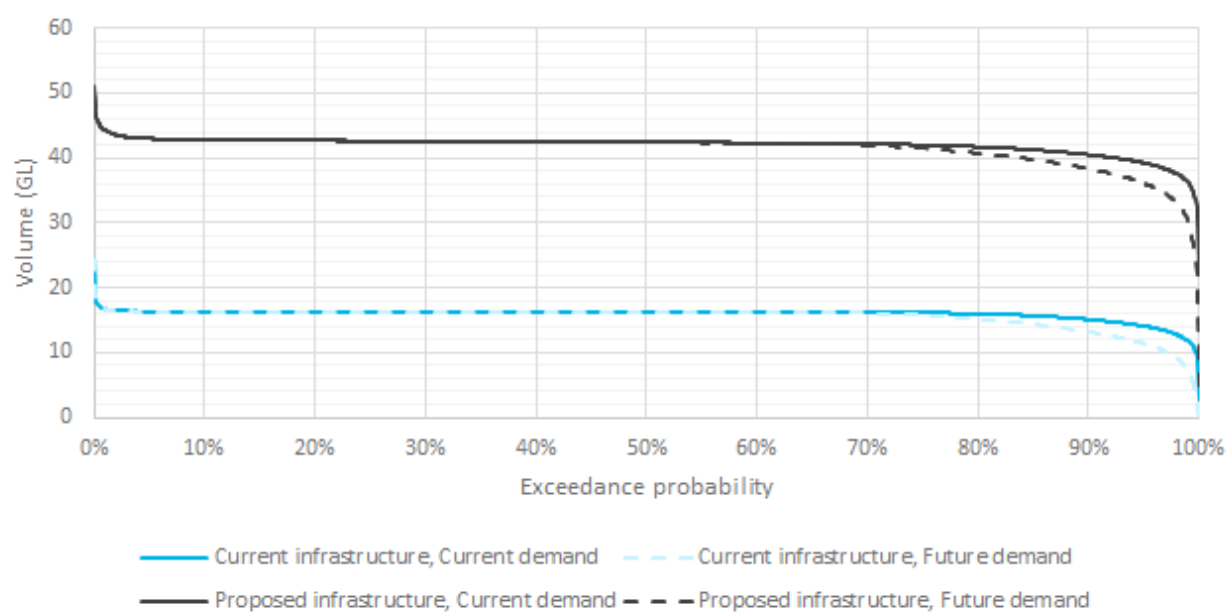


Figure 5.14 Duration curve for storage volumes at Clarrie Hall Dam, current climate

6 Model results with future climate

6.1 Assessment approach

6.1.1 Future climate

DPE-Water have developed a climate change assessment methodology for water storage projects, included as Attachment A. This methodology describes a method of selecting discrete periods of data from the perturbed palaeo-stochastic climate data set for analysis rather than analysis of the data in its entirety. By doing so, the variance which could be generated through selecting one climate model over another is reduced, as the periods selected for analysis are selected based on descriptive statistics presented on the Climate Change in Australia (CCA) website.

For the East Coast (South) NRM sub-cluster, the CCA website provided the following projections for 2070:

- 90th percentile (wet future): +22.2% rainfall (average 2,375 mm/year)
- 50th percentile (median future): -0.8% rainfall (average 1,929 mm/year)
- 10th percentile (dry future): -18.3% rainfall (average 1,587 mm/year)

Three wet, dry and median sequences of 126 years were extracted from the stochastic model results (Table 6.1), with each of these sequences having different temporal characteristics (i.e. sequencing and variability).

Table 6.1 Data sequences analysed (each 125 years)

	Start date	End date	Average Rainfall (mm)
Wet	1/01/7769	31/12/7894	2,116
	1/01/8002	31/12/8127	2,120
	1/01/5504	31/12/5629	2,058
Median	1/01/1790	31/12/1915	1,932
	1/01/5472	31/12/5597	1,918
	1/01/7660	31/12/7785	1,913
Dry	1/01/667	31/12/792	1,692
	1/01/5677	31/12/5802	1,690
	1/01/8484	31/12/8609	1,644

6.1.2 Future demand

Future climate effects were assessed using the future demand case (i.e. demand at 2065), as both climate change and demand growth relate to future events.

6.2 Overview

A summary of project effects with future climate data and future demand is presented in Table 6.2, which illustrates that:

- mean extraction volumes for TWS would be unchanged
- managed releases from Clarrie Hall Dam would become more frequent as a result of the Proposal (+3% to +10%)
- the percentage of time when dam storage levels are low will reduce significantly as a result of the Proposal
 - 13.6 GL is 85% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which level 1 restrictions are imposed, 7.2 GL is 45% of the current capacity of Clarrie Hall Dam and corresponds to the dam storage level below which emergency restrictions are imposed (Tweed Shire Council, 2022).
 - Storage levels fall below 13.6 GL (the current threshold volume for Stage 1 water restrictions) approximately 45% of the time in a dry sequence. With the Proposal, this is reduced to 3.4% of the time.
 - Storage levels fall below 7.2 GL (the current threshold volume for Emergency level water restrictions) approximately 14% of the time in a dry sequence. With the Proposal, this is reduced to 1.7% of the time.
- the amount and frequency of demand shortfall is significantly reduced as a result of the Proposal. Note: demand management measures which would be implemented to prevent shortfalls, are not modelled in the Source model
 - in a dry sequence, demand shortfalls occur in 9% of years, similar to the frequency of very low dam levels. This reduces to 2.6% of years with the Proposal.
- The Proposal could result in a decrease in mean flow past BPW of around 0.5%. This is likely due to increased net evaporation from the dam surface. This is particularly pronounced in a dry sequence where there is increased evaporation over the dam surface which is not offset by a similar increase in rainfall.

Table 6.2 Overview of model results with the future climate

Infrastructure scenario:		Current			Revised spillway (80 m wide)		
Demand case:		Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)
		wet	median	dry	wet	median	dry
Clarrie Hall Dam:							
capacity	ML	16,000	16,000	16,000	42,300	42,300	42,300
FSL	m AHD	61.5	61.5	61.5	70	70	70
mean managed releases	ML/year	5,677	6,164	7,189	5,833	6,435	7,843
mean spills	ML/year	44,875	35,649	23,536	44,254	34,608	21,834

Table 6.2 Overview of model results with the future climate

Infrastructure scenario:		Current			Revised spillway (80 m wide)		
Demand case:		Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)	Future (2065)
		wet	median	dry	wet	median	dry
mean evaporation volume	ML/year	3,184	3,054	2,744	6,843	6,726	6,372
mean rainfall volume	ML/year	3,074	2,684	2,116	6,268	5,604	4,643
TWS:							
mean extraction at Bray Park Weir	ML/year	17,258	17,367	17,489	17,269	17,410	17,681
mean demand shortfall (assuming full demand, unaffected by restrictions)	ML/year	11	44	219	0	1	27
% of years with shortfall		0.8%	3.2%	9.0%	0.3%	0.5%	2.6%
Time below 13.6 GL (Current Stage 1 restrictions trigger)	%	25.4%	31.7%	45.3%	0.1%	0.6%	3.4%
Time below 7.2 GL (current Emergency level water restrictions trigger)	%	2.2%	5.2%	13.5%	0.0%	0.1%	1.7%
River flows:							
mean flow in Doon Doon Creek d/s of Clarrie Hall Dam	ML/year	50,552	41,813	30,725	50,087	41,044	29,678
mean flow in the Tweed River at Uki	ML/year	157,285	128,139	92,648	156,793	127,340	91,548
mean flow in the Tweed River at Braeside	ML/year	185,033	153,532	114,074	184,506	152,727	112,997
mean flow at Bray Park Weir	ML/year	268,765	222,150	163,391	268,313	221,521	162,614
Project effect on EOS	%	-	-	-	-0.2%	-0.3%	-0.5%

6.3 Flow regime

6.3.1 Flow duration curves

Seasonal flow duration curves for Doon Doon Creek and the Tweed River with future climate and demand are shown in Figure 6.1 to Figure 6.4.

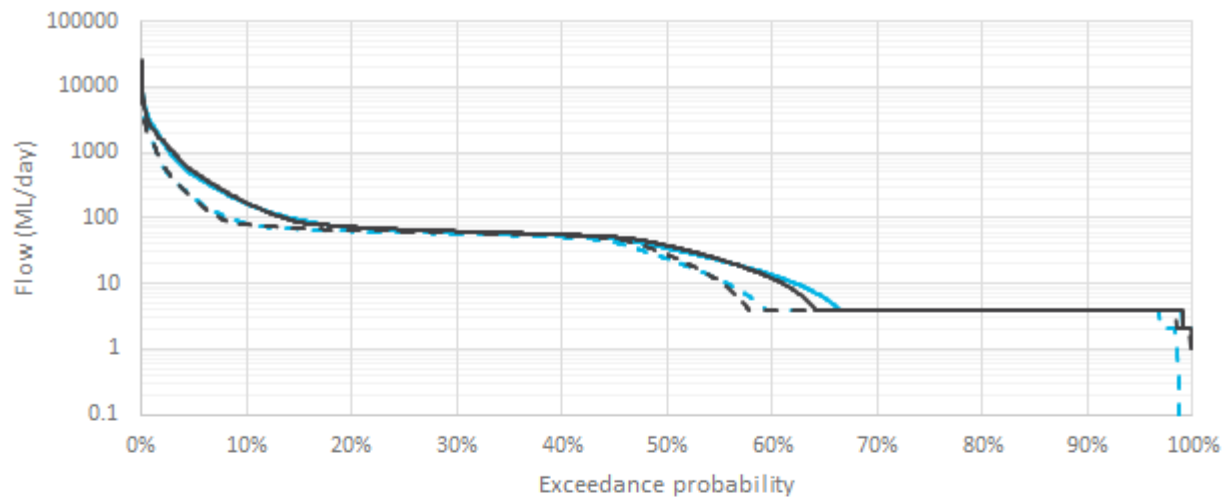
Flow duration curves for Doon Doon Creek (Figure 6.1) show that:

- There is an increase of approximately 6-7% in the amount of time flow is due to minimum releases in Doon Doon Creek in a dry climate versus a wet climate. The effect due to climate is consistent with and without the Proposal, however minimum releases also occur more frequently due to the Proposal (an increase of approximately 5-6%), which may be due to increased evaporation from the larger dam surface area under a drier climate.

- There is a corresponding decrease in spill from the dam in a dry climate versus a wet climate, associated with the lower probability (0% - 15%) section of the curve. This is likely due to less rainfall and higher evaporation levels causing reduced runoff from the catchment area during rainfall events and because dam storage levels are at less than FSL more of the time (Figure 6.5) meaning flow entering the dam is captured.
- The “stepped” nature of the flow duration curves is due to the majority of flow from the dam being managed releases – with an increase from environmental releases of 4 ML/day to releases for water supply, which are approximately 40 ML/day under future demand conditions. This is most pronounced under dry sequences and during spring, when conditions are driest.

Within 5 km downstream at Uki (Figure 6.2), most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional catchment area and unaffected tributaries. The reduction in high flow events and increase in moderate flow events due to the increased flood capture and attenuation capacity of the dam and longer flood recession, are still present but have reduced influence on the flow statistics.

Flow duration curves for the Tweed River at Braeside (Figure 6.3) and Bray Park Weir (Figure 6.4), 7.5 km and 10 km downstream of the dam respectively, show that there is negligible change in the long term Tweed River flow regime due to the proposed infrastructure under future climate conditions. In general, flows are lower during dry sequences. This was simulated but is not caused by the Proposal.



— Current infrastructure, Wet - - - Current infrastructure, Dry
 — Proposed infrastructure, Wet - - - Proposed infrastructure, Dry

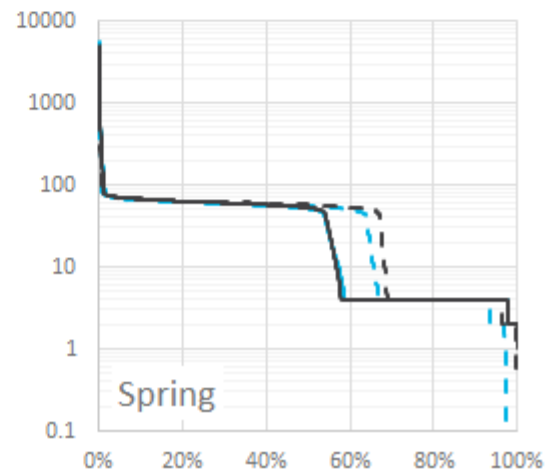
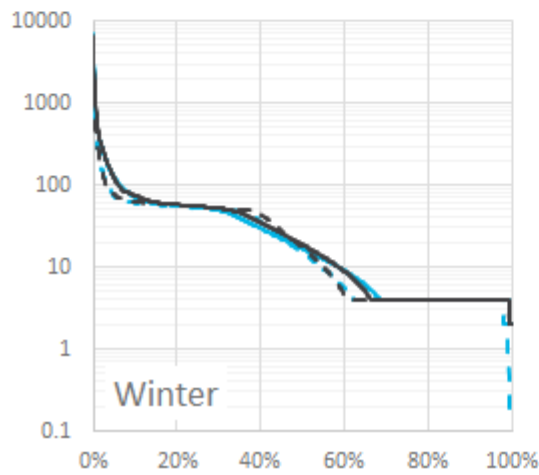
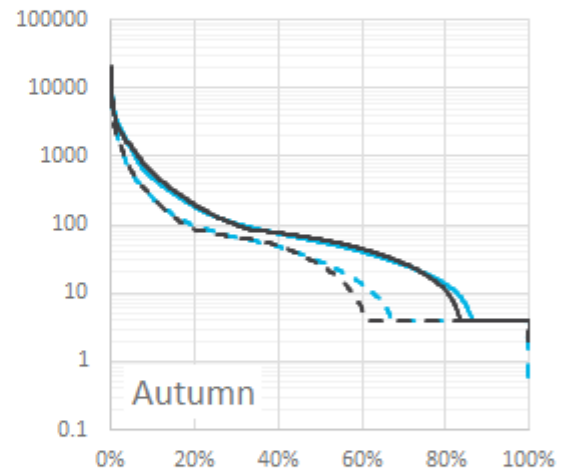
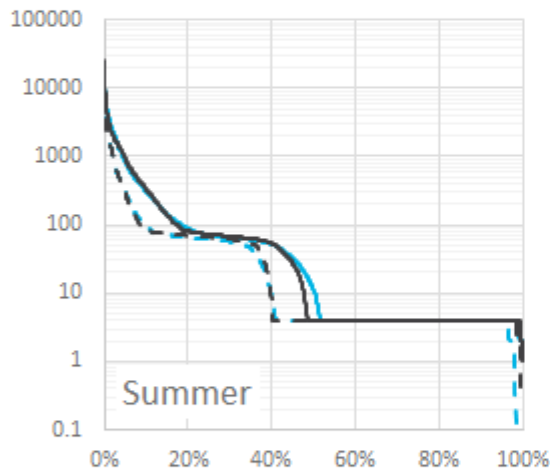


