TWEED SHIRE COUNCIL

# TWEED VALLEY FLOOD STUDY UPDATE AND EXPANSION

FINAL REPORT

AUGUST 2024

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## FINAL REPORT

AUGUST 2024

| **Project**<br>Tweed Valley Flood Study Update and Expansion | **Project Number**<br>120068 |
|---|---|
| **Client**<br>Tweed Shire Council | **Client's Representative**<br>Leon McLean |
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Front Image: https://www.youtube.com/watch?v=UsPF5DTl44U

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# LIST OF ACRONYMS

| | |
|---|---|
| AEP | Annual Exceedance Probability |
| ARI | Average Recurrence Interval |
| ALS | Airborne Laser Scanning |
| ARR | Australian Rainfall and Runoff |
| BOM | Bureau of Meteorology |
| DECC | Department of Environment and Climate Change (now DCCEEW) |
| DCCEEW | Department of Climate Change, Energy, the Environment and Water |
| DNR | Department of Natural Resources (now DCCEEW) |
| DRM | Direct Rainfall Method |
| DTM | Digital Terrain Model |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| IFD | Intensity, Frequency and Duration (Rainfall) |
| mAHD | meters above Australian Height Datum |
| OEH | Office of Environment and Heritage (Now DCCEEW) |
| PMF | Probable Maximum Flood |
| SRMT | Shuttle Radar Mission Topography |
| TUFLOW | One-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model) |
| WBNM | Watershed Bounded Network Model (hydrologic model) |

# ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2016) recommends terminology that is not misleading to the public and stakeholders. Therefore, the use of terms such as “recurrence interval” and “return period” are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals, such as every 100 years. However, rare events may occur in clusters. For example, there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

ARR 2016 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful, and misleading particularly in areas with strong seasonality.

Therefore, the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example, an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6-month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding, a PMP does not translate to a PMF of the same AEP. Therefore, an AEP is not assigned to the PMF.

This report has adopted the approach recommended by ARR and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

| Frequency Descriptor | EY | AEP (%) | AEP (1 in x) | ARI |
|---|---|---|---|---|
| Very Frequent | 12 | | | |
| | 6 | 99.75 | 1.002 | 0.17 |
| | 4 | 98.17 | 1.02 | 0.25 |
| | 3 | 95.02 | 1.05 | 0.33 |
| | 2 | 86.47 | 1.16 | 0.5 |
| | 1 | 63.21 | 1.58 | 1 |
| Frequent | 0.69 | 50 | 2 | 1.44 |
| | 0.5 | 39.35 | 2.54 | 2 |
| | 0.22 | 20 | 5 | 4.48 |
| | 0.2 | 18.13 | 5.52 | 5 |
| | 0.11 | 10 | 10 | 9.49 |
| Rare | 0.05 | 5 | 20 | 19.5 |
| | 0.02 | 2 | 50 | 49.5 |
| | 0.01 | 1 | 100 | 99.5 |
| Very Rare | 0.005 | 0.5 | 200 | 199.5 |
| | 0.002 | 0.2 | 500 | 499.5 |
| | 0.001 | 0.1 | 1000 | 999.5 |
| | 0.0005 | 0.05 | 2000 | 1999.5 |
| Extreme | 0.0002 | 0.02 | 5000 | 4999.5 |
| | | | ↓ | |
| | | | PMP/ PMP Flood | |

## DISCLAIMER

# EXECUTIVE SUMMARY

The Tweed Valley has a long history of flooding, and over the past 15 years, several flood studies and updates have been completed for the Tweed Valley. Some of these projects undertook a regional scale assessment while others have focussed on specific areas in the Local Government Area (LGA). As such, there is a substantial amount of existing flood information available for the Tweed Valley, from both recorded data and previous flood modelling.

Tweed Shire Council (Council) has received financial support from the State Floodplain Management Program managed by the Department of Climate Change, Energy, the Environment and Water (DCCEEW) (previously Department of Planning and Environment) to undertake an updated and expanded flood study of the Tweed Valley catchment. The intent of this project is to review and expand upon the latest existing flood study, completed by BMT WBM in 2009, to include the full catchment and incorporate the latest guidance from Australian Rainfall and Runoff 2019 (ARR19).

## Hydrology and Hydraulic Models

A hydrologic model using Watershed Bounded Network Model (WBNM) was used for the flood study to understand the hydrology within the Tweed Valley catchment area. The flows generated in the WBNM was used for the inflows in the development of the hydraulic model. A hydraulic TUFLOW model was developed to accurately identify the flood behaviour within the Tweed Valley catchment area. Calibration and verification of the WBNM and TUFLOW models were undertaken as part of the flood study.

## Calibration

Joint calibration of the WBNM hydrologic model and TUFLOW hydraulic model was undertaken based on flows and levels that were recorded during flood events in February 2022, March 2017, February 2020 and March 1989. The February 2022 flood event was considered the primary calibration event, as this flood event is the largest on record for most parts of the Tweed Valley. The secondary calibration event was the March 2017 flood event, which was the previously largest flood on record. The February 2020 (minor flood) and March 1989 (moderate flood) events were assessed based on the availability of recorded data (2020) and their use in the previous flood study (1989). The four selected events were considered to provide a good range of magnitude events and provided confidence in the model at a large range of flows.

### February 2022 Results

For the 2022 flood event, 298 flood survey locations were available, with 266 locations reviewed in the hydraulic model. Overall, the calibration achieved is considered good. A statistical assessment indicated better calibration at the lower end of the model, with less agreement in the upper reaches of the catchment.

### March 2017 Results

There are over 275 flood survey locations available for the 2017 flood event. This information has been used to inform the calibration effectiveness of the model. Of the 275 survey levels provided

203 locations could be reviewed in the hydraulic model, with 180 deemed accurate. Overall, the calibration achieved is considered to be very good. Generally better calibration is achieved at the lower end of the model, with less agreement achieved in the upper reaches of the catchment.

### February 2020 Results

For the 2020 flood event, over 40 survey locations were provided, with 24 reviewed in the hydraulic model. Generally better calibration is achieved along the Rous River and Eungella reach of the river. Less agreement is achieved upstream of Uki. This is consistent with the findings at the gauges in the area, which indicate an overestimation in flow through the reach.

### March 1989 Results

There were seven (7) flood survey locations provided for the 1989 flood event. The 1989 calibration within the 2009 Flood Study, struggled to adequately model the tidal gauges. The current model is much better at modelling the tidal area of the system and has achieved better calibration in these areas compared to the 2009 Flood Study.

## Sensitivity

Sensitivities were explored for the 2017 calibration and demonstrated that the model is representing the flood behaviour well. Based on the analysis, localised modifications to model roughness were undertaken in the upper reaches of the catchment to achieve improved calibration results.

## Design Event Results

Design event modelling, climate change analysis and post processing of model results has also been completed. A comparison of the flood levels observed, compared to the previous study indicate that while some variances are present, the variances are within the bounds of expected changes. Cross checking of the areas with the largest changes confirm that observed flood level information present in the areas align well with the modelled levels, in both the 2017 and 2022 flood events.

## Design Event Flood Behaviour

### Murwillumbah

In Murwillumbah, the effects of flooding are varied. The Murwillumbah Township is protected by flooding from a river levee, which provides immunity up to the 1% AEP event, but is overtopped in the 0.2% AEP event from riverine flooding.

At the peak of the 1% AEP flood event, inundation in Murwillumbah CBD is minimal with small patches near Prince Street, Princes Lane and King Street. There is some inundation near the Dorothy Street levee near the Murwillumbah Leagues Club. Near the northern end of the East Murwillumbah levee near Mayal Creek there is a small pocket of inundation behind the levee on Tumbulgum Road.

In a 0.2% AEP event the Dorothy Street Levee, East Murwillumbah and the Murwillumbah CBD levees are completely overtopped leading to widespread flooding.

A detailed overtopping assessment of the levee and flooding in the Murwillumbah Township was undertaken in 2018 by Catchment Simulation Solutions. The local study is of a higher detail than this study and should be used to inform flood knowledge in the Murwillumbah Township.

**South Murwillumbah**

South Murwillumbah is affected by flooding in small events with depths up to 4 m in some low-lying areas (between Wardrop Street and Tweed Valley Way, and River Street) in the 20% AEP event. The South Murwillumbah levee provides some protection but begins to overtop when levels at the Murwillumbah Bridge reach approximately 4.8 mAHD.

South Murwillumbah is predicted to be fully inundated during the 1% AEP event from both Tweed River breakout and local runoff. Peak depths are up to 5 m in low lying areas, and up to 1.5 m over Tweed Valley Way.

The airfield acts as the major flow path from South Murwillumbah to Condong Creek during flood events velocity-depth products are greater than 0.3 $m^2$/s across much of South Murwillumbah during the 1% AEP flood event.

**Condong**

Some areas of Condong are predicted to be inundated in small events including the 20% AEP flood. In the 1% AEP flood, most of Condong is inundated apart from a small, isolated area at the northern end of town (Maria and Carmen Place). Peak depths are up to 2 m in low lying areas, and up to approximately 1 m over Tweed Valley Way in the 1% AEP flood. Most buildings are located on the higher ground along Tweed Valley Way where depths are lower.

**Tumbulgum**

Tumbulgum is also predicted to be inundated by small flood events including the 20% AEP flood. At the peak of the 20% AEP flood event, most of the town is inundated apart from small areas of higher ground, with depths up to 1.5 m in low lying areas. During the 1% AEP flood event, the whole town is inundated, with depths up to 3 m in low lying areas. Velocities through town are small. In events larger than the 1% AEP flood event, Tweed Valley Way and the floodplain to the south become high flow areas with velocity-depth products above 0.3 $m^2$/s.

Within the design event assessment, it is noted the hydraulic grade was seemingly different to the grades present in the calibrated flood events between the river mouth (Entrance) and Tumbulgum. A review of the mechanism of this was undertaken. What is immediately identified is the ocean boundary conditions of the design events are significantly higher than the calibration events in the 1% and 0.2% AEP. This is a requirement of design flood modelling, set by NSW Flood Risk Management Manual guidance, and is to ensure that a conservative approach to ocean/tidal and riverine flood interactions is considered. This tailwater condition affects the levels in the design events up to approximately the western end of Dodds Island.

Once around the sharp bend near the Tweed Broadwater, there is a level change which starts to significantly reduce the tidal influence. At this location the 0.2% AEP and the 2022 event start to diverge, with the 2022 event becoming higher. This indicates that downstream of this location the tidal condition set was influencing the 0.2% AEP flood levels. Similar divergence in flood results are observed when comparing the 1% AEP and 2017 events. Downstream of this the higher tailwater present in the 1% AEP was affecting the design flood levels. Upstream of this location the water level grade between the modelled events is very similar. Based on the review it is considered that the majority of differences present in water level gradient are driven by the ocean tailwater condition applied to the design event simulations.

Review of historic event outputs from previous studies (Tweed Valley Flood Study, 2005, WBM Oceanics Australia) indicates similar behaviour has been present for all previous calibrated events, including the 1974 and 1989 events.

**Chinderah**

Large areas of Chinderah experience flooding in the 5% AEP event with depths up to 1.5 m in low lying areas adjacent to the Kingscliff drain. In the 1% AEP event, most of Chinderah is inundated with depths up to 2.5 m. Velocities are generally low (less than 0.1 m/s in most areas), and velocity-depth products are also generally low (less than 0.3 $m^2/s$) in the 1% AEP flood event.

**Kingscliff**

The northwestern edge of Kingscliff, extending approximately halfway from Sand Street to Kingscliff Street, is inundated in the 1% AEP flood event, with depths up to approximately 1 m within properties, and 1.5 m in the streets. Velocities are generally less than 0.5 m/s and velocity-depth products are less than 0.1 $m^2/s$ in the 1% AEP event in this area. Residential streets inundated include Sand Street, Ozone Street, Kindee Street, Ocean Street, Surf Street, Terrace Street and Eddy Avenue.

Properties within the southern area of Kingscliff are generally free of flooding in the 1% AEP flood event. However, in the 0.2% AEP and greater, low-lying properties are inundated, with majority of residential streets inundated, west of Kingscliff Street, with depths of up to approximately 1 m along Elrond Drive.

**Fingal Head**

The main centre of Fingal Head is not affected by flooding up to the 0.2% AEP flood event. However, Letitia Road to the north (including some adjacent properties) and Fingal Road leading into Fingal Head from the south (also including some adjacent properties) are predicted to be inundated in the 5% AEP event. The depth of inundation over Fingal Road is up to 1.5 m near Wommin Lake in the 1% AEP flood event.

**Banora Point**

Banora Point is expected to be mostly flood free in the 1% AEP flood (see Figure 6-11) with the exception of the Kirkwood Road area which is inundated from Terranora Creek in the 5% AEP flood and larger. Velocity-depth products are less than 0.3 $m^2/s$ in the 1% AEP event. The Banora Point Golf Course provides flood storage in events larger than the 20% AEP, with depths between 1.5 m and 2 m in the 1% AEP event.

No inundation of developed areas is expected in Flame Tree Park in the 1% AEP event with the exception of some streets. Note however, that this is only based on flooding from either storm surge or a catchment flood. It does not include areas inundated by stormwater flooding, usually caused by shorter-duration, higher-intensity local rainfall events, such as that which occurred in June 2005. There is currently a Tweed Heads South Levee and Drainage Study being undertaken which will provide further local flooding conditions for this region.

**Tweed Heads South**

The Tweed Heads South levee was designed to provide immunity for the 1954 flood levels. Based on the survey of the levee, there are some sections of the levee that are overtopping in the 5% AEP event, including several locations along both the Dry Dock Road and Minjungbal Drive sections of the levee. The levee is overtopped by up to 0.3 m near the South Tweed Bowls Club. Depth of inundation in the northern residential areas are mostly between 0.5 m and 1 m in the 1% AEP event. Velocity-depth products are less than 0.3 $m^2/s$ in the 1% AEP event. Most of the southern commercial area is flood free in the 1% AEP event with the exception of some of the northern streets including Minjungbal Drive north of Machinery Drive. There is currently a Tweed Heads South Levee and Drainage Study being undertaken which will provide further local flooding conditions for this region.

**Tweed Heads**

Most of the developed areas of Tweed Heads are flood free in the 1% AEP event with the exception of a few properties along Endeavour Parade in the north and Margaret Street near the canals. Some streets are also inundated in this event, including sections of Kennedy Drive up to 1 m, Ducat Street up to 1 m and Keith Compton Drive up to 0.5 m near the old Tweed Heads District Hospital.

**Tweed Heads West**

Low lying areas of Tweed Heads West are expected to be inundated in the 5% AEP event and larger. Widespread inundation occurs in the 1% AEP event including most properties along Kennedy Drive, Gray Street, Rose Street, Blue Waters Crescent and Wyuna Road. Depths are typically 1 m to 1.5 m in this event. Approximately two-thirds of Seagulls Estate and all of the streets are inundated in the 1% AEP flood, with depths up to 1.5 m along Sunset Boulevard.

**Uki**

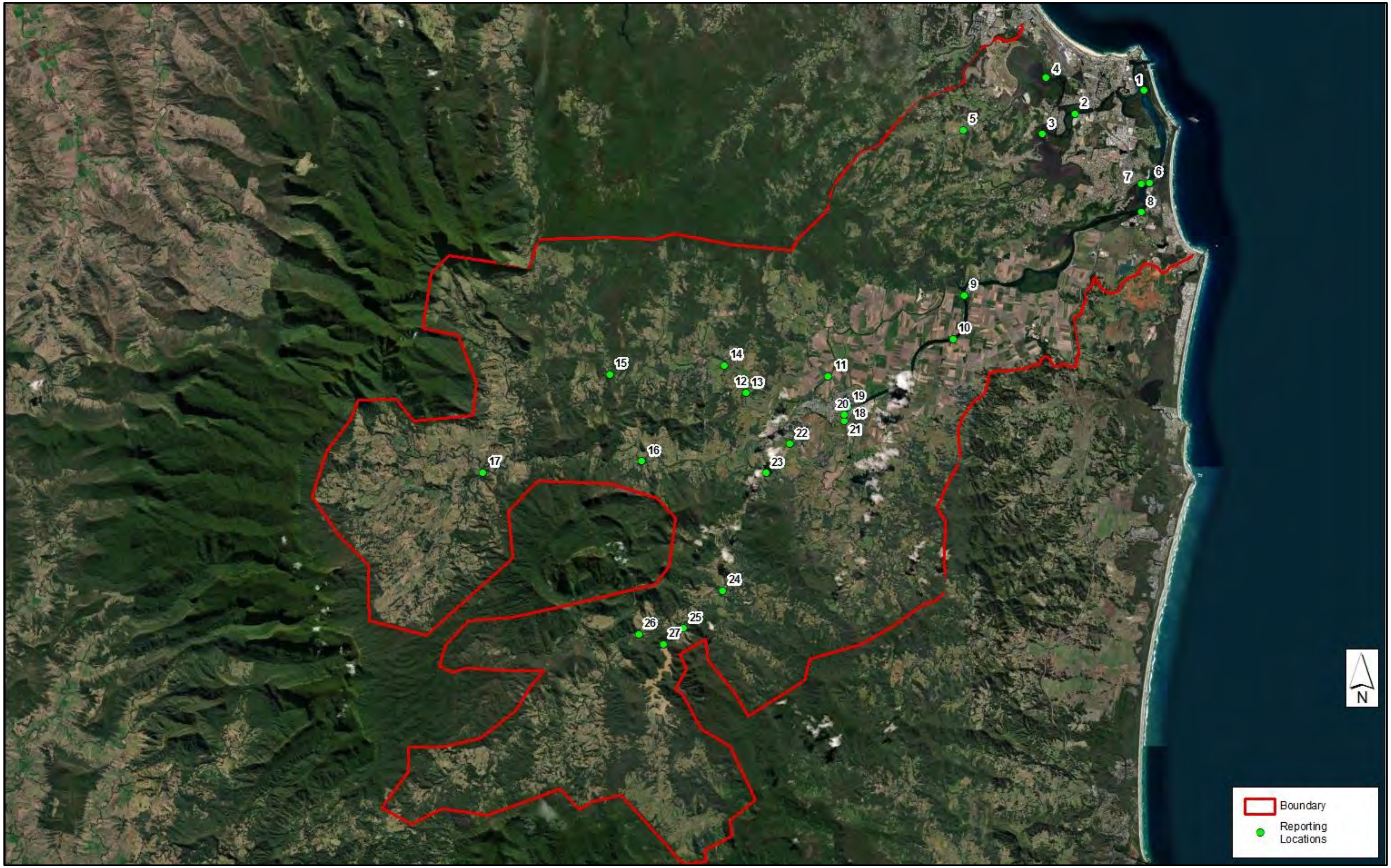
Low lying areas and properties of Uki are expected to be inundated in the 5% AEP event and larger. Inundation of Kyogle Road occurs as a result of the convergence of Rowlands Creek with the Tweed River. The majority of properties within Uki are flood free in the 1% AEP event, with the exception of some properties along Kyogle Road, with depths up to approximately 2 m, and some properties along Smiths Creek Road, with depths up to approximately 2.5 m.

**Design Water Levels**

Peak water levels within the model at key locations are presented below. The report locations are presented overleaf.

Peak Water Levels

| River Location | ID | Name | Peak Water Level (mAHD) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 20% | 5% | 1% | 0.20% | PMF |
| Lower Tweed | 1 | 558041 Gauge-Letitia2A | 1.03 | 2.06 | 2.61 | 2.66 | 4.87 |
| | 2 | 558029 Gauge-Dry_Dock | 1.03 | 2.07 | 2.61 | 2. 66 | 4.94 |
| | 3 | 558056 Gauge-Terranora | 1.03 | 2.08 | 2.61 | 2.68 | 4.94 |
| | 4 | 558045 Gauge-Cobaki | 1.03 | 2.03 | 2.61 | 2.85 | 4.94 |
| | 5 | Cobaki Ck | 6.18 | 6.61 | 7.08 | 7.24 | 8.89 |
| Mid Tweed | 6 | Barneys Point | 1.27 | 2.03 | 2.66 | 3.24 | 6.45 |
| | 7 | 558102 Gauge_BarneysPt | 1.31 | 2.03 | 2.67 | 3.41 | 7.00 |
| | 8 | 558010 Flood_Gauge_Chinderah | 1.36 | 2.03 | 2.73 | 3.50 | 7.12 |
| | 9 | 558014 Tumbulgum | 2.72 | 3.32 | 4.02 | 4.54 | 8.53 |
| | 10 | Tygalgah (Smiths) (Reader) | 3.16 | 3.57 | 4.19 | 4.68 | 8.69 |
| Rous | 11 | Kynn Bridge No.3 (Reader) | 4.10 | 4.50 | 4.83 | 5.13 | 9.22 |
| | 12 | Boat Harbour (Rous River) (2) | 6.22 | 6.72 | 7.12 | 7.41 | 9.54 |
| | 13 | Boat Harbour (Rous River) | 6.29 | 6.90 | 7.34 | 7.65 | 9.96 |
| | 14 | 58204 Rous @ Boat Harbour 3 | 9.22 | 9.72 | 9.98 | 10.31 | 12.95 |
| | 15 | 58011 Chillingham_Bridge | 30.26 | 22.94 | 31.62 | 32.22 | 26.63 |
| Oxley River | 16 | 58193 Eungella | 21.01 | 31.35 | 23.78 | 24.01 | 35.41 |
| | 17 | 558088 Tyalgum_Bridge | 51.56 | 53.36 | 54.31 | 54.61 | 58.68 |
| Upper Tweed | 28 | 58186 North Murwillumbah | 4.87 | 5.41 | 6.01 | 6.41 | 10.37 |
| | 18 | 558067 Murwillumbah Bridge | 4.80 | 5.30 | 5.89 | 6.29 | 10.36 |
| | 19 | US_Murwillumbah Bridge | 4.88 | 5.44 | 6.06 | 6.46 | 10.46 |
| | 20 | Murwillumbah Lavender Ck | 4.99 | 5.63 | 6.29 | 6.65 | 10.53 |
| | 21 | Commercial Road (Reader) | 5.11 | 5.76 | 6.43 | 6.75 | 10.59 |
| | 22 | 558065 Bray Park Weir | 6.96 | 9.87 | 9.50 | 9.93 | 15.99 |
| | 23 | Bakers Byangum (Reader) | 8.51 | 8.55 | 10.69 | 11.09 | 14.94 |
| | 24 | 58167 Tweed @ Uki | 19.09 | 20.94 | 21.59 | 22.08 | 29.17 |
| | 25 | 558009 Clarrie Hall Dam Rd | 25.54 | 27.67 | 28.55 | 29.19 | 34.39 |
| | 26 | 558018 Tweed R @ D/s Palmer | 37.01 | 38.38 | 39.16 | 39.75 | 43.22 |
| | 27 | 558028 Clarrie Hall Dam | 64.63 | 65.62 | 66.50 | 66.86 | 68.77 |




Water Level Reporting Locations

# Climate Change

Climate change will result in a significant number of additional properties floors being inundated. Two climate change scenarios have been modelled using a high and low emission case and the same projected year of 2090.

Low Climate Change Scenario (9.5% increase in rainfall and a sea level rise of 0.71 m):

- An additional 98 residential buildings will be impacted in the 5% AEP with Climate Change compared to the current 5% AEP inundation.
- There are minor increases in the number of industrial and commercial properties that will be impacted in the 5% AEP with Climate Change.
- An additional 762 residential buildings will be impacted in the 1% AEP with climate change compared to the current 1% AEP inundation.
- An additional 73 commercial buildings will be impacted in the 1% AEP with Climate Change compared to the current 1% AEP inundation.
- There are minor increases in the number of industrial properties that will be impacted in the 1% AEP with Climate Change.

High Climate Change Scenario (19.7% increase in rainfall and a sea level rise of 0.91 m):

- An additional 163 residential buildings will be impacted in the 5% AEP with Climate Change compared to the current 5% AEP inundation,
- There are minor increases in the number of industrial and commercial properties that will be impacted in the 5% AEP with Climate Change.
- An additional 1,615 residential buildings will be impacted in the 1% AEP with Climate Change compared to the current 1% AEP inundation,
- An additional 143 commercial buildings will be impacted in the 1% AEP with Climate Change compared to the current 1% AEP inundation,
- There are minor increases in the number of industrial properties that will be impacted in the 1% AEP with Climate Change.

Climate change is impacting more residential properties than commercial and industrial properties. In the current 1% AEP event, the Murwillumbah CBD levee is not overtopped but with climate change this levee is overtopped resulting in a significant number of residential properties being impacted behind the levee.

The majority of changes are identified in Chinderah, Murwillumbah, Tweed Heads, Tweed Heads West, Tweeds Head South and Fingal. These localities are all impacted more than another other localities within the Tweed catchment as they are located within the tidal zone that is impacted by both the increase in rainfall and tidal levels.

# Conclusion

Following the review of existing material an update to the hydrology and hydraulic models that represent the Tweed catchment were undertaken.

The hydraulic model was updated to include modifications in the catchment since the previous model build and included an update of the complete geometry of the model based on the latest LiDAR. Bathymetric data was used to represent the main channel up to Bray Park Weir, and up to Cobaki Creek. Calibration of the roughness in this model was then undertaken, with good matches to observed levels recorded throughout the model. Sensitives were explored for the 2017 calibration model and demonstrated that the model is representing the flood behaviour well. Based on the sensitivity analysis, localised modifications to model roughness was undertaken in the upper reaches of the catchment to achieve appropriate calibration results. The 2022 hydraulic model adopted hydraulic roughness was used for the design models as it accounts for the current scour conditions in the catchment.

Design event modelling, climate change analysis and post processing of model results has also been completed. A comparison of the flood levels observed, compared to the previous study indicate that while some variances are present, the variances are within the bounds of expected changes. Cross checking of the areas with the largest changes confirm that observed flood level information present in the areas align well with the modelled levels in both the 2017 and 2022 flood events.

This study has used the best available data, incorporated recent flood experiences and utilised best practice industry guidance to provide a representation of flooding in the Tweed Valley.

# 1. INTRODUCTION

The Tweed Valley has a long history of flooding, and over the past 15 years, several flood studies and updates have been completed for the Tweed Valley. Some of these projects undertook a regional scale assessment while others have focussed on specific areas in the Local Government Area (LGA). As such, there is a substantial amount of existing flood information available for the Tweed Valley, from both recorded data and previous flood modelling.

Tweed Shire Council (Council) has received financial support from the State Floodplain Management Program managed by the Department of Climate Change, Energy, the Environment and Water (DCCEEW) (previously Department of Planning and Environment) to undertake an updated and expanded flood study of the Tweed Valley catchment. The intent of this project is to review and expand upon the latest existing flood study, completed by BMT WBM in 2009, to include the full catchment, incorporating the latest guidance from Australian Rainfall and Runoff 2019 (ARR19).

As part of the project, verification of the hydraulic model using the most recent February 2022 event has also been completed. This process has enabled an improved understanding of flood behaviour and impacts and will better inform management of flood risk in the study area. Community consultation was also undertaken as a means of further verification of model results, through the understanding of flood behaviour experienced by the community. The consultation sessions also provided the opportunity to increase flood awareness within at-risk communities.

Ultimately, this updated and expanded flood study will be used in the development of a robust Floodplain Risk Management Plan (FRMP), and will inform the following Council functions:

- Local Environment Planning (flood certificates);
- Development Assessments;
- Local flood policy and plan (or DCP);
- Identification on future developable land (use and zoning) and associated strategic planning and infrastructure decision making (including development controls);
- Emergency management planning; and
- Design and impact assessment for infrastructure projects.

This report details the investigations, results and findings of the updated and expanded flood study for the Tweed Valley catchment. This includes some of the aforementioned work conducted as part of previous studies. The key elements of this study include:

- Summary of previous work and available data;
- Community engagement;
- Hydrologic model updates and adaptation;
- Hydraulic model development and expansion;
- Hydraulic model calibration and incorporation of the new 2017 and 2020 events; and
- Design event modelling.

# 2. BACKGROUND

## 2.1. Study Area

The Tweed Shire Local Government Area (LGA) is located in the Northern Rivers Region of New South Wales. Tweed Shire covers a total catchment area of 1,303 km$^2$ and has a population of approximately 100,000. It is estimated that the population will increase to 128,000 by 2031 (TSC, Reference 12). The Tweed Valley catchment is bounded by the Border Ranges and Mebbin National Park to the west, the McPherson Range on the Queensland/New South Wales border to the north, and the Nightcap, Mount Jerusalem and Mooball National Parks to the south. The catchment outlets to the ocean via the Tweed River, between Point Danger and Fingal Head. Diagram 1 shows the extent of the Tweed Valley catchment.

The Tweed Valley catchment is complex and diverse, with a mix of urban and rural land, a water supply dam, tidal influences and numerous tributaries with the potential for individual or joint flooding. It incorporates a wide range of topography, from steep channelised valleys to wide, flat floodplain areas and coastal estuaries. The catchment includes the city of Tweed Heads, the riverside towns of Chinderah, Tumbulgum, Condong and Murwillumbah, the rural villages of Kunghur, Uki, Tyalgum, Chillingham and Bilambil, as well as the northern parts of Kingscliff. A system of levees has been constructed to protect the main townships of Murwillumbah (including South Murwillumbah) and South Tweed from frequent flooding events. Other flood mitigation measures including flood pumps, flood gates and the construction of drainage systems have also been undertaken within the catchment.

The main streams through the catchment include the Tweed River, Oxley River and the Rous River, which joins the Tweed River at Tumbulgum. Another unique feature of the catchment are the broadwaters at Terranora and Cobaki which combine and converge with the Tweed River, approximately 2 km upstream of the ocean outlet at Tweed Heads.

The Tweed River is known to experience tidal effects to just upstream of Murwillumbah, a total distance of approximately 30 km (Reference 6). Breakwaters were constructed at the river mouth between 1962-1964 to control the entrance. The Tweed River Entrance Sand Bypassing system was implemented in 2001 to pump sand under the river and feed the beaches of the southern Gold Coast (Reference 6). There is also a weir located at Bray Park, upstream of Murwillumbah, which is used to prevent salt water from permeating the fresh water upstream which feeds Tweed's potable water supply. However, previous tidal driven events have caused overtopping of the weir.

The Tweed has an average rainfall of approximately 1,600 mm per year and experiences a sub-tropical climate with mild winters and hot, humid summers. The Tweed has a defined wet season from around November to May (Reference 5).


Diagram 1:Tweed Valley Catchment Area (Google Maps, 2020)

# 3. AVAILABLE DATA

A Data Review of all relevant existing and readily available data was completed to identify the data most appropriate for use in this study. The Data Review examined the quality of this data and indicated any known associated assumptions and limitations. The data has been reviewed in the context of the modelling to be undertaken for this study and has been built on the data collation exercise undertaken as part of the existing Flood Study (completed in 2005 and updated in 2009, References 7 and 8).

## 3.1. Previous Studies

A number of flood studies and assessments have been conducted within the Tweed Valley catchment. These studies vary in scale from lot sized flood assessments to large scale studies incorporating significant areas of the catchment. A brief overview of the more recent and relevant studies is provided below.