Figure 6.1 Flow duration curve at Doon Doon Creek downstream of Clarrie Hall Dam, future climate

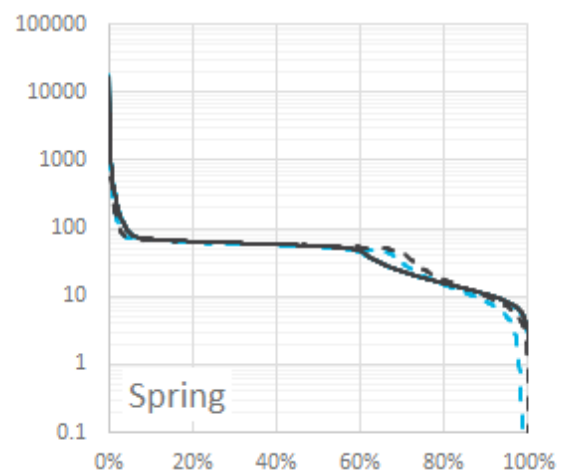
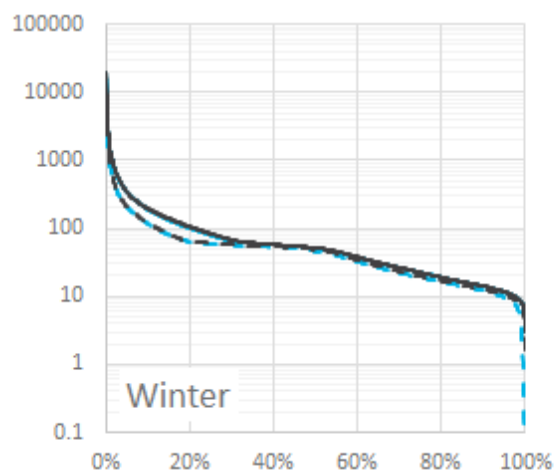
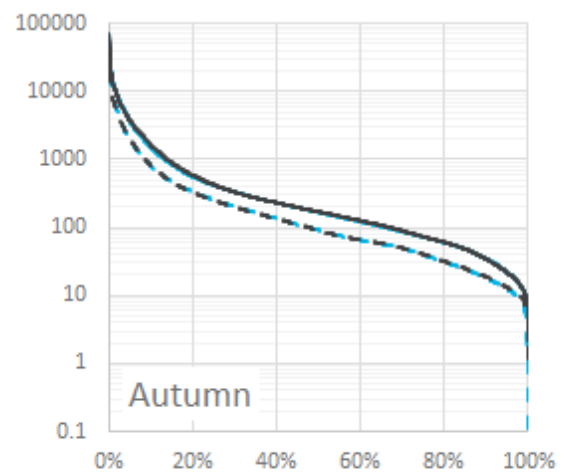
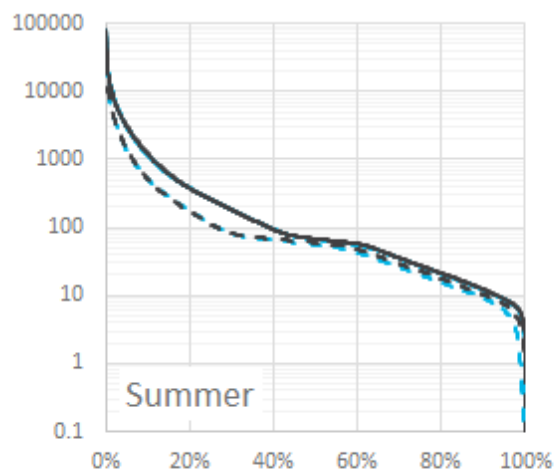
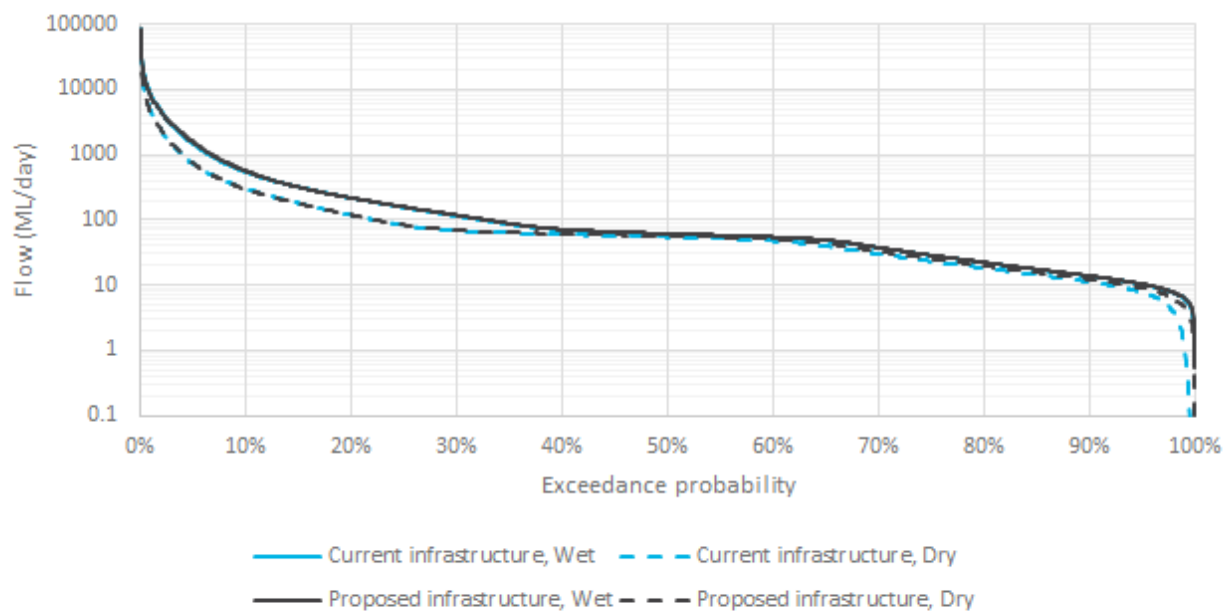


Figure 6.2 Flow duration curve for Tweed River at Uki (201900), future climate

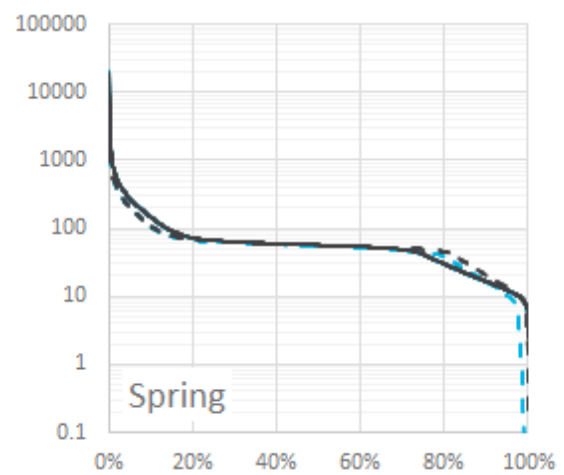
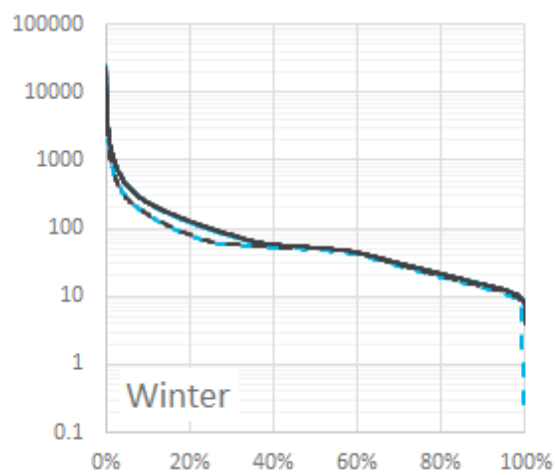
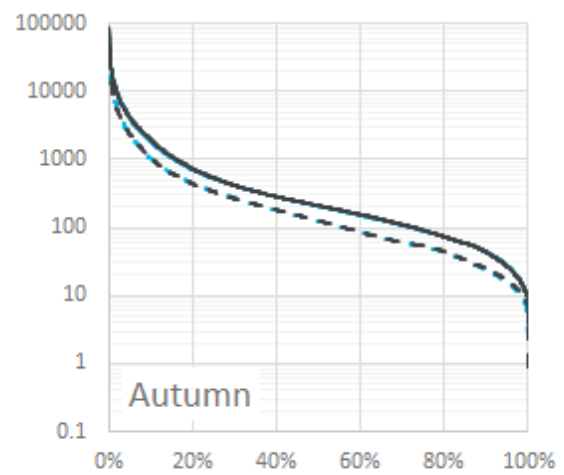
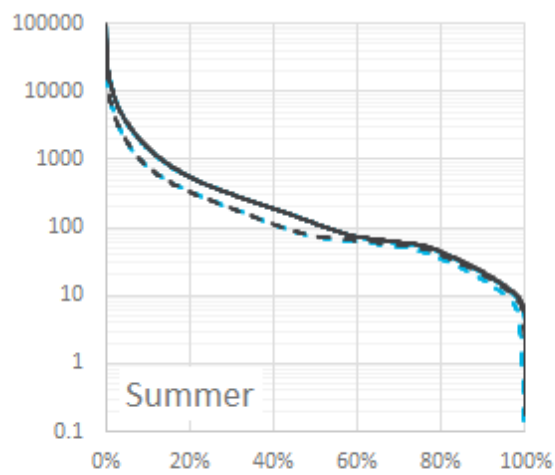
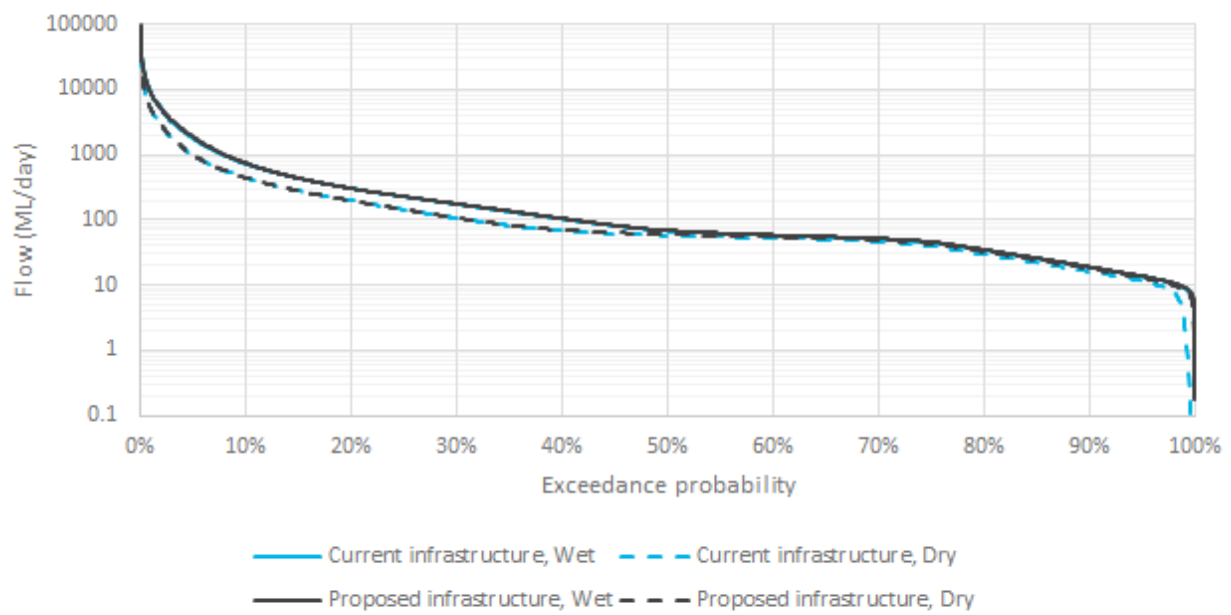


Figure 6.3 Flow duration curve for Tweed River at Braeside (201003), future climate

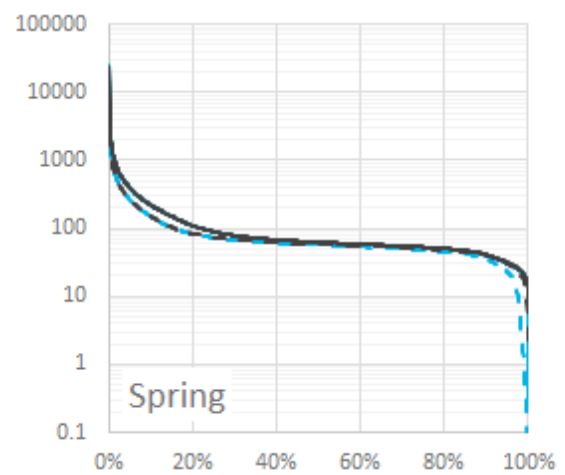
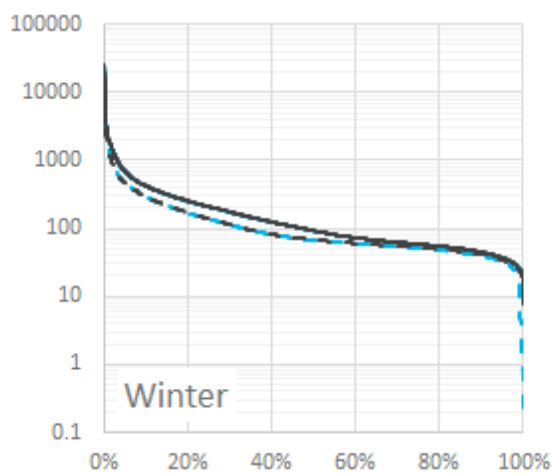
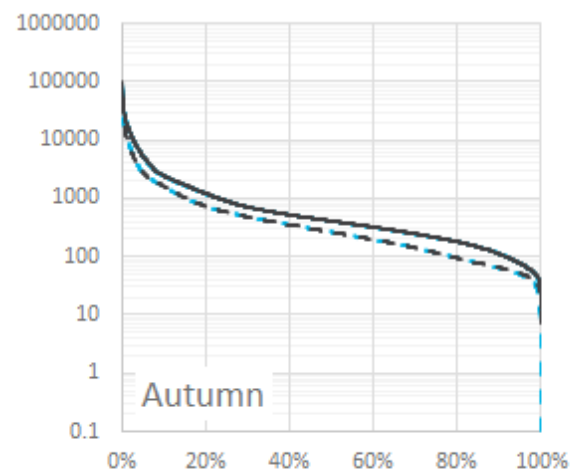
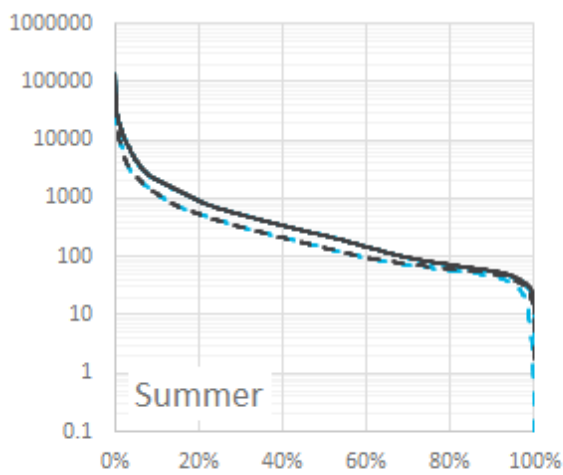
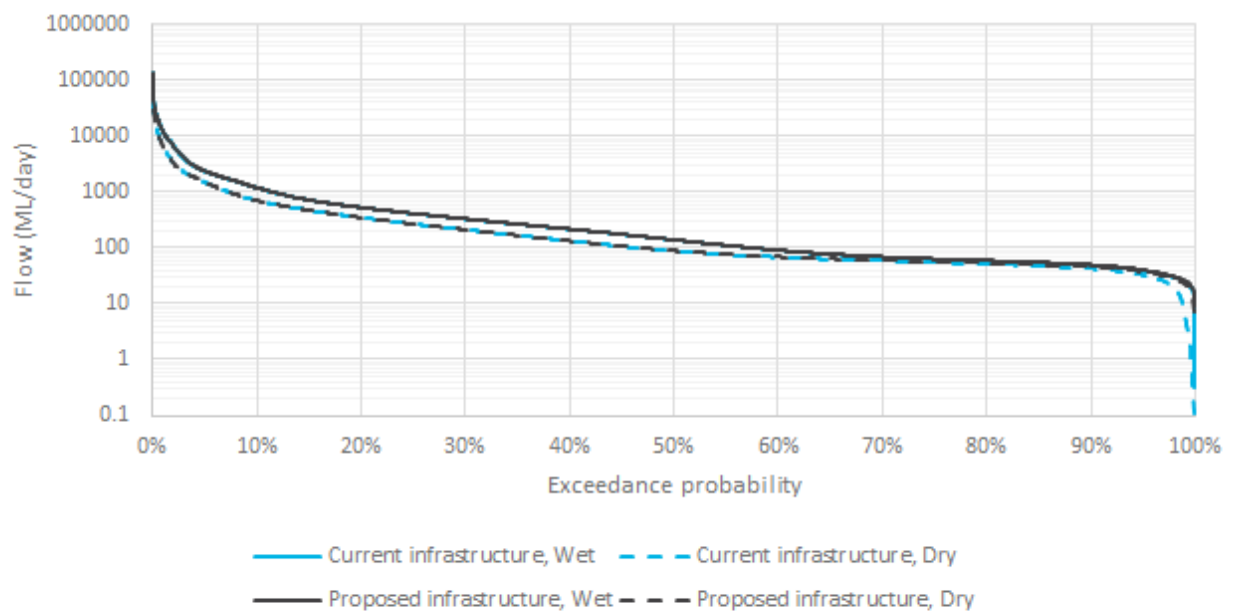