**Tweed Valley Flood Study (WBM, 2005)**
The Tweed Valley Flood Study (Reference 7) was the first study to implement hydrology and the information from a one-dimensional ESTRY model to develop a 2D hydraulic model of the floodplain, from Murwillumbah to Tweed Heads. A Digital Elevation Model (DEM) was created to the necessary bathymetric and topographic requirements for a 2D hydraulic model. The hydraulic model was developed on a 40 x 40 m grid, with a total of almost 140,000 individual cells. The TUFLOW model was calibrated and verified against the Historical Events of March 1974, March 1978, and April 1989 to simulate the 5-, 20-, 100- and 500-year ARI, and PMF design flood events. The key outputs of the study were a detailed representation of flow conditions of the river and floodplain.

**Clarrie Hall Dam Dambreak Study (NSW Water Solutions, 2007)**
The Clarrie Hall Dam Dambreak Study (Reference 14) details the results of the dam break and the consequences of flooding downstream. The study considered five scenarios of dam break from Sunny Day to the PMF. The study determined that the severity of the dambreak and losses downstream, are category ‘High A’ for a Dam Crest Flood (DCF) Dambreak case. Furthermore, the FCC of the dam was classified as ‘Extreme’ for a PMF event.

**Tweed Valley Flood Study Update (BMT WBM, 2009)**
The primary purpose of the Tweed Valley Flood Study Update (Reference 8) was to update the hydraulic model with improved topographic data of the catchment, this being the ALS/LiDAR data collected in July 2007. The new data generally reduced the ground levels by 200 mm as compared to the original topography adopted. Further levees were introduced into the model including the Tweed Heads South levee, the Dorothy Street and East Murwillumbah levees constructed in 2006. Further technological improvements such as the TUFLOW 2008 software update, an updated and refined hydrologic model due to improved GIS techniques and updated rainfall data due to improved GIS spatial distribution, were all implemented. As a result, design flood event outputs were created and impacts in comparison to the 2005 model were developed.

**Tweed Valley Floodplain Risk Management Study & Plan (BMT WBM, 2014)**

The Tweed Valley Floodplain Risk Management Study (Reference 9) was implemented to assess the existing and future flood risk across the Tweed Valley Floodplain. The results of the study were to be used to inform the subsequent Tweed Valley Floodplain Risk Management Plan (Reference 9). The study was developed from the hydrologic and hydraulic models developed in the Tweed Valley Flood Study 2009 Update (Reference 7) and determined that approximately 41,500 people were living on flood prone land within the Tweed Valley. Subsequently modification measures were assessed including flood, property and response measures, in response to potential impacts. Future flood risk was also evaluated through a climate change assessment, and planning and future development was considered.

**Post Event Flood Behaviour Analysis and Review of Flood Intelligence – Tweed River (BMT WBM, 2018)**

This report (Reference 11) determined that the Flood Study 2009 Update (Reference 8) and the associated Floodplain Risk Management Study and Plan (References 9 and 10) remain a reasonable assessment of flood behaviour for the region. The primary concern was for flood behaviour through Murwillumbah, where the simulation performed badly in comparison to the March 2017 event. As such, recommendations for future modelling included:

- Update topography and bathymetry, including detailed levee survey;
- Utilise higher resolution modelling (i.e. smaller grid cell size), enabling a more accurate assessment of structure performance and associated impacts/afflux;
- Improve the schematisation of critical areas;
- Incorporate the findings of the Murwillumbah Levee Overtopping Study which is currently being completed;
- Undertake calibration of the March 2017 event as a joint hydrologic/hydraulic model calibration; and,
- Implement the latest best practice guidelines, Australian Rainfall and Runoff 2019 (Reference 1).

**Murwillumbah CBD Levee & Drainage Study (Catchment Simulation Solutions, 2018)**

The purpose of the Murwillumbah CBD Levee & Drainage Study (Reference 15) was to further the Tweed Valley Floodplain Risk Management Plan (Reference 10) by investigating the hydraulic behaviour around the levees, including local drainage and potential levee overtopping scenarios. The hydraulic model used in the Tweed Valley Flood Study (Reference 7) was updated with more detailed terrain and additional hydraulic structures around Murwillumbah. Options such as new pump systems, remediation of levees, flood warning system upgrades and community education amongst others were considered for reducing the flooding and drainage impact. Although options investigated would potentially reduce the existing flood risk, there was no one option or combination of options that would fully eliminate flood risk throughout Murwillumbah.

**South Murwillumbah Floodplain Risk Management Study & Plan (Catchment Simulation Solutions, 2019)**

The purpose of the South Murwillumbah Floodplain Risk Management Study & Plan (Reference 16) was to determine the nature and extent of flooding in the region of South Murwillumbah and develop potential flood risk management options for this area. Models were developed and calibrated against three historic events including the recent 2017 event, and then used to simulate the 20% AEP, 5% AEP, 1% AEP and 0.2% AEP design events. These results were then implemented into a Floodplain Risk Management Plan, providing mitigation options where the hydraulic benefits, costs, implementation schedules and funding opportunities were assessed for each option.

#### 3.1.1. Models Received

WMAwater has received the model data listed below in Table 1 as part of the data pack provided by Council for this study.

Table 1: Summary of Model Data Received

| Study | Year | Model Type | Software | Model Name |
|---|---|---|---|---|
| Tweed Valley Flood Study Update 2009 | 2009 | Hydrology | WBNM | tw_800_March1974.wbn, tw_800_March1978.wbn, tw_800_April1989.wbn, tw_809_Designevent.wbn |
| | | Hydraulics | TUFLOW | tw_808_~calib~.tcf, tw_811_~design~.tcf, tw_812_QPMF.tcf (Design events, PMF, calibration events: 1974, 1978, 1989) |
| Murwillumbah CBD Flood Study | 2018 | Hydrology | WBNM | css_Jan2012.wbn, css_Jan2013.wbn, css_Jun2016.wbn, tw_809_Design.wbn |
| | | Hydraulics | TUFLOW | Murwillumbah_CBD_~e1~_~e2~_~s1~.tcf (Design events, calibration events: June 2007, Jan 2012, Jan 2013, June 2016, March 2017) |
| South Murwillumbah Floodplain Risk Management Study | 2019 | Hydrology | WBNM | Apr_1989.wbn, css_Jan2013.wbn, css_Mar2017_30minOut.wbn, tw_809_Q100_fixed.wbn, tw_809_SensitivityAnalysis.wbn |
| | | Hydraulics | TUFLOW | Sth_Murwillumbah_~e1~_~e2~_~s1~.tcf (Design events, calibration events: April 1989, Jan 2013, March 2017) |

### 3.2. Hydrologic Model Setup

The current WBNM model of the Tweed River catchment consists of 207 sub-catchments, varying in size from 186 ha to 1,573 ha.

In general, this level of discretisation is suitable for describing broad scale inflows along the major watercourses within the catchment; however, now that the hydraulic modelling is to be further refined and extended, the hydrologic model would benefit from refinements made particularly in the upper reaches of the catchment. This will enable local features and key accessways around townships to be better captured, which will in turn benefit the evacuation and planning component of this study. A list of points of interest capturing items like homesteads, schools, retirement villages, community facilities and tourist facilities throughout the region has been provided by Council within the data pack. This will be used to guide the updated model discretisation.

## 3.3. Historic Rainfall Data

Historic rainfall data is utilised to recreate historic events within a hydrologic model and as a means of calibrating the hydrologic model parameters. Table 2 shows the rainfall gauges within the Tweed Valley LGA from sources including the Bureau of Meteorology (BoM), Manly Hydraulics Lab (MHL) and WaterNSW.

BoM provides daily historic rainfall grids for the past 100 years across Australia, whilst the Weather Chaser website (https://theweatherchaser.com) enables the review of radar imagery of historic events to fill data gaps and provide further context of historic storms. Figure 1 shows the spatial distribution of rainfall stations utilised within this study.

Table 2: Summary of Available Rainfall Data

| Gauge Type | Gauge Name | Gauge ID |
|---|---|---|
| Alert | Doon Doon (McCabes Road) | 58019 |
| Alert | Kunghur | 58129 |
| Alert | Palmers Road | 558018 |
| Alert | Clarrie Hall Dam | 558028 |
| Alert | Upper Burringbar | 558107 |
| Alert | Burringbar North Arm | 558104 |
| Alert | Uki (Tweed River) | 58167 |
| Alert | Brays Creek (Misty Mountain) | 58005 |
| Alert | Tyalgum Bridge (Tyalgum River) | 558088 |
| Alert | Eungella (Oxley River) | 58193 |
| Alert | Limpinwood (Bald Mountain | 558032 |
| Alert | Chillingham | 58011 |
| Alert | Upper Rous River (Hopkins Ck) | 558080 |
| Alert | Numinbah | 558081 |
| Alert | Couchy Creek | 558079 |
| Alert | Murwillumbah (Sewerage Treatment) | 558093 |
| Alert | Tomewin Alert | 540354 |
| Alert | Bray Park (Water Treatment Plant) | 558092 |

| Gauge Type | Gauge Name | Gauge ID |
|---|---|---|
| Daily | Darlington | 40044 |
| Daily | Numinbah State Farm | 40162 |
| Daily | Green Mountains | 40182 |
| Daily | Coolangatta Aero | 40288 |
| Daily | Chigigum Farm | 40342 |
| Daily | Central Kerry | 40413 |
| Daily | Green Valley | 40433 |
| Daily | Alpine Panorama | 40439 |
| Daily | Binna Burra | 40487 |
| Daily | Wunburra | 40534 |
| Daily | Numinbah | 40550 |
| Daily | Glengaven | 40558 |
| Daily | Widgee | 40583 |
| Daily | Camberra | 40599 |
| Daily | Darlington | 40610 |
| Daily | Rottington | 40615 |
| Daily | Lenore Vale | 40620 |
| Daily | Ingleside | 40621 |

| Gauge Type | Gauge Name | Gauge ID | Gauge Type | Gauge Name | Gauge ID |
|---|---|---|---|---|---|
| Alert | Murwillumbah (Tweed River) | 58186 | Daily | Currumbin Valley | 40634 |
| Alert | Tumbulgum | 558014 | Daily | Springbrook Quoll House | 40700 |
| Alert | Bilambil Heights (Marana Reserve) | 558085 | Daily | Coolangatta | 40717 |
| Alert | Tweed Heads (Duranbah) | 558011 | Daily | Binna Burra Alert | 40845 |
| Alert | Kingscliff (Sewerage Treatment) | 558090 | Daily | Lower Springbrook Alert | 40848 |
| Alert | Chinderah (Tweed River) | 558010 | Daily | Darlington TM | 40866 |
| Alert | Banora (Sewerage Treatment Plant) | 558089 | Daily | Numinbah Alert | 40882 |
| Alert | COOLANGATTA | 40717 | Daily | Tomewin - Tallowood | 40899 |
| Alert | Currumbin Ck Alert | 540640 | Daily | O'Reillys Alert | 40931 |
| Alert | Upper Springbrook Alert | 540400 | Daily | Darlington Alert | 40932 |
| Daily | New Italy (Aberdare) | 558082 | Daily | Cudgen Plantation | 58017 |
| Daily | Billinudgel | 558083 | Daily | Murwillumbah (Dungay Taleswood) | 58020 |
| Daily | Tweed Heads | 558084 | Daily | Mullumbimby (Fairview Farm) | 58040 |
| Daily | Nimbin (Mount Nardi) | 58125 | Daily | Murwillumbah Post Office | 58042 |
| Daily | Kingscliff (Woram Place) | 58137 | Daily | Pumpenbil (Tyalgum) | 58054 |
| Daily | Lillian Rock (Williams Road) | 58148 | Daily | Tweed Heads Golf Club | 58056 |
| Daily | Upper Crystal Creek (Arkuna) | 58150 | Daily | Uki (Sunnyvale) | 58058 |
| Daily | Carool (Stitzs) | 58153 | Daily | Tomewin (Border Gate) | 58067 |
| Daily | Tyalgum (Warning View) | 58156 | Daily | Brunswick Heads Bowling Club | 58103 |
| Daily | Terranora | 58163 | Daily | Burringbar (Harnett) | 58107 |
| Daily | Upper Commissioners Creek (Doon Doon) | 58182 | Daily | Mount Warning | 58118 |
| Daily | Doon (Doughboy Mountain) | 58183 | Daily | Upper Crystal Creek | 58123 |
| Daily | Mount Numinbah | 58197 | Pluvio | Coolangatta Bowls Comp | 40052 |
| Daily | Bald Mountain | 58203 | Pluvio | Springbrook Forestry | 40192 |
| Daily | Boat Harbour (Rous River) | 58204 | Pluvio | Springbrook Road | 40607 |
| Daily | Pottsville Bowls Club | 58209 | Pluvio | Springbrook TM | 40750 |
| Daily | Commissioners Creek (Blue Ridge) | 58210 | Pluvio | Condong Sugar Mill | 58013 |
| Daily | Numinbah Gate | 58213 | Pluvio | Murwillumbah (Bray Park) | 58158 |
| Daily | Tumbulgum (Bawden | 58217 | Pluvio | Tyalgum (Wanungara | 58057 |

| Gauge Type | Gauge Name | Gauge ID | Gauge Type | Gauge Name | Gauge ID |
|---|---|---|---|---|---|
| | St) | | | View) | |
| Daily | Kunghur Post Office | 58031 | Pluvio | Tyalgum (Kerrs Lane) | 58109 |
| Daily | Lillian Rock | 58035 | Pluvio | Green Pigeon (Morning View) | 58113 |
| Daily | Chillingham (Limpinwood) | 58036 | | | |

## 3.4. Design Rainfall Data

Design rainfall data will be sourced from the BoM's Intensity-Frequency-Duration (IFD) data for each of the revised sub-catchments as part of the hydrologic model update. The most recent data available from the BoM website will be utilised. As part of the project, the IFD data from BoM will be reviewed against the rainfall data that has been obtained for the project to determine if there are large discrepancies between BoM generated IFD datasets and observed information.

## 3.5. Water Level Data – Time Series

A number of stream gauges exist in the Tweed River catchment; these are listed in Table 3. The spatial distribution of the stream gauges (with coordinates) throughout the catchment is shown on Figure 2.

Data for these gauges is available through several sources including Council provided data, MHL, BoM and WaterNSW. The time series of water levels will be used for model calibration, and caution will be taken when reviewing gauges within the tidal limit zone. Gauges within the tidal limit lack the ability to be translated into a flow hydrograph, however, are valuable as a record of historical flood events.

Table 3: Summary of Stream Flow Gauges

| Gauge Name | Waterway | BoM Gauge ID | WaterNSW Gauge ID | Owner | Data Period | Datum |
|---|---|---|---|---|---|---|
| Backwater Environ | | | 201414 | MHL | 1953-1956 | Standard Datum |
| Bakers Byangum | Tweed River | | 201404 | MHL | 1952-1955, 1987-1989 | Standard Datum |
| Barletts Creek | Tweed River | | 201454 | MHL | 1994-1996 | Standard Datum |
| Barneys Point | Tweed River | 558010 | 201426 | MHL, BOM | 1987-2017 | TRHD, Adj 0.883 mAHD |
| Barneys Point | Tweed River | 558102 | | BOM | 2019-2022 | AHD |
| Bray Park Weir | Tweed River | 558065 | 201455 | MHL, BOM | 2002-2022 | TRHD, Adj 0.934 mAHD |
| Boat Harbour | Rous River | 558077 | | BOM | 2010-2022 | Standard Datum |
| Rous(Boat | Rous River | 58204 | 201005 | WaterNSW, | 1957-2022 | 2.575 mAHD |

| Gauge Name | Waterway | BoM Gauge ID | WaterNSW Gauge ID | Owner | Data Period | Datum |
|---|---|---|---|---|---|---|
| Harbour) | | | | BOM | | |
| Cobaki | Cobaki Creek | 558045 | 201448 | MHL, BOM | 1987-2022 | TRHD, Adj 0.863 mAHD |
| Cobaki Ck | Cobaki Water | | 201012 | WaterNSW | 1982-2022 | 2.457 mAHD |
| Commercial Road | Tweed River | | 201410 | MHL | 1952-1954 | Standard Datum |
| Dry Dock | Terranora Creek | 558029 | 201428 | MHL, BOM | 1987-2022 | TRHD, Adj 0.875 mAHD |
| Eungella | Oxley River | 58193 | 201001 | MHL, BOM, WaterNSW | 1954-1955, 1947-2022 | Standard Datum, 13.285 mAHD |
| Fingal | Tweed River | | 201427 | MHL | 1953-1954 | Standard Datum |
| Kynn Bridge | Rous River | | 201406 | MHL | 1952-1967 | Standard Datum |
| Kynnumboon | Rous River | 558051 | 201422 | MHL, BOM | 1990-2022 | TRHD, Adj 0.926 mAHD |
| Leddays Creek | Main Trust Canal / Leddays Creek | | 201452 | MHL | 1995-1996 | Standard Datum |
| Letitia 2A | Tweed River | 558041 | 201429 | MHL, BOM | 1987-2022 | TRHD, Adj 0.886 mAHD |
| Letitia 2B | Tweed River | | 201430 | MHL | 1987-2008 | TRHD, Adj 0.894 |
| Mcleods Drain | Stotts creek | | 201436 | MHL | 1994-1996 | Standard Datum |
| Murwillumbah Bridge | Tweed River | 558067 | 201465 | MHL, BOM | 2002-2022 | TRHD, Adj 0.909 mAHD |
| Murwillumbah Lavendar Ck | Tweed River | | 201411 | MHL | 1953-1954 | Standard Datum |
| Norco Factory | Tweed River | | 201419 | MHL | 1953-1954 | Standard Datum |
| North Murwillumbah | Tweed River | 58186 | 201420 | MHL, BOM | 1987-2022 | TRHD, Adj 0.909 mAHD |
| North Wharf | Tweed River | | 201418 | MHL | 1953 | Standard Datum |
| Salmons Farm | | | 201415 | MHL | 1955-1956 | Standard Datum |
| South | Tweed | | 201416 | MHL | 1953-1954 | Standard |

| Gauge Name | Waterway | BoM Gauge ID | WaterNSW Gauge ID | Owner | Data Period | Datum |
|---|---|---|---|---|---|---|
| Murwillumbah | River | | | | | Datum |
| Terranora | Terranora Broadwater | 558056 | 201447 | MHL, BOM | 1987-2017 2005-2022 | TRHD, Adj 0.853 mAHD |
| The Bluff | Tweed River | | 201417 | MHL | 1953-1954 | Standard Datum |
| Tumbulgum | Tweed River | 558014 | 201432 | MHL, BOM | 1985-2022 | TRHD, Adj 0.893 mAHD |
| Tweed Power House | Tweed River | | 201405 | MHL | 1938-1945 | Standard Datum |
| Tygalgah (Browns) | Tweed River | | 201408 | MHL | 1952-1966 | Standard Datum |
| Tygalgah (Smiths) | Tweed River | | 201409 | MHL | 1952 | Standard Datum |
| Tweed River (Palmers Road Crossing) | Tweed River | 558018 | 201015 | WaterNSW | 2008-2022 | ASS, 29.18 m |
| Tweed (Uki) | Tweed River | 58167 | 201900 | WaterNSW, BOM | 1937-2020 | 8.966 mAHD |
| Chillingham | Rous River | 58011 | | BOM | 2010-2022 | adj. 23.62mAHD |
| Clarrie Hall Dam Rd | Doon Doon Creek | 558009 | | BOM | 2009-2022 | Adj. 20.31 mAHD |
| Tweed River Downstream of Palmers Rd Crossing | Tweed River | 558018 | 201015 | BOM | 2009-2022 | Standard Datum |
| Clarrie Hall Dam | Clarrie Hall Dam | 558028 | | BOM | 2005-2022 | Standard Datum |
| Tyalgum Bridge | Pumpenbil Creek | 558088 | | BOM | 2011-2022 | Standard Datum |

## 3.6. Water Level Data - Peak Flood Heights

Flood records in the Tweed River catchment date back to 1887, with peak flood levels recorded at five gauges for major events. Recent major events with significant data applicable for model calibration and validation have been compiled in Table 4. Earlier flood level records have been compiled by Council, and more recent event records have been provided by the local SES. The SES peak gauge heights from recent events have been verified with information from BoM, MHL and WaterNSW.

Table 4: Peak Flood Levels for Major Historical Flood Events

| Year | Gauge Height (m) | | | | | | | | Source |
|---|---|---|---|---|---|---|---|---|---|
| | Murwillumbah | Uki | Eungella | Tyalgum | Chillingham | Boat Harbour | Barneys Point / Chinderah | Tumbulgum | |
| February 1954 | 6.04 | 10.90 | - | 8.08 | - | 6.10 | 2.91 | 3.92 | TSC: Schedule of Peak Height Gauge Readings |
| March 1974 | 5.82 | 11.40 | - | 8.46 | 5.60 | - | 2.20 | 3.56 | Tweed Shire Council: Schedule of Peak Height Gauge Readings |
| March 1989 | 5.62 | 10.9 | - | 10.95 | 6.80 | 7.46 | 1.40 | 3.11 | Tweed Shire Council: Schedule of Peak Height Gauge Readings |
| January 2012 | 4.67 | 9.98 | 6.24 | - | 5.84 | 6.00 | 1.48 | 2.72 | Processed by local SES |
| January 2013 | 4.68 | 9.34 | 6.4 | - | 5.95 | 6.16 | 1.78 | 3.29 | Processed by local SES |
| March 2017 | 6.20 | 12.91 | 9.85 | 8.77 | 5.97 | 7.42 | 2.22 | 3.91 | Processed by local SES |
| February 2020 | 3.81 | 9.2 | 6.28 | 5.92 | 5.09 | 5.93 | 1.29 | 2.3 | Processed by local SES |
| February 2022 | 6.50 | 12.92 | 7.83 | 7.07 | 6.50 | 6.70 | | 4.80 | MHL/TSC |

## 3.7. Flood Survey Levels for Calibration

Calibration of a hydraulic model relies on recorded flood information from past events. Surveyed flood level information is available for a number of events and more so in recent history.

A small number of flood marks are available for the 1989 event, less than 10 survey locations, which are generally located upstream of Eungella and near Murwillumbah.

For the 2020 event, there was approximately 40 survey locations that were scattered through the upper catchment, including near Uki, along Oxley River, Rous River and South Murwillumbah. For the March 2017 flood event over 217 surveyed levels were collected. For the February 2022 event 268 survey points are present. These are scattered throughout the whole catchment from the upper reaches to the Tweed River entrance. These events provide the most comprehensive amount of information regarding flood survey levels.

## 3.8. Rating Curves

A rating curve is required to convert historical flood levels to flows. Whilst there are some rating curves for the Tweed River catchment available online or from previous studies, in cases where no gauged rating was available at the site, they have been developed based on hydraulic model results.

Additional rating curves at selected gauges will be required to complete FFA analysis within this study. WaterNSW has a gauged rating available for each of the selected sites. However, it is synthetic rating curves have been developed for some of these locations, particularly for gauges where the fit has already been identified as problematic.

**Murwillumbah**

The 2005 Flood Study (Reference 7) developed a synthetic rating curve at Murwillumbah using the hydraulic model to represent three historical states of the floodplain, these being post-1974, post-1989 (inclusion of Murwillumbah Levee) and post-1990 (present case). A singular representative curve was fit through these results; this is shown in Diagram 2. There is no gauged rating curve for this location as it is tidally influenced. This rating curve has been used in the 2009 Flood Study Update (Reference 8) and during the initial stages of further studies (Reference 16).

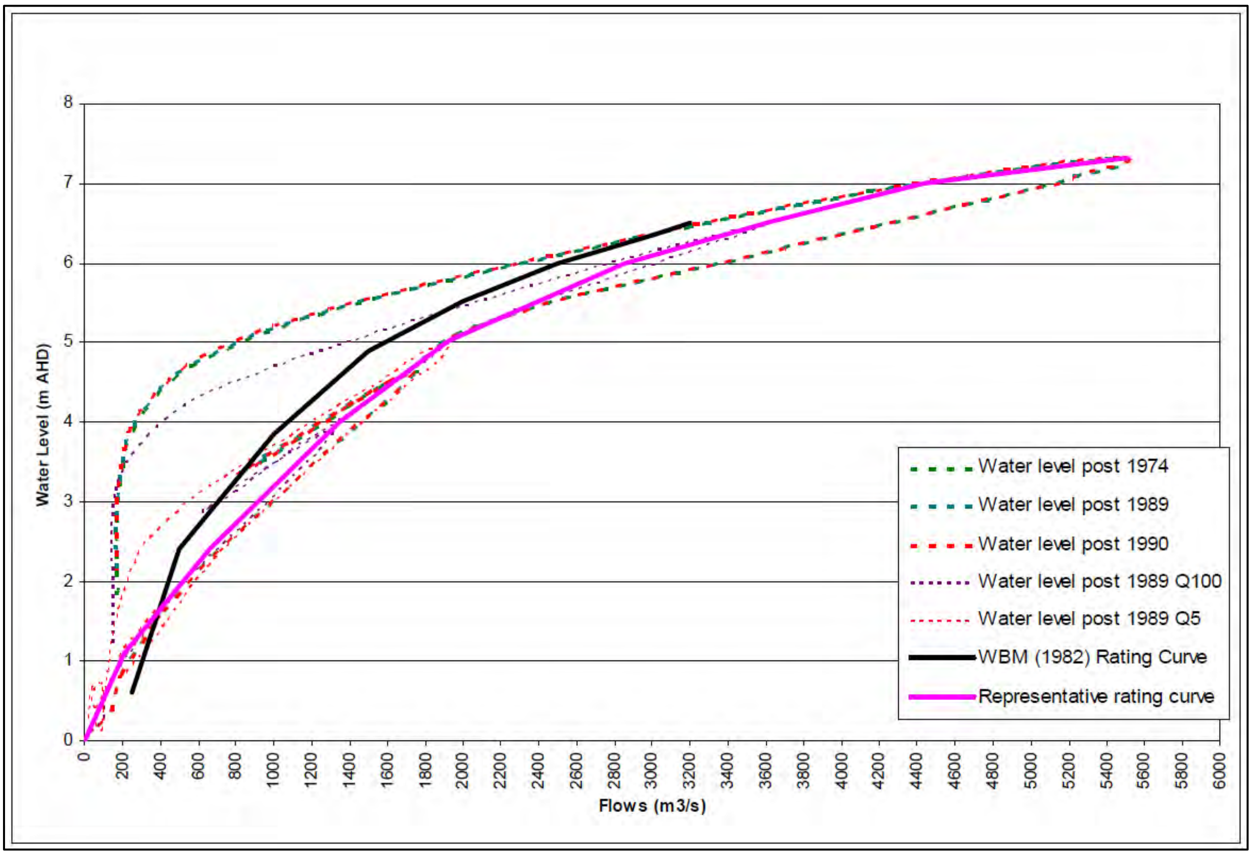



Diagram 2: Synthetic Murwillumbah Gauge Rating Curve (Source: WBM 2005 Flood Study, Reference 7)

A second synthetic rating curve was generated as part of the South Murwillumbah Flood Risk Management Study & Plan (FRMS&P) (Reference 16) due to having more detailed bathymetry available in the hydraulic model; this is shown in Diagram 3. Tabulated flow and height information used to plot this synthetic curve is available as part of the South Murwillumbah FRMS&P (Reference 16).

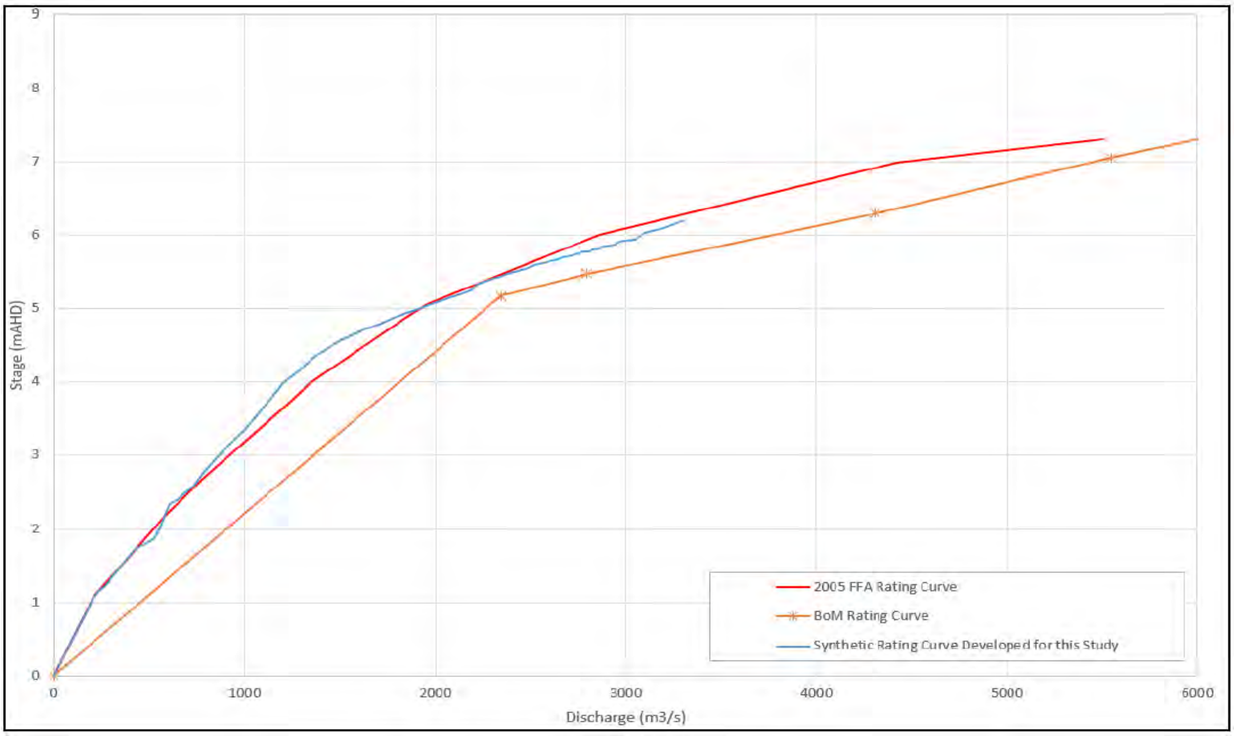



Diagram 3: Updated Synthetic Murwillumbah Gauge Rating Curve (Source: South Murwillumbah FRMS&P, Reference 16)

**Tumbulgum**

No rating was available for the Tumbulgum gauge at the time the South Murwillumbah FRMS&P (Reference 16) was completed, and therefore a synthetic rating, shown in Diagram 4 was developed. Tabulated flow and height information used to plot this synthetic curve is available as part of the South Murwillumbah FRMS&P (Reference 16).

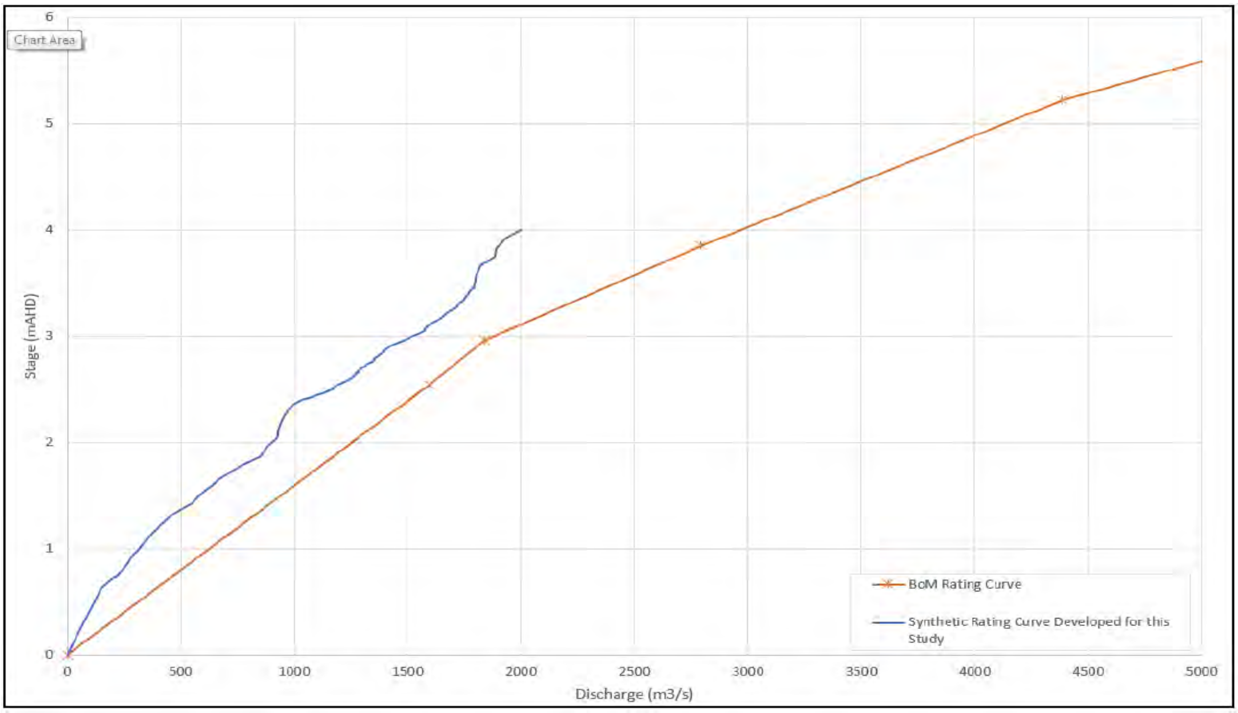



Diagram 4: Synthetic Tumbulgum Gauge Rating Curve (Source: South Murwillumbah FRMS&P, Reference 16)

**Uki, Eungella, Palmers Road – Tweed River, Boat Harbour No. 2 – Rous River**

These four gauges were included in the recently completed Post Event Flood Behaviour Analysis report (BMT WBM, Reference 10). Hydrologic simulation of the 2017 event suggested that the gauged rating curves available may not be accurate at the Uki and Boat Harbour No. 2 gauges.

## 3.9. Flood Frequency Analysis

At site Flood Frequency Analysis (FFA) uses statistical analysis to determine the likely recurrence interval of natural events. FFA has been completed at select locations as part of the previous assessments.

**Murwillumbah**

The 2009 Flood Study Update (Reference 7) included an FFA at the Murwillumbah gauge using an annual maxima series for the years 1916 to 2004, which is a period of 89 years. Data prior to this (i.e. from 1889-1915) was excluded, as significant estimation of the flood level was required for most years and this could have skewed the results. For other years with no recorded flood levels, it was assumed that a large event did not occur and a 'no flood' classification was assigned. The flood frequency curve was fit using both the Generalised Extreme Value (GEV) theoretical probability distribution and the Log Pearson Type III (LPIII) distribution, however the GEV results were favoured at the time.

This analysis was later revised and expanded to include new data (1916-2017) in the South Murwillumbah FRMS&P (Reference 16) for the Murwillumbah gauge. Low flows below 850 $m^3/s$ were censored in this analysis through the use of the Grubbs-Beck test.

**Tumbulgum**

An FFA at the Tumbulgum gauge for a period of 33 years (1985-2023) was also completed in the South Murwillumbah FRMS&P (Reference 16). As for the Murwillumbah gauge, low flows were censored based on the Grubbs-Beck test. This removed flows below approximately 800 $m^3/s$.

The revised FFA (Reference 16) determined the LPIII distribution to provide the best fit and to produce peak discharges that were within 2% of the previous study for all AEP events. ARR19 guidance is that the GEV and LPIII distributions are reasonable initial choices for annual maxima series as these families fit most flood data adequately (Reference 1). However, there is no rigorous justification for use of either distribution.

Additional at site FFA using multiple distributions was completed as part of this assessment to determine the validity of flows and ensure that there is no bias present between the recorded gauge data and the BoM 2016 IFD data. The sites selected for analysis all have annual maxima data and ratings available online at WaterNSW and include the following:

- Tweed River at Uki (ID 201900, 102 years of records), supplemented by level recordings provided by Council;
- Tweed River at d/s Palmers Road (ID 201015, 36 years of records);
- Rous River at Boat Harbour No. 3 (ID 201005, 64 years of records); and
- Oxley River at Eungella (ID 201001, 74 years of records).

## 3.10. Topographic Data

Topographic survey is typically used to define hydraulic characteristics of a floodplain. There is a considerable amount of topographic data available for the study area thanks to previous studies.

This study makes use of the most recent dataset provided by Council, this being the 2020 LiDAR which has recently been flown. This is used as the basis of recent flood events and design event assessment.

### 3.10.1. LiDAR Information

For the purposes of this study, the primary data source for terrain information will be recently acquired LiDAR. This information has been received by WMAwater and consists of a full DEM coverage of the entire study area. This information is considered, outside of the channels that have water present, to be the best available information.

### 3.10.2. Bathymetric Data

Bathymetry was incorporated into the previous 2009 Flood Study Update (Reference 7) hydraulic model in the form of 1D channels rather than a DEM.

For this study, recent bathymetric data for the Tweed River was provided and has been converted into a DEM for the extent that is present. This is between the Highway Bridge up to the Bray Park Weir. Downstream of the Highway, 5m gridded bathymetric dataset is available from Elvis (https://elevation.fsdf.org.au/). This has been used up until the model boundary, outside the Tweed River entrance. Table 5 summarises the data sources. Diagram 5 shows the extents of the data sources.

For the Rous River, Terranora Creek and Cobaki Creek bathymetry information has been derived from the information present in the 2009 Flood Study Update. This information, where relevant, was converted from 1D sections into a DEM covering the area. Only a very small portion of the catchment waterways are represented using 2009 data and this is primarily in the Broadwater storage areas where bathymetry is not likely to have a strong influence on results. The upper reaches of the catchment are represented by the LiDAR returns within the supplied 2020 LiDAR.

Table 5: Bathymetry Data Sources

| Feature | Data source |
|---|---|
| Tweed River – downstream of the Pacific Motorway Bridge | NSW Marine Bathymetry 2018 |
| Terranora and Cobaki Broadwaters | 2009 Flood Study |
| Tweed River – Pacific Motorway Bridge to Bray Park weir | 2020 Bathymetry |
| Rous River | 1979 surveyed cross sections |

It is understood that by the end of 2024 new bathymetry data may be available for some locations in the study area. As the model developed in this study has been calibrated to recent events, it is considered that the calibration process, which undertakes roughness value modification to achieve good calibration outcomes, would need review prior to utilisation of this dataset. It is recommended however, that a review of best available information (noting this extends to more than just new bathymetric data) is undertaken as part of future stages of the flood risk management process and incorporated as relevant.

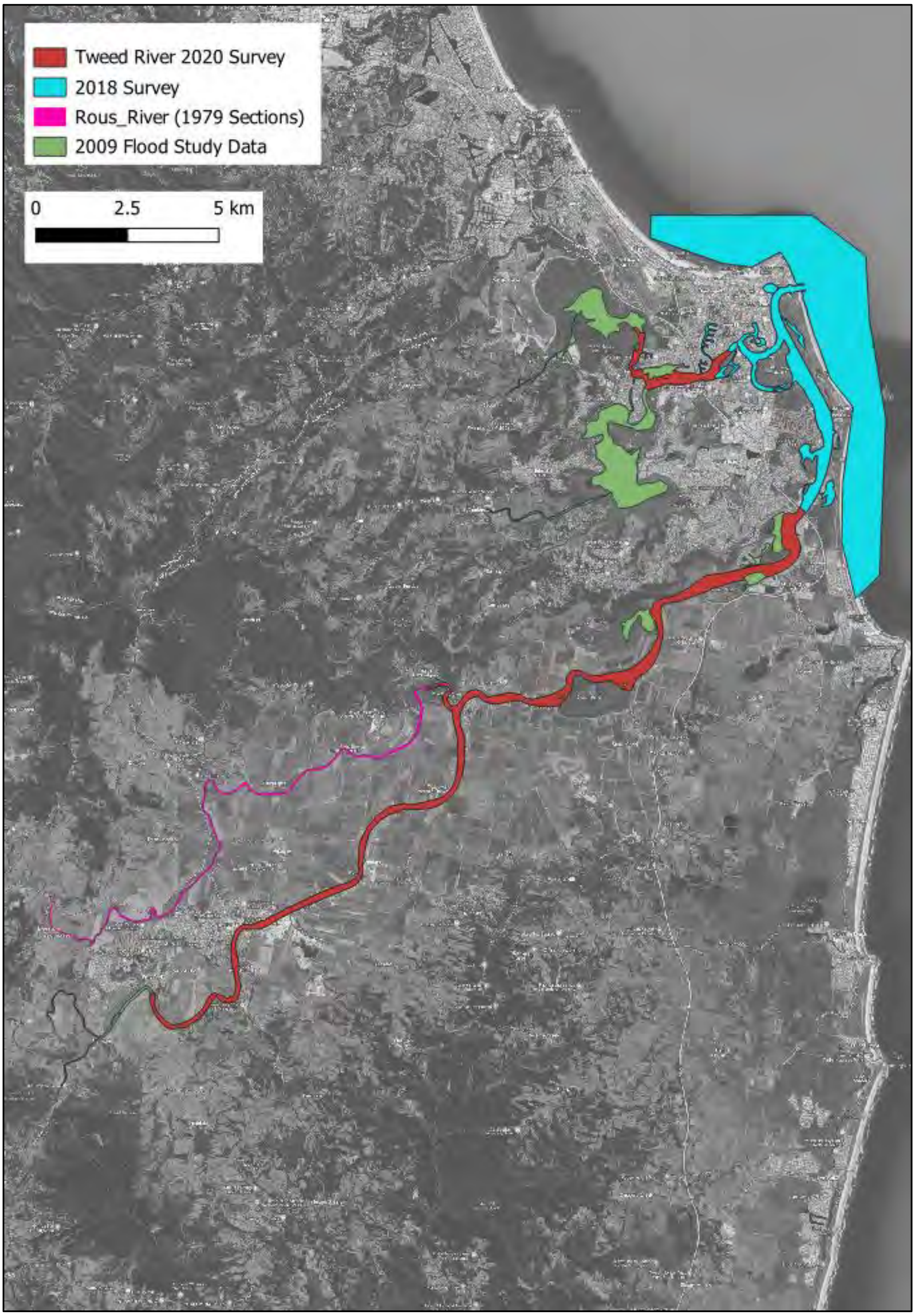



Diagram 5 – Bathymetric Data Sources

### 3.10.3. Levees

The data pack provided by Council includes a GIS file showing the levee crest location for levees in the region, beginning at Chinderah and travelling up to Murwillumbah and Dungay. It is assumed that all levees within the region have been captured in this file. As Constructed and Survey drawings have also been provided in the data pack; these are listed in Table 6.

Table 6: Summary of Levee Data Provided by Council (prior to 2021 survey)

| Levee | Plan Number | Plan Date | Approx. Construction Date |
|---|---|---|---|
| East Murwillumbah (raised) | WT04037-1 to 21 | 2005 | 2006 |
| Dorothy Street (at Murwillumbah STP) | WT04037-40 to 49 | 2005 | 2006 |
| Murwillumbah CBD RC Commercial Road | A1-890-1 to 23 | 1990 | 1990 |
| Bray Park | A1-913-1 to 4 | 1990 | 1990 |
| Tweed River Flood Mitigation Work | AO 124 | 1979 | Various |
| East Murwillumbah | A1-140-1 to 7 | 1972 | 1976 |
| Tweed Heads South | A1-39-001 to 4, A1-40-1 to 2, A1-44-1 to 4 MS07019-01 to 06 | 1970, upgraded 2011 | NA |
| South Murwillumbah Levee (raised) | A1-888-1 to 8 | 1989 | 1990 |

Levee information is also available from the previous 2009 Flood Study (Reference 7) and from the 2005 Flood Study (Reference 6), where levee layout plans were digitised and updated with ground survey, where available (i.e. for the Tweed Heads South levee).

Detailed survey of the levees was recommended in WMAwater's Stage 1 Report. This information has been provided and is the primary dataset for the levees in the hydraulic model. In 2021 a survey of the levees in Tweed was undertaken. Levees that were captured as part of this survey were:

- Dorothy Street (at Murwillumbah STP)
- Murwillumbah CBD Levee
- South Murwillumbah Levee
- Quarry Road Levee
- Tweed Heads South Levee
- East Murwillumbah Levee

These surveyed levees are illustrated in Figure 3.

## 3.11. Building Floor Level Survey

Included in the data pack was finished floor level (FFL) survey for over 12,000 buildings, which were surveyed in 2011/2012. While this information may not be used directly in the flood model, it will be utilised within the risk and vulnerability assessment to be undertaken within the project. It is noted that the building levels provided are generally contained to the floodplain areas within the previous flood model extent. The floor level survey from 2011/2012 does not cover areas not mapped as part of the 2009 study. This will especially affect the area upstream of Murwillumbah such as Uki, and Eungella. In areas which were not part of previous floor level survey, building footprints will be used in the vulnerability assessment.

## 3.12. Hydraulic Structures

The set of hydraulic structures to be used in the hydraulic assessment will be developed based on data from previous studies and the data provided by Council. Structures adopted from previous studies were reviewed to ensure that these are appropriate for use, and any new structures that are captured match against the latest 2020 LiDAR information.

As part of the data pack, Council has provided GIS locations of road and foot bridges and culverts. These features also contain information regarding structure configuration and sizing of the hydraulic structures. The information within the dataset is deemed adequate for modelling culverts sizes, however invert levels have not been included and was estimated from the LiDAR unless otherwise provided. Similarly, the bridge data provided contains some information for sizing but does not contain levels or depths of the deck.

The bridges, culverts, weirs, floodgates and other structures within the 2009 Flood Study model were created from a variety of data sources. Most of the structures were developed for the 2005 Flood Study (Reference 6) with updates to areas such as the cross-drainage structures beneath the Pacific Highway, completed as part of the 2009 update (Reference 7) and some improvements within localised areas around Murwillumbah.

## 3.13. Clarrie Hall Dam

Clarrie Hall Dam is located on Doon Doon Creek in the upper reaches of the Tweed Valley catchment, upstream of the township of Uki and approximately 15 km south-west of Murwillumbah, as shown in Diagram 6. The dam is a concrete faced rockfill embankment and has an uncontrolled concrete-lined chute with an ogee weir and flip bucket located on the left abutment of the spillway. The spillway outlets into Doon Doon Creek. Construction of the dam commenced in 1974 and was completed is 1984 by the Public Works Department (References 11 and 13).


Diagram 6: Clarrie Hall Dam, Crams Farm on Commissioners Creek Road

The primary function of the dam is to provide storage for Tweed Shire’s water supply. When required, water is released from the intake tower through the wet and dry tunnel and cone valve into downstream Doon Doon Creek, and flows into the Tweed River. From there, water for domestic water supply is drawn off and treated at the Bray Park water treatment plant (Reference 9). The dam (and Crams Farm) is also used recreationally, for the following activities:

- Picnicking and family outdoor activities;
- Bush walking;
- Sports fishing;
- Swimming;
- Boating (electric motors and manually powered boats only); and
- Photography.

### 3.13.1. Spillway Upgrade (2014)

An upgrade of the Clarrie Hall Dam to widen and raise the existing spillway crest to meet ANCOLD standards and allow the spillway to pass the theoretical PMF event was completed in 2014. Table 7 shows the details of the dam prior to and following the 2014 upgrade works (References 9, 12 and 13).

Table 7: Clarrie Hall Dam Details Pre- and Post-Spillway Upgrade

| Parameter | Pre-2014 upgrade | Post-2014 upgrade |
|---|---|---|
| Type of dam | Concrete face rock fill | |
| Catchment area ($km^2$) | 60.2 | |
| Full Supply Level, FSL (mAHD) | RL 61.5 | |
| Storage Capacity at FSL (ML) | 15,600 | 16,000 |
| Storage Area at FSL ($km^2$) | 2.2 | |
| Spillway type | Ogee crest | Dog leg Ogee & chute |
| Spillway crest level (mAHD) | RL 61.5 | |
| Spillway crest length (m) | 21.3 | 110 |
| Spillway crest width (m) | Not supplied | 36 |

A visual representation of the storage capacity relationship pre-2014 spillway upgrade, as used in previous studies, is available and is shown in Diagram 6. Additionally, there is a storage-discharge relationship present within the 2009 Flood Study Update (Reference 7) WBNM model. If available however, tabulated information of the rating curve is preferred, to confirm the previous rating curve in the model is correct.

For the post-2014 spillway upgrade scenario, tabulated data for the storage capacity curve and spillway rating curve information is required to develop a storage-discharge relationship. This information has been provided visually in TSC's Dam Safety Emergency Plan (Reference 9) and is shown in Diagram 7 and Diagram 8.

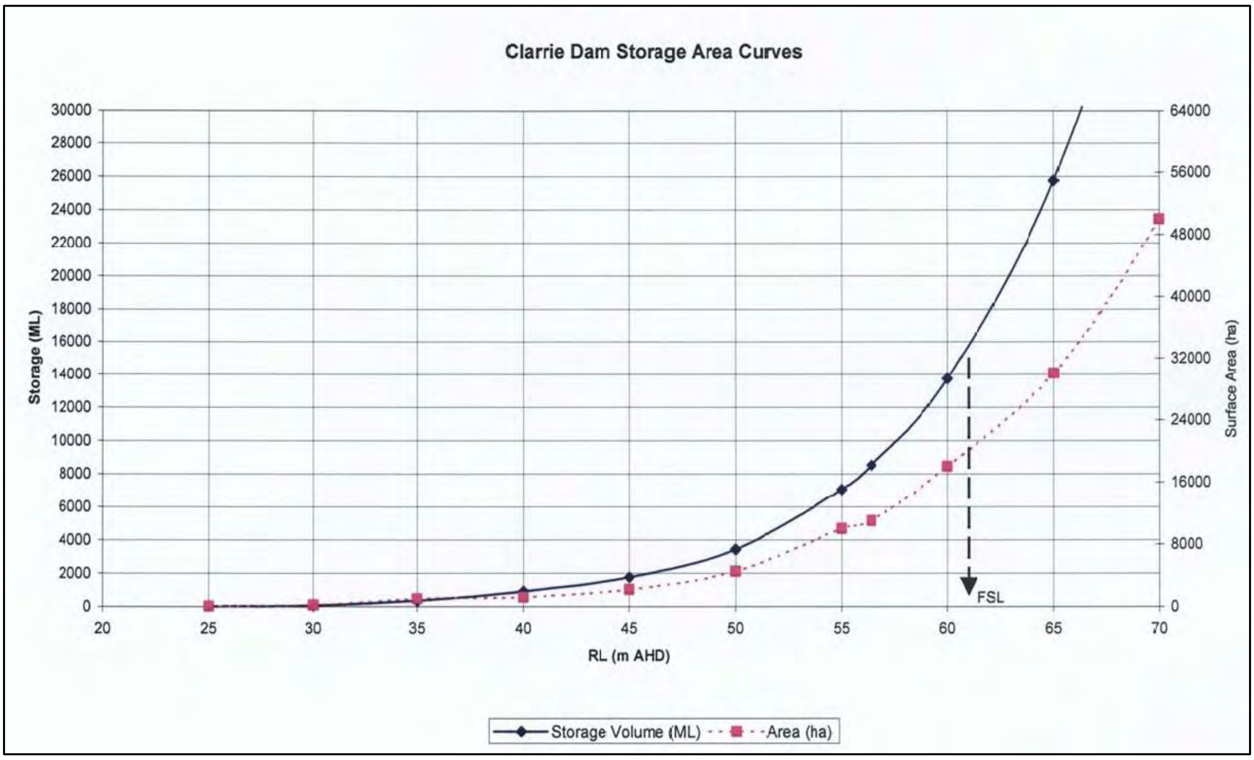



Diagram 7: Clarrie Hall Dam Storage Capacity Pre-2014 Dam Upgrade (Source: Reference 13)

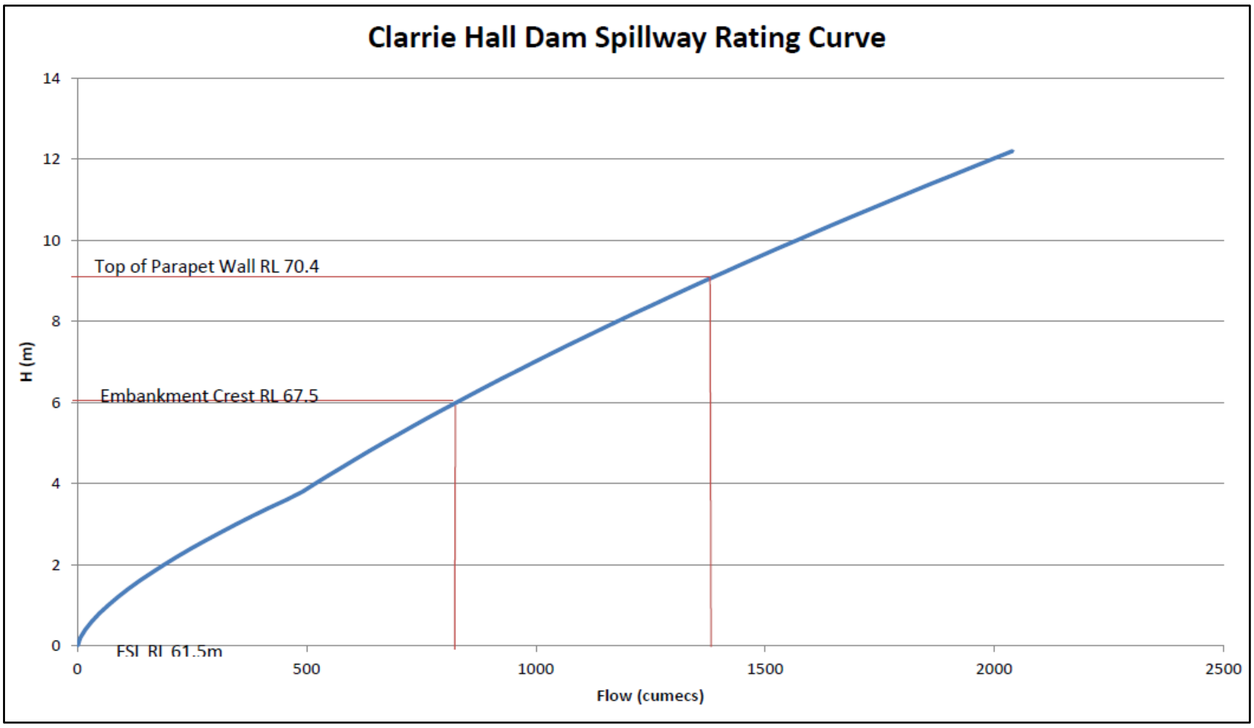



Diagram 8: Spillway Rating Curve Post-2014 Dam Upgrades (Source: Reference 9)

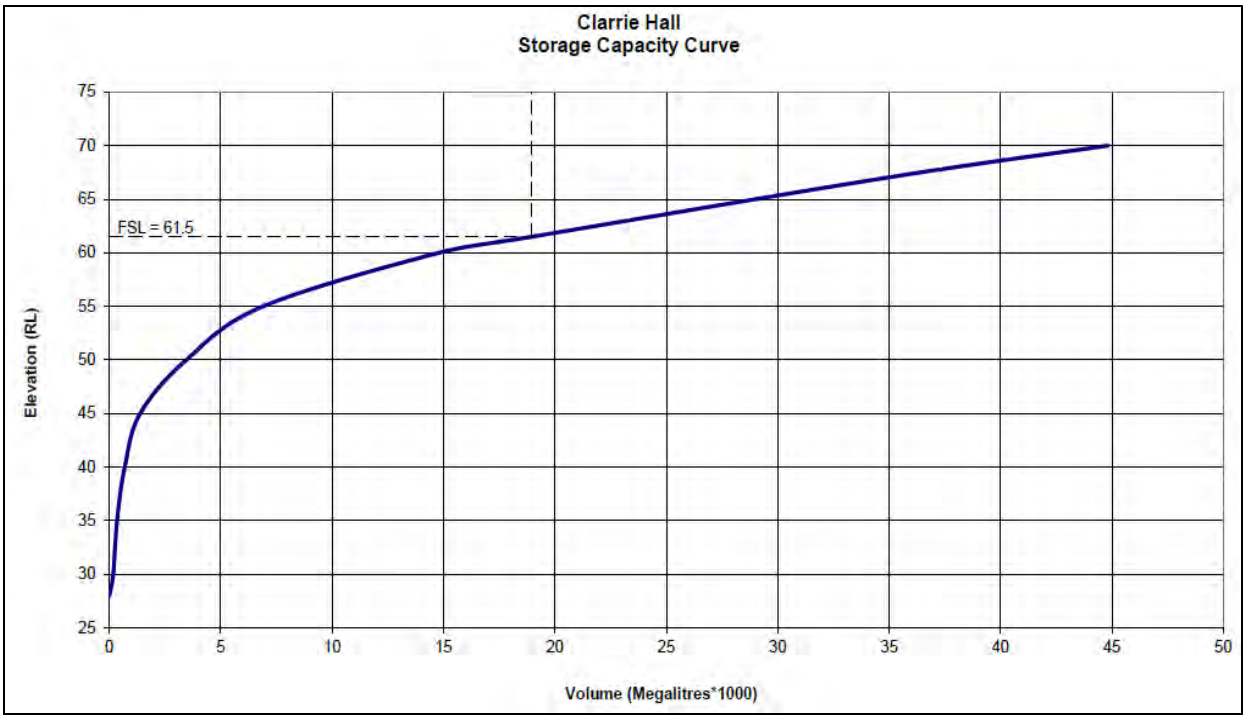



Diagram 9: Clarrie Hall Dam Storage Capacity Curve Post-2014 Dam Upgrade (Source: Reference 9)

### 3.13.2. Future Works

TSC have a project in the works to raise the Clarrie Hall Dam wall. This will provide adequate water supply to the shire until approximately 2065 and is due to be finished by 2028. The preferred dam raising option includes the construction of a new concrete lined spillway higher up in the left abutment (Reference 12).

This project will result in changes to the storage discharge relationship adopted in this flood study and as such, updates to the current modelling will be required.

## 3.14. Bray Park Weir

The Tweed District Water Supply is a run-of-river supply augmented by releases from Clarrie Hall Dam. Raw water is drawn from upstream of Bray Park Weir, effectively a saltwater barrage, in the Tweed River.

The weir has a level of 1.23 mAHD as presented on drawing ED-05098-001.pdf (SunWater, 2004). This is represented as a 2-dimensional weir in the hydraulic model.

It is understood that on 21 and 22 August 2017, the weir was overtopped, causing the raw water to be contaminated by salt water. As a consequence, the raw water for the Bray Park Water Treatment Plant was contaminated by salt, resulting in a water-quality incident. Research commissioned by Tweed Shire Council (TSC) highlights that the occurrence of such incidents is predicted to increase in frequency and severity. No changes to the design of the weir to consider alternative arrangements to manage this have been incorporated into the model.

## 3.15. Existing Flooding Environment

### 3.15.1. Existing Land Uses

A suite of information in GIS format has been provided by Council which will aid in determining the existing land uses. This information, coupled with information generated from the LiDAR capture (building footprints etc.) will be used to inform the development of both the hydrologic and hydraulic model.

The GIS information provided by Council includes:

- Historic aerial imagery;
- Vegetation classification layer covering the LGA;
- Land zoning layer covering the LGA;
- Cadastral layer covering the LGA;
- Distinctive Land Surface (DLS) area layer covering the LGA;
- Extents of major waterways and waterbodies, and hydro lines covering smaller tributaries;
- Local features including extents of the airport runway, rail line, roads and various islands; and,
- Contours.

The land zoning layer and land use categories applied are shown in Diagram 9.

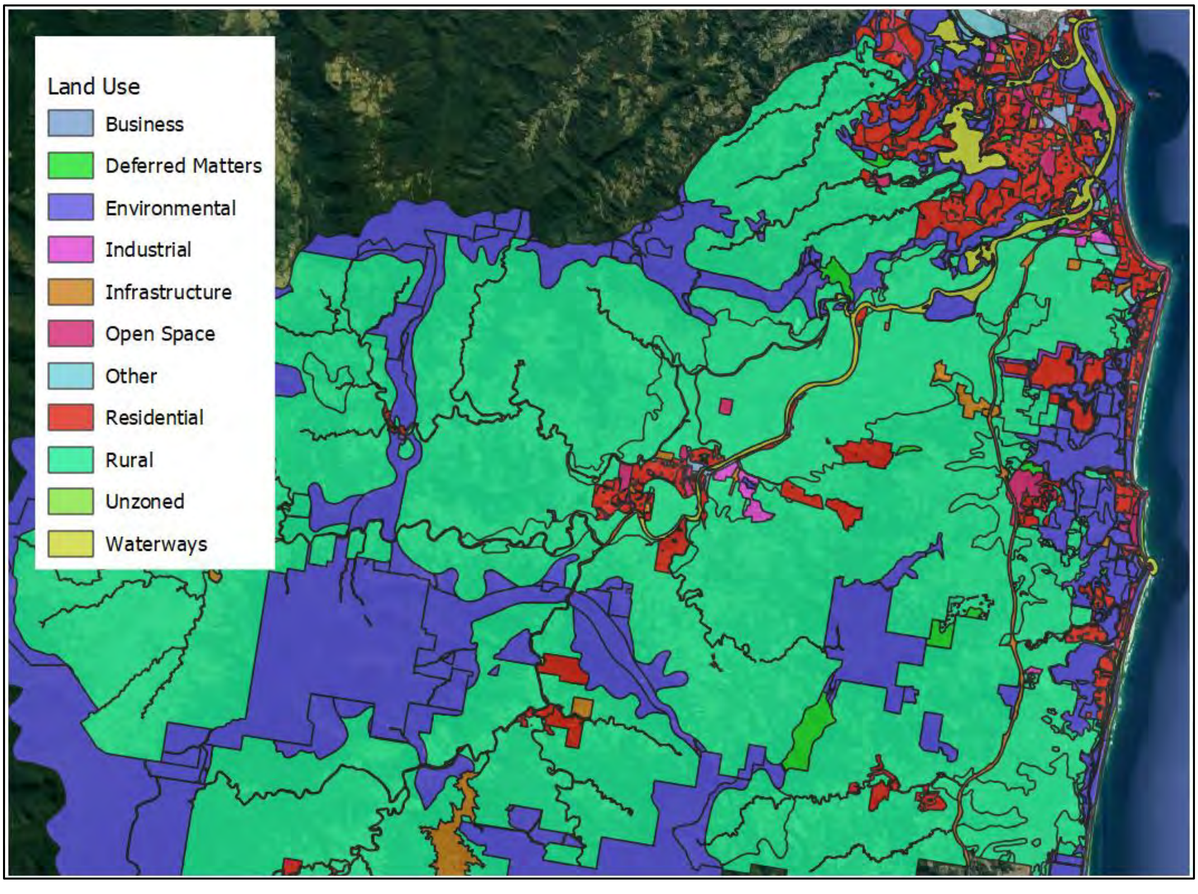



Diagram 10: Land Use Zones Coverage

### 3.15.2. Vegetation, Waterbodies & Roads

The supplied information on key features within the LGA including vegetation, major waterbodies and waterways, roads and rail was provided. This information will be used to inform hydraulic model parameters where relevant.