Figure 6.4 Flow duration curve for Tweed River downstream of Bray Park Weir, future climate

6.4 Clarrie Hall Dam Storage

Figure 6.5 shows probability of exceedance curves for Clarrie Hall Dam storage levels, developed from the flow results of simulations using future climate data.

This figure shows that under both infrastructure scenarios (i.e. with and without the Proposal):

- storage levels significantly exceed FSL only very infrequently (0% - 3%)
- Clarrie Hall Dam is full approximately 35% of the time, even in dry sequences. In wet sequences, this increases to just over 50% of the time
- in Spring and Summer, however, dam storages are full less than 20% of the time under dry sequences

In general, storage levels are lower during dry sequences.

Modelling indicates that during a dry future with the existing infrastructure, Stage 1 water restrictions would be required 46% of the time. This would reduce to 4% of the time with the larger dam. Emergency restrictions would be required 14% of the time with the existing infrastructure, reducing to 2% of the time with the Proposal.

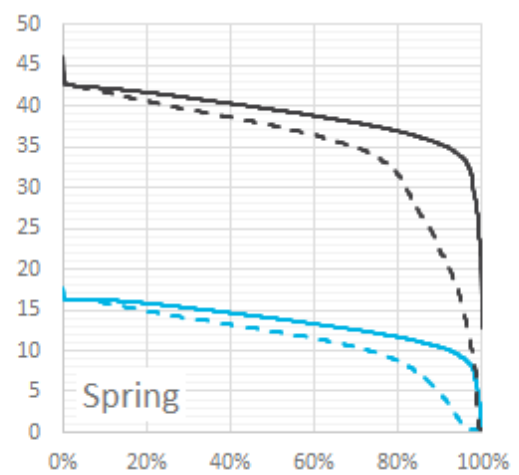
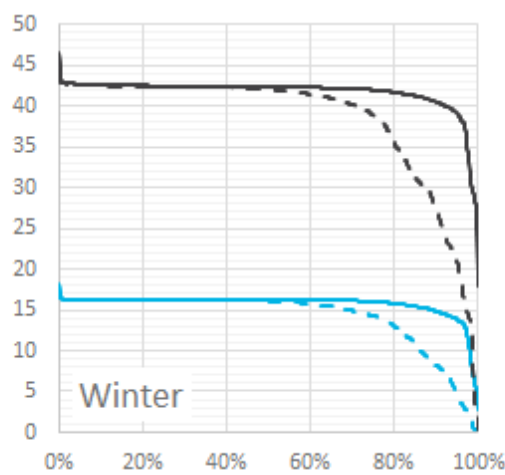
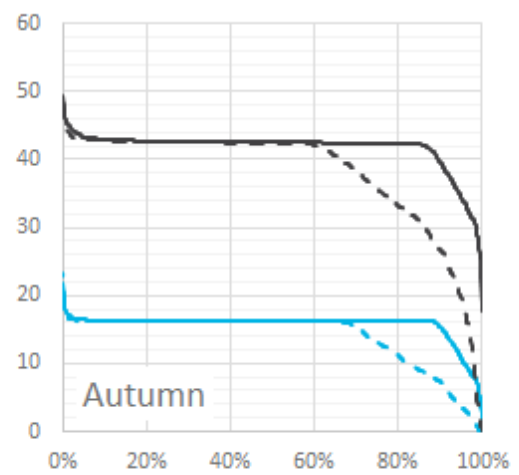
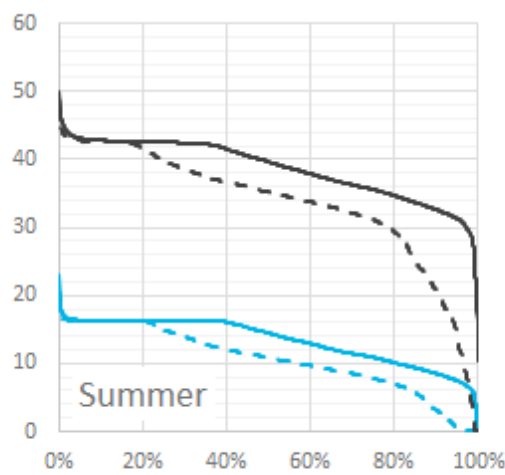
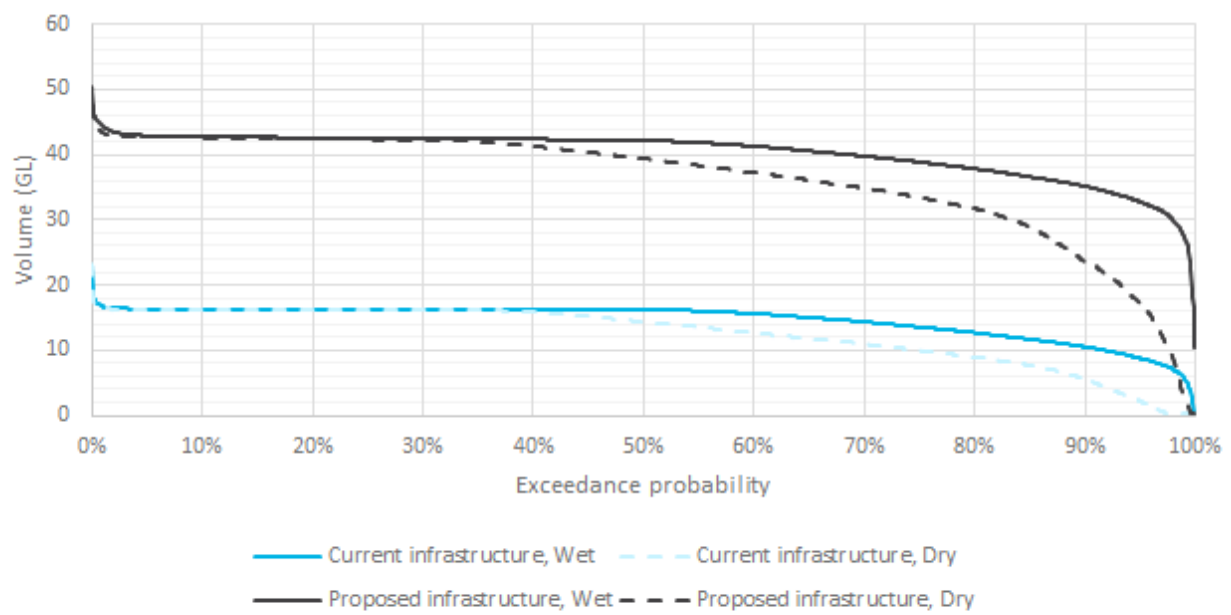


Figure 6.5 Probability of exceedance curve for storage volumes at Clarrie Hall Dam, future climate

7 Summary

Long term flow modelling using palaeo-stochastic climate data has illustrated:

- mean extraction volumes for TWS would be unchanged by the Proposal
- mean managed releases from Clarrie Hall Dam would not materially change as a result of the Proposal
- the percentage of time when dam storage levels are below 13.6 GL (trigger for Stage 1 water restrictions) will reduce significantly as a result of the Proposal
- high flows will be attenuated in the larger dam, resulting in:
 - reduced flood peaks in Doon Doon Creek
 - slightly longer duration of flood recession
- the frequency of minimum releases (4 ML/day) required to be released manually from the dam will increase from approximately 30% of the time to 35% of the time due to increased evaporation from the dam surface
- the increased loss of water to evaporation would be offset over the year by a minor increase in rainfall runoff upstream from the dam due to the additional reservoir area
- within 5 km downstream at Uki, most of the changes observable in Doon Doon Creek are negligible due to the contribution of the unregulated upstream reaches of the Tweed River runoff from additional catchment area and unaffected tributaries.

Further modelling completed utilising DPE Water advice regarding climate change analysis has illustrated that:

- by 2065 climate change is expected to result in significant water shortages and time with water restrictions within the Tweed Valley if the existing infrastructure is maintained
- time in restrictions and shortfalls would decrease by 90% with the proposed larger reservoir
- the balance of evaporation and rainfall is expected to change, such that with the proposed larger reservoir additional evaporation loss could result in a decrease to end of system flow (i.e. flow past Bray Park Weir) in the order of 0.5%.

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Attachment A

Climate change assessment for water infrastructure proposals

Climate change assessment for water infrastructure proposals

Water Analytics has proposed a method to use the climate risk data sets developed for Regional Water Strategies to assess climate change impacts relating to infrastructure projects

Introduction

The extreme climate conditions experienced in south-east Australia in recent years has highlighted the importance of our understanding these conditions so we can best manage river systems to provide for key water dependent sectors. The patterns of drought and flood experienced in observational climate record since the later 1890s provide a guide to the climate we need to plan for. However, we also know from other evidence in the physical environment that more extreme conditions occurred before then. We also have strong evidence from climate science and modelling that increased emissions of CO₂ and other greenhouse gases will increase temperatures, may intensify extreme conditions, and alter rainfall seasonality.

DPE Water has acknowledged the need to better represent the full extent of climate conditions by developing climate risk data sets that takes account of past records of climate variability and modelled projections of climate change. This data is used to support the objectives of our Regional Water Strategies through our water computer simulation models.

We use these computer simulation models to inform how our river systems in NSW respond to climate and water management. These models transform climate into water availability that varies in time and space. The models also simulate how natural climatically determined patterns of water availability are changed by infrastructure, water access arrangements, and consumptive water use. Using outputs from these models, we can report on how much water key water dependent sectors receive under different climate conditions and/or water management conditions. These management conditions may include changes to water sharing rules or water infrastructure.

Purpose of this paper

This paper is intended to explain the rationale and method for undertaking climate change assessments for water infrastructure proposals targeting a range of climate change projections, while retaining consistency with the methods and data sets developed for the Regional Water Strategies and endorsed by an independent expert panel.

Background

Earlier work

Water management in NSW was until recently informed by water modelling relying solely on observational data from the late 1890s till present. However, climate conditions such as experienced for the Millennium Drought in the 2000s highlighted the need to consider climate conditions outside that historically observed. The department in the mid-2010s undertook the first water strategy in the Greater Hunter Region to better understand water security for key economic sectors and identified drought length as a significant climate risk factor. Risk mitigation options included infrastructure options, including pipelines to transfer water across different sub-regions.

The basis for this work was the water models developed of the regulated Upper Hunter and Lower Hunter river systems, with climate as the main input. Decisions to invest in these risk mitigation options requires understanding their robustness to more extreme climate conditions. The department engaged researchers to develop stochastic climate data sets as input to the water models. These were perturbed with higher evaporation rates to represent climate change impacts.

Regional water strategy climate risk approach

Following completion of this strategy, the department then established a program to develop water strategies for all rural catchments in NSW. A similar approach to that used in the Greater Hunter Region was implemented to develop climate risk data sets. Key enhancements were made to the method to include paleo-climate data to generate stochastic climate data and incorporate information from the NARClIM climate program to represent projections of climate change.

A design choice was made to select the NARClIM 1.0 projections with the largest annual decrease in rainfall, to provide an approximation of a worst-case scenario. This approach was reviewed and endorsed by an independent expert panel. A full description of the method is provided on the department's website from this [link](#).

The data sets developed are 10,000 years of daily rainfall and evaporation at all rain gauge data points used in our modelling. The inclusion of the paleo-climate data produces an enhanced representation of the multi-decadal wet and dry cycles apparent in our observational record.

The 10,000 years of daily rainfall data has been aggregated to annual total rainfall and graphed as an annual time series (light blue columns), showing a wide range of inter-annual variability. A 100-year moving average filter has been applied to this annual time series to highlight the comparative wetness and dryness of long periods or rainfall. Those periods circled would have had extended periods of below average rainfall and would manifest in our modelling results as periods with low water availability.