The vegetation layer, as shown in Diagram 11, includes extents of some, but not all, vegetation occurring around the banks of various creeks as well as extents of the more heavily forested areas within the catchment. This information will be utilised to check the fraction impervious of sub-catchments and define the appropriate roughness values to assign in the hydraulic model.

Also of note is the DLS layer which includes extents of mangroves, swamps, intertidal flats, cliffs, sand and land subject to inundation. The hydroarea GIS layer contains extents of the main water bodies such as the Terranora and Cobaki Broadwaters and Clarrie Hall Dam as well as extents of the main waterways such as the Tweed River and the Rous River. It is noted that the smaller tributary creek extents are not captured but these are represented spatially via the hydro line GIS layer.

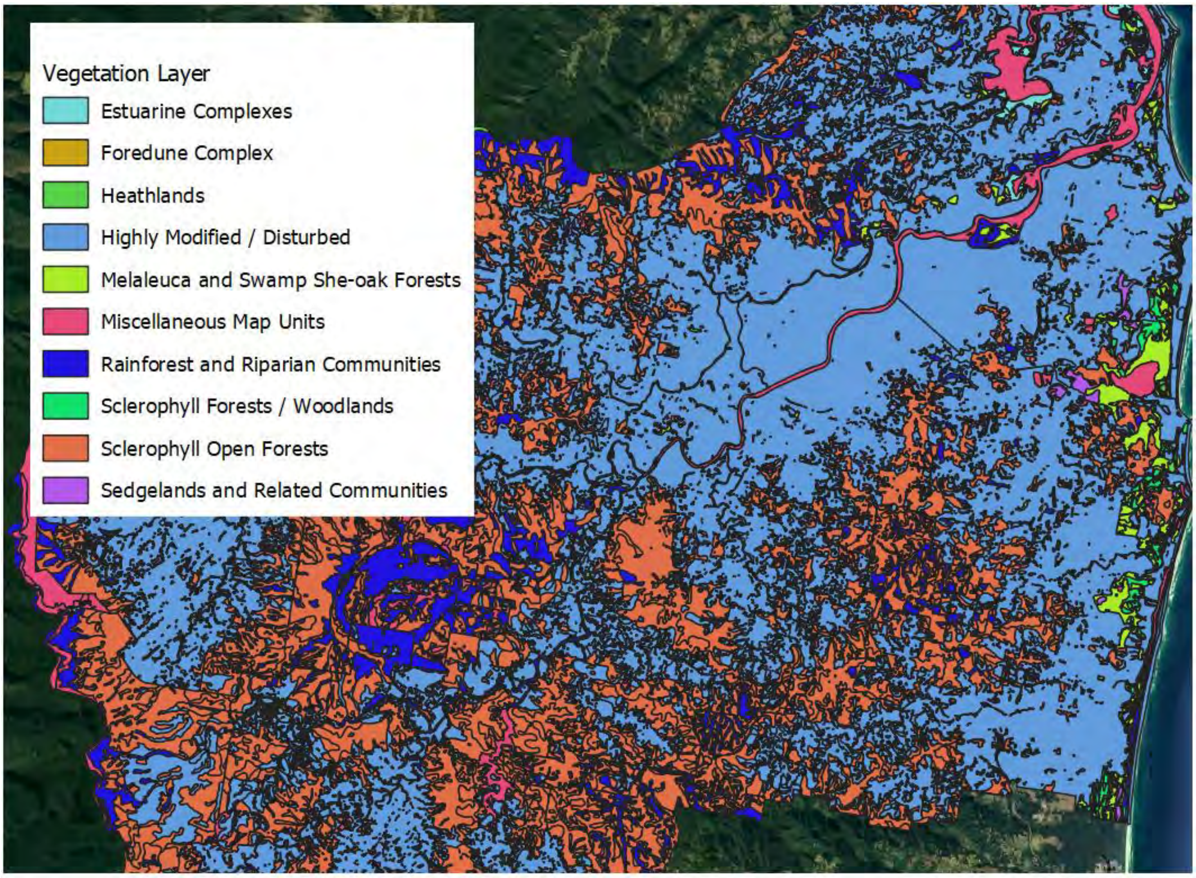



Diagram 11: Forest/Disturbance Zones Coverage

The extent of the disused rail line (now the 'Northern Rivers Rail Trail') and the roads throughout the region have also been supplied by Council, along with building finished floor survey levels (FFLs). The FFL data covers buildings located in the floodplain regions of the Tweed River catchment.

### 3.15.3. Historical Imagery

A GIS layer for historic aerial imagery has also been included within the data pack. Within the extended model extent, there is substantial imagery for the following years: 1962, 1970, 1987, 1991, 1993 and 1996.

There is more localised imagery in sections of the catchment for the following years:
- 1976 – lower reaches around Tweed Heads and Banora Point;
- 1977 – upper reaches from Terragon to Mount Burrell and Commissioners Creek; and,
- 1995 – lower reaches around Tweed Heads, Banora Point and Kingscliff.

### 3.15.4. Development of the Floodplain

The floodplain has evolved over time due to development in the region and significant weather events which have invoked changes in the river systems. Some of these developments are visible in the historical imagery discussed in Section 3.13.3 and will be easily represented in the updated hydraulic model. However, other changes such as variations to the cross-section of a river over time is much more difficult to represent.

The changes to the terrain have been reflected in updates made to the hydraulic model over time. The previous hydraulic model developed for the 2009 Flood Study Update (Reference 7) undertook calibration for the March 1974, March 1978 and April 1989 flood events and therefore has represented these three states of development of the floodplain within the model extent.

The representation of the catchment at different points in time (for the calibration events) was revisited to ensure its adequacy for use based on the historical data available, and to expand the provided data to the larger proposed model extent. Many significant changes such as the addition of levees and highway upgrades (Yelgun to Chinderah, Chinderah Bypass, Ballina to QLD) have occurred within the catchment.

Review of relatively new key developments was undertaken to ensure these are incorporated adequately within the hydraulic model for design event runs. Examples include:
- Tugun Bypass (completed mid-2008);
- Pacific Highway upgrades (completed circa 2015);
- Fraser Cove residential subdivision (completed 2017);
- Altitude Aspire residential subdivision in Terranora (ongoing);
- Seaside City residential subdivision in Casuarina (ongoing);
- Kingscliff Dunes residential subdivision (ongoing); and
- Tweed Valley Hospital Development (ongoing).

As the topography to be used in the model was flown in 2020, these features should be well captured at the appropriate level of progress.

### 3.15.5. New Release Areas

Several land release areas created as part of major developments in the region are identified on the Council website. Major developments are required to cope with the expected population growth to approximately 120,000 people by 2031 (Reference 16). Major developments listed include:

- Area E Urban Release Area; and,
- Cobaki Development.

**Area E Urban Release Area**

Following a comprehensive Local Environmental Study in 2004 prepared to support the rezoning of ‘Area E’ to accommodate urban land uses, a new Section (B24) of the Tweed Development Control Plan (DCP) for the Area E Urban Release Area was adopted in 2011 (Reference 16). Area E comprises of an infill urban release area in the Banora Point/Terranora residential area and presents an opportunity to consolidate the urban footprint by providing housing opportunities for approximately 3,500 people.

To date, some of the construction of Area E development has been completed as shown in Diagram 12. Work will be undertaken to ensure the zoning of this area and the development that has occurred to date is reflected in the hydraulic model.


Diagram 12: Area E Urban Release Area in November 2009 (left) and October 2020 (right) (Source: Nearmap 2020)

**Cobaki Lakes Development**

The Cobaki Lakes residential community development is a proposed new suburb located approximately 1.5 km west of the Gold Coast Airport and approximately 6 km inland of Tweed Heads (Reference 16). The development adjoins protected coastal wetlands to its east and environmental protection areas (remnant bushland) to the north and west. The Concept Plan proposes 17 residential precincts and a new mixed residential, commercial and community use redevelopment.

To date, some earthworks and beginnings of road formations appear to have occurred, particularly north of Sandy Lane/Boyd Street, west of the Pacific Motorway as shown in Diagram 13. Work will be undertaken to ensure the zoning of this area and the development that has occurred to date is reflected in the hydraulic model.


Diagram 13: Cobaki Lakes Development Area in May 2010 (left) and October 2020 (right)
(Source: Nearmap 2020)

## 3.16. Site Visit

A virtual ‘fly-through’ meeting between the Council and WMAwater was undertaken over 16-17 September 2020 as a means of highlighting points of interest and providing background on the study area.

A physical site visit was undertaken in December of 2020 focussing on key villages in the area, large infrastructure and evacuation routes. A subsequent site visit was undertaken after the February 2022 event, focussing on the areas worst affected in the event.

Upon completion of the calibration process a follow up site visit, focussing on ground truthing of the results will be undertaken.

# 4. COMMUNITY CONSULTATION

One of the central objectives of the update and expansion of this flood study is to provide the local community with an understanding of flood behaviour in the previously unmapped upper regions of the catchment. This includes the townships of Chillingham, Tyalgum and Uki as shown in Diagram 14.


Diagram 14: 2009 Flood Study Area and The Upper Expansion Area

## 4.1. Community Consultation - Stage 1

A community consultation program was developed with the purpose of:

- Informing the community about the flood study and flood risk;
- Identifying community concerns; and
- Gathering flood-related information.

As part of this plan, a newsletter and survey were created to inform the community about the study objectives and outcomes and to gain an understanding of experiences and insights from past flooding events and to better understand community concerns around flooding.

The consultation period ran from 24 June 2021 to 30 May 2021, and comprised the following engagement methods:

- Newsletter and questionnaire, via Tweed yoursayTweed (https://www.yoursaytweed.com.au/flood-study).
- Mail out versions of the questionnaire to potentially affected regions.
- Option for residents to provide flood photos to Council directly via yoursayTweed; and
- Option for residents to provide flood marks via identification of locations and Council surveyors then inspecting.

### 4.1.1. Questionnaire Response

A questionnaire was created with the aim of gathering information about specific experiences and observations of flooding in the community. Residents were given the option to complete this survey as a hard copy from council or online.

In total, 82 responses were received from the online survey in addition to another 60 hard copy responses. Most of these responses came from properties used as a residence (100) as opposed to those used for business (6). An additional 31 identified as Rural/ Farmland. The responses highlighted that the community is generally aware of the location of riverine or creek (99) flow paths that may affect them. 68 respondents indicated they have historically been impacted by flooding. 43 respondents had also been impacted by storm surge flooding previously. Some examples of the outcomes of the community consultation are provided below in Diagram’s 15, 16 and 17.

Several respondents provided details of their experience during the 2017 flood events, which to many, was the largest event endured in the area at that time. Of the respondents 47 provided details of flood survey marks that have subsequently been investigated by the Council and were be used within the calibration of the model within this study. Further details of the outcomes of the consultation are provided in the Technical Report.

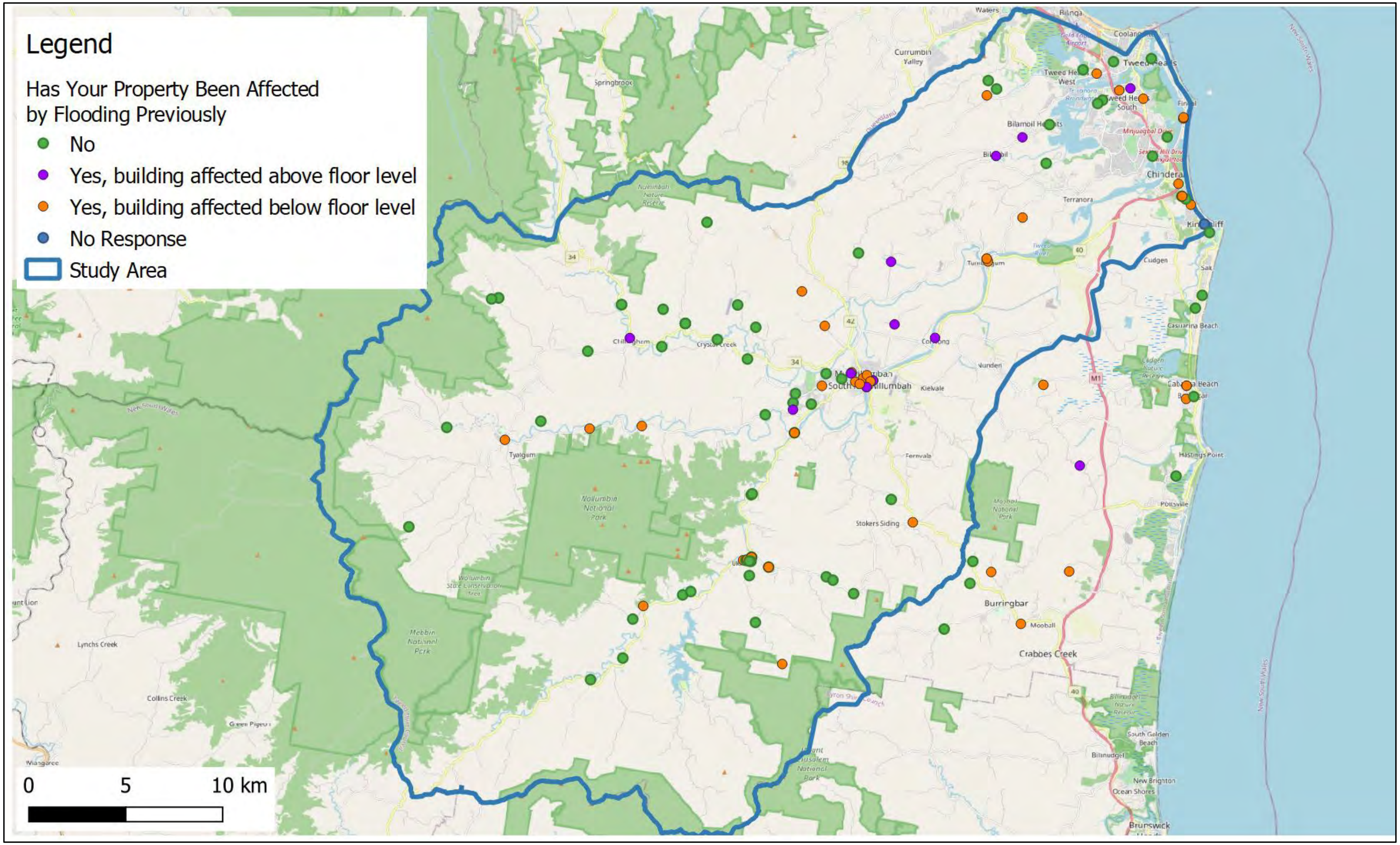



Diagram 15: Community Responses – Property Flood Affectation

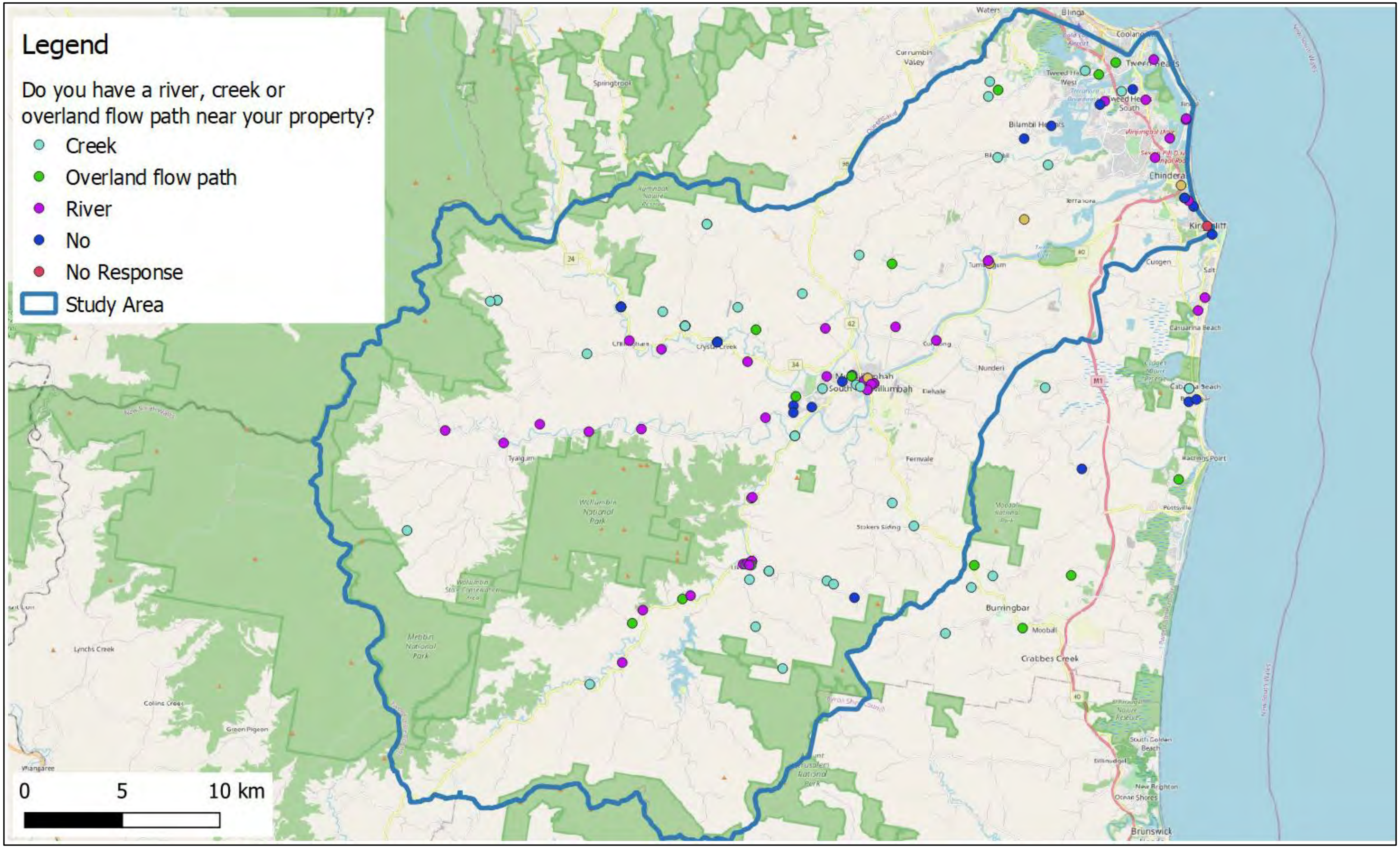



Diagram 16: Community Responses – Flow Path Knowledge

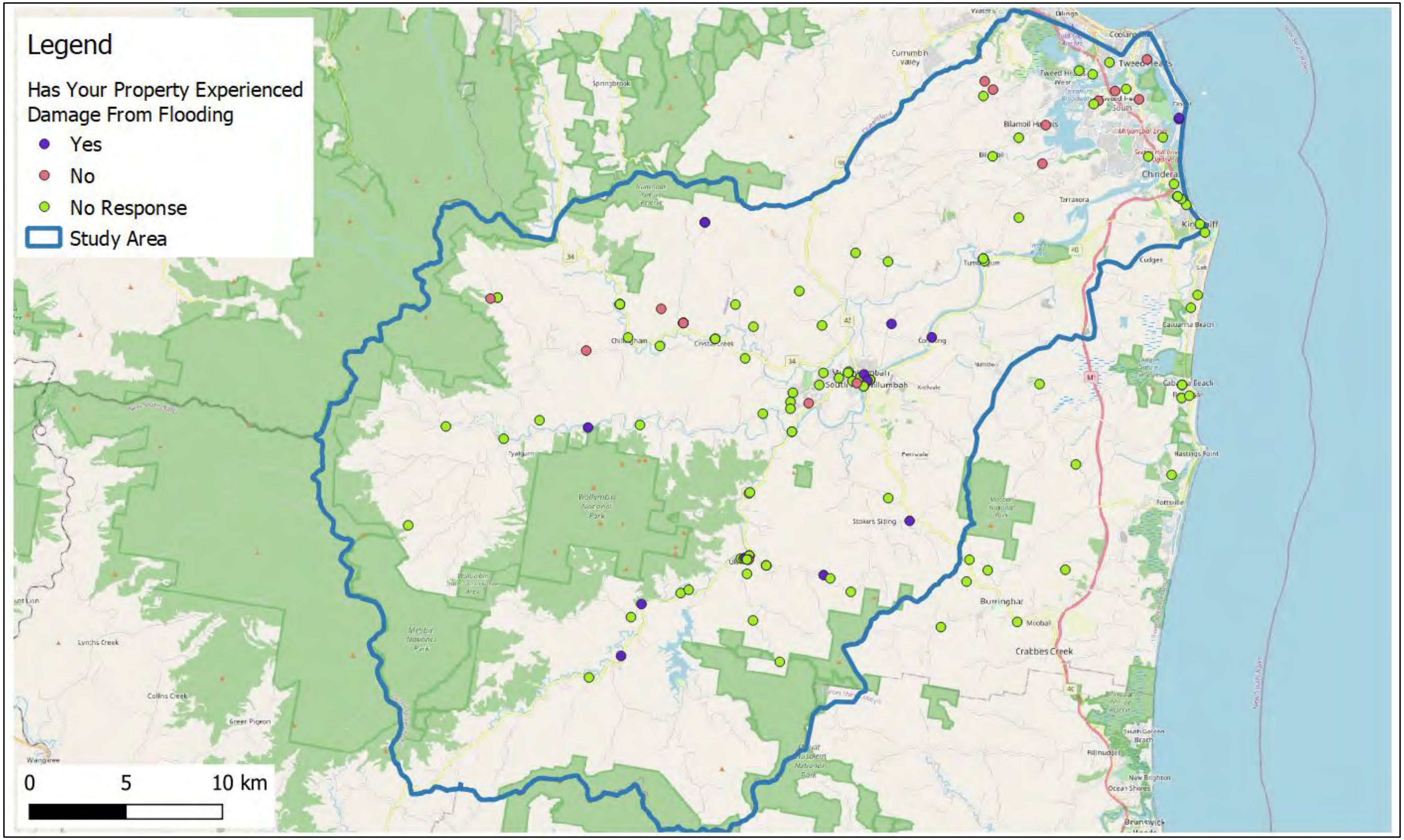



Diagram 17: Community Responses – Historic Flood Damage

## 4.2. Tweed Council – Share your 2022 Flood Story

Following the 2022 flood event, Tweed Council provided an online portal for residents to upload their experiences during the event. the following information was provided by individual persons within the community within the "Share your 2022 Flood Story" on the Tweed Shire Council website. Based on the reports posted on this portal from the community, which have not been verified, the following is understood to have occurred during the event: All the below information is subjective and based on individual interpretations and is not Council's opinion.

- CBD / Murwillumbah Creek
  - On the 28 February, due to significant rainfall in the Murwillumbah Creek Catchment (behind the levee), the CBD was inundated, as shown in Photo 1 near the Tweed Regional Aquatic Centre.
  - The carpark near the Tweed Regional Aquatic Centre was also inundated (Photo 2).
  - The water was brown within the CBD due to a landslide on Hospital hill behind the Tweed Regional Aquatic Centre
  - At a similar time in the CBD near Wharf Street was also experiencing significant inundation (Photo 3).
  - During the event several minor landslips occurred, resulting in sediment load in the runoff, as depicted in Photo 4.
  - The levee overtopped on the 28/02/2022 between 11am to 5pm at the Tweed High School. The Tweed Shire Council Facebook post posted the time of overtopping at 02.30pm 28/02/2022.
- Mayal Creek
  - River water flowed back along the drainage and in behind the levee. There is some community discussion that some of the flood gates along the levee may not have been closed. Key concern of the community was as they were evacuating river water had started to enter their property. This was before the levee overtopped. However, Tweed Shire Council has clarified that there are no manually closed floodgates on the East Murwillumbah levee.
  - Flood Gate 20 was lost due to riverside scour reportedly at about 02.00am on the 01/03/2022 according to Tweed Shire Council. At this reported time, Murwillumbah had ready peaked 11 hours prior.
  - The river overtopped the levee between Tumbulgum Road and the East Murwillumbah school. Widespread local stormwater flooding was already present prior to the levee overtopping.
  - Photo of flooding on the 01/03/2022 on Tumbulgum Road near Racecourse Road illustrated in Photo 7.
  - People on the corner of York Street and George Street showed water on York Street at 16:23 on the 28/02/25022 (Photo 5).
- Tweed River bank stability problems
  - Along the southern rural end of Commercial Road there were comments that people had their land drop 1.5 m along their property boundary with the Tweed River
  - It is known that the river had changed as there is significant scour and loss of bank stability along the upper reaches of the river.
- Cobaki Creek

- The bridge along Cobaki Road was damaged during the event is illustrated in Photo 8.
- Water overtopped Cobaki Road near Robinson Road on the 28/02/2022.
- Water completely inundated Piggabeen Road near the lower end of Cobaki Creek (Photo 10).


Photo 1: 28/02/2022 at 8:17 Pit surcharging at the Tweed Regional Aquatic Center

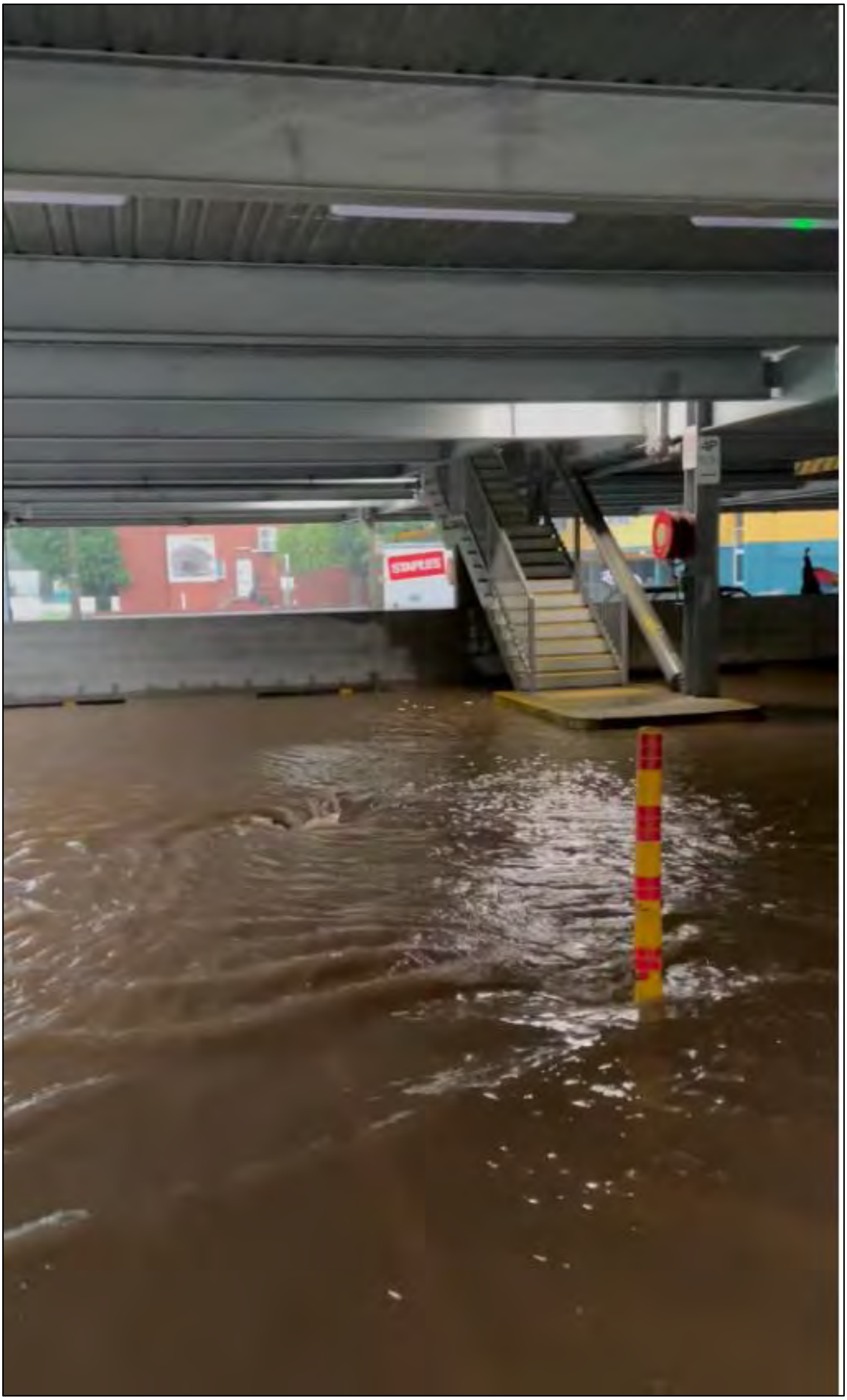



Photo 2: 28/02/2022 at 8:17 Tweed Regional Aquatic Center Carpark


Photo 3: 28/02/2022 at 8:10 Corner of Wharf Street and Commercial Street


Photo 4: 28/02/2022 at 11:05 Corner of Wharf Street and Queen Street


Photo 5: 28/02/2022 at 16:23 York Street


Photo 6: CBD Levee overtopping near Cricket Club and High School (https://www.youtube.com/watch?v=UsPF5DTl44U)

Photo 7: 28/02/2022 at 14:00 Tumbulgum Street near Racecourse Road (https://www.youtube.com/watch?v=UsPF5DTl44U)

Photo 8: 01/03/2022 Cobaki Road Bridge damaged by the floods

Photo 9: 28/02/2022 at 09:30 Cobaki Road near Robinsons Road under water


Photo 10: 2/03/2022 at 09:30 Piggabeen Road near Cobaki Road

## 4.3. Community Consultation - Stage 2

Upon completion of the draft flood study report, Stage 2 community information sessions were conducted by Tweed Shire Council and WMAwater. These sessions took place in February and March 2024 across several locations, including Tyalgum, Uki, Chillingham, Murwillumbah, Chinderah, and Tweed Heads, as well as 1 online session. A total of approximately 200 members of the Tweed Valley community attended the consultation sessions. The aim of the consultation sessions was to:

- Communicate the outcomes of the flood study: Ensuring that the community understood the findings and implications of the draft flood study.
- Respond to questions and concerns from the community: Providing a platform for residents to voice their concerns and receive immediate responses from experts.
- Provide a survey to gather feedback on the draft flood study: Collecting detailed feedback to refine and improve the study based on community input.

A survey was distributed by Tweed Shire Council during the sessions to provide the opportunity for the community to submit comments, questions, and concerns about the draft flood study. This feedback mechanism was essential for ensuring that the final report accurately reflected the needs and insights of the community.

### 4.3.1. Survey Response

In total, 57 responses to the survey were received by Tweed Shire Council. All responses were submitted by residents of the Tweed Valley catchment area, with some members of the community being business owners. Of the 16 submissions that indicated suburb of residence, 38% reside in Kingscliff, 13% in each of the suburbs of Fingal Head, Murwillumbah, Banora Point, and 6% in each of the suburbs of Tyalgum, Bogangar, Duranbah and Tweed Heads.

Overall, the responses highlighted that the purpose of the flood study is generally clear (80%). Submissions were 28% positive, 39% negative and 33% neutral towards the draft flood study. Several respondents provided details of their experience during the 2022 flood events and evidence of the impacts of flooding within their properties.

All survey submissions have been reviewed by Tweed Shire Council and WMAwater. Where appropriate, the flood study has been updated to address concerns raised by the Tweed Valley community.

# 5. DEM DEVELOPMENT

The Digital Elevation Model (DEM) developed for a 2D hydraulic model should represent all key topographic features that influence the flow of water in a region. This section details the development of the Tweed model DEM from a range of data sources to achieve a high level of model detail, as well as ensuring the most up to date information was included. It is important to draw a distinction between topographic features which are included in the development of the DEM, and the hydraulic features which are included as features in the hydraulic model. Where these elements are deemed critical, they have been discussed in the following sections.

## 5.1. DEM – Outside of the Channels

The 2020 Lidar is the highest priority data source in all areas outside of the banks of channels. It is considered the most accurate and up to date information for the DEM. The complete DEM used in the model is shown in Figure 4. A major limitation of most LiDAR datasets is that the LiDAR cannot penetrate deep into water bodies and will not represent the bottom of the channel. The in-channel topography (bathymetry) must be represented from data from other data sources. If no other information was available in an area it is represented by the 2020 LiDAR survey.

## 5.2. DEM – Inside the Channels

There are multiple data sources utilised for each of the major water features that were not accurately captured by the most recent lidar. These features are:

Table 8: Summary Major DEM Features and Datasource

| Feature | Data source | Section |
|---|---|---|
| Topography – External to Channels | 2020 LiDAR | 3.10.1 |
| Tweed River – downstream of the Pacific Motorway Bridge | NSW Marine Bathymetry 2018 | 3.10.2 |
| Terranora and Cobaki Broadwaters | 2009 Flood Study | 3.10.2 |
| Tweed River – Pacific Motorway Bridge to Bray Park weir | 2020 Bathymetry | 3.10.2 |
| Rous River | 1979 surveyed cross sections | 3.10.2 |
| Clarrie Hall Dam | Estimated from storage curve | 3.12 |
| Levees | Survey, additional extracted from 2009 flood study | 3.10.3 |

All major bridges in the system are represented as 2D structures in the model, and so in instances where the bridge deck was picked up as a surface in the model, these were removed. All other minor hydraulic features, such as culverts, are represented as 1D modelling elements. A check was made to ensure the top surface of the element was applied in the DEM and enforced with break lines where necessary.

### 5.2.1. Tweed River - Downstream of the Pacific Motorway

The area between the tailwater and the bridge and extending up Terranora Creek, as outlined in Diagram 18, is represented by 5 m bathymetric survey from 2018. This is considered the most up to date representation of this region and has been utilised as is within the DEM. The Cobaki and Terranora broadwaters, upstream of the motorway are based upon information present within the 2009 flood study model (BMT, 2009). This is due to an absence of alternative information.

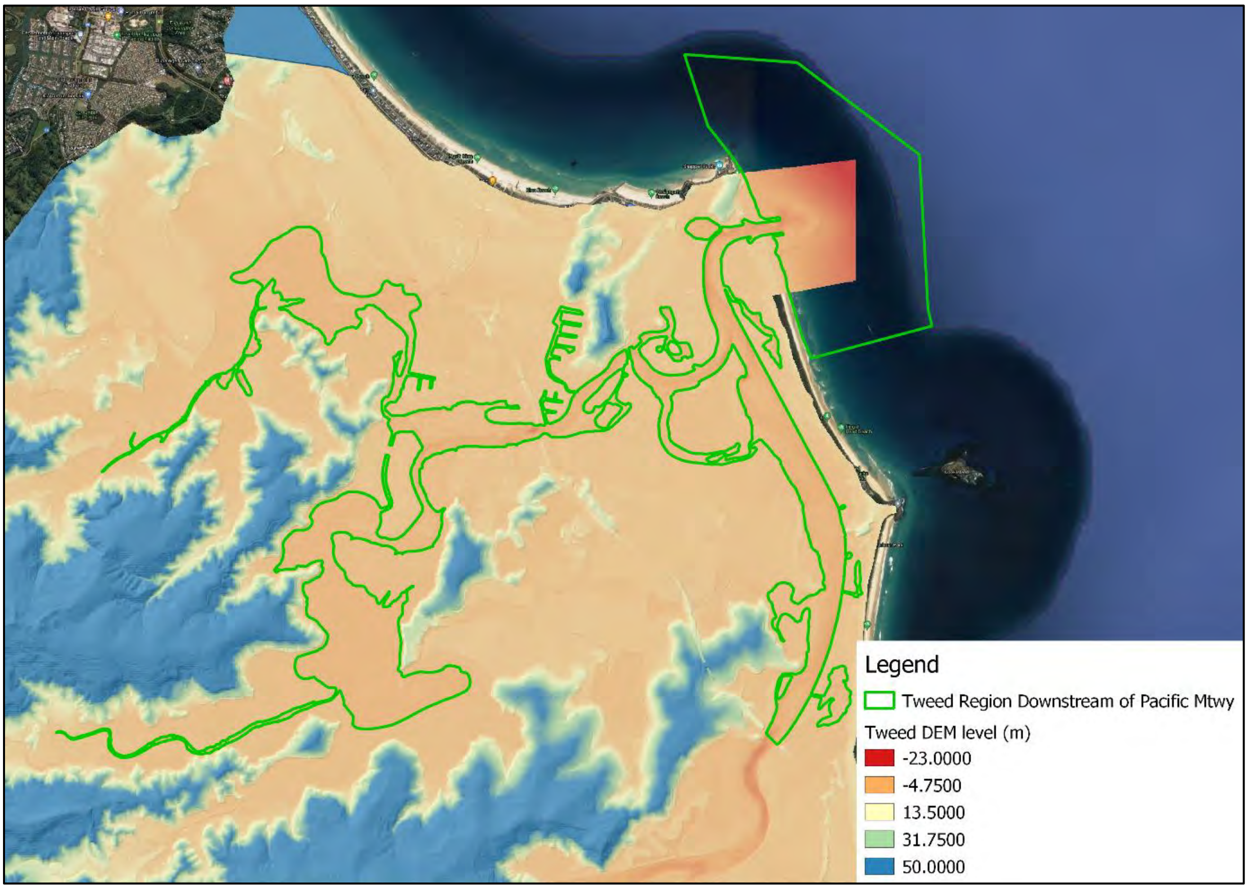



Diagram 18: Area Downstream of the Pacific Motorway Bridge

The ocean is represented by the 5 m DEM for several hundred metres before interpolating to a flat bottom (set to -27 mAHD) at the boundary. This ensures that the boundary zone does not influence results within the study area while also ensuring model stability at the boundary.

Barney's Point Bridge is represented as a layered flow constriction utilising information supplied (drawing 0010438BC5060, RTA, 1992).

### 5.2.2. Tweed River from Pacific Motorway to Bray Park Weir

High quality bathymetric survey (NSW OEH, 2018) was available for the Tweed River between the Pacific Motorway Bridge and Bray Park weir. Diagram 19 shows the extent of this dataset.

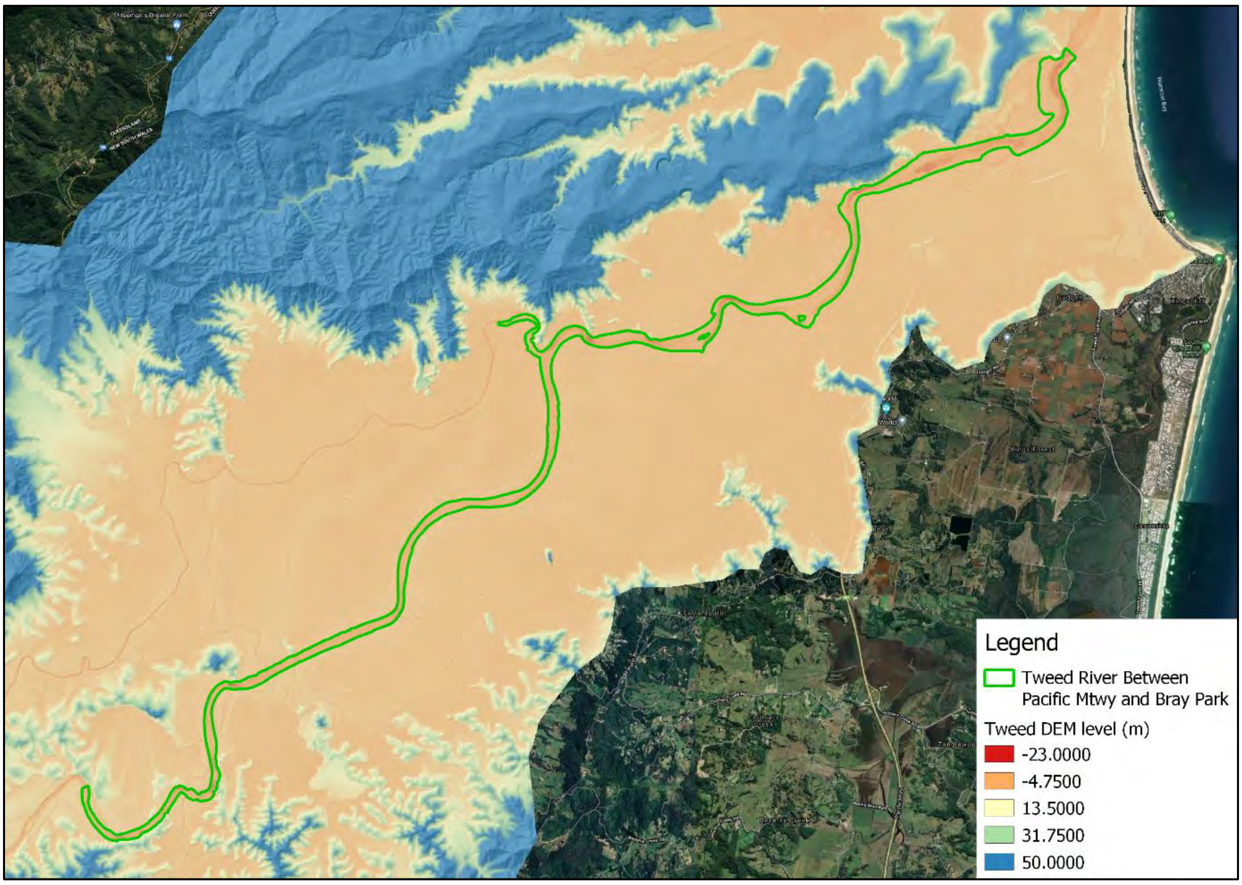



Diagram 19: Tweed River Between the Pacific Motorway Bridge and Bray Park Weir

This information was utilised to develop a detailed representation of the riverbed within this region. An accurate representation of the bathymetric surface in a hydrodynamic model is essential for simulating in-bank flow and ensuring appropriate hydraulic response within the model. The developed bathymetric surface was then merged with the surrounding DEM to form a continuous surface. Diagram 20 shows an example of the merged surface and the utilised bathymetry points.

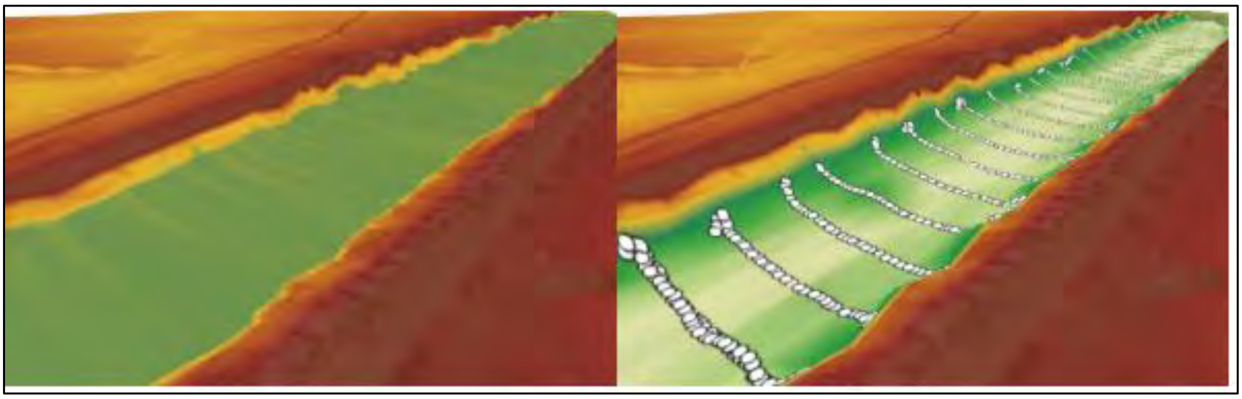


Diagram 20: Inclusion of Interpolated Bathymetry into LiDAR

At the interface of the detailed 2020 bathymetry and the 2 m 2018 bathymetry (located at the Pacific Motorway) a linearly interpolated combination, “stitch”, was conducted blending the two datasets. Diagram 21 shows the treatment at this location. At the upstream end of the dataset is the Bray Park weir. No adjustments were necessary at this location.

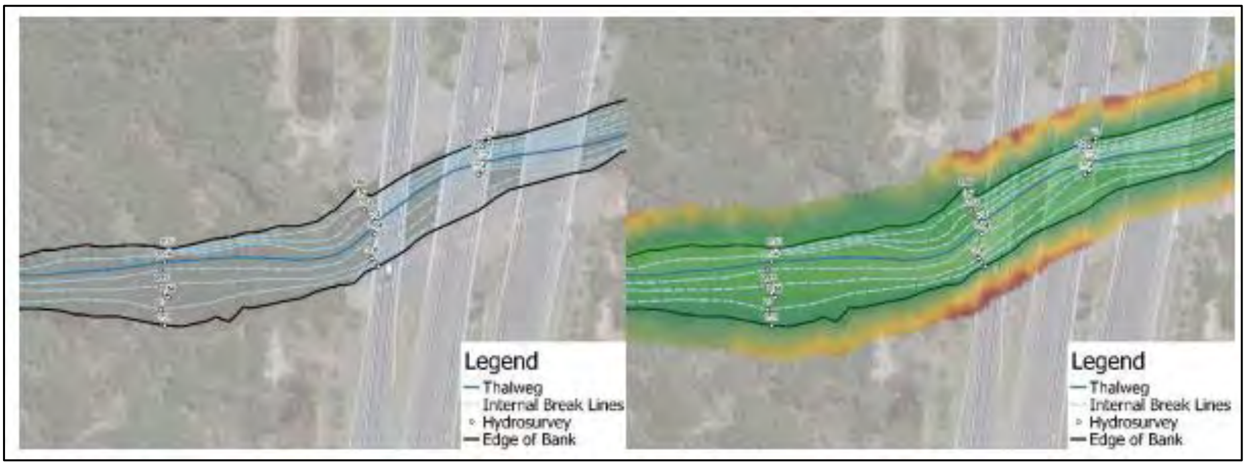



Diagram 21: Addition of Training Lines to Improve Surface Representation.

### 5.2.3. Bray Park Weir and Storage area

The top of Bray Park weir is enforced in the 2D hydraulic model with a break line at the surveyed crest level. The top width of the weir was enforced at 1.23 mAHD as thick line to ensure the correct friction of the weir flow over the surface.

No bathymetric information was provided for the area upstream of Bray Park weir. The provided LiDAR information behind the weir (noting the LiDAR in this area will be a mix of water returns and interpolation of bank returns) has been removed, with a single wedge storage down to the level of -1.7 mAHD utilised in its place. This approach has been undertaken to provide a reasonable representation of the channel in the area so the weir can act in a hydraulically appropriate manner. Noting generally the water level is at the weir crest level, within the hydraulic model an initial water level equal to the crest level is utilised to ensure the water level is correct.

### 5.2.4. Flood Mitigation Levees

Figure 5 shows the locations of the defined levees within the study area. These levees provide various levels of protection for key areas throughout the study area and as such appropriate representation within the model is required.

The form of the levees in the study area is primarily captured from the LiDAR, and as such the volume representation and location is defined by this data source. The level of the top of the levees was provided as additional survey that was undertaken by Council after the Stage 1 data review. Levees that were captured as part of this survey were:

- Dorothy Street (at Murwillumbah STP)
- Murwillumbah CBD Levee
- South Murwillumbah Levee
- Quarry Road Levee
- Tweed Heads South Levee
- East Murwillumbah Levee

This information was included as an enforced thick break line. For the Murwillumbah CBD levee wall however (concrete wall along Commercial Road) a thin enforced line has been used to represent the structure and ensure there is no loss of volume due to the structure.

### 5.2.5. Rous River

The Rous River, as outlined in Diagram 22, is represented utilising information taken from the 1D representation utilised in the 2009 flood study (Reference 8), which is cross-sections of the system recorded in 1979. Some cross-sections required a shift to align the bank crest of the cross-section with the bank crest of the channel represented in the LiDAR. No other information was supplied within this area. Diagram 19 shows the extent of the Rous River where the previous model information was utilised.

The cross-sections were interpolated using the same approach as used for the Tweed River bathymetry. Noting a significant variance in the available data, the approach required the addition of large sections of training lines to represent the shape between cross-sections. This area was 'stitched' to the Tweed River bathymetry through linear interpolation of the two datasets at the interface.

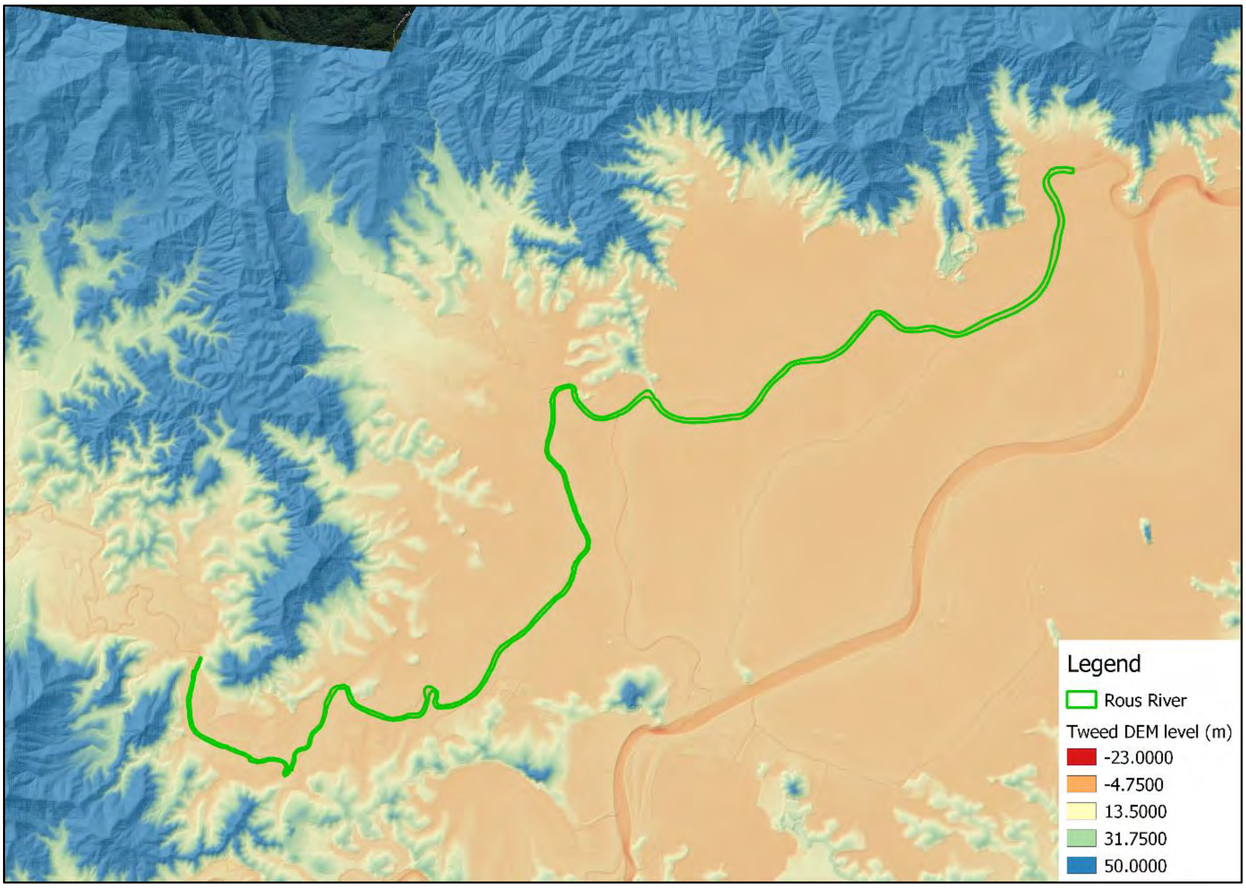



Diagram 22: Rous River 2009 Representation Adopted in Current Model

### 5.2.6. Clarrie Hall Dam

To represent the dam, an area behind the dam was depressed by the extent of the water surface identified in the LiDAR to 2 m below the lowest level expected in the calibration events to be modelled. While this does not model the exact surface area below the spillway level, this should serve as sufficiently accurate for the purposes of the study. This assumption was confirmed by reviewing the hydraulic model response against the hydrologic model response (which utilises the provided storage-discharge relationship for the dam). Based on results from the hydraulic model illustrated in Diagram 23, using this assumption in the hydraulic model does not affect the flows coming through the dam.

It should be noted that Clarrie Hall Dam has no specific flood mitigation function and as such for all design events the Dam water level will be full supply level, resulting in the storage assumption below the spillway having limited influence on the overall result.

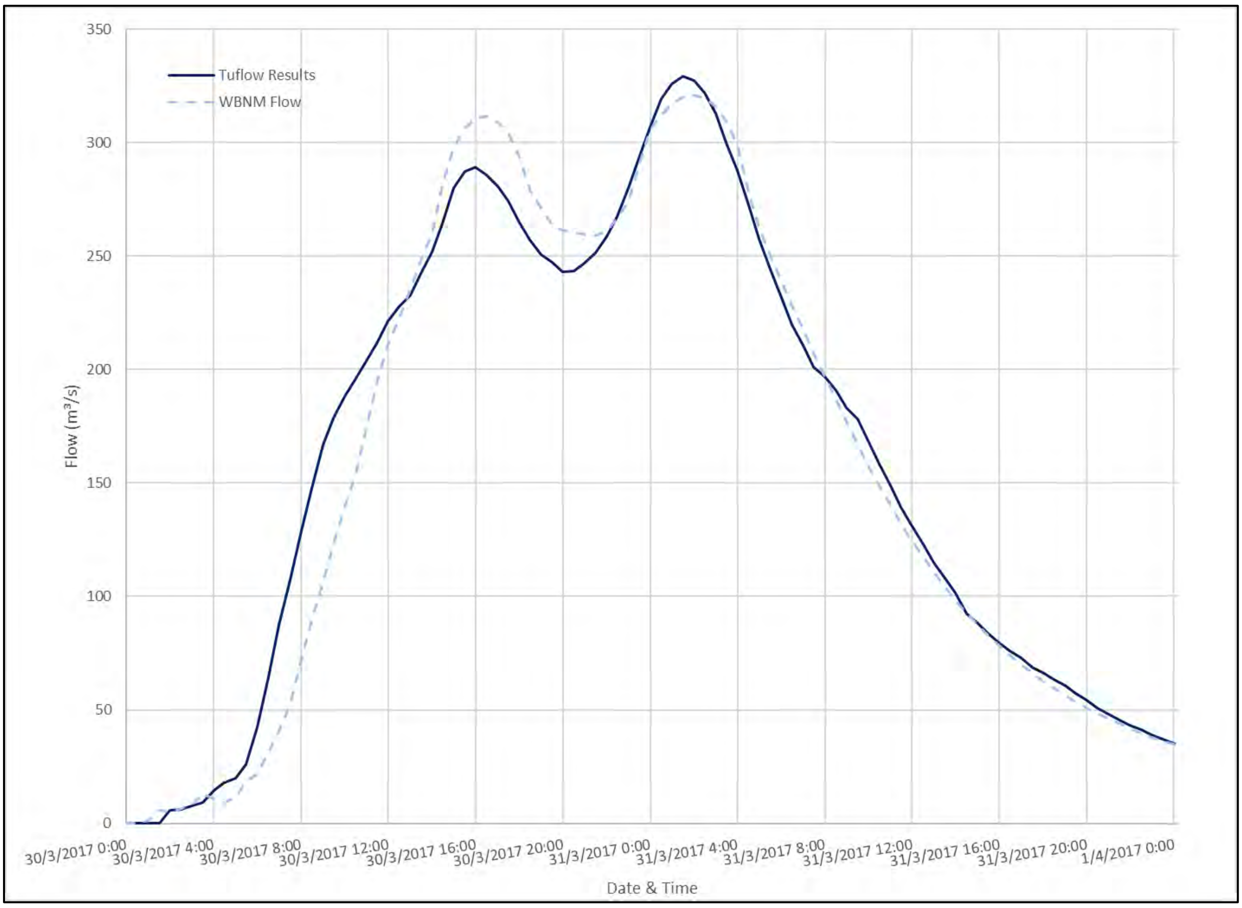



Diagram 23: 2017 Event – Clarrie Hall Dam

# 6. MODEL UPDATES

Hydrological and hydraulic models are required for the study area, with the WBNM and TUFLOW software as the preferred options to complete this project. The Tweed Valley catchment is impacted by riverine, overland and coastal flooding. Flooding scenarios for consideration in this study include:

- Mainstream flooding only;
- Overland flow flooding only; and
- Both mainstream and overland flow flooding.

The coastal interaction is represented in the model by using a tidal boundary. For design events the tidal level is governed by the recommendations within the floodplain management handbook (Reference 21), while the tidal boundaries for historic flood events are derived from observed water levels with no wave action assumed.

To simulate flood behaviour in the Tweed River floodplain, both a hydrologic model capturing the entirety of the Tweed River catchment and its tributaries, and a 1D/2D hydraulic model covering all populated areas within the catchment have been used.

The general approach and methodology employed to update and expand the flood study in line with the project objectives involves the following steps:

1. Update to the hydrology model with smaller sub-catchments for better flow definition.
2. Update the rainfall for all calibration events.
3. Calibrate the hydrological model to all available gauges, with local modifications as necessary.
4. Update the hydraulic model with most current Digital Elevation Models (DEM) which includes LiDAR (Light Detection and Ranging) information and bathymetry survey.
5. Jointly calibrate the behaviour of downstream gauges.
6. Prepare additional inputs of and perform at site rainfall Intensity-Frequency-Duration (IFD) comparison and at site Flood Frequency Analysis’s (FFA).

## 6.1. Hydrologic Methodology

The data review identified elements of the hydrology which require updating. The approach is summarised as follows:

1. Refine sub-catchment breakup to include local features, and definition of the upper reaches of the catchment.
2. Update of the rainfall inputs for the new catchment break up. This includes an expansion of the inputs used to include daily and sub daily records throughout the catchment.
3. Modification of local model characteristics to best match the recorded stream flow throughout the catchment.

The overall objective of this study is to deliver an updated Tweed River regional hydrology model which can produce the required level to detail at all key locations in the study area. This will be used to inform floodplain management planning, emergency management and evacuation response along with being the major input to the accompanying flood study. The purpose of the hydrology model update and calibration is to ensure that the hydrologic model is representing, as much as possible, the various flooding mechanisms throughout the catchment for a range of event magnitudes.

The existing hydrology model for the catchment was reviewed and significant revision was required to be appropriate for use in this study. The existing model is a WBNM model that consists of 207 sub-catchments varying in size from 186 ha to 1,573 ha. Figure 6 shows the hydrologic model sub-catchment breakup, network and centroids.

Refinements were required to meet the objective of the study are discussed in the Hydrologic Model Review & Proposed Procedure Memorandum (Reference 17). Some key refinements are outlined below:

- Refinement of sub-catchments to provide adequate resolution to represent local features.
- Update the fraction impervious for all refined sub-catchments via the land use planning layers provided by TSC.
- Updating the model to ARR2019 methodology:
    - IFD
    - Temporal Patterns
    - Areal Reduction Factors
    - Losses

### 6.1.1. Sub-Catchment Refinement

The main focus of this update was to improve resolution in the catchment output in critical areas in the headwaters of the catchment, and up stream of key pieces of infrastructure. It is generally suggested that multiple routes be included before a critical measurement is taken from a hydrological model. The target for this new catchment break-up was to include at least three catchments upstream of key infrastructure, such as roadways identified as potential evacuation routes.

A comparison of the two catchment breakups is shown below on Diagram 24, with a complete diagram of the new catchment layout on Figure 6. There was no modification in the lower reaches as the definition used within the previous 2009 study was considered appropriate. The average area of the updated hydrology sub-catchments is 250 ha, with all refinement occurring in the Tweed and Rous rivers upstream of Murwillumbah, and Bilambil and Terranora Creeks.

### 6.1.2. Local Model Modifications

Several localised modifications were made to the model to better capture the flood behaviour in the upstream sections, particularly around the flows at Uki. Local flow modifications fell into two categories, the first was based on the shape of the flow record. In areas where the shape of the flow record was not captured accurately by the hydrology model, an initial modification to the channel route was adopted to best match the model to reality. In areas where the volume of flow was deemed to be incorrect, local variation to the losses were adopted to ensure the correct flows. Modification of losses can also account for local variation in applied rainfall depth due to a lack of rainfall information in a local area.