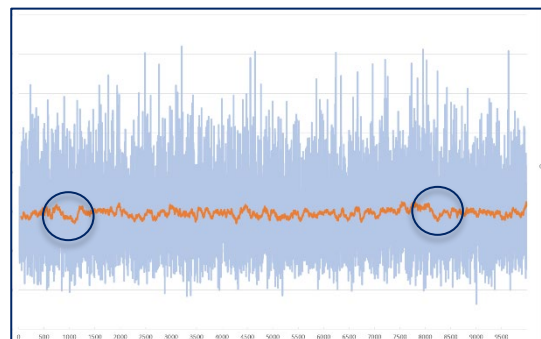


Figure 1. 10,000 years of annual rainfall totals from RWS paleo-stochastic climate data sets

The multi-millennial data sets used have the advantage compared with the shorter observational data of comprehensively representing climate variability, with multiple examples of wet and dry periods of different lengths occurring within.

The way we incorporate climate change projections with this dataset is to apply average monthly factors of changes in mean rainfall for each month at every climate station used in modelling. These factors vary across NSW consistent with the NARcliM modelled results. The average monthly factors were based on results from modelled projections of far-future (2060-79) high emission scenario using the CSIRO mk3.0 General Circulation Model (GCM), dynamically downscaled to a high spatial resolution using high resolution regional climate models (RCMs). RCMs are based on the Weather Research Forecasting (WRF) modelling system. Our factors were the multi-model mean of three RCM replicates.

A typical set of factors in northern NSW looks like that shown in Figure 2 with an increase in late summer to early autumn rainfall, followed by a decrease through to spring.

Applying these factors to the stochastic data set generally broadly preserves patterns of inter-annual variability, while decreasing overall rainfall totals. However, for years with high rainfall in the summer period this might paradoxically result in an increase in total rainfall for those years

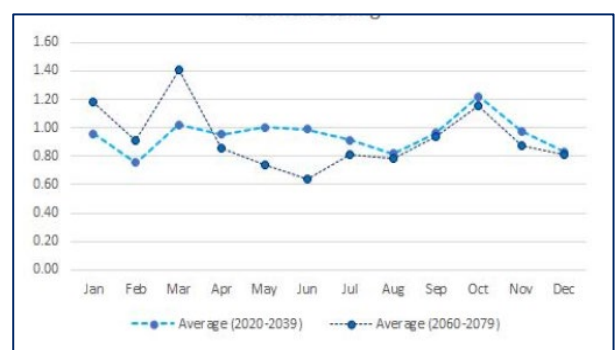


Figure 2. NARcliM Rainfall factor for used for RWS climate change projections

We have also used changes in potential evaporation from the NARcliM program, which has increased across all months of the year. The combination of lower rainfall and higher potential evaporation has resulted in a large reduction in modelled water availability, with commensurate adverse modelled outcomes for key water dependent sectors.

The Regional Water Strategies has adopted an approach of using the historical climate as a reference condition, and the full 10,000-year paleo-stochastic datasets, with and without climate factors applied, to report on water security related outcomes. They have also used multiple 40-year replicates sampled from the 10,000-year datasets to provide results for economic analysis.

Using this data for climate change assessment

The datasets developed represents most of the uncertainty regarding what our climate could be in the foreseeable future, and together with our water models provide a sound basis for our Regional Water Strategies to identify vulnerabilities in our regulated and unregulated river systems, and to then formulate and test risk mitigation options. The 10,000-year data sets also provide some insights into the probability of occurrence of these vulnerabilities.

Issues with using regional water strategies climate risk datasets.

Feedback provided by practitioners and decision makers indicate two characteristics of this data set that presented difficulties in interpreting; (i) results arising from the length of data and (ii) the severity of climate change imposed.

Difficulties interpreting dataset length are in part is perceptual as well as relating to our skill to analyse and report critically important results. Whereas we can relate to datasets that are part of our lived experience for example, how do we then visualise and process outcomes over periods which are a hundred times longer and compare these with the shorter time periods.

As the datasets include much wetter or much drier periods, a challenge in using this longer time series is to present the modelled results in a way that informs a particular outcome, for example, changes in frequency of environmentally important flow events or water security for a town. The combining of results from the full period may obscure important results from more critical extreme climate conditions within that dataset.

The second characteristic is our design decision to select the driest NARClIM 1.0 scenario to factor our paleo-stochastic datasets. The decision was intended to represent a 'worst case' scenario to identify vulnerabilities in meeting water related outcomes, especially regarding testing the robustness of mitigation options. Feedback on this dataset was that it produced results that were too severe to constructively inform decision making. The comments relating to analysis and reporting of 10,000-year data sets also apply to using the factored sequence.

However, this does not at first glance align with approaches adopted elsewhere that test a range of modelled projected climate changes, which may vary from much wetter to much drier. Decision makers have indicated they would like to see how infrastructure options would perform under conditions that not as dry as the worst-case scenario, or even wetter than the historical period.

Method

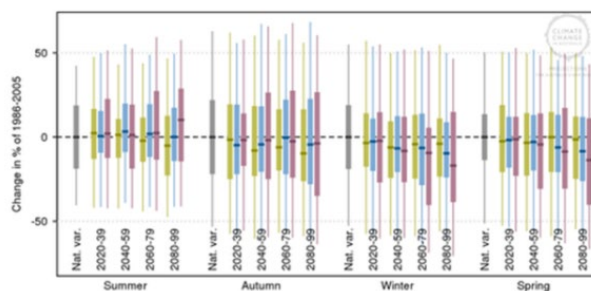
Overview

The method proposed to assess climate change for infrastructure environmental impact assessment addresses this feedback by aligning the length of climate risk data analysed with that of the historical period, and by assessing a range of change in mean rainfall compared with historical. It does this while being consistent with the climate risk datasets development method endorsed by the independent expert panel. The method identifies suitable shorter periods of data within the longer 10,000-year data set for detailed analysis and reporting. The suitability of data is based on the mean rainfall over this period.

The method takes advantage of a characteristic of the 10,000-year dataset having significant interannual and multidecadal variability that results in different 100-year periods having mean rainfall that vary considerable compared to the historical mean.

To understand the range of changes to rainfall we should be testing for, we have adopted the results from the CSIRO and Bureau of Meteorology analysis of results from the climate models used for the recent IPCC assessment.

To understand the range of changes to rainfall we should be testing for, we have adopted the results from the CSIRO and Bureau of Meteorology analysis of results from the climate models used for the recent IPCC assessments¹. The site reports the distribution of modelled seasonal rainfall changes compared to a reference period for different emission scenarios at different periods of time in the future Figure 3.



rainfall¹

Figure 3. Distribution of modelled projected seasonal changes in

These results are analysed to determine what changes in mean rainfall we should be analysing for. We then select periods for the 10,000-year data set factored with NARClIM factors with this mean rainfall. The usage of the NARClIM factors is important to account for the modelled changes in seasonality of rainfall changes.

¹ CSIRO and Bureau of Meteorology, Climate Change in Australia website

(<http://www.climatechangeinaustralia.gov.au/>), cited [17/03/2022]

Detailed steps

The detailed steps in developing the datasets to assess climate change for our infrastructure projects is set out in Figure 4 and described in Table 1, noting that steps 1.0, 2.0, 2.1, 3.0 and 3.1 were completed in developing the RWS climate risk datasets.

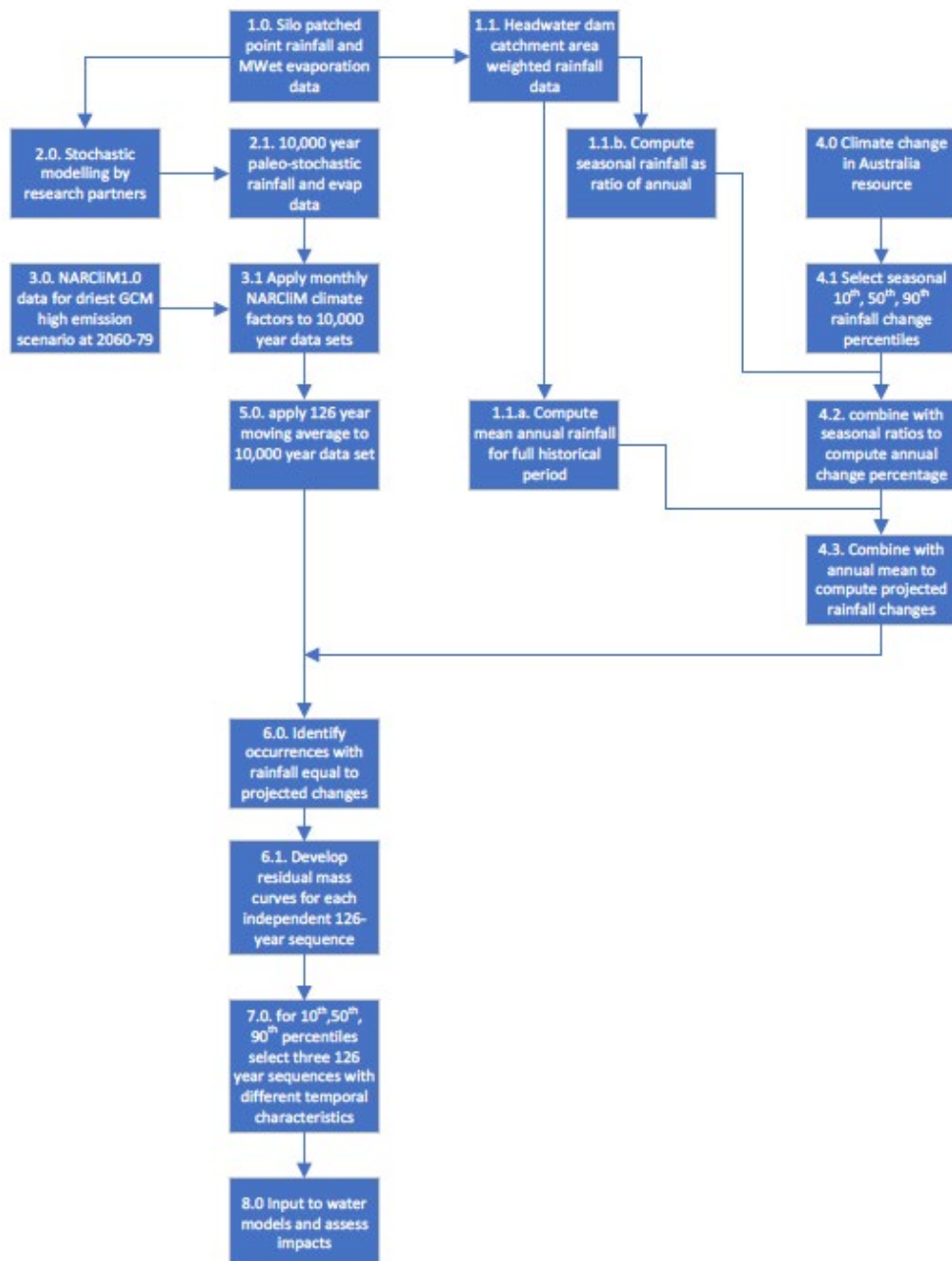


Figure 4. Detailed steps for climate change scenarios for infrastructure

Table 1. Description of steps for developing climate change scenarios for infrastructure assessment

Step	Description
1.1	<i>Headwater dam catchment area weighted rainfall data.</i> The subregion of our water sources that dominate the water related outcomes is the catchment that inflows. Here we take the weighting factors from our rainfall runoff modelling and multiply them by the daily rainfall data at that station, and aggregate to a single daily rainfall time series.
1.1.a	<i>Compute mean annual rainfall for full historical period.</i> Sum the total rainfall to annual totals and take the mean of these annual totals.
1.1.b	Compute seasonal rainfall as ratio of annual. Sum the rainfall for each season and compute the ratio of the total annual rainfall. This allows for the conversion of seasonal changes from the Climate Change in Australia resource to an annual change
4.0	<i>Go to Climate Change in Australia resource.</i> Select the appropriate region and rainfall in the Climate Change in Australia Summary Data explorer ² on the Climate Change website
4.1	<i>Select seasonal 10th, 50th and 90th rainfall change percentiles.</i> From the graphical depiction of the distribution of modelled percentage changes in seasonal rainfall (see Figure 3 for example) read off the seasonal percentage changes for the above percentiles for greenhouse gas concentration pathway scenario RCP8.5 for the 2060-2079 time period. This step covers the range of change estimates from 80% of the climate models, including instances where we may see an increase in rainfall.
4.2	<i>Combine with seasonal ratio to computer annual change percentage.</i> Multiplying the seasonal ratios from observed data by the percentage projected change for this seasonal rainfall, and aggregating, we can get an approximation of the changes to annual rainfall for each percentile. Our NARClIM factored 10,000-year daily time series rainfall datasets already include a climate change affected seasonal pattern, so applying these factors directly to this data set would double account the seasonal changes.
4.3	<i>Combine with annual mean to compute projected rainfall changes.</i> Multiplying the computed change in mean annual rainfall by the computed area weighted observed mean rainfall produces the mean rainfall for 126 years we would like sample for from our datasets.
5.0	<i>Apply 126 year moving average filter to NARClIM factored 10,000-year dataset.</i> This produces a product that can be used to identify when and how often rainfall is at the target means over 126-year periods. A graphical representation of that is shown at Figure 5.
6.0	<i>Identify occurrences with rainfall equal to projected changes.</i> These need to be non-overlapping periods. An example for simulated flow from dam inflow catchment rainfall is shown at Figure 6.

² Summary Data Explorer (climatechangeinaustralia.gov.au)

Step	Description
6.1	<i>Develop residual mass curves for each independent 126-year occurrence.</i> In most cases, there will be multiple occurrences of non-overlapping periods, and this graphical technique can be used to identify sequences with materially different characteristics. An example is shown at Figure 7
7.0	<i>Select maximum of three 126-year sequences with based on different temporal characteristic displayed by residual mass curves.</i> An advantage of the stochastic method is that it accounts for variability along with long term mean. Periods with the same mean rainfall may produce quite different outcomes for a water system, depending on sequences of significant events and lengths of floods. Testing of the water system with samples with the same means allows for a statement of confidence in the robustness of these outcomes.
8.0	<i>Input to water models and assess impacts.</i> In many cases this modelling has already been completed, and results of existing models can be assessed independently for the sequences identified in step 7.0

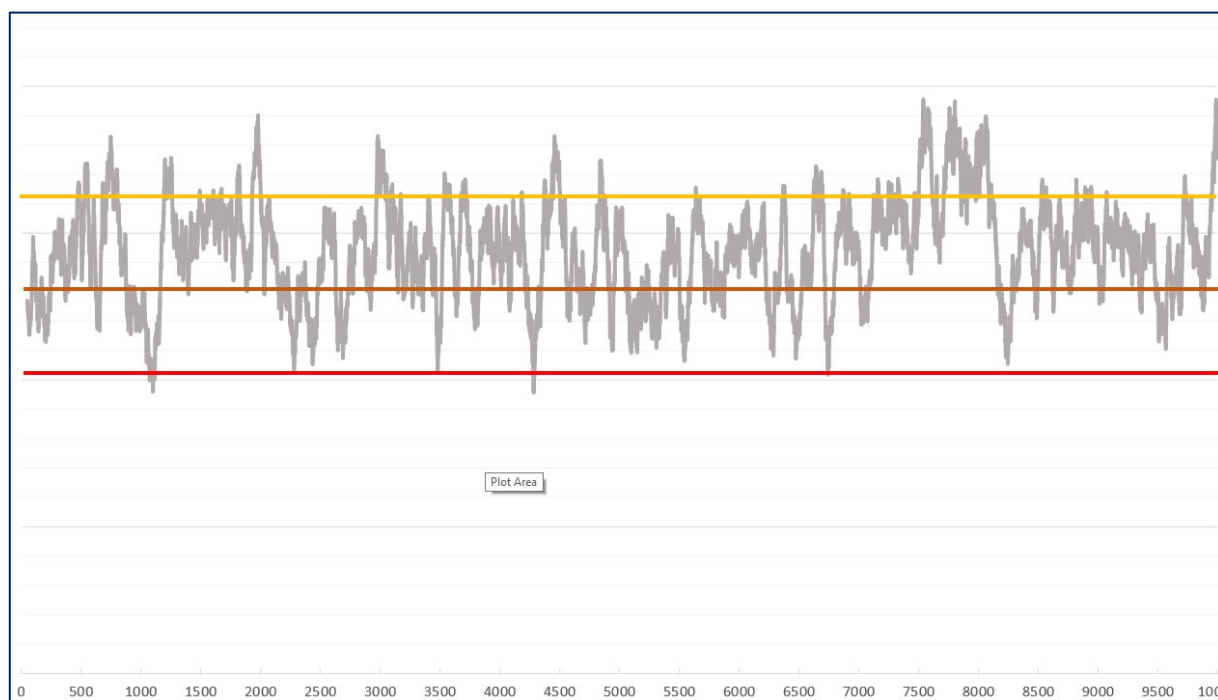


Figure 5. 126 year moving average of a NARClIM factored paleo-stochastic rainfall data set (grey line) with indicative lines showing mean annual rainfalls for further analysis (yellow, brown and red for 10th, 50th and 90th percentiles respectively)

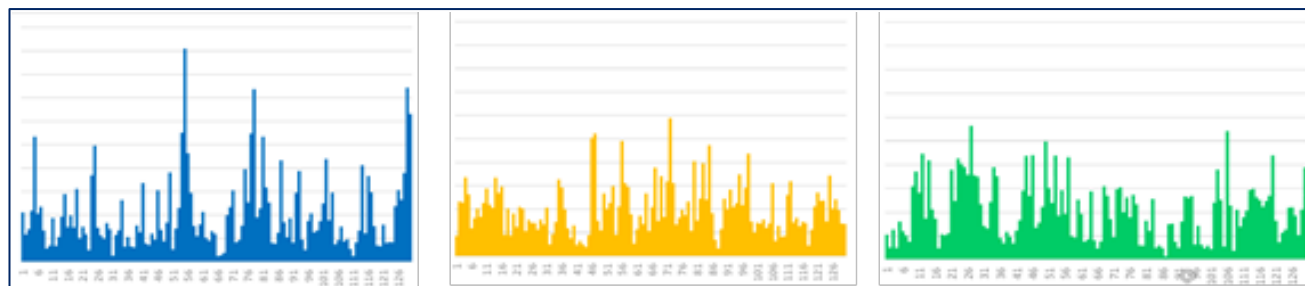


Figure 6. Three non-overlapping samples from 10,000-year time series of annual time series of flows with the same average for a 126-year period

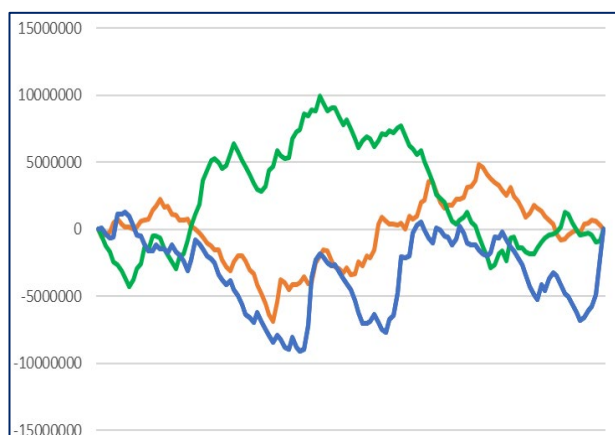


Figure 7. Residual mass curves (a.k.a. cumulative departure from mean) of three annual time series from Figure 6, with trends and changes of direction of gradient highlighting sequences of wet and dry periods

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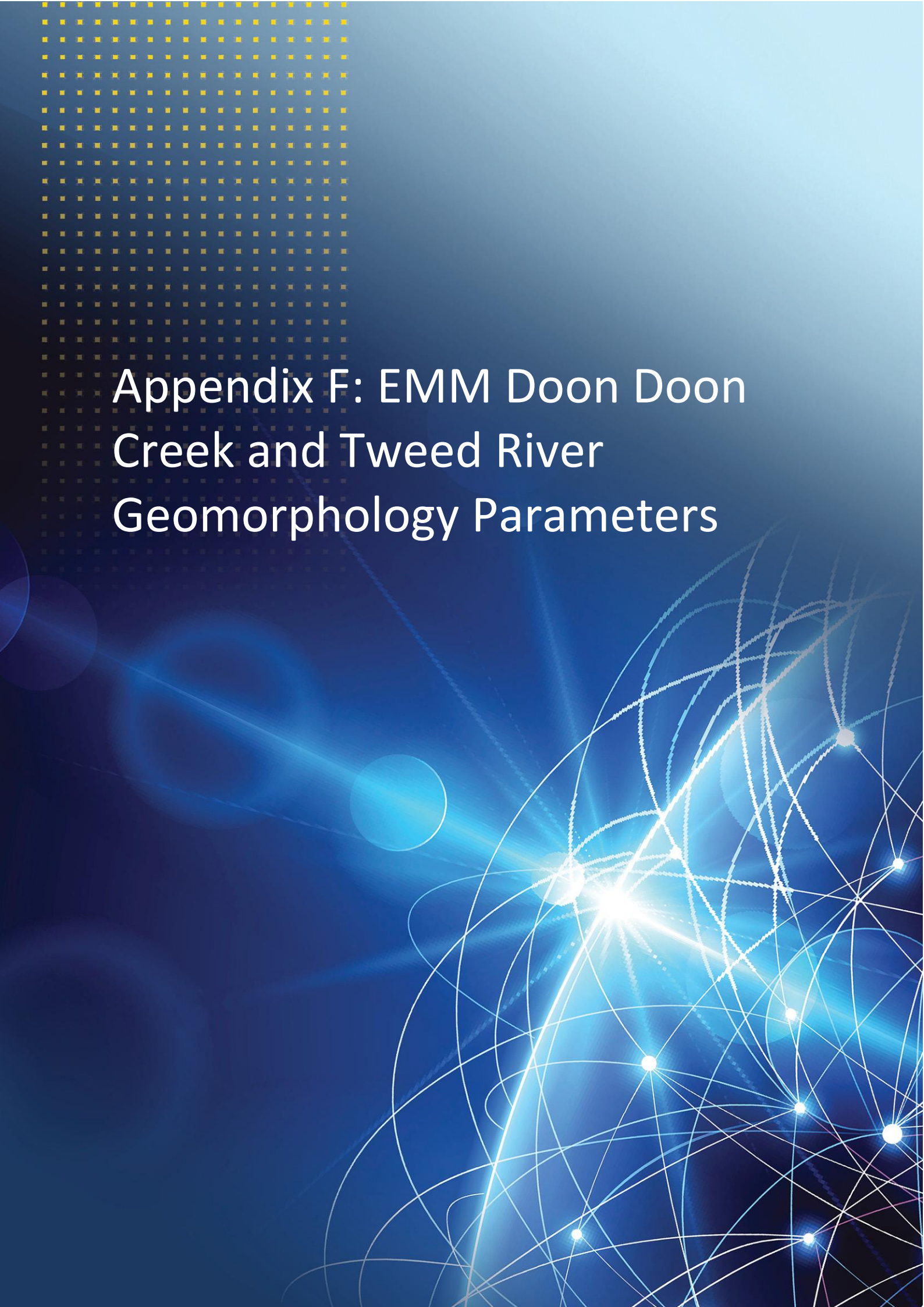
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Appendix F: EMM Doon Doon Creek and Tweed River Geomorphology Parameters

Doon Doon Creek and Tweed River

Geomorphology parameters

Prepared for Prepared for Tweed Shire Council / KBR

November 2025

Doon Doon Creek and Tweed River

Geomorphology parameters

Prepared for Tweed Shire Council / KBR

E230036 Annexure D

November 2025

Version	Date	Prepared by	Reviewed by	Comments
1	2 August 2024	J Muller	N Bartho	Issue for publication
2	6 November 2025	J Muller	-	Revised spillway

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This report has been prepared in accordance with the brief provided by Prepared for Tweed Shire Council / KBR and, in its preparation, EMM has relied upon the information collected at the times and under the conditions specified in this report. All findings, conclusions or recommendations contained in this report are based on those aforementioned circumstances. The contents of this report are private and confidential. This report is only for Prepared for Tweed Shire Council / KBR's use in accordance with its agreement with EMM and is not to be relied on by or made available to any other party without EMM's prior written consent. Except as permitted by the Copyright Act 1968 (Cth) and only to the extent incapable of exclusion, any other use (including use or reproduction of this report for resale or other commercial purposes) is prohibited without EMM's prior written consent. Except where expressly agreed to by EMM in writing, and to the extent permitted by law, EMM will have no liability (and assumes no duty of care) to any person in relation to this document, other than to Prepared for Tweed Shire Council / KBR (and subject to the terms of EMM's agreement with Prepared for Tweed Shire Council / KBR).

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Executive Summary

ES1 Context

This document describes the result of hydraulic modelling undertaken for the Clarrie Hall Dam EIS.

Version 1 of this document was prepared as an annexure to the EIS Surface Water Assessment, and submitted as part of the EIS in 2024, and described the potential changes to stream flow parameters such as bed shear, velocity, and depth in Doon Doon Creek and the Tweed River which may occur due to dam wall raising.

This Version 2 was prepared during the Response to Submissions phase of the project and investigates the potential changes to those same stream flow parameters if the raised dam were constructed with a wide (80 m) spillway. A comparison of the spillway rating curves is provided in Figure ES1.

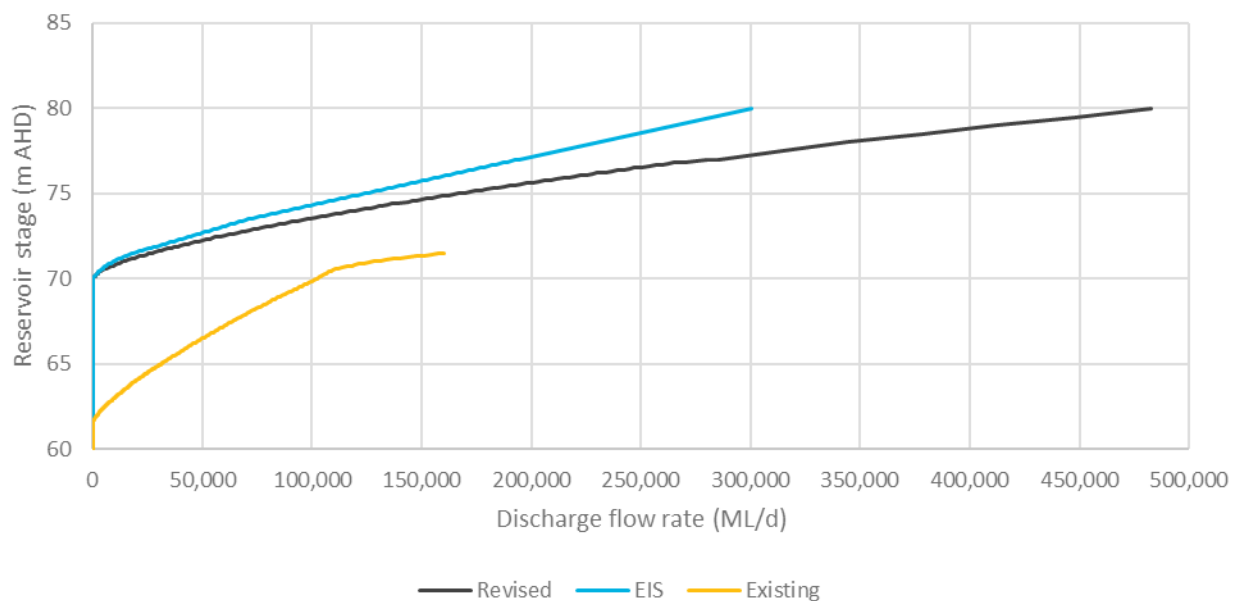


Figure ES1 Spillway curves

ES2 Effects of spillway revision

The spillway presented in the EIS attenuated flood flows through the reservoir, such that peak flows in Doon Doon Creek were expected to be reduced, but the duration of the falling limb would be extended and result in increased duration of higher flows (Figure ES2).

The revised wider (80 m) spillway reduces the effects of the project on stream power, depth and velocity within Doon Doon Creek, such that these flow descriptors are expected to be effectively unchanged by the project (Figure ES3).