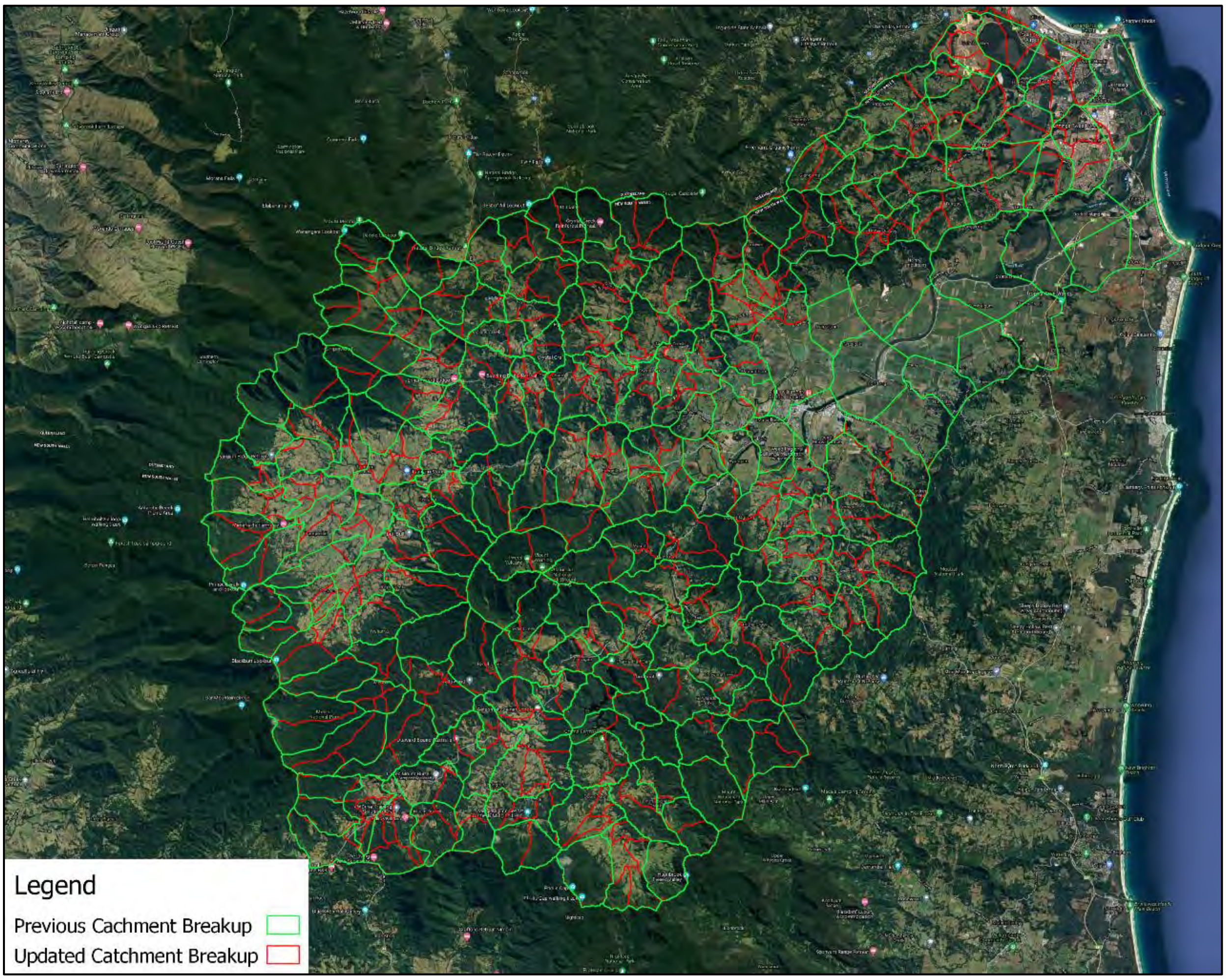



Diagram 24: WBNM Subcatchment Refinement

### 6.1.3. Calibration events and rating curves

Based on the data review undertaken and the available information, the following calibration events were selected to confirm the validity of the model:

- February 2022
- February 2020;
- March 2017; and
- March 1989.

These events were selected to cover a range of flood sizes, from the smaller flood size of the 2020 event up to the larger 2017 and 2022 events. This ensures the primary flood mechanisms were calibrated and that the model calibration is scalable across a range of flood magnitudes. Finally, 2017 and 2022 were selected as they are events of particular note to the community, having occurred recently and having very good data coverage. Model timing, volume, shape and peak water level and flow informed the analysis to determine goodness of fit.

Rating curves were extracted from the previous studies as necessary to allow the comparison of hydrology and hydraulic results, however these were mainly available for areas where there was a deviation between the hydrology and the hydraulics due to the large floodplain (i.e. at Tumbulgum). Additional hydraulic rating curves were extracted from the hydraulic model and used for comparison as discussed in Section 10.

### 6.1.4. Calibration Event Rainfall

WBNM applies the rainfall based on the inverse distance weighting of the total rainfall at each pluviograph location, and then applies the temporal pattern by the nearest neighbour approach.

This methodology has been applied to the derivation of the rainfall for the calibration events within the developed model. However, the method is applied outside of the WBNM program to enable the use of all rainfall information for the area, including the daily records (given that these were multi day events). This approach expands the total amount of information available for each event and improves the resolution of the applied rainfall. Figure 10, Figure 13, Figure 16 and Figure 19 show the rainfall depths at gauges and the spatial distribution of rainfall, as applied within the developed hydrologic model.

### 6.1.5. Lag Parameters

WBNM is a split model, meaning that it models the catchment runoff separately to channel flow, and combines the hydrographs at each catchment outlet. The flow in both channels and catchments are affected by a single catchment routing parameter C, with a further routing parameter included to modify the channel flow inside each catchment.

The C value is used to calculate the catchment response time for runoff, which ultimately informs the shape of the runoff hydrograph. This parameter is determined via calibration to recorded data and is to remain consistent across a range of events to ensure appropriate application.

Additionally, there is a channel routing lag multiplier, this value is a multiplier applied to the catchment C value and is used to model the stream flow within a catchment. This parameter is best modified to capture the difference in behaviour between the hydrology and hydraulic model as they are both calibrated towards matching reality.

It should be noted that in general it is not recommended to vary the C parameter on a sub-catchment basis. Given the large variation in landform however within the Tweed Valley catchment (hinterland in at the upper reaches, floodplain at the lower reaches) and the apparent change in response present at the gauges throughout, in this scenario it was deemed appropriate to ensure local catchment response characteristics were captured. This has been undertaken for all calibration events and assumes a slightly faster response time in the hinterland zones west of Murwillumbah and in the Terranora Creek and Cobaki Creek catchments. A summary of the parameters used are provided within Section 8 for each calibration event modelled.

# 7. HYDRAULIC MODEL SETUP

## 7.1. Hydraulic Methodology

The data review identified elements of the hydraulic model which require updating. The approach is summarised as follows:

1. Expand the existing (BMT, 2009) hydraulic model upstream to include local features, and definition of the upper reaches of the catchment.
2. Update of the inflow inputs due to the new hydrologic catchment break up.
3. Update the model terrain to include the newly flown 2020 LiDAR.
4. Included the Tweed River into the 2D domain of the model instead of 1D network such as the previous model.
5. Include the bridges within the model based on supplied information.
6. Include the additional culverts and pipes with an equivalent size of 750 mm width/diameter and greater within the model.
7. Modification of Mannings roughness to obtain adequate calibration.

## 7.2. Model Overview

The TUFLOW package was adopted to establish a hydraulic model in this study as it meets requirements for best practice and is currently the most widely used model of this type in Australia for riverine flood modelling.

The TUFLOW modelling package includes a finite difference or finite volume numerical model for the solution of the depth averaged shallow water equations in two dimensions. The TUFLOW software has been widely used for a range of similar floodplain projects both internationally and within Australia and is capable of dynamically simulating complex overland flow regimes.

The TUFLOW model version used in this study was 2020-01-AB-w64 (using the finite volume HPC solver), and further details regarding TUFLOW software can be found in the User Manual (Reference 18).

In TUFLOW the ground topography is represented as a uniform grid with a ground elevation and Manning's 'n' roughness value assigned to each grid cell. The size of grid is determined as a balance between the model result definition required and the computer processing time needed to run the simulations. The greater the definition (i.e. the smaller the grid size) the greater the processing time need to run the simulation.

## 7.3. Model Extents

The TUFLOW model 2D domain covers the Tweed Catchment from its headwaters in the south-western highlands, with an area of approximately 840 $km^2$. Figure 4 shows the hydraulic model extent.

## 7.4. Grid Size

A grid cell size of 8 m has been adopted for the entire study area. The grid cell size selected is an appropriate balance of computation time and resolution. Sub-grid sampling (SGS) is included in the model, sampling at 4 m, to ensure minor drainage features were captured sufficiently for local breakouts within the regional flood study.

## 7.5. Base topography

The TUFLOW model 2D terrain was based on the 2020 LiDAR dataset. The 1 m DEM within the study area was sampled at a 2 m scale to develop the underlying terrain of the TUFLOW model. The model topography is shown in Figure 4.

## 7.6. Bathymetry

The Digital Elevation Model (DEM) developed for a 2D hydraulic model should represent all key topographic features that influence the flow of water in a region. This section details the development of the Tweed model DEM from a range of data source to achieve a high level of model detail, as well as ensuring the most up to date information was included. It is important to draw a distinction between topographic features which are included in the development of the DEM, and the hydraulic features which are included as features in the hydraulic model. The development of the DEM is outlined in the WMAwater Stage 1 Report (Reference 18).

## 7.7. Levees

The form of the levees in Tweed is mostly captured from the LiDAR, and as such the volume representation of them has been included from this data source.

The top of the levees was provided as additional survey, and this was included as enforced break line crest, again not modifying the volume representation illustrated in Figure 5, but to ensure that the crest of the levees was always enforced.

It is noted that during the 2017 event some damage occurred to the Murwillumbah South Levee. In the hydraulic calibration events that occurred in 2017 and earlier the survey from 2009 has been applied in the model. While it is understood that no level change occurred as part of the repair works after the 2017 event, the 2009 LiDAR information provided a better representation of spill into South Murwillumbah than the 2020 LiDAR. For the 2020 and 2022 events the 2020 LiDAR and the 2021 South Murwillumbah Levee survey was utilised. The newest information will also be used for all design events.

## 7.8. Breaklines

As the model utilises SGS, it is necessary to ensure that known hydraulic features are captured within the DEM through the use of breaklines. If this is not undertaken the SGS approach within TUFLOW generates a rating curve for the cell that has the potential to bypass small hydraulic features. The breaklines utilised within the developed hydraulic model are shown on Figure 7.

## 7.9. Initial Water Level

Initial water levels have been applied at key hydraulic controls such as the downstream ocean boundary, Bray Park weir and Clarrie Hall Dam. The downstream ocean boundary initial water levels are based on gauged water levels from the Tweed Ocean gauge. The hydraulic model utilises a warm-up time prior to inflows being applied within the hydraulic model to ensure an appropriate representation of tide is present.

Clarrie Hall Dam has had the initial water level in the dam set to the full supply level of 61.5 mAHD for all modelled events and the Bray Park weir initial water level is set to 1.18 mAHD, which is slightly lower than the crest level however this ensures good stability and does not affect the results. The model was started at an initial water level that matched the tidal boundary.

## 7.10. Inflows and Boundary Conditions

The hydrologic model outputs have been implemented in the hydraulic model as source inflow polygons, where each polygon covers the extent of a sub-catchment within the code boundary. The placement and size of existing inflows has been revised to better represent the hydrologic model outputs, by placing the source inflows around the outlet of sub-catchments corresponding to where the flows are routed within the WBNM software.

For the tidal boundaries, the Letitia Spit gauge is flood influenced in the events, therefore other sources of information had to be used to inform the boundary of the model. The tidal boundary for the model has been extracted from the recordings of the SES for the 1989 event and 2017 event. For the 2020 event the tidal boundary was extracted from the Gold Coast Seaway gauge. For the 2022 event the tidal level from the Tweed Entrance gauge was utilised and the influence of the flood water removed (as the Gold Coast Seaway information was not readily available). Checks of the response outside of the flood peaks were undertaken at the Letitia 2A gauge to confirm the use of the gauges, with a good match to the tidal signal present.

## 7.11. Roughness

In the hydraulic model, Manning's roughness is used to define the frictional resistance that water will experience when passing over different surfaces. The roughness is primarily based on the land use as part of the TSC GIS dataset. Sugar cane is the only land use that was assigned depth varying Manning's, as outlined in Table 9. Figure 8 illustrates the model roughness across the catchment. There were two types of sugar cane land that was assigned in the model, all sugar cane land upstream of Murwillumbah was assigned a depth-varying manning while sugar cane land downstream of Murwillumbah was assigned a single Manning's value.

This determination was made after inspecting aerial imagery of the sugar cane area before and after the March 2017 flood event and identifying that the sugar cane land near Bray Park was pushed over during a flood event, indicating the area may be subject to greater force. The values presented in Table 9 are based on the outcomes of the validation of the study area.

Table 9: Manning's 'n' Values Used in the TUFLOW Model

| Material Category | Manning's 'n' |
|---|---|
| River / Waterways | 0.03 |
| Tidal waterways | 0.026 |
| River banks | 0.09 |
| Dense forest | 0.12 |
| Vegetated islands in river | 0.08 |
| Cleared / grazing / bare land | 0.03 |
| Parks | 0.04 |
| Sugar cane - varying | 0.06 (y1*-1m, n 0.15 y2*-2m, n 0.06) |
| Sugar cane | 0.15 |
| High density urban | 0.07 |
| Highway / Roads | 0.025 |
| Open water | 0.025 |
| Rail corridor | 0.045 |
| Rural residential | 0.045 |
| Medium density residential | 0.06 |
| Community facility / Commercial | 0.045 |
| Carparks | 0.02 |
| Standing water | 0.02 |

*note: y1 - The depth below which the Manning's n value n1 applied; y2 - The depth above which the Manning's n value n2 applied

It should be noted that to achieve a good calibration in the 2022 event in upper reaches, modification to some roughness areas to consider the impacts of lost vegetation and scour, was required. It is considered the 2022 roughness scenario, noting it is the most recent and has the highest level of confidence, should be used for design modelling.

## 7.12. Hydraulic Structures

The hydraulic structures were modelled either as a 1D network dynamically linked to the 2D domain or as layered flow constrictions. For culverts and stormwater networks with pipes greater than 750 mm, these were implemented within the model as 1D networks.

### 7.12.1. Culverts and Bridges

All major road culverts that were provided within the TSC GIS (refer section 3.11) were incorporated into the hydraulic model. Major road culverts that were not surveyed in the TSC GIS layer within the model extent were found and included in the model. The dimensions of these culverts were estimated based on the latest available panorama view in Nearmap. The invert levels were estimated at ground levels from the LiDAR data. The majority of culverts within the study area were incorporated into the system as 1D elements.
Figure 9 presents all stormwater networks and culverts provided by Council, as well as estimated

major culverts across the Tweed catchment. Key bridge information has been determined from supplied drawings and pictures provided by TSC.

### 7.12.2. Tide Gates / Non-Return Valves

Where information was known on the presence of tide gates and non-return valves in the system, this information has been incorporated into the model. It has been assumed all gates are closed. Figure 9 highlights the locations where these elements are present within the model.

### 7.12.3. Stormwater Network

The pits exchange flows between 2D ground surface and underground 1D pipes. The pit and pipe data from Council could not be used directly and following modifications were made to enable an adequate representation of the network in the model:

- Pipes and box culverts were assigned Manning's n values of 0.013 for reinforced concrete material assuming some minor degradation;
- Missing invert levels were estimated to be the ground level minus the pipe diameter or height with a general 600 mm cover where viable;
- For pipes with missing size, data provided in the upstream and downstream pipes was used to estimate a reasonable diameter;
- For pits with missing size, a general dimension of 1.2 x 0.9 m was assigned;
- Invert levels of field outlets (where they were not provided) were obtained from the LiDAR data; and
- Pipe directions were reviewed and modified as TUFLOW requires the polylines representing the pipes to be digitised from upstream to downstream.

Culverts with an equivalent size of 750 mm width/diameter and greater based on the given TSC GIS data were included in the TUFLOW model as 1D elements. The invert levels were estimated at ground levels from the LiDAR data to ensure full capacity and stable flow within the model.

# 8. CALIBRATION

The calibration of the hydrologic and hydraulic model is a complex and interactive process that requires the investigation of multiple combinations of calibration parameters to establish an adequate representation of a historical flood event for the catchment.

There are assumptions included in the modelling inputs, such the amount that flow gets routed in a channel or the amount of infiltration into the soil, which can be adjusted to improve the match between observed and modelled flood levels and flows. A good match to historical flood behaviour provides confidence that the modelling methodology and schematisation has accurately captured the key flood processes in the catchment.

Joint calibration of the WBNM hydrologic model and TUFLOW hydraulic model was undertaken based on flows and flood levels recorded for the following events:

- February 2022;
- March 2017;
- February 2020; and
- March 1989.

The 2022 flood was the largest on record for much of the Tweed Valley at the time of calibration. This event also had a significant amount of data both at many gauges and at spot heights recorded by Council and the community. The large amount of data for this event provides an opportunity to gather a strong understanding of how the model is performing throughout the study area. The February 2022 event was considered the primary calibration event. The secondary calibration event was the March 2017 event which was the previous flood of record as it was generally lower than the February 2022 event but had a significant amount of information.

Two additional events, the February 2020 and March 1989 flood events have also been assessed. The choice of these flood events for calibration was largely dictated by the availability of recorded data and were generally considered minor (February 2020) and moderate (March 1989) flood events.

The purpose of selecting a range of magnitude events was to ensure the scalability of both the hydrologic and hydraulic models. If the focus of the calibration was only on larger events there would be uncertainty as to the accuracy of the model during more frequent events. It is considered the four (4) selected events provide a good range of magnitude events, to provide confidence in the model at a large range of flows.

The calibration of the Tweed hydrology model focused on the five (5) key gauges which cover key areas with a record of the event and have a recorded rating curve. These gauges are; Eungella, Palmers Road, Uki, Boat Harbour, and Cobaki Creek. The Palmers Road gauge was not available for the 1989 event. For each event the temporal patterns and rainfall depths we applied based on the methodology described in section 6.1.4, and the parameters in the WBNM model were adjusted within the accepted range until a reasonable match to the recorded flow hydrograph was achieved.

To review the performance of the hydraulic model, four key information sources were used:

- recorded level gauge results;
- the recorded flow gauge results;
- historical survey flood levels; and
- previous calibration results (2017 and 1989 event).

The hydraulic model focused on ten (10) key level gauges that cover both the upper reaches of the catchment and the lower tidal reaches of the Tweed River. These gauges are:

- Bray Park weir;
- Murwillumbah Bridge (except 1989);
- North Murwillumbah;
- Tumbulgum;
- Barney's Point;
- Cobaki Creek;
- Tyalgum Bridge;
- Chillingham;
- Terranora; and
- Dry Dock.

Note that at several locations the rating curve present was shown to deviate significantly to the hydraulic model. Section 10 provides a discussion on the rating curve checks that have been completed. The results Appendices present flow results utilising both the current rating curves and the rerated curves.

The hydraulic model also utilised historic flood survey levels to review the performance of the model away from the main channel. This dataset enables an understanding of the performance of the model in replicating out of bank flows throughout the system,

## 8.1. March 2017 Event

The March 2017 event was selected as a key event both as a large event in the catchment with a good record, as well as providing a comparison point to previous flood studies. This event, resulting from ex-Tropical Cyclone Debbie, caused widespread damage to property and the community.

During the last 2 weeks of March, up to 300 mm of rainfall had been recorded across the Tweed River catchment. There had been little recorded rainfall in the week before the event. The catchment was therefore likely to have been wet, although not saturated.

The heaviest rainfall commenced after 0:00 on 30 March, lasting until 06:00 on 31 March (30 hours). During this period, up to 773 mm was recorded in the Tweed Valley. Major flooding was experienced throughout the floodplain, with floodwaters receding during 31 March and 1 April.

Responding to the rainfall, the Tweed River at Murwillumbah exceeded the minor flood threshold at 10:55 on 30 March, before exceeding the moderate and major flood thresholds at 13:00 and

16:20 respectively on the same day. The flood peaked at the North Murwillumbah gauge at 6.30 mAHD, breaking the previous record of 6.07 mAHD observed during the 1954 flood event. The MHL Report 2017 event notes a peak flood level of 6.13 m at North Murwillumbah, but this level was used with caution as the orifice line may have failed due to a large amount of scouring on that section of the river. Based on this the revised peak level at North Murwillumbah was established by flood markers during the post event analysis.

The Murwillumbah township levee only experienced minor overtopping at the peak of the event, with a relatively small volume of water adding to localised flooding behind the levee due to rainfall. South Murwillumbah experienced severe flooding with the levee overtopping early in the event.

Downstream at Tumbulgum where the Rous River flows into the Tweed River, major flooding was also experienced. Further downstream at Chinderah, at the Barneys Point River gauge, river heights exceeded the major flood threshold. This event was not the result of a storm surge or king tide, with the primary source of flooding downstream of the Highway due to riverine floodwater.

### 8.1.1. 2017 Calibration Data

The rainfall generated for the calibration event followed the methodology as described in Section 4.3.2, with the event specific calibration data shown on Figure 10. There were over 217 flood survey levels recorded for the event with a number of these located in upper reaches of the catchment.

#### 8.1.1.1. Tweed River at Uki Flow Understanding

Initial reviews of the recorded flow results at Uki indicated a poor match between flows and observed levels using the WaterNSW rating curve. Timing of peaks could be matched between modelled and recorded, but the quantity of water discharged, is a point of error. A similar issue was identified in the BMT Post Event Flood Behaviour Analysis and Review of Flood Intelligence – Tweed River (Reference 11) however it was not investigated in detail.

As part of the calibration process this issue has been further investigated to achieve adequate calibration of the gauges and flood levels along the Tweed River upstream of Uki gauge. To undertake this a review of the flows in the area, including upstream reaches, has been undertaken.

The Palmers Road gauge is located 6.5 km upstream of Uki, which has been used to understand the likely flows at Uki. Both Uki and Palmers Road gauges are WaterNSW gauges. As part of the study synthetic rating curves, based on the 2020 LiDAR data, have been generated for both gauges. The catchment area upstream of Palmers Road is approximately 156 km$^2$. On a separate catchment upstream of Uki sits Clarrie Hall Dam. The dam has a catchment area of approximately 60 km$^2$.

Diagram 25 presents the recorded 2017 flood flows taken directly from the WaterNSW website (Reference 20). To achieve the estimated flows at Uki, flows needed to double between Palmers

Road and Uki. While Uki has a draining catchment area of 275 km$^2$ or 1.75 times that of Palmers Road, the influence of Clarrie Hall Dam means that 80% of the catchment downstream of Palmers Road is only generating 300 m$^3$/s. As a result, there is limited catchment remaining to contribute another 1,100 m$^3$/s, which is required to achieve the recorded flows.

Based on this information, both rating curves at Palmers Road and Uki could be wrong, leading to incorrect flows being recorded at one or both of these gauges.

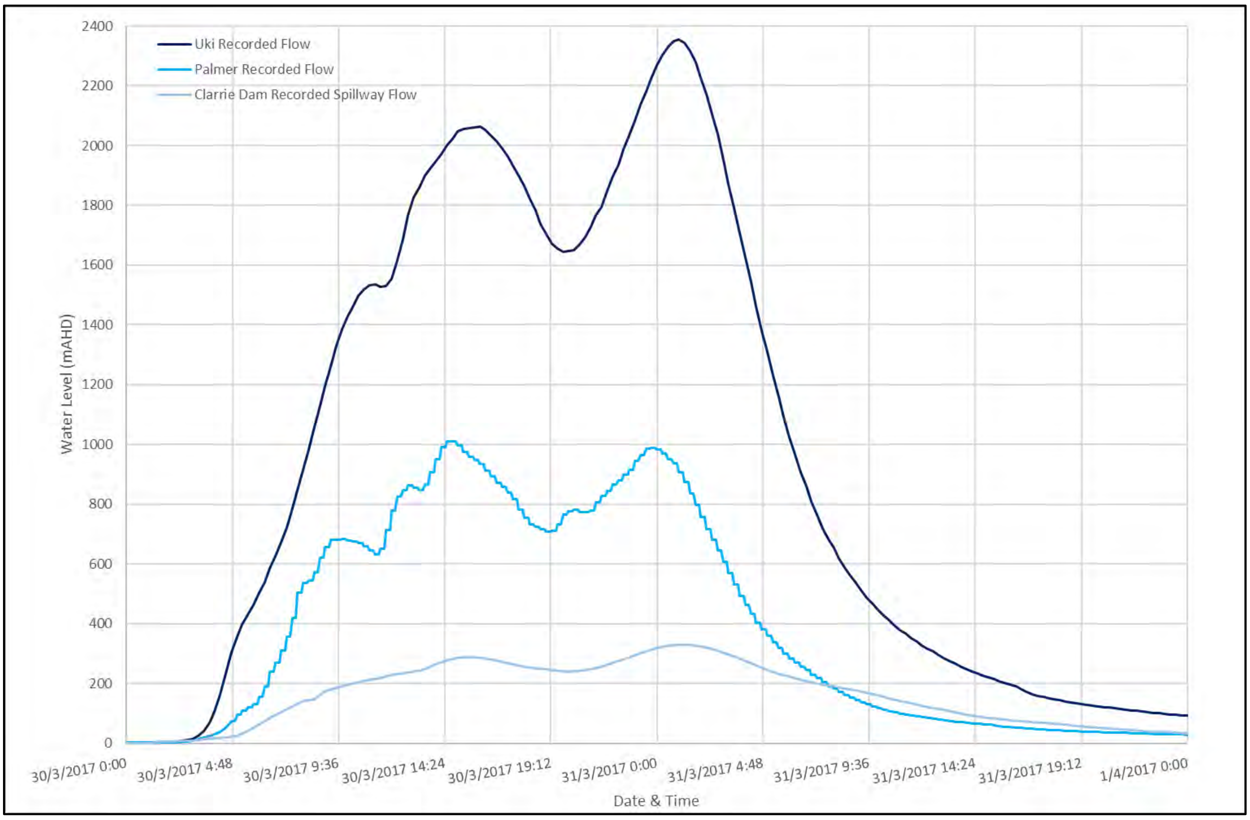



Diagram 25: 2017 Event – Recorded Palmers Road/Clarrie Dam/Uki Gauge Flood Flow

During the 2017 flood event it is noted that significant vegetation was removed from the area. It is quite likely that during the event the area experienced water levels higher than anticipated due to turbulence and debris accumulation in the channel. As the flows estimated are correlated to the rating curve based on the landform prior to the flood, it is likely that there is significant uncertainty in the flows 'observed'.


Photo 11: Aerial Photo of channel prior to (left) and after (right) the 2017 event at Uki

As such a rating curve review was undertaken at both the Palmers Road and Uki gauges. Full discussion about the each of the rating curves is provided in Section 10.

### 8.1.2. Hydrologic Model Parameters

WBNM is a split model, meaning that it models the catchment runoff separately to channel flow, and combines the hydrographs at each catchment outlet. The flow in both channels and catchments are affected by a single catchment routing parameter C, with a further routing parameter included to modify the channel flow inside each catchment.

Rainfall losses in the model have been represented using the Initial Loss (IL) and Continuing Loss (CL) method. Table 10 illustrates the adopted hydrologic parameters for the March 2017 event. Figure 10 shows the spatial distribution of rainfall for this event. The distribution of lag parameters and losses is illustrated in Figure 11 and Figure 12 respectively. The variation in losses in the event are mostly to account for variations in rainfall information that is captured through the flow record in areas that lack definition.

Table 10: WBNM Model Parameters - 2017 Event

| Parameter | March 2017 Parameters |
|---|---|
| Lag parameter | 2.2 (1.8 in upper catchment) |
| Stream lag | 1 (1.12 local variations) |
| Initial loss (mm) | 20 (10 local variations) |
| Continuing loss (mm/h) | 2.5 (0 local variations) |

### 8.1.3. Calibration Results

The results of the calibration for both flow and water levels are shown at each of the 5 calibration points in Appendix B. Table 11 and Table 12 outline the comparison between the recorded, hydrologic model and hydraulic model in terms of flows and water level for the 2017 event.

Of the five (5) gauges where recorded flood levels and flow were available, generally a good fit was achieved at four (4) of the five (5) gauges with results at Eungella deviating from the recorded flow and water level. Despite the slight over estimation of flow and level at this gauge, in general it is still a good match to observed data.

Table 11: 2017 Comparison of Modelled and Recorded Flood Flows

| Gauge | Recorded Flow ($m^3/s$) (a) | WBNM Modelled Flow ($m^3/s$) (b) | TUFLOW Modelled Flow ($m^3/s$) (c) | Ratio b/a | Ratio c/a |
|---|---|---|---|---|---|
| Eungella | 1119 | 1533 | 1614 | 1.4 | 1.4 |
| Palmers Road | 1025 | 1248 | 1275 | 1.2 | 1.2 |
| Uki | 2352 | 1837 | 1811 | 0.8 | 0.8 |
| Boat Harbour at Rous River | 1376 | 1394 | 522 (1,514 including breakout flow) | 1.0 | 1.1 |
| Cobaki Creek | 144 | 106 | 127 | 0.7 | 0.9 |

Table 12: 2017 Comparison of Modelled and Recorded Flood Levels – WBNM & TUFLOW

| Gauge | Recorded Peak Level (mAHD) (a) | WBNM Modelled Peak Level (mAHD) (b) | TUFLOW Modelled Peak Level (mAHD) (c) | Difference (m) b-a | Difference (m) c-a |
|---|---|---|---|---|---|
| Eungella | 23.13 | 23.27 | 23.42 | 0.14 | 0.29 |
| Palmers Road | 38.08 | 38.16 | 38.27 | 0.07 | 0.18 |
| Uki | 21.89 | 20.41 | 21.12 | -1.47 | -0.77 |
| Boat Harbour at Rous River | 10.18 | 10.11 | 10.24 | -0.07 | 0.06 |
| Cobaki Creek | 6.87 | 6.56 | 6.73 | -0.31 | -0.14 |

The comparison of flows and water levels throughout the model are generally considered good in all locations for this event. Given this is a two peaked storm, the larger peak has been matched well through the calibration process.

- A good match is achieved at Palmers Road for flow and level (slight over estimation in both) this indicates the rating curve at the site is appropriate for this magnitude of event.

- The modelled levels at Uki were lower than observed levels based on the flows achievable in the hydrologic model. Noting the good match at Palmers Road it is considered that local hydraulic complexities (vegetation, debris) during the event have resulted in higher water levels.
- The complex set of inflows in the head waters upstream of Uki includes confluences which compound to drive up water levels, local adjustment of the channel routing was performed to attempt to account for this effect with the best achievable outcome presented.
- Levels were matched at Boat Harbour even though there is a discrepancy between modelled and recorded flows. This indicates the rating curve present at the location may be erroneous. A rating curve review for the site has been undertaken (Section 8).
- Eungella flows are generally higher than recorded but based on the level analysis for this gauge there is a good fit to recorded flood levels. Rating curve was reviewed and further information about this is discussed in Section 10.3.
- The modelled Eungella gauge flood level matched the rise and fall of the flood peak but also the three district peaks. It is slightly high compared to the recorded flood level.
- Flows and levels at Cobaki match well between recorded and modelled.
- The hydraulic model does struggle to replicate the low flow regime at Cobaki Creek with more discrepancy at the lower end of the rating curve as outlined in Section 10.5. Likely the channel is not picked up sufficiently making it hard to replicate low flow events.
- Gauges further downstream where the floodplain flattens out and is tidally affected are generally not well captured in hydrology models and shall be considered separately in the hydraulic model.

#### 8.1.3.1. Hydraulic Model Gauge Calibration Locations

An additional eight (8) gauges were investigated in the hydraulic model only due to these locations being tidally influenced. Generally, a good fit was achieved at all gauges.

Comparison of recorded and modelled peak flood levels are outlined Table 13. Graphs of the results at each gauge listed are provided in Appendix C.

Table 13: 2017 Comparison of Modelled and Recorded Flood Levels

| Gauge | Recorded Peak Level (mAHD) | Modelled Peak Level (mAHD) | Difference (m) |
|---|---|---|---|
| Bray Park Weir | 9.25 | 8.99 | -0.26 |
| Murwillumbah Bridge | 5.89 | 6.00 | 0.11 |
| North Murwillumbah | 6.13 | 6.38 | 0.25 |
| Tumbulgum | 3.96 | 3.80 | -0.16 |
| Barney’s Point | 2.22 | 2.34 | 0.12 |
| Cobaki | 1.52 | 1.54 | 0.01 |
| Terranora | 1.58 | 1.42 | -0.16 |
| Dry Dock | 1.39 | 1.36 | -0.03 |
| Tyalgum Bridge | 53.71* | 53.42 | -0.29 |
| Chillingham | Gauge recordings poor | | |

*Note that the recorded information had significant noise present

The comparison of gauged water levels throughout the model are generally considered good in all locations for this calibration.

- The first peak at Bray Park is matched to the recorded with the second peak below the recorded level.
- Good calibration was achieved at Murwillumbah Bridge and North Murwillumbah based on timing and peak water level.
- At Tumbulgum gauge, the modelled flood level is slightly below the recorded level however is a generally a good fit of shape and response.
- The model adequately represents the rising limb of the hydrograph at Barney's Point gauge and presents a good correlation to recorded levels and timings.
- At Cobaki gauge the modelled flood levels match the recorded flood level. The timings of the tides are reproduced well at Cobaki, although there is departure between the modelled and recoded levels during low tides.
- Dry Dock also struggles to replicate the low tide pattern, but the peak modelled flood levels match the recorded level.
- Terranora demonstrates a similar modelled pattern to the recorded pattern, but the peak flood level is slightly below the recorded level. The model adequately reproduces the timings of the tides and there is no departure between the modelled and recoded levels during low tides.

### 8.1.4. Flood Survey Points

There are over 275 flood survey locations available for the 2017 flood event. This information has been used to inform the calibration effectiveness of the model. Of the 275 survey levels provided 203 locations could be reviewed in the hydraulic model, with 180 deemed accurate. Maps illustrating the differences between the modelled and recorded flood levels is outlined in Appendix D.

A simple statistical assessment has been undertaken on the result to understand where good calibration is achieved and areas of lower confidence. Table 14 outlines the statistic in key regions. It should be noted clear errant points have been removed from the tables however they are presented on the maps for reference.

Overall, the calibration achieved is considered to be very good. Generally better calibration is achieved at the lower end of the model, with less agreement achieved in the upper reaches of the catchment. Overall, the model's standard deviation is 0.47 m which indicates that 66% of the sampled points are within 0.47 m of the recorded. 57% of the sampled locations were within +- 0.25 m and 93% were within 1 m.

Table 14: 2017 Comparison of Modelled and Recorded Flood Survey Levels

| Assessment | Median (m) | Average (m) | Standard Deviation (m) | No. of Calibration Points |
|---|---|---|---|---|
| Whole Model Extent | 0.04 | 0.09 | 0.47 | 180 |
| Catchment downstream of Tumbulgum | 0.15 | 0.17 | 0.22 | 15 |
| Catchment between Bray Park and Tumbulgum | 0.04 | 0.02 | 0.29 | 133 |
| Eungella | 0.34 | 0.26 | 0.19 | 20 |
| Uki | 0.00 | 0.24 | 0.95 | 13 |
| Rous | 0.13 | 0.24 | 0.32 | 15 |

There are some discrepancies in Dunbible Creek in the 2017 event, it is unclear what the issue is within this location, however the levels reported are significantly lower than the levels within the Tweed River and Murwillumbah South as illustrated in Diagram 26. Upon further investigation, there were many obviously erroneous survey pickups in this area in both the 2017 and 2022 event. There is no topographic feature present that would cause a negative flood gradient in this area. Therefore, it was established that these survey points were erroneous and not included in the model adequacy comparison.


Diagram 26: 2017 Event – Survey Points at Dunbible

### 8.1.5. Comparison to Post Flood Event Report

Following the 2017 flood event, a review of the event within the 2009 flood model was undertaken (Reference 11). The assessment was not a recalibration of the previous model but rather a review of the performance of the model and a process undertaken to gather intelligence on the event. Nevertheless, the assessment undertaken produced a reasonable replication of flood levels in the lower study area,

The current calibration result is not dissimilar to the 2017 calibration results achieved by BMT, but there are some differences between the two calibration results. A better calibration was achieved at Murwillumbah Bridge and Rous River at Boat Harbour in the current calibration compared to the previous BMT 2017 calibration (Reference 11), along with an improved representation of flood levels in Murwillumbah South.

The post flood model did however look slightly better at Tumbulgum however this was at the detriment of calibration at the Murwillumbah gauge. Looking at the numerous surveyed calibration points especially between Murwillumbah to the Tweed outlet demonstrates that the present calibration is appropriately representing the flood characteristics of the 2017 flood event.

## 8.2. February 2022 Event

The start of 2022 was a very wet summer with above average rainfall falling over the Tweed catchment. In February/March 2022, the north coast of NSW experienced a blocking high pressure system in the Tasman Sea resulting in a very humid environment along much of the coast (Reference 22). On 27 and 28 February, the high-pressure system in the Tasman Sea in conjunction with a slow-moving trough and upper atmospheric support, produced very heavy multi-day rainfall over the northern rivers of NSW.

The SES flood classification for the Tweed River region was major at the Chinderah, Tumbulgum and North Murwillumbah gauges as shown in Table 15.

Table 15: 2022 Event Flood Classifications

| **Station Name** | **Flood Classification** | | | **Flood Peak (mAHD)** |
|---|---|---|---|---|
| | Minor | Moderate | Major | |
| | Water Level (mAHD) | | | |
| Chinderah | 1.3 | 1.7 | 2.0 | 3.0 |
| Tumbulgum | 1.4 | 1.8 | 2.5 | 4.78 |
| North Murwillumbah | 3.0 | 4.0 | 4.8 | 6.51 |

The heaviest rainfall commenced after 0:00 on 28 February, lasting until 1 March. There was a previous intense rainfall event on 23 and 24 February with a combined total rainfall of 208 mm falling with this 48 hour period at Chillingham. Between 27 February to 1 March over 690 mm of rainfall was recorded at Chillingham rainfall gauge.

In the upper reaches of the Tweed near Palmers Road over 942 mm was recorded between 27 February and 1 March. On 28 February it was recorded that Palmer rainfall gauge had over

611 mm in a single day. These high rainfall records were recorded throughout the catchment making the event one of the most significant events to impact the Tweed region.

### 8.2.1. 2022 Calibration Data

The rainfall generated for the calibration event followed the methodology as described in section 4.3.2, with the event specific calibration data shown on Figure 10. There were over 298 flood survey levels recorded for the event with a number of these located in upper reaches of the catchment.

### 8.2.2. Hydrologic Model Parameters

WBNM is a split model, meaning that it models the catchment runoff separately to channel flow, and combines the hydrographs at each catchment outlet. The flow in both channels and catchments are affected by a single catchment routing parameter C, with a further routing parameter included to modify the channel flow inside each catchment.

Rainfall losses in the model have been represented using the Initial Loss (IL) and Continuing Loss (CL) method. Table 16 illustrates the adopted hydrologic parameters for the February 2022 event. Figure 13 shows the spatial distribution of rainfall for this event. The distribution of lag parameters and losses is illustrated in Figure 14 and Figure 15 respectively. The variation in losses in the event are mostly to account for variations in rainfall information that is captured through the flow record in areas that lack definition.

Table 16: WBNM Model Parameters - 2022 Event

| Parameter | February 2022 Parameters |
|---|---|
| Lag parameter | 2.2 (1.8 in upper catchment) |
| Stream lag | 1 (1.12 local variations) |
| Initial loss (mm) | 10 |
| Continuing loss (mm/h) | 1.5 |

### 8.2.3. Calibration Results

The results of the calibration for both flow and water levels are shown at the 5 gauge locations calibrated in both the hydrologic and hydraulic models are presented in Appendix E. Table 17 and Table 18 outline the comparison between the recorded, hydrologic model and hydraulic model in terms of flows and water level for the 2022 event.

Of the five (5) gauges where recorded flood levels and flow were available a good fit was achieved at four (4) of the five (5) gauges with results at Eungella deviating from the recorded flow and water level. Despite the slight over estimation of flow and level at this gauge, in general it is still a good match to observed data.

Table 17: 2022 Comparison of Modelled and Recorded Flood Flows

| Gauge | Recorded Flow (m³/s) (a) | WBNM Modelled Flow (m³/s) (b) | TUFLOW Modelled Flow (m³/s) (c) | Ratio b/a | Ratio c/a |
|---|---|---|---|---|---|
| Eungella | 804 | 923 | 936 | 1.1 | 1.2 |
| Palmers Road | 1278 | 1337 | 1309 | 1.0 | 1.0 |
| Uki | 2557 | 2639 | 2564 | 1.0 | 1.0 |
| Boat Harbour at Rous River | 650 | 906 | 876 | 1.4 | 1.3 |
| Cobaki Creek | 139 | 106 | 37 | 0.8 | 0.9 |

Table 18: 2022 Comparison of Modelled and Recorded Flood Levels – WBNM & TUFLOW

| Gauge | Recorded Peak Level (mAHD) (a) | WBNM Modelled Peak Level (mAHD) (b) | TUFLOW Modelled Peak Level (mAHD) (c) | Difference (m) b-a | Difference (m) c-a |
|---|---|---|---|---|---|
| Eungella | 21.11 | 23.94* | 21.79 | 2.83 | 0.68 |
| Palmers Road | 38.63 | 38.70 | 38.49 | 0.07 | -0.14 |
| Uki | 22.42 | 22.5 | 22.42 | 0.08 | 0.00 |
| Boat Harbour at Rous River | 9.20 | 10.06 | 9.54 | 0.86 | 0.34 |
| Cobaki Creek | 6.83 | 6.56 | 6.69 | -0.27 | -0.13 |

*First peak

The comparison of flows and water levels throughout the model are generally considered good in all locations for this event. Given this is a two peaked storm, the larger peak has been matched well through the calibration process.

- The match at Uki was deemed reasonable, the model captures the two distinct peaks and the smaller peaks that occurred during the two storm events.
- The match at Palmers Road is generally okay during high flows but struggles to replicate the relationship at low flows most likely the result of the channel bed not being captured sufficiently in the LiDAR.
- The match at Uki was deemed reasonable, the model captures the two distinct peaks and the smaller peaks that occurred during the two storm events.
- The recorded flows at Palmers Road were a bit low compared to the modelled but after re-assessing the flows using the revised rating curve, there was a better agreement between the modelled and recorded flows.
- Levels were matched at Boat Harbour, with the model adequately capturing the rise and fall of the flood. There is a major discrepancy in the flows but as discussed in Section 10.4, this is due to the WaterNSW rating curve not capturing the breakout flow that occurs at this gauge. Once the flows were revised using the new rating curve there was a better match between the modelled and recorded flows. This is further outlined in Section 10.6.
- Flows and levels at Cobaki match well between recorded and modelled.
- The hydraulic model does struggle to replicate the low flow regime at Cobaki Creek with more discrepancy at the lower end of the rating curve as outlined in Section 10.5. Likely the channel is not picked up sufficiently making it hard to replicate low flow events.
- Gauges further downstream where the floodplain flattens out and is tidally affected are generally not well captured in hydrology models and shall be considered separately in the

hydraulic model.

#### 8.2.3.1. Hydraulic Gauge Calibration Locations

An additional ten (10) gauges were investigated in the hydraulic model only, due to these locations being tidally influenced. Generally, a good to very good fit was achieved at all gauges.

Comparison of recorded and modelled peak flood levels are outlined Table 19. Graphs of the results at each gauge listed are provided in Appendix F.

Table 19: 2022 Comparison of Modelled and Recorded Flood Levels

| Gauge | Recorded Peak Level (mAHD) | Modelled Peak Level (mAHD) | Difference (m) |
|---|---|---|---|
| Bray Park Weir | 9.26 | 9.34 | 0.08 |
| Murwillumbah Bridge | 6.23 | 6.20 | -0.03 |
| North Murwillumbah | 6.51 | 6.37 | -0.14 |
| Tumbulgum | 4.78 | 4.70 | -0.07 |
| Barney's Point | 2.91 | 3.03 | 0.13 |
| Cobaki | 1.95 | 1.88 | -0.07 |
| Terranora | 1.94 | 1.70 | -0.24 |
| Dry Dock | 1.74 | 1.88 | 0.14 |
| Tyalgum Bridge | 52.01 | 52.01 | 0.00 |
| Chillingham | 30.12 | 30.64 | 0.52 |

The comparison of gauged water levels throughout the model are generally considered good in all locations for this calibration.

- At Bray Park there is a good match to the recorded in both the initial peak on the 24/02/2022 and the main peak on the 28/02/2022.
- Good calibration was achieved at Murwillumbah Bridge based on timing and peak water level.
- Good calibration was achieved at North Murwillumbah based on timing and peak water level.
- At Tumbulgum gauge, the modelled flood level is slightly below the refined recorded level however is a generally a good fit of shape and response. The first peak is slightly low in the hydraulic model with a better agreement on the second peak.
- The model adequately represents the rising limb of the hydrograph at Barney's Point gauge and presents a good correlation to recorded levels and timings. The hydraulic model does peak higher than the recorded, but it is evident by the recorded results that water levels at the peak fluctuated.
- At Cobaki gauge the modelled flood levels match the recorded flood level. The timings of the tides are reproduced well at Cobaki.
- Dry Dock adequately models the low tide pattern but struggles to replicate the first peak recorded level. Overall, the model is reasonable at replicating the water level pattern at this gauge.
- Terranora demonstrates a similar modelled pattern to the recorded pattern, but the peak flood level is below the first recorded level. We have modelled the final scour condition in

this section which has impacted the peak water level at this gauge being modelled. The model adequately reproduces the timings of the tides and there is some departure between the modelled and recoded levels during low tides.

- Chillingham demonstrates a similar modelled pattern to the recorded pattern, but the peak flood level is below the recorded level.
- At Tyalgum gauge, the modelled flood level matches the recorded level and there is generally a good fit of shape and response. There are some peaks that the hydraulic model does not illustrate this is most likely due to the hydrologic model not including these in the rainfall patterns used to generate flows.

### 8.2.4. Flood Survey Points

There are 298 flood survey locations available for the 2022 flood event. This information has been used to inform the calibration effectiveness of the model. Of the 298 survey levels provided 266 locations could be reviewed in the hydraulic model. Maps illustrating the differences between the modelled and recorded flood levels is outlined in Appendix G.

A simple statistical assessment has been undertaken on the result to understand where good calibration is achieved and areas of lower confidence. Table 20 outlines the statistics in key regions.

Generally better calibration is achieved at the lower end of the model, with less agreement achieved in the upper reaches of the catchment. Overall, the model's standard deviation is 0.49 m which indicates that 66% of the sampled points are within 0.49 m of the recorded. 65% of the sampled locations were within +-0.25 m and 93% were within 1 m. Of note is that along the Eungella reach the surveyed levels are generally lower however levels recorded at both gauges were generally higher – as a result this area has been balanced to achieve a good fit for all available information.

Table 20: 2022 Comparison of Modelled and Recorded Flood Survey Levels

| Assessment | Median (m) | Average (m) | Standard Deviation (m) | No. of Calibration Points |
|---|---|---|---|---|
| Whole Model Extent | 0.08 | 0.08 | 0.57 | 266 |
| Catchment downstream of Tumbulgum | 0.06 | 0.00 | 0.53 | 96 |
| Catchment between Bray Park and Tumbulgum | 0.08 | 0.13 | 0.38 | 111 |
| Eungella | -0.11 | -0.23 | 0.89 | 10 |
| Uki | 0.04 | -0.05 | 0.44 | 9 |
| Rous | -0.01 | 0.03 | 0.30 | 18 |

There are some discrepancies in Dunbible Creek in the 2022 event, it is unclear what the issue is within this location however the levels reported are significantly lower than the levels within the Tweed River and Murwillumbah South as illustrated in Diagram 27.


Diagram 27: 2022 Event – Survey Points (Dunbible)

## 8.3. February 2020 Event

The February 2020 flood was a smaller event relative to the 2017 event and has been included to ensure that the calibration covers both ends of the design events, with the event specific calibration data shown on Figure 16.

The event was a surface trough over central NSW and Queensland, that consisted of significant rainfall. Minor flooding occurred along the Tweed River. The event coincided with high tides which exacerbated flooding conditions in the lower section of the Tweed catchment.

The catchment had a wet two weeks before the flood event resulting in the majority of rainfall that fell on 13 February considered instant runoff as the catchment was saturated. On the first day of the flooding event (13 February) Murwillumbah recorded 191 mm and Tweed Heads recorded 153 mm in 24 hours. Tweed Heads Golf Club recorded 953 mm for the whole of February.

### 8.3.1. 2020 Calibration data

The rainfall generated for the calibration event followed the methodology as described in Section 4.3.2, with the event specific calibration data shown on Figure 16. There were over 40 flood survey levels recorded for the event with a number of these located within the upper reaches.

### 8.3.2. Hydrologic Model Parameters

Rainfall losses in the model have been represented using the Initial Loss (IL) and Continuing Loss (CL) method. Table 21 illustrates the adopted hydrologic parameters for the February 2020 event. Figure 16 shows the spatial distribution of rainfall for this event. The distribution of lag parameters and losses is illustrated in Figure 17 and Figure 18 respectively. The variation in losses in the event are mostly to account for variations in rainfall information that is captured through the flow record in areas that lack definition.

Table 21 : WBNM Model Parameters - 2020 Event

| Parameter | February 2020 Parameters |
|---|---|
| Lag parameter | 2.2 (1.8 local variations) |
| Stream lag | 1 (1.12 local variations) |
| Initial loss (mm) | 10 |
| Continuing loss (mm/h) | 2.0 |

### 8.3.3. Calibration Results

The results of the calibration for both flow and water levels are shown at each of the 5 calibration points in Appendix H. Table 22 and Table 23 outline the comparison between the recorded, hydrologic model and hydraulic model in terms of flows and water level for the 2020 event.

Of the five (5) gauges where recorded flood levels and flow were available, generally a good fit was achieved at three (3) of the five (5) gauges with results at Uki and Palmers Road deviating from the recorded flow and water level.

Table 22: 2020 Comparison of Modelled and Recorded Flood Flows

| Gauge | Recorded Flow ($m^3/s$) (a) | WBNM Modelled Flow ($m^3/s$) (b) | TUFLOW Modelled Flow ($m^3/s$) (c) | Ratio b/a | Ratio c/a |
|---|---|---|---|---|---|
| Eungella | 585 | 557 | 560 | 1.0 | 1.0 |
| Palmers Road | 540 | 480 | 457 | 0.9 | 0.8 |
| Uki | 1140 | 734 | 708 | 1.0 | 0.9 |
| Boat Harbour at Rous River | 220 | 289 | 263 | 1.3 | 1.2 |
| Cobaki Creek | 23 | 36 | 26 | 1.6 | 1.1 |

Table 23: 2020 Comparison of Modelled and Recorded Flood Levels – WBNM & TUFLOW

| Gauge | Recorded Peak Level (mAHD) (a) | WBNM Modelled Peak Level (mAHD) (b) | TUFLOW Modelled Peak Level (mAHD) (c) | Difference (m) b-a | Difference (m) c-a |
|---|---|---|---|---|---|
| Eungella | 19.58 | 19.35 | 19.66 | -0.23 | 0.09 |
| Palmers Road | 35.57 | 35.04 | 36.43 | -0.53 | 0.86 |
| Uki | 18.25 | 19.33 | 18.96 | 1.08 | 0.71 |
| Boat Harbour at Rous River | 8.55 | 8.67 | 8.75 | 0.12 | 0.21 |
| Cobaki Creek | 5.28 | 5.68 | 5.08 | 0.40 | -0.20 |

The comparison of flows and levels throughout the model are generally considered reasonable:

- The match at Palmers Road and Uki were generally timed well, with less flow at the peak at Palmers Road and Uki compared to the measured values. The levels are generally over-estimated at the main peak, it is considered that the temporal pattern used is resulting in slightly too much flow being present. This could be resolved with an increased continuing loss in the catchment upstream of Uki however this would result in a lowering of peak further downstream (which are all slightly low already).
- Flows are low at Eungella but based on the water levels, the modelled matches the recorded values. Differences with flow likely a result of the rating curve.
- Flows are slightly higher than those recorded at Boat Harbour at Rous River but the shape of the hydrograph matches the recorded shape. From a level perspective, modelled levels match the recorded levels.
- The timing and peaks at Cobaki Creek are inconsistent to the hydrograph shape recorded. The flows at Cobaki Creek were generally late in comparison to the measured event. It is expected that this is due to the applied temporal pattern given the timing of other calibration events are generally close.
- Although the flow timing at Cobaki Creek is completely off, the peak water level generally aligns with the recorded peak levels.

#### 8.3.3.1. Hydraulic Model Gauge Calibration Locations

An additional seven (7) gauges were investigated in the hydraulic model only due to these locations being tidally influenced. Generally, a good fit was achieved at five (5) of the seven (7) gauges with the hydraulic model results at Murwillumbah Bridge and Tumbulgum lower than recorded. Comparison of recorded and modelled peak flood levels are outlined Table 24. The result of the 2020 calibration is illustrated Appendix I.

Table 24: 2020 Comparison of Modelled and Recorded Flood Levels

| Gauge | Recorded Peak Level (mAHD) | Modelled Peak Level (mAHD) | Difference (m) |
|---|---|---|---|
| Bray Park Weir | 5.25 | 5.16 | -0.09 |
| Murwillumbah Bridge | 3.82 | 3.47 | -0.35 |
| North Murwillumbah | 3.86 | 3.59 | -0.26 |
| Tumbulgum | 2.31 | 2.00 | -0.31 |
| Barney's Point | 1.25 | 1.11 | -0.15 |
| Terranora | 1.06 | 1.01 | -0.05 |
| Dry Dock | 1.06 | 0.99 | -0.07 |
| Tyalgum Bridge | 50.92 | 51.24 | 0.32 |
| Chillingham | 28.72 | 28.58 | -0.14 |

The comparison of gauged water levels throughout the model are generally considered good in all locations for this calibration.

- The first peak at Bray Park is a bit low compared to the recorded but the second peaks match the recorded.
- Good calibration was achieved at Murwillumbah Bridge based on timing and peak water level.
- At Tumbulgum gauge, the modelled flood level is below the recorded level. Given the event is a relatively small event the Manning's through the channel is likely required to be higher to account for less scour occurring during this event.
- The timings of the tides are reproduced well at Barney's Point, with the modelled peak flood level generally low compared to the recorded flood level.
- Terranora demonstrates a similar modelled pattern to the recorded pattern, but the peak flood levels is slightly below the recorded level. There is a slight delay in the rising limb of the tidal pattern and the hydraulic model does struggle to replicate the low flow pattern.
- Dry Dock also struggles to replicate the low tide pattern, but the peak modelled flood levels match the recorded level.

### 8.3.4. Flood Survey Points

There were over 40 flood survey locations provided for the 2020 flood event. This information has been used to inform the calibration effectiveness of the model. Of the 40 survey levels provided 24 locations could be reviewed in the hydraulic model. Maps illustrating the differences between the modelled and recorded flood levels is outlined in Appendix J.

A simple statistical assessment has been undertaken on the result to understand where good calibration is achieved and areas of lower confidence. Table 25 outlines the statistics in key regions for the 2020 flood event. Note due to the limited sample size there is a finite amount of information that can be extrapolated from these values.

Generally better calibration is achieved along the Rous River and Eungella reach of the river. Less agreement is achieved upstream of Uki. This is consistent with the findings at the gauges in the area, which indicate an overestimation in flow through the reach.

Table 25: 2020 Comparison of Modelled and Recorded Flood Survey Levels

| Assessment | Median | Average | Standard Deviation |
|---|---|---|---|
| Whole Model Extent | -0.01 | 0.04 | 0.57 |
| Eungella | 0.28 | 0.27 | 0.74 |
| Uki | 1.30 | 1.10 | 0.36 |
| Rous | -0.25 | -0.19 | 0.26 |

## 8.4. March 1989 Event

The March 1989 event was selected as a key event both as a large event in the catchment, as well as providing a comparison point to previous flood studies. The 1989 flood was produced by tropical low causing extended period of rain falling between 31 March and 4 April (with the most intense downpour occurring on 1 April).

Over 500 mm of rain fell across the upper catchment areas during this event. Conversely, the coastal areas of the catchment received less than 100 mm of rainfall. Due to the significant spatial variation in rainfall during this event, the allocation of rainfall gauge to catchment was important.

The rainfall from the 1989 WBNM model adopted by BMT in the previous study was adopted for simulation, being redistributed into the updated hydrology model. During this flood event 72 hour rainfall total of 317 mm were recorded at Murwillumbah (Taleswood) and 519 mm at Tyalgum (Wanungara View).

Noting the age of the event, it was considered appropriate to utilise the same approximate DEM setup that was used within the 2009 flood study. This ensured that the correct arrangement of levees and other local features were adequately captured.

### 8.4.1. 1989 Calibration data

The rainfall generated for the calibration event followed the methodology as described in Section 4.3.2, with the event specific calibration data shown on Figure 19. There were only five (5) flood survey levels recorded for the event with a number of these located near Eungella and Murwillumbah.

### 8.4.2. Hydrologic Model Parameters

Rainfall losses in the model have been represented using the Initial Loss (IL) and Continuing Loss (CL) method. Table 26 illustrates the adopted hydrologic parameters for the March 1989 event. Figure 19 shows the spatial distribution of rainfall for this event. The distribution of lag parameters and losses is illustrated in Figure 20 and Figure 21 respectively. The variation in losses in the event are mostly to account for variations in rainfall information that is captured through the flow record in areas that lack definition.

Table 26: WBNM model parameters – 1989 Event

| Parameter | March 1989 Parameters |
|---|---|
| Lag parameter | 1.8 |
| Stream lag | 1 |
| Initial loss (mm) | 10 |
| Continuing loss (mm/h) | 2 |

### 8.4.3. Calibration Results

There were very few gauges and surveyed flood levels for the 1989 event. Only six (6) historical; flood survey marks were available for the 1989 event, which were all located in South Murwillumbah or the upper reaches of the catchment near Eungella gauge. Table 27 and Table 28 outline the comparison between the recorded, hydrologic model and hydraulic model in terms of flows and water level for the 1989 event.

The results of the calibration for both flow and water levels are shown at each of the five (5) calibration points in Appendix K.

Of the five (5) gauges where recorded flood levels and flow were available, generally a good fit was achieved at four (4) of the five (5) gauges with results at Eungella deviating from the recorded flow and water level.

Table 27: 1989 Comparison of Modelled and Recorded Flood Flows

| Gauge | Recorded Flow ($m^3/s$) (a) | WBNM Modelled Flow ($m^3/s$) (b) | TUFLOW Modelled Flow ($m^3/s$) (c) | Ratio b/a | Ratio c/a |
|---|---|---|---|---|---|
| Eungella | 1238 | 2085 | 1943 | 1.7 | 1.6 |
| Uki | 1174 | 1708 | 1591 | 1.5 | 1.4 |
| Boat Harbour at Rous River | N/A* | 998 | 966 | - | - |
| Cobaki Creek | 55 | 58 | 57 | 1.1 | 1.0 |

*The gauge was at a different location in 1989 and thus the current rating is irrelevant

Table 28: 1989 Comparison of Modelled and Recorded Flood Levels

| Gauge | Recorded Peak Level (mAHD) (a) | WBNM Modelled Peak Level (mAHD) (b) | TUFLOW Modelled Peak Level (mAHD) (c) | Difference (m) b-a | Difference (m) c-a |
|---|---|---|---|---|---|
| Eungella | 23.59 | 23.99 | 23.87 | 0.40 | 0.28 |
| Uki | 19.86 | 21.80 | 21.11 | 1.95 | 1.26 |
| Boat Harbour at Rous River | 6.32** | N/A | 6.75 | - | 0.43 |
| Cobaki Creek | 6.02 | 6.05 | 6.09 | 0.03 | 0.07 |

*The gauge was at a different location in 1989 and thus the current rating is irrelevant
** Assumed datum

The comparison of flows and water levels throughout the model are generally considered good in all locations for this calibration.

- Generally, the flows were considered a good match at Eungella and Cobaki Creek, given

this is a two peaked storm, generally the larger peak has been matched well through the calibration process.
- The match at Uki was high but the flow was required to get adequate calibration within the bottom end of the model.
- Due to the flow being high at Uki this meant the water level was also high.
- The peak water level at Boat Harbour is based on an assumed datum. The gauge was moved in 1985.
- This is a lower rainfall resolution model than the previous calibrations and as such there could be too high a rainfall depth applied upstream of Boat Harbor.
- The modelled Eungella gauge flood level matched the rise and fall of the flood peak. It is slightly high compared to the recorded flood level.
- Flow at Cobaki Creek and Eungella were much better understood after retracting the hydraulic model rating curve, and considering the joint calibration of the hydrology and hydraulic model.
- Gauges further downstream where the flood plain flattens out and is tidally affected are generally not well captured in hydrology models, and shall be considered separately in the hydraulic model.

There were not many rainfall gauges that recorded this event, therefore it is likely that the rainfall distribution has not been adequately captured leading to high flows at Uki and Boat Harbour.

#### 8.4.3.1. Hydraulic Model Gauge Calibration Locations

An additional five (5) gauges were investigated in the hydraulic model only due to these locations being tidally influenced. Generally, a good fit was achieved at four (4) of the five (5) gauges with the hydraulic model results at Murwillumbah Bridge and Tumbulgum lower than recorded.

Comparison of recorded and modelled peak flood levels are outlined Table 29. The result of the 1989 calibration is illustrated Appendix L.

Table 29: 1989 Comparison of Modelled and Recorded Flood Levels

| Gauge | Recorded Peak Level (mAHD) | Modelled Peak Level (mAHD) | Difference (m) |
|---|---|---|---|
| North Murwillumbah | 5.62 | 5.64 | 0.02 |
| Tumbulgum | 3.08 | 2.92 | -0.16 |
| Barney's Point | 1.40 | 1.51 | 0.11 |
| Terranora | 0.89 | 0.89 | 0 |
| Dry Dock | 0.90 | 0.86 | -0.03 |

The comparison of gauged water levels throughout the model are generally considered good in all locations for this calibration.
- Good calibration was achieved at North Murwillumbah based on timing and peak water level.
- At Tumbulgum gauge, the modelled flood level is below the recorded level.
- The timings of the tides are reproduced well at Barney's Point, with the modelled peak

flood level generally low compared to the recorded flood level.

- Terranora demonstrates a similar modelled pattern to the recorded pattern, with peak flood levels matching the recorded level. There is a slight delay in the receding limb of the tidal pattern and the hydraulic model does struggle to replicate the low flow pattern.
- Dry Dock also struggles to replicate the low tide pattern, but the peak modelled flood levels match the recorded level.

### 8.4.4. Flood Survey Points

There were seven (7) flood survey locations provided for the 1989 flood event. This information has been used to inform the calibration effectiveness of the model. Maps illustrating the differences between the modelled and recorded flood levels is outlined in Appendix M.

A simple statistical assessment has been undertaken on the result to understand where good calibration is achieved and areas of lower confidence. Table 30 outlines the statistics for the 1989 event. Standard deviation is not shown as it is of limited value on a small sample size.