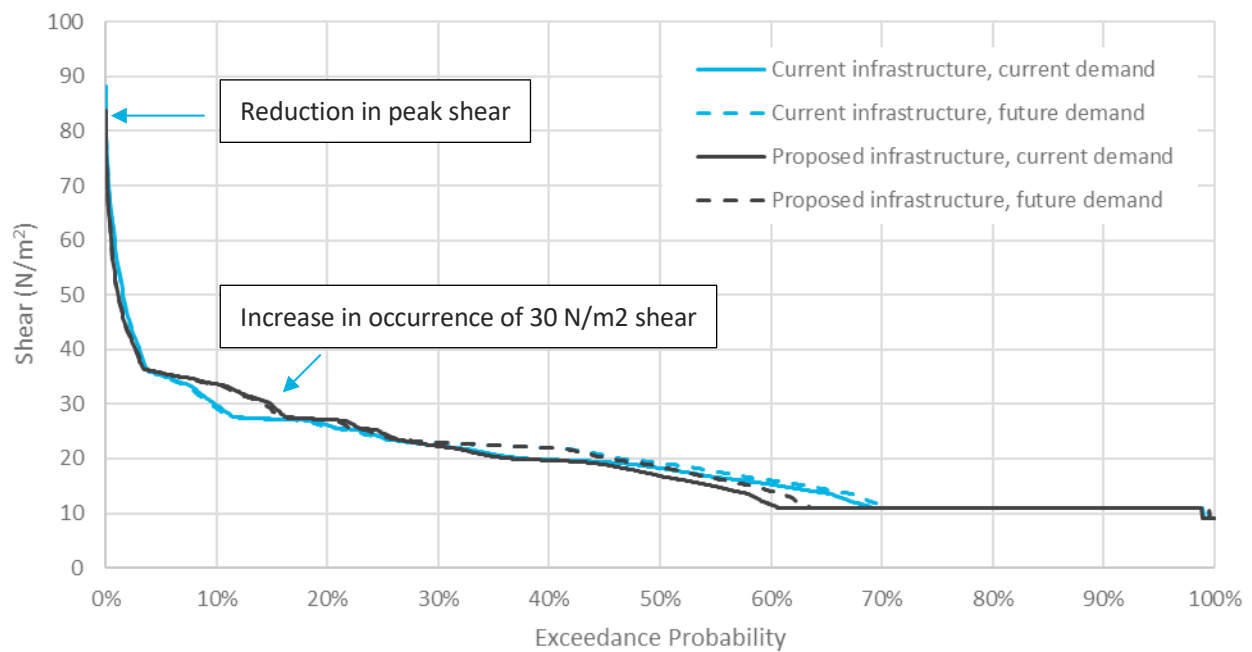


Figure ES2 EIS model results: Modelled shear stress in a Doon Doon Creek riffle

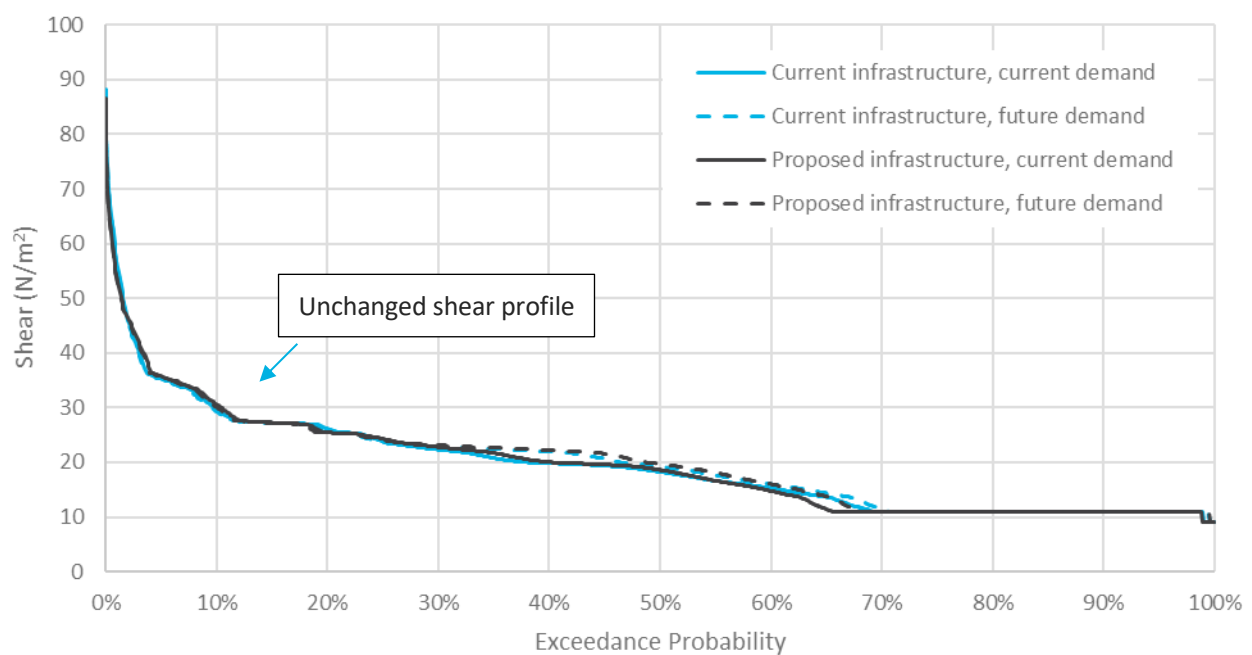


Figure ES3 Revised spillway: Modelled shear stress in a Doon Doon Creek riffle

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1 Introduction

A HEC-RAS model was used to describe the hydraulic behaviour of Doon Doon Creek and the Tweed River between Clarrie Hall Dam and Bray Park Weir to support and inform the assessment of the proposed raising of Clarrie Hall Dam (the Proposal). This report describes the hydraulic changes in representative reaches of these two watercourses that may occur due to predicted changes to the streamflow regime as a result of the Proposal.

HEC-RAS is an industry standard hydraulic modelling software package developed by the US Army Corps of Engineers for modelling rivers and creeks. HEC-RAS is widely used for water management assessments and can be used to describe hydraulic parameters resulting from flow in waterways. The one-dimensional (1D) formulation of HEC-RAS solves the hydraulic Manning's equation using channel sections developed from cross section data in order to resolve the hydraulic conditions within all watercourses represented in a model.

Development of the HEC-RAS model is described in Annexure C of the surface water assessment.

The Doon Doon Creek and Tweed River streamflow regime was simulated using a catchment model, described in Annexure A of the surface water assessment.

The flow regimes described by the Source model for Doon Doon Creek and the Tweed River at Uki with the existing dam and proposed larger dam were applied to the HEC-RAS hydraulic model to describe depth, velocity, and shear stress regimes. The hydraulic regime of the Tweed River downstream from Uki was not assessed as the hydrologic changes at Uki due to the Proposal were found to be negligible.

The HEC-RAS model was run with flows from 4 ML/d up to 30,000 ML/d to develop curves describing how hydraulic parameters within Doon Doon Creek and the Tweed River (near Uki) relate to flow. These curves were then used to transform the flow regime predicted by the Source modelling.

2 Bed material mobilisation theory

The initiation of particle movement on the bed depends on the hydraulics of the near bed region. As determination of velocity near the bed is difficult, bed shear stress is a commonly used method of determining incipient motion. In 1D (cross-sectional) space, mean bed shear stress (N/m^2) (τ_b) is conventionally calculated as per Equation 2-1 (Gordon, McMahon, Finlayson, Gippel, & Nathan, 2004).

Equation 2-1 Bed shear stress

$$\tau_b = \rho g R S$$

Parameter	Description	Value
R	hydraulic radius of the channel (m)	equal to A/P where A is the cross-sectional area of the flow, and P is the length of the wetted perimeter
S	energy slope of the water (m/m)	equal to the bed and water surface slopes in uniform reaches
ρ	water density (kg/m^3)	1,000
g	acceleration due to gravity (m/s^2)	9.8

The critical shear stress (τ_c) is the shear stress required to set the bed particles in motion, represented by the Shields equation (Equation 2-2).

Equation 2-2 Critical shear stress

$$\tau_c = \theta_c g d (\rho_s - \rho)$$

Parameter	Description	Value
θ_c	dimensionless critical Shields stress	typically 0.6-0.75
g	acceleration due to gravity (m/s^2)	9.8
d	representative particle size (d_{50}) (m)	See Table 2.1
ρ_s	particle density (kg/m^3)	2,650
ρ	water density (kg/m^3)	1,000

For particles to move, the actual shear stress (τ_b) (estimated through modelling) must exceed the critical shear stress (τ_c) (Table 2.1).

Table 2.1 Critical shear stress for selected bed materials

Bed material	Representative particle size d_{50} (m)	Critical shear stress (N/m^2)
Silt	0.00001	0.1
Sand	0.001	10
Gravel	0.01	100
Boulder	0.5	5,000

3 Watercourse hydraulic properties

Curves describing watercourse hydraulics (Figure 3.1) were developed for pool and riffle sequences in Doon Doon Creek and the Tweed River near Uki (Figure 3.2).

From the results it is noted that the Tweed River riffle section turns into a pool at higher flows due to backwater effects. This is evident in the drop in bed shear stress and velocity when flow is over approximately 7,500 ML/d.

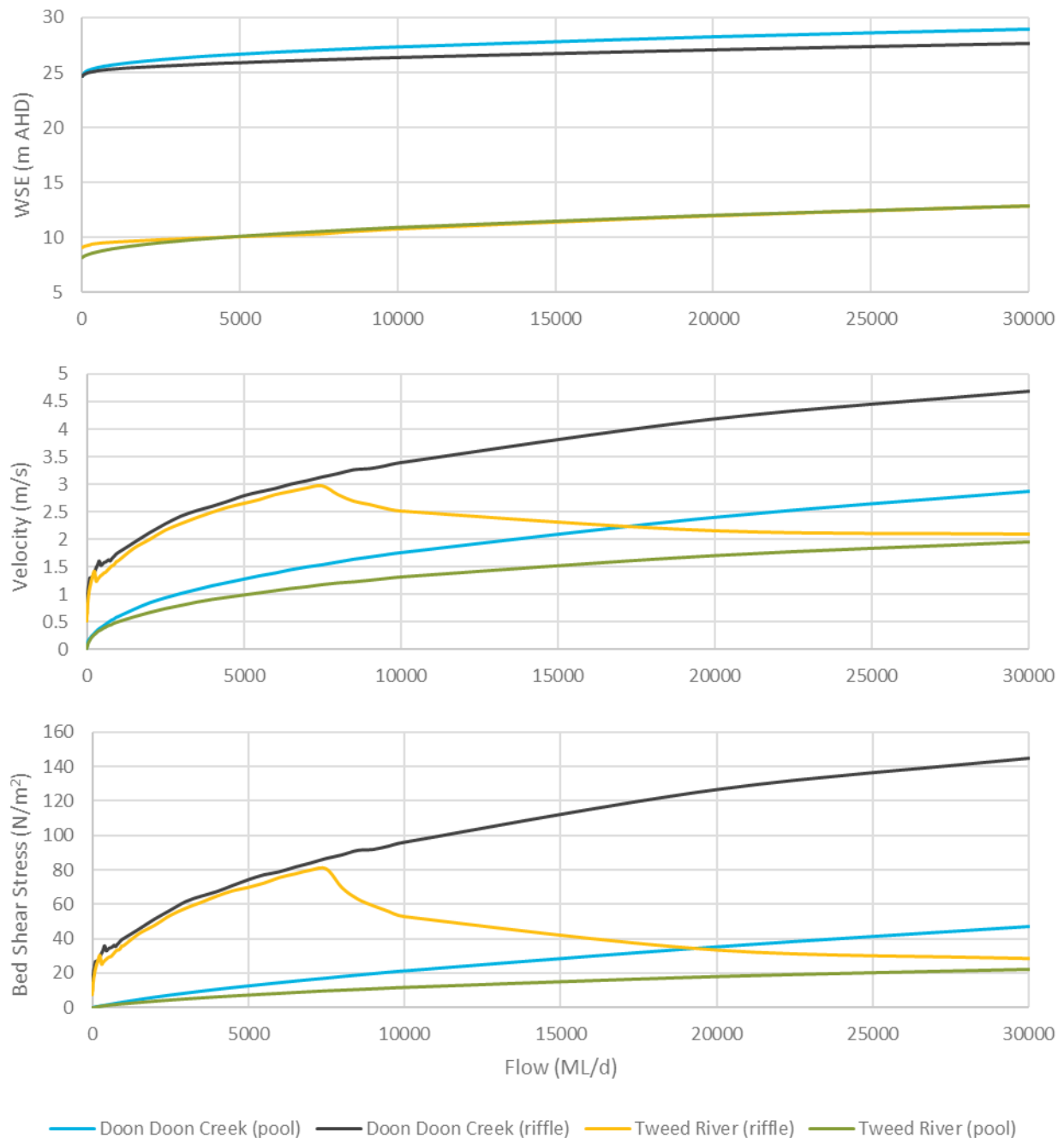


Figure 3.1 Water surface elevation, velocity and bed shear stress descriptive curves

4 Impact assessment

4.1 Overview

The flow regimes described by the Source model (see SWA Annexure A v2) were transformed using the hydraulic properties presented in Chapter 3, producing the results presented in Attachment A.

Results presented in this report are targeted at the assessment of surface water interactions with groundwater and soils over extended periods, and do not consider seasonality.

4.2 Doon Doon Creek

Water levels, velocities and bed shear stress in doon Doon Creek are not expected to be materially affected by the Proposal (Figure A.1 to Figure A.6).

4.3 Tweed River

Water levels, velocities and bed shear stress in the Tweed River are not expected to be materially affected by the Proposal (Figure A.7 to Figure A.12).

References

Gordon, N. D., McMahon, T. A., Finlayson, B. L., Gippel, C. J., & Nathan, R. J. (2004). *Stream hydrology: An Introduction for Ecologists* (Second Edition ed.). John Wiley & Sons.

Attachment A

Waterway hydraulics plots

A.1 Doon Doon Creek riffle

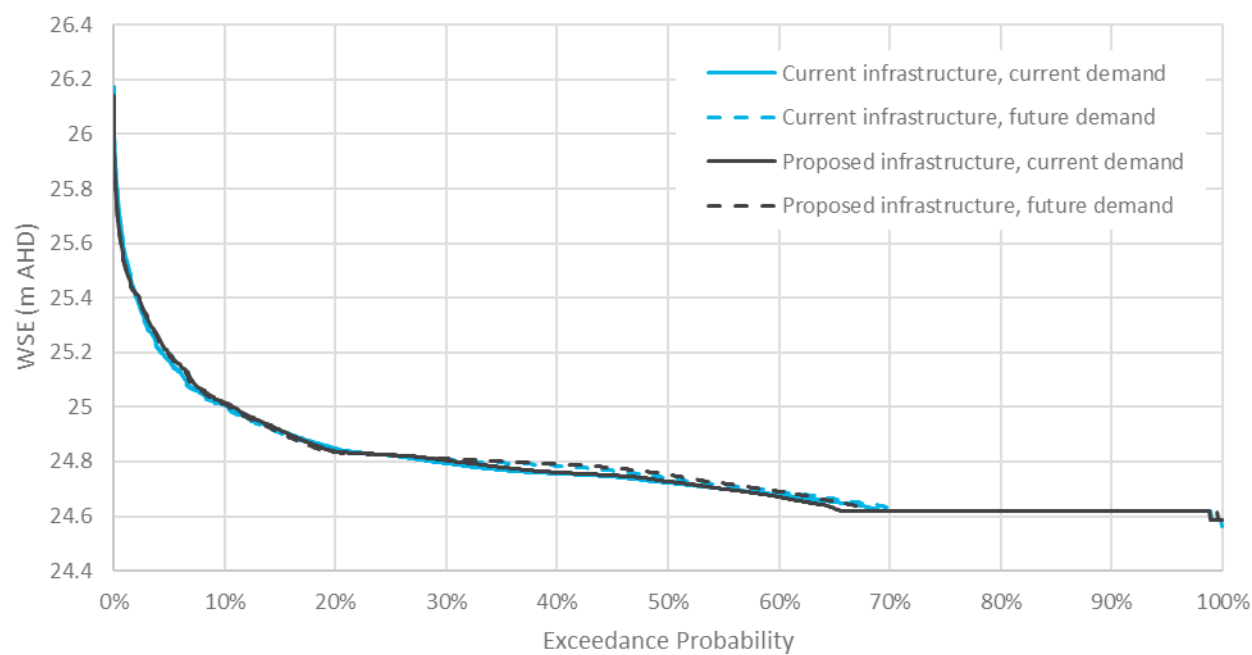


Figure A.1 Water surface elevation, Doon Doon Creek riffle

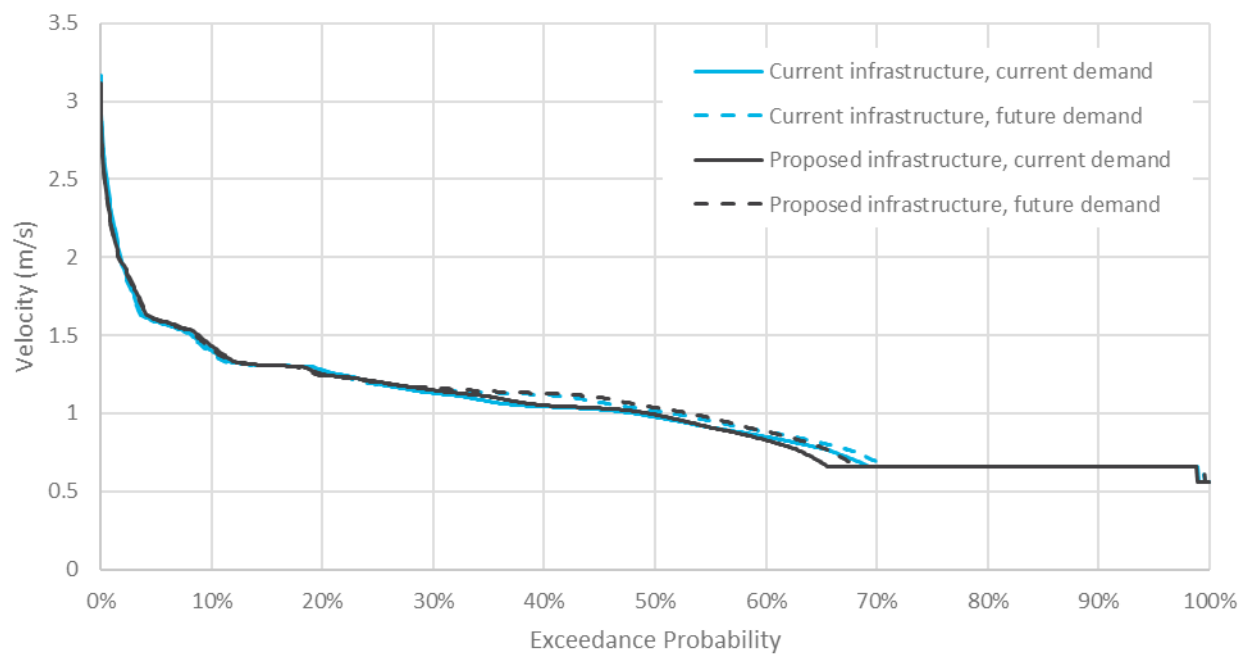


Figure A.2 Velocity, Doon Doon Creek riffle

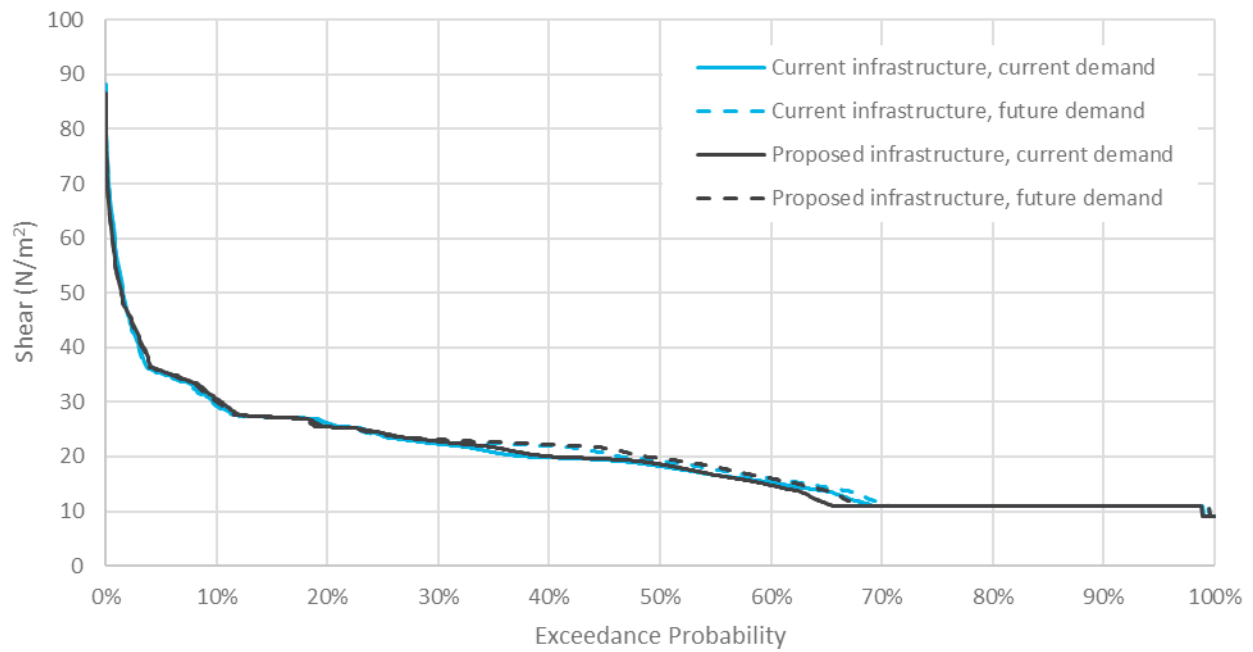


Figure A.3 Bed shear stress, Doon Doon Creek riffle

A.2 Doon Doon Creek pool

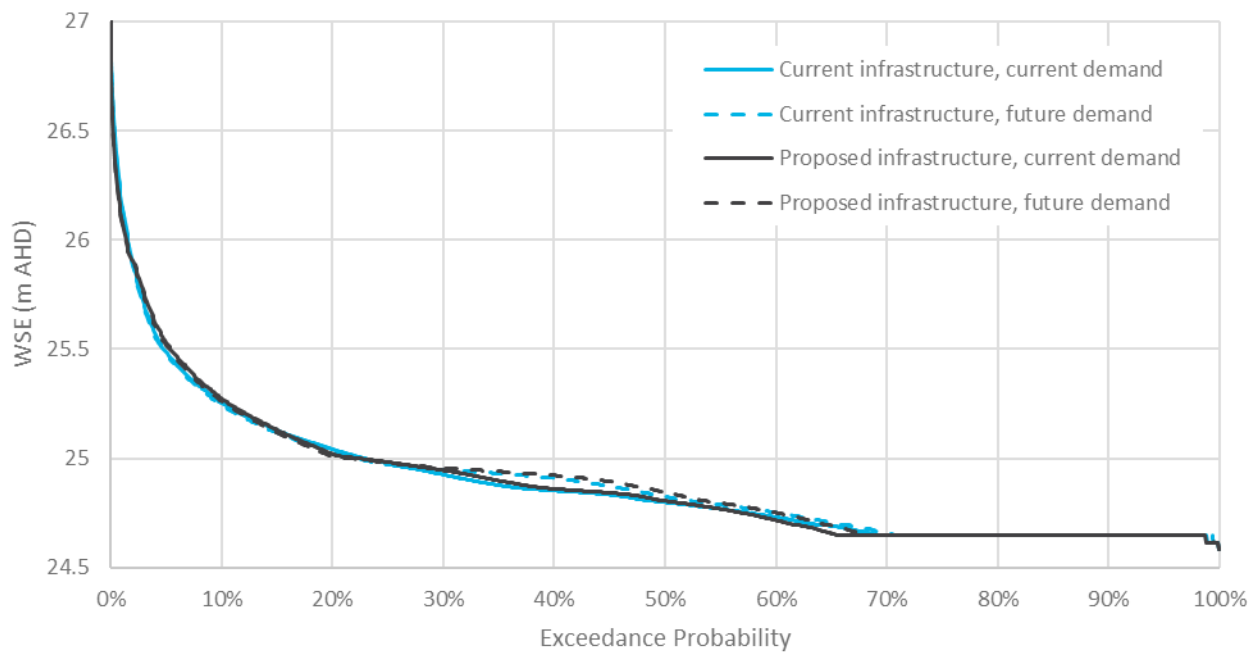


Figure A.4 Water surface elevation, Doon Doon Creek pool

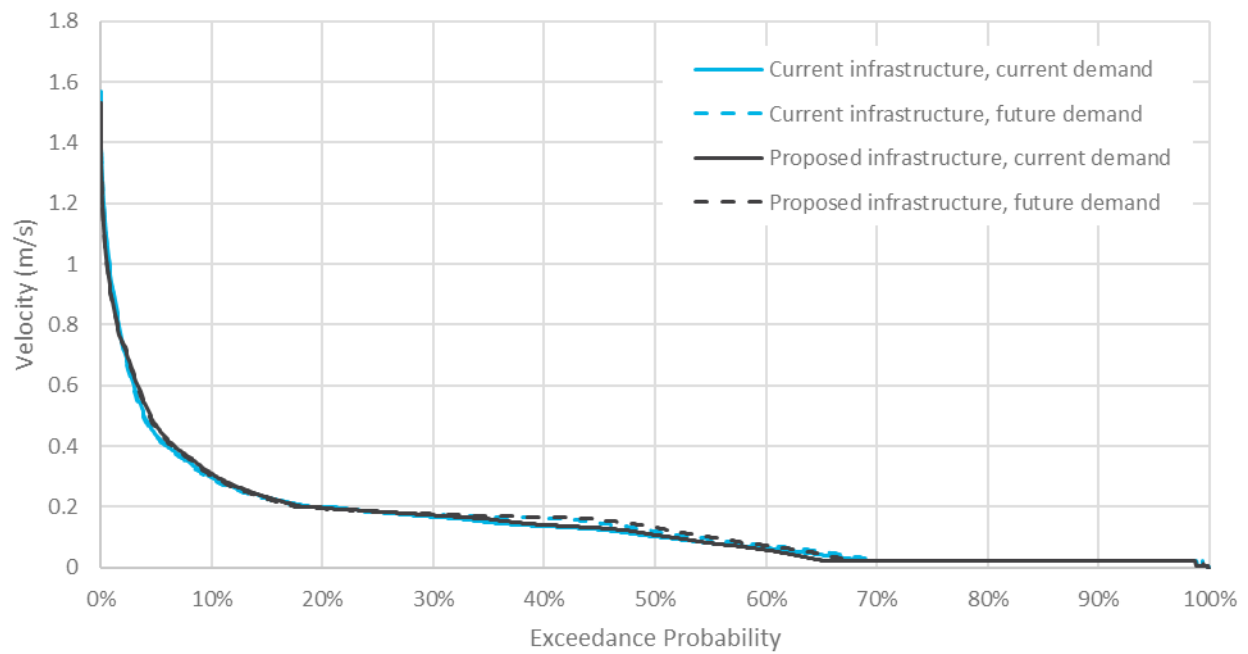


Figure A.5 Velocity, Doon Doon Creek pool

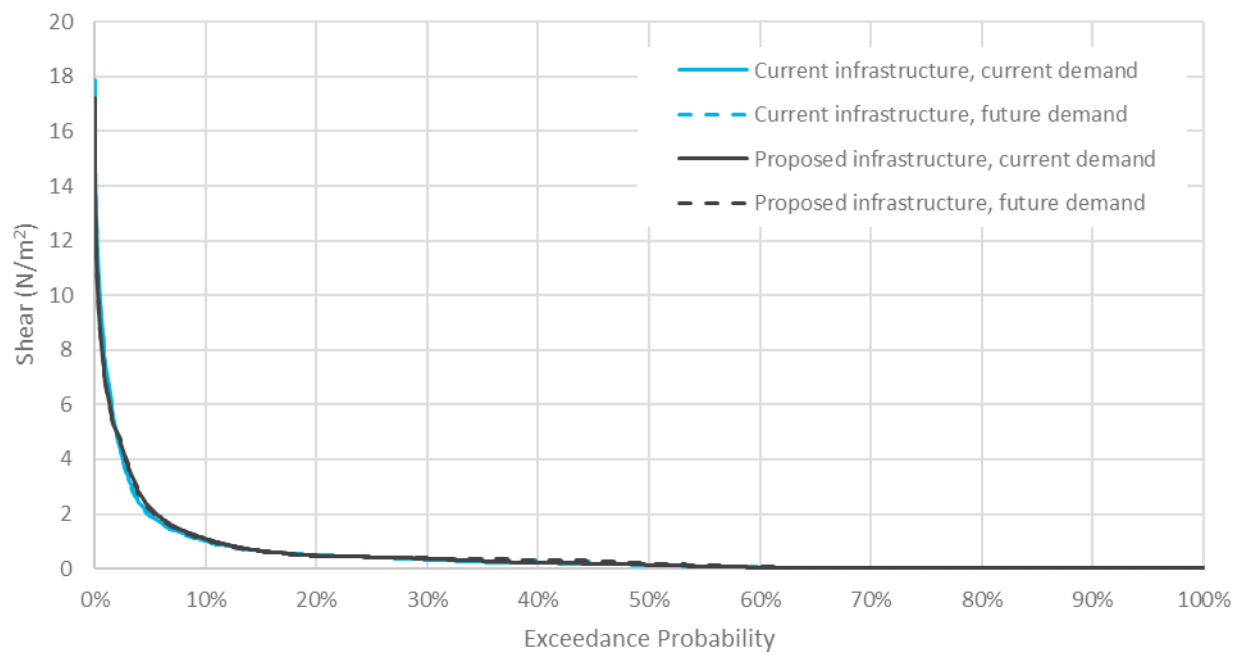


Figure A.6 Bed shear stress, Doon Doon Creek pool

A.3 Tweed River riffle

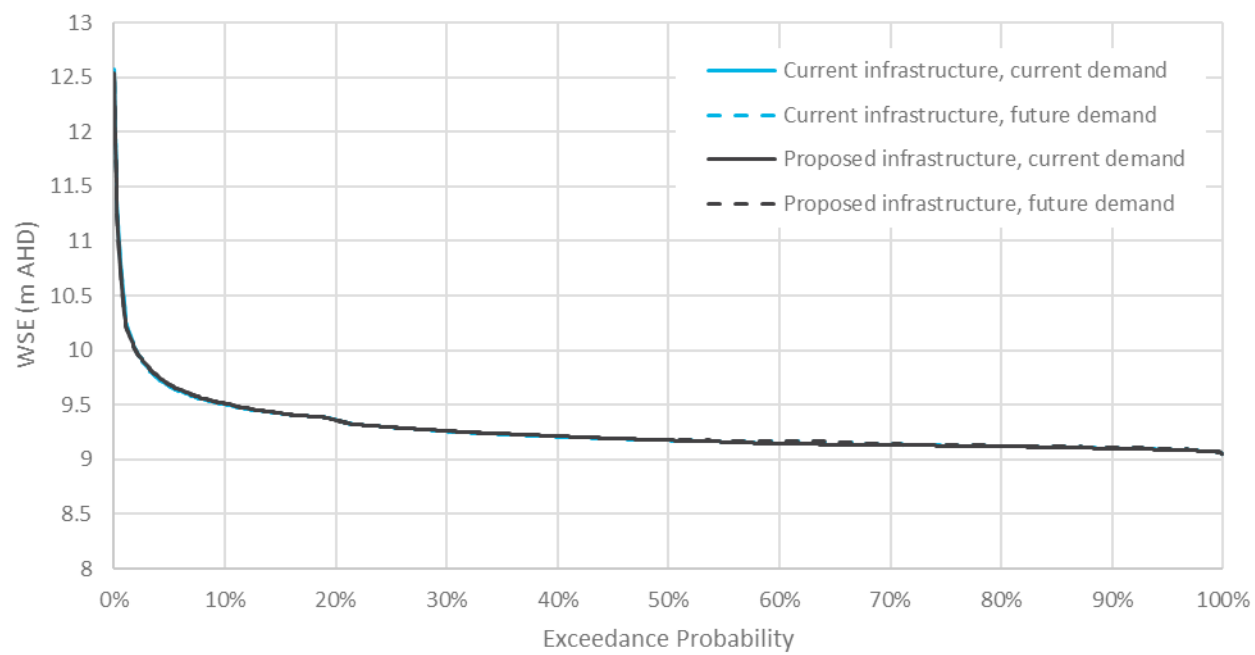


Figure A.7 Water surface elevation, Tweed River riffle

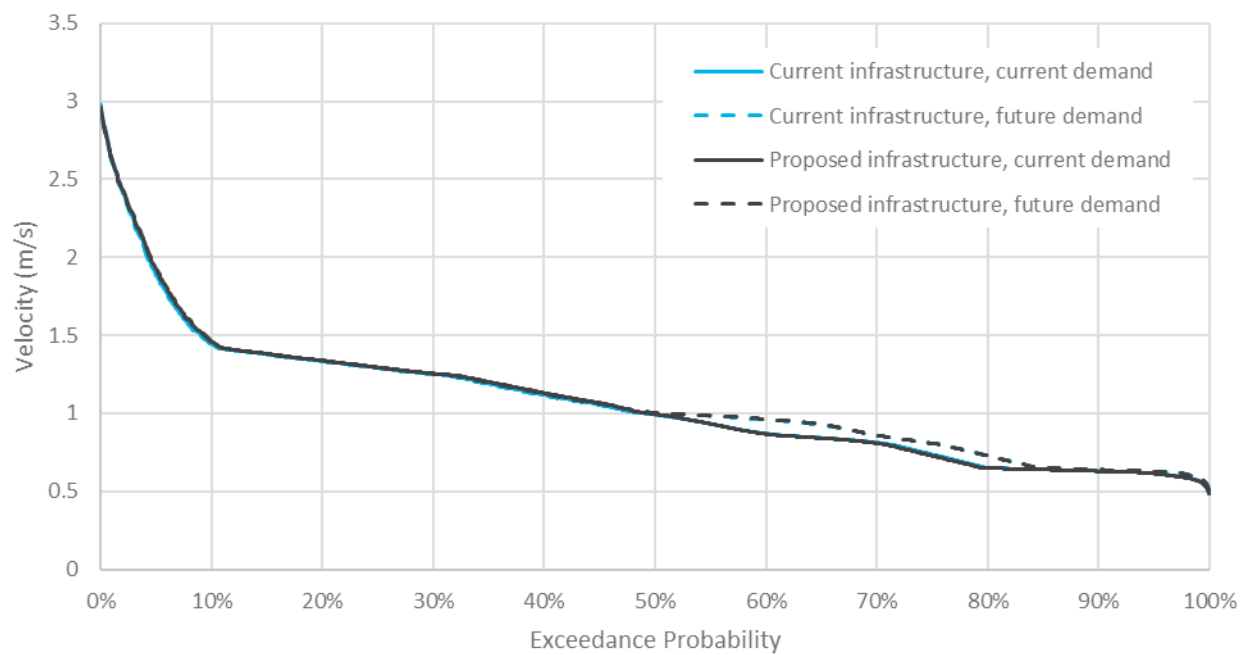


Figure A.8 Velocity, Tweed River riffle

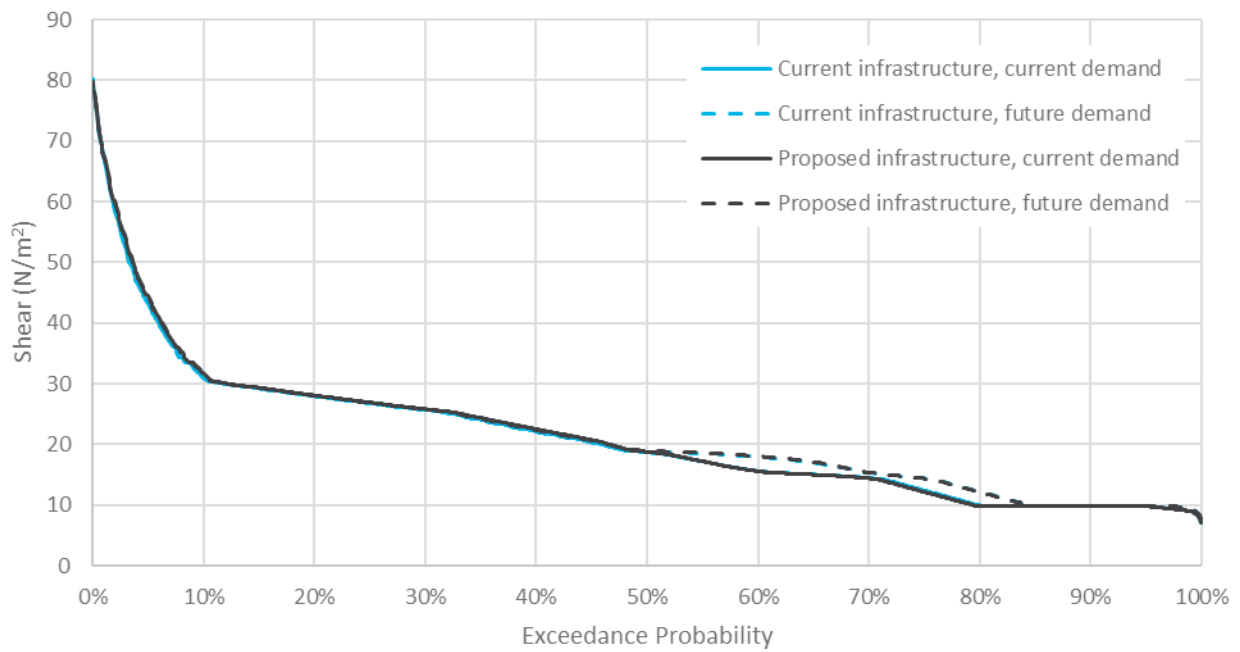


Figure A.9 Bed shear stress, Tweed River riffle

A.4 Tweed River pool

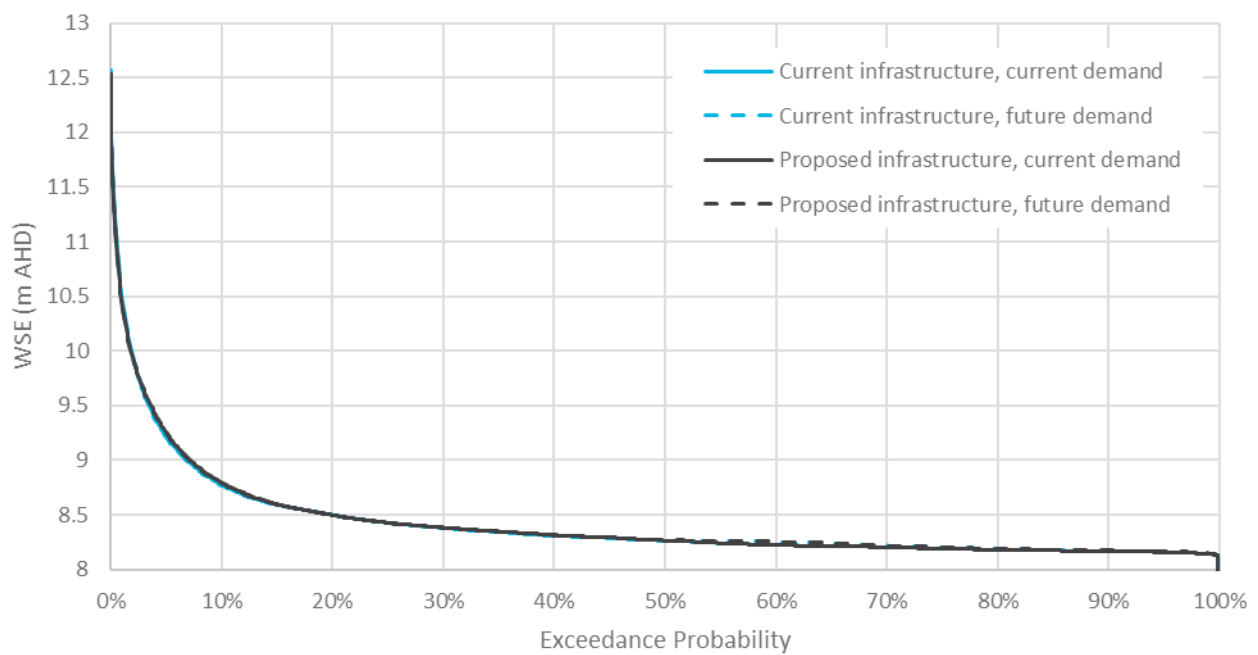


Figure A.10 Water surface elevation, Tweed River pool

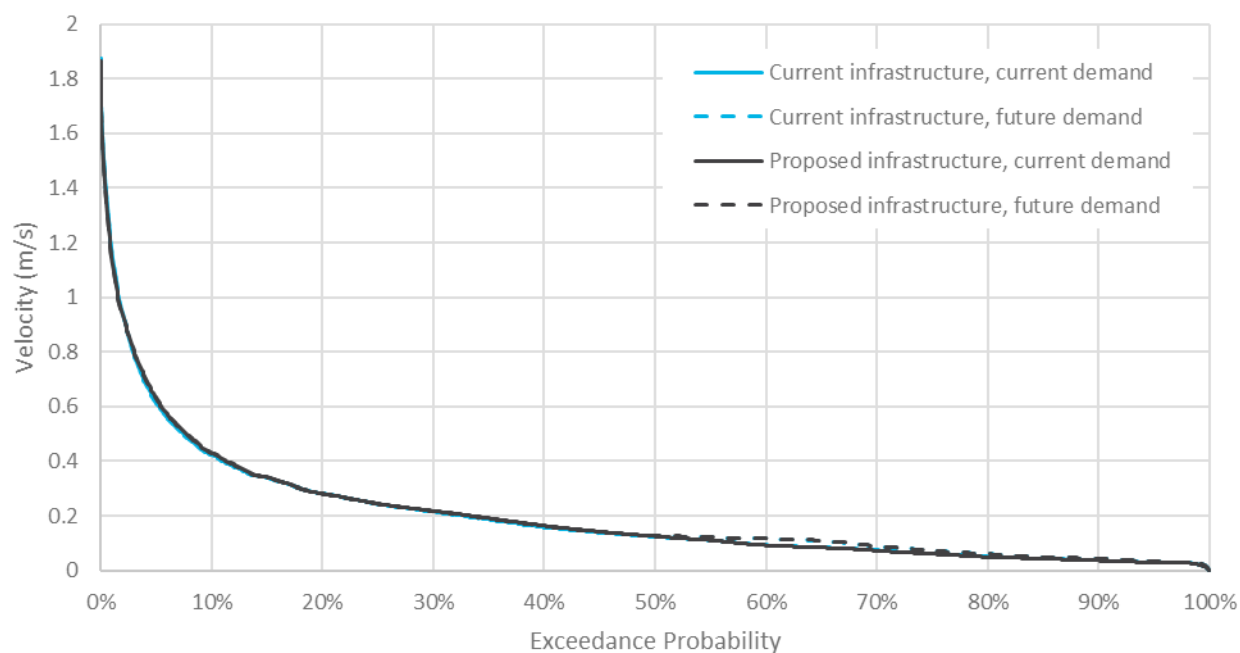


Figure A.11 Velocity, Tweed River pool

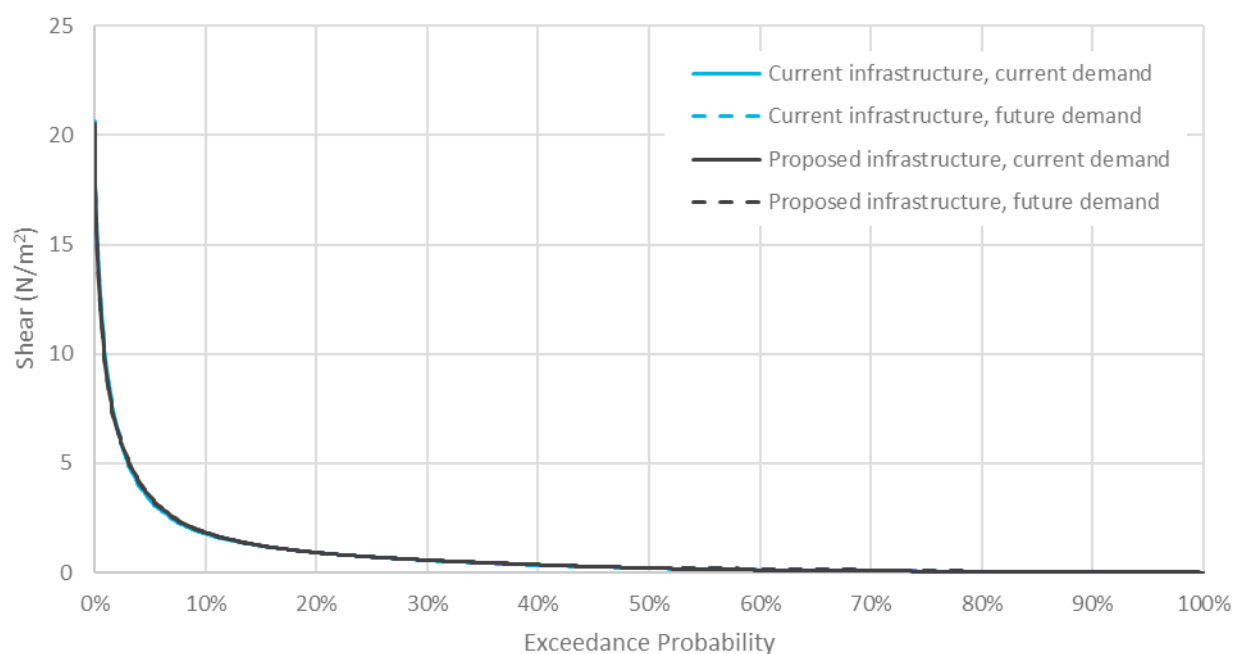


Figure A.12 Bed shear stress, Tweed River pool

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