Table 30: 1989 Comparison of Modelled and Recorded Flood Survey Levels

| Assessment | Median | Average |
|---|---|---|
| Whole Model Extent | 0.09 | 0.28 |
| Catchment between Bray Park and Tumbulgum | 0.09 | 0.07 |
| Eungella | 0.18 | 0.44 |

### 8.4.5. Comparison to the Previous Flood Model

The 1989 calibration within the 2009 Flood Study, struggled to adequately model the tidal gauges. The current model is much better at modelling the tidal area of the system and has achieved better calibration in these areas than was accomplished in the 2009 Flood Study.

Results at Murwillumbah and Tumbulgum are similar to the previous calibration results with the main difference in the receding tail of the flood level with the current model receding faster than the previous model. This is likely due to the assumed roughness within the tidal region downstream of Barney’s Point.

It is WMAwater’s opinion that the current calibration model for the 1989 event, models the flood mechanisms as well as or better than the previous BMT calibration. This is most evident within the tidal zone of the model where results are closer to the recorded flood levels than previous calibration results.

# 9. SENSITIVITY ASSESSMENT

## 9.1. Hydrology Sensitivity Analysis

Given the distributed nature of the calibration elements of the hydrology model, a sensitivity analysis of the calibration parameters was performed on the higher flow 2017 case, to confirm that modification of these parameters would not lead to an improved calibration.

### 9.1.1. Lag Parameter Sensitivity

The catchment lag parameter C was modified ±20% either side of the selected value throughout the catchment. A comparison between the levels and the timing of the peak flows between the accepted case and the sensitivity case was undertaken at key gauged locations. The chosen gauge locations were Uki, Eungella, and Boat Harbour, representing the most downstream gauged location of each of the major tributaries. The results of this sensitivity are shown in absolute flows, and level and timing of peak taken as relative to the maximum flows and levels from the calibrated model.

Table 31: 2017 Sensitivity of WBNM Route Parameter (C)

| | **-20% route parameter (C)** | | | **Accepted Values** | **+20% route parameter (C)** | | |
|---|---|---|---|---|---|---|---|
| **Location** | **Flow ($m^3/s$)** | **Level (Δm)** | **Timing (Δhr)** | **Flow ($m^3/s$)** | **Flow ($m^3/s$)** | **Level (Δm)** | **Timing (Δhr)** |
| Uki | 2,159 | 0.2 | 0.0 | 2,044 | 1,952 | -0.9 | -0.5 |
| Eungella | 1,689 | 0.2 | 0.5 | 1,532 | 1,416 | -1.8 | 0 |
| Boat Harbor | 1,575 | 0.2 | -0.5 | 1,393 | 1,241 | -0.4 | 0.5 |

From this analysis is it is possible to deduce that the selected distribution of catchment routing parameter achieved the combination of timings throughout the catchment for the given level of complexity in the model. There are some values that improve a single parameter slightly, the best overall fit is the existing parameter set, and thus they were adopted for the model to go forward to design.

## 9.2. Hydraulic Sensitivity Analysis

Based on the hydraulic model calibration results, it was determined that two main items need further investigation to understand the sensitivity of hydraulic model results. These areas that need further investigation were:

- Viscosity;
- Manning's Roughness.

### 9.2.1. Viscosity Sensitivity

TUFLOW's preferred method of determining the viscosity in the model is the Wu eddy viscosity formulation. The TUFLOW model has been run using the default values and a higher viscosity coefficient which are outlined in Table 32.

Table 32: Wu Values

| Model | Viscosity Coefficient (2d, 3d) |
|---|---|
| Sensitivity Model (default) | 7, 0 |
| Adopted Model | 10, 0 |

The model was also tested to the sensitivity of adopting the old eddy viscosity method of Smagorinsky (Tuflow Classic).

#### 9.2.1.1. Sensitivity To Viscosity Coefficient Results

Using the high viscosity coefficient and Smagorinsky method offered similar results within the tidal zone areas of the model, this is demonstrated in Diagram 28, Diagram 29 and Diagram 30, for Barney's Point, Dry Dock and Tumbulgum gauges respectively.

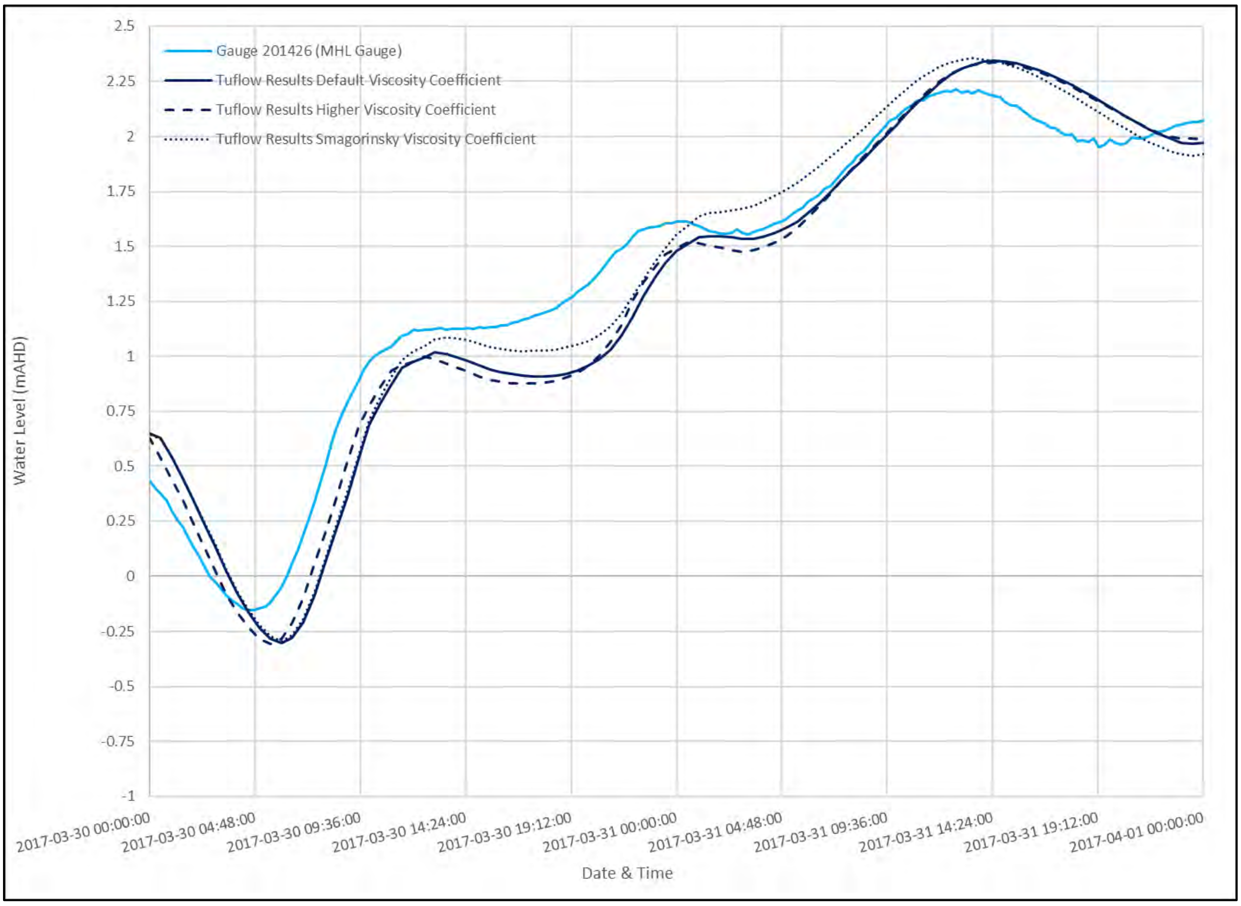



Diagram 28: 2017 Event - Barney's Point Gauge – Viscosity Sensitivity

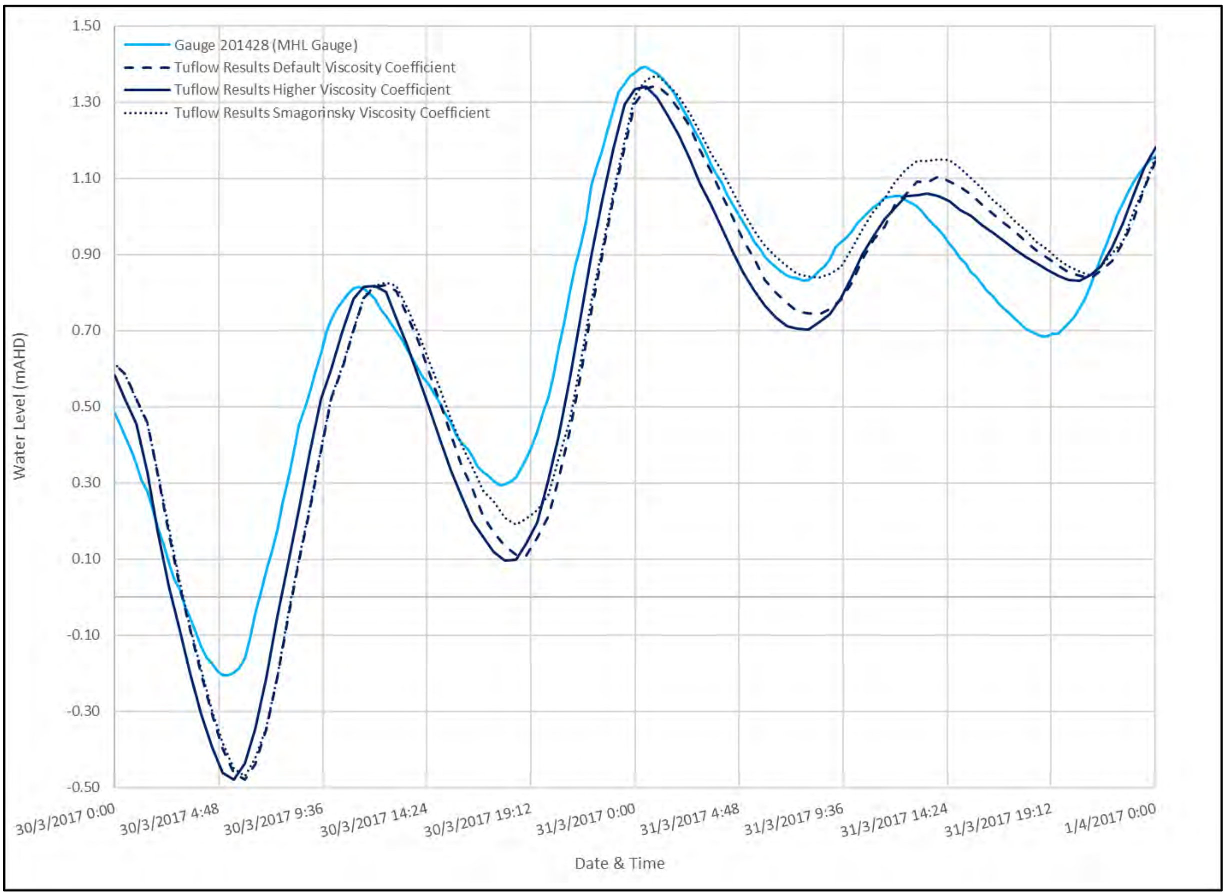



Diagram 29: 2017 Event - Dry Dock Gauge – Viscosity Sensitivity

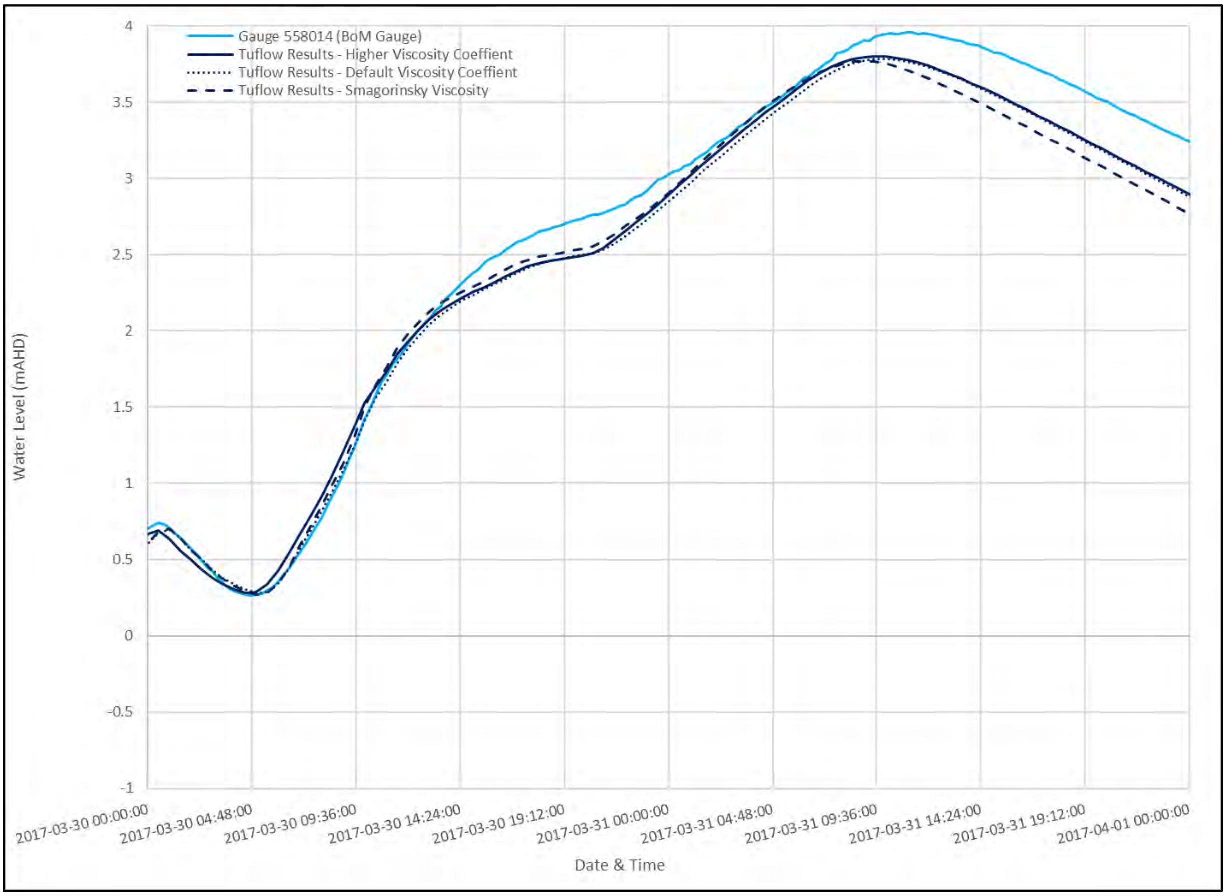



Diagram 30: 2017 Event - Tumbulgum Gauge – Viscosity Sensitivity

This information has been used to inform the calibration effectiveness of the model. A simple statistical assessment has been undertaken on the result to understand where good calibration is achieved and areas of lower confidence. Table 33 outlines the statistics in key regions between the three viscosity methods. Flood survey levels agreement for Murwillumbah and the whole Tweed catchment is in Figure 22 and Figure 23.

Looking at a whole model perspective, both the Wu options provided a good representation of flood levels. The higher Wu assessment however resulted in a slightly conservative median and ultimately a better representation of the majority of the study area. All three methods were generally the same at determining peak flood levels downstream of Tumbulgum.

Between Bray Park and Tumbulgum, the high Wu coefficient achieved modelled flood levels that were in better agreement than the modelled flood levels achieved using the default Wu coefficient or the Smagorinsky method.

Although a better calibration was achieved using the Smagorinsky method than using the WU values on the Eungella and Rous reaches (noting only a small amount of sample values present in these areas), using this approach over the entire catchment results in a poor calibration outcome at a large number of areas. Based on this the Wu approach, using a value of 10 has been adopted for the study.

Table 33: 2017 Statistical Analysis of Model Effectiveness – Viscosity Sensitivity

| | **Wu as Adopted (10)** | | | **Default Wu (7)** | | | **Smagorinsky** | | |
|---|---|---|---|---|---|---|---|---|---|
| Assessment | Median | Average | Standard Deviation | Median | Average | Standard Deviation | Median | Average | Standard Deviation |
| Whole Model Extent | 0.04 | 0.09 | 0.47 | -0.04 | 0.07 | 0.69 | -0.23 | -0.14 | 0.96 |
| Catchment downstream of Tumbulgum | 0.15 | 0.17 | 0.22 | 0.07 | 0.11 | 0.27 | 0.05 | 0.11 | 0.26 |
| Catchment between Bray Park and Tumbulgum | 0.04 | 0.02 | 0.29 | -0.08 | -0.05 | 0.38 | -0.30 | -0.25 | 0.43 |
| Eungella | 0.34 | 0.26 | 0.19 | 0.32 | 0.29 | 0.30 | 0.13 | 0.05 | 0.30 |
| Uki | 0.00 | 0.24 | 0.95 | 0.19 | 0.37 | 0.91 | -0.23 | -0.11 | 1.00 |
| Rous | 0.13 | 0.24 | 0.32 | 0.14 | 0.19 | 0.28 | 0.06 | 0.08 | 0.26 |

### 9.2.2. Manning’s Roughness Sensitivity

The adopted 2017 calibration result discussed in Section 7 achieves the best overall calibration for the overall catchment but generally achieves the best calibration from Bray Park to the Tweed outlet. Less agreement was achieved for the upper reaches of the catchment such as Eungella and Uki. A sensitivity to Manning’s roughness of ±20% was tested to understand if better calibration could be achieved for the upper reaches of the catchment. Applied manning values in the sensitivity is outlined in Table 34.

Table 34: Manning's 'n' Values Used in the TUFLOW Model – Sensitivity

| Material Category | Manning's | +20% Mannings | -20% Mannings |
|---|---|---|---|
| River / Waterways | 0.03 | 0.036 | 0.024 |
| Tidal Waterways | 0.026 | 0.0312 | 0.0208 |
| River Banks | 0.09 | 0.108 | 0.072 |
| Dense forest | 0.12 | 0.144 | 0.096 |
| Vegetated islands in river | 0.08 | 0.096 | 0.064 |
| Cleared / grazing / bare land | 0.03 | 0.036 | 0.024 |
| Parks | 0.04 | 0.048 | 0.032 |
| Sugar Cane - Varying | 0.06 (y1*-1m, n 0.15 y28-2m, n 0.06) | 0.072 (y1*-1m, n 0.18 y28-2m, n 0.072) | 0.048 (y1*-1m, n 0.12 y28-2m, n 0.048) |
| Sugar Cane | 0.15 | 0.18 | 0.12 |
| High density Urban | 0.07 | 0.084 | 0.056 |
| Highway / Roads | 0.025 | 0.03 | 0.02 |
| Open water | 0.025 | 0.03 | 0.02 |
| Rail Corridor | 0.045 | 0.054 | 0.036 |
| Rural Residential | 0.045 | 0.054 | 0.036 |
| Medium Density Residential | 0.06 | 0.072 | 0.048 |
| Community Facility/ commercial | 0.045 | 0.054 | 0.036 |
| Carparks | 0.02 | 0.024 | 0.016 |
| Standing water | 0.02 | 0.024 | 0.016 |

*note: y1 - The depth below which the Manning's n value n1 applied; y2 - The depth above which the Manning's n value n2 applied

#### 9.2.2.1. Increasing the Manning's by 20%

It was generally found that improvements could be achieved at Bray Park Weir (Diagram 31) and Tumbulgum gauge (Diagram 32) using a higher roughness. Survey flood points between Bray Park to Barney's Point however deviated more than the recorded flood levels using this higher Manning's (Figure 23 and Hydraulic Model – Murwillumbah Flood Levels - 2017 Event Viscosity Sensitivity
Figure 24). The increased roughness specifically within the Tweed River has been utilised and adopted within the 2022 event and will be utilised within design modelling.

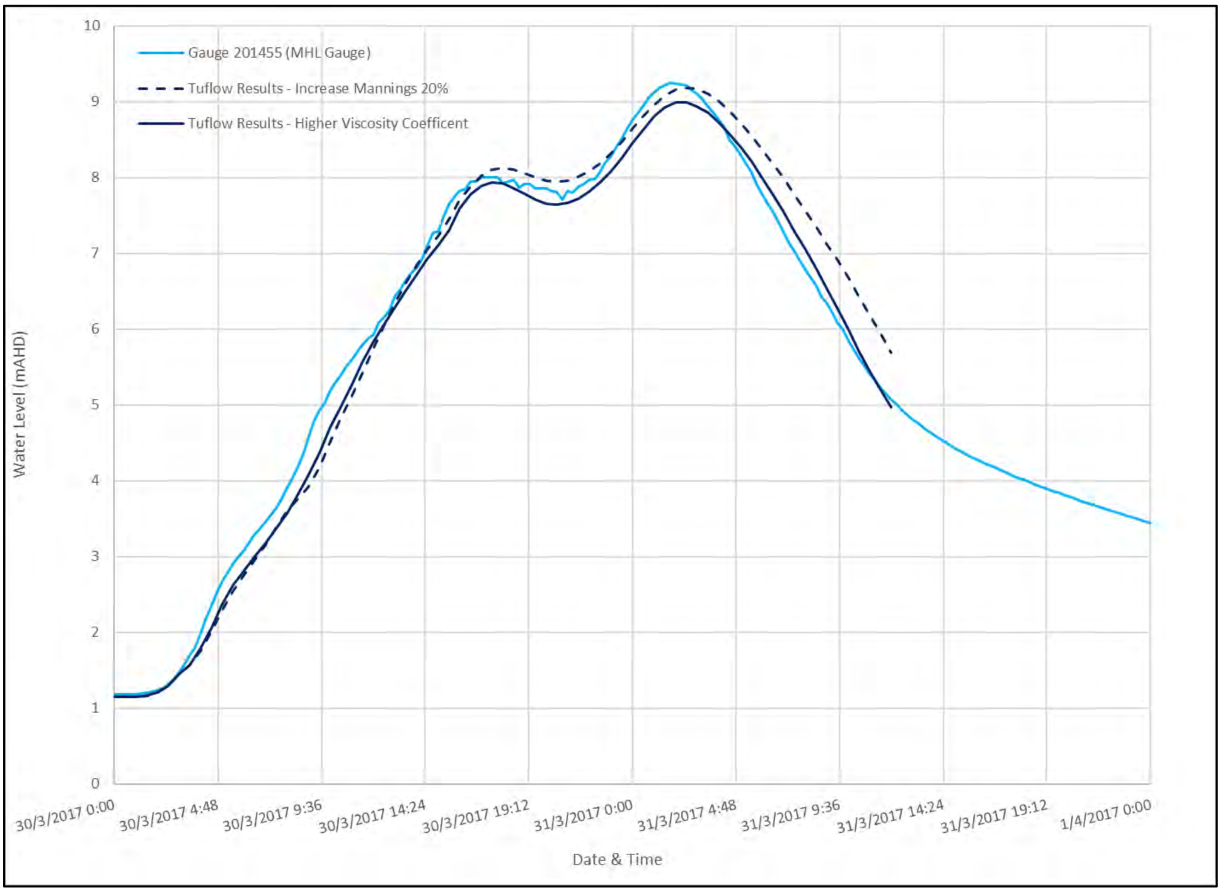



Diagram 31: 2017 Event – Bray Park Gauge – Increased 20% Mannings

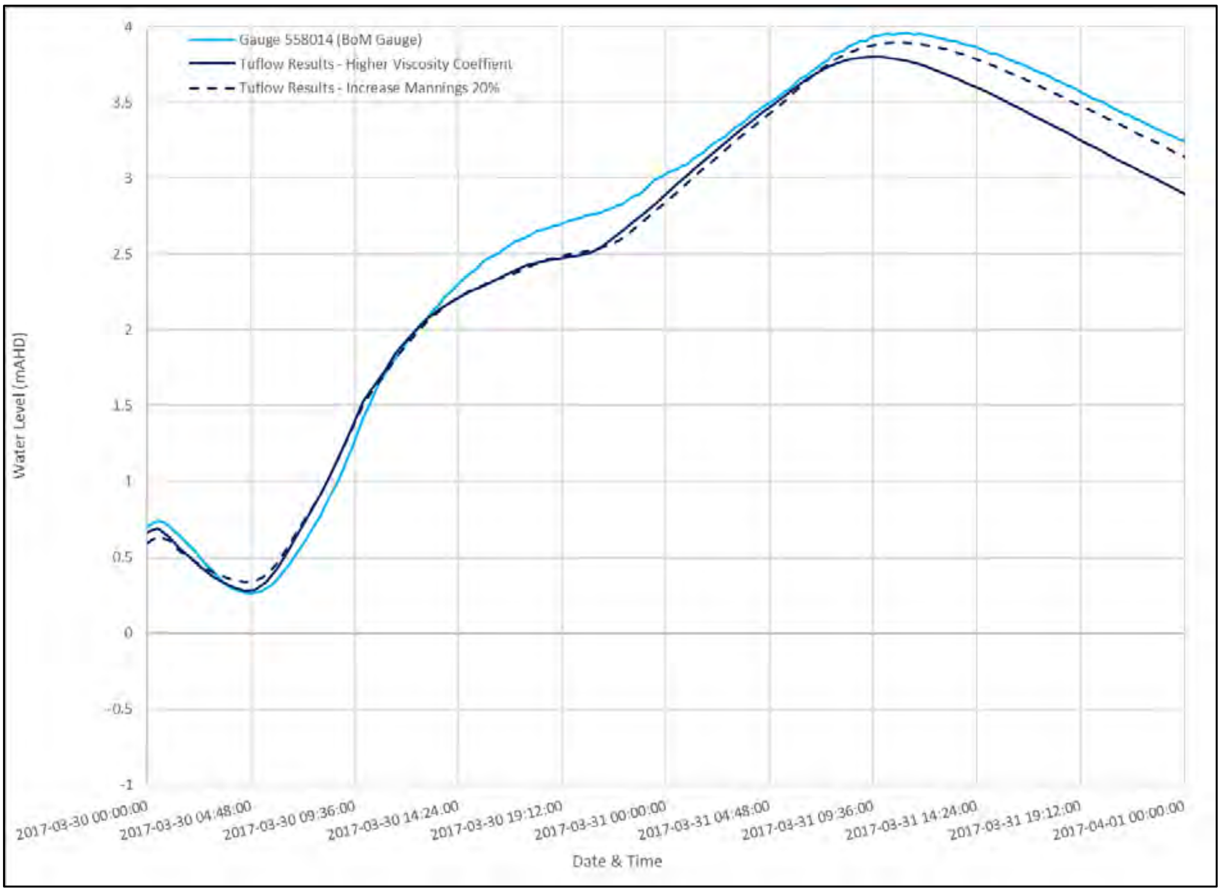



Diagram 32: 2017 Event – Tumbulgum Gauge – Increased 20% Mannings

It was found that Dry Dock and Cobaki gauge results are not sensitive to the adopted Manning's values.

#### 9.2.2.2. Decreasing the Manning's by 20%

It was found better calibration could be achieved on the Tweed River downstream of Uki gauge using a lower Manning's. Reducing the Manning's values provides better calibration at Eungella Gauge with flood levels within 0.10 m of the recorded flood level at this location compared to 0.29 m for the adopted model which is illustrated in Diagram 38.

Using reduced Manning's offers better agreement between the modelled and the surveyed flood levels upstream of Bray Park Weir. All calibration points downstream of Bray Park Weir get better calibration using the adopted model Manning's as illustrated in Diagram 33.

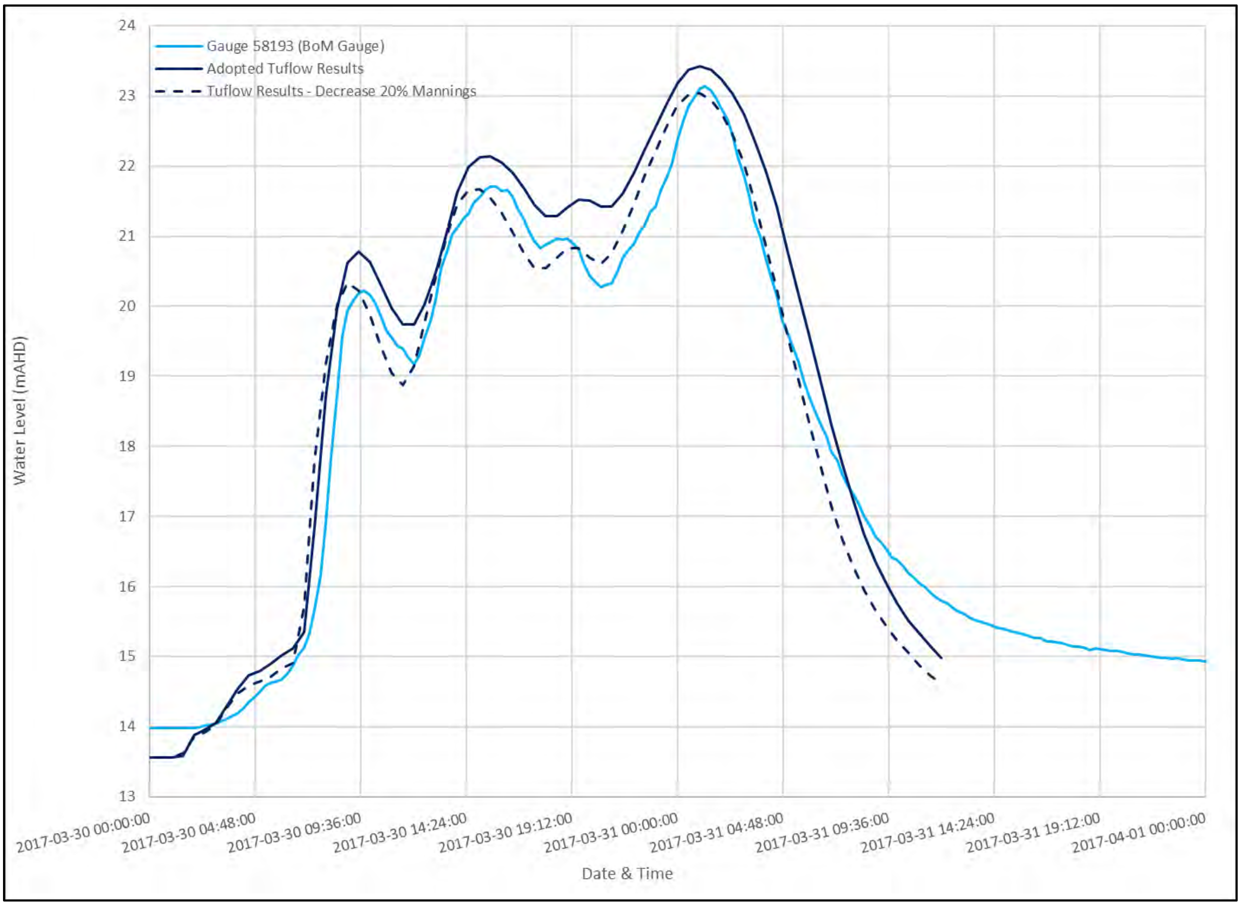



Diagram 33: 2017 Event – Eungella Gauge Flood Level – Reduction 20% Mannings

At the Rous River upstream of the Boat Harbour gauge similar results are achieved in the lower roughness sensitivity test. Modelled flood levels are within 0.08 m of the recorded flood level at this location. Diagram 39 illustrates the difference in the modelled flood levels using the adopted Manning's and reducing the manning values by 20%. Reducing the manning values results in a better agreement between the modelled and the recorded flood survey levels upstream of the junction of Crystal Creek and Rous River which is illustrated in Diagram 34.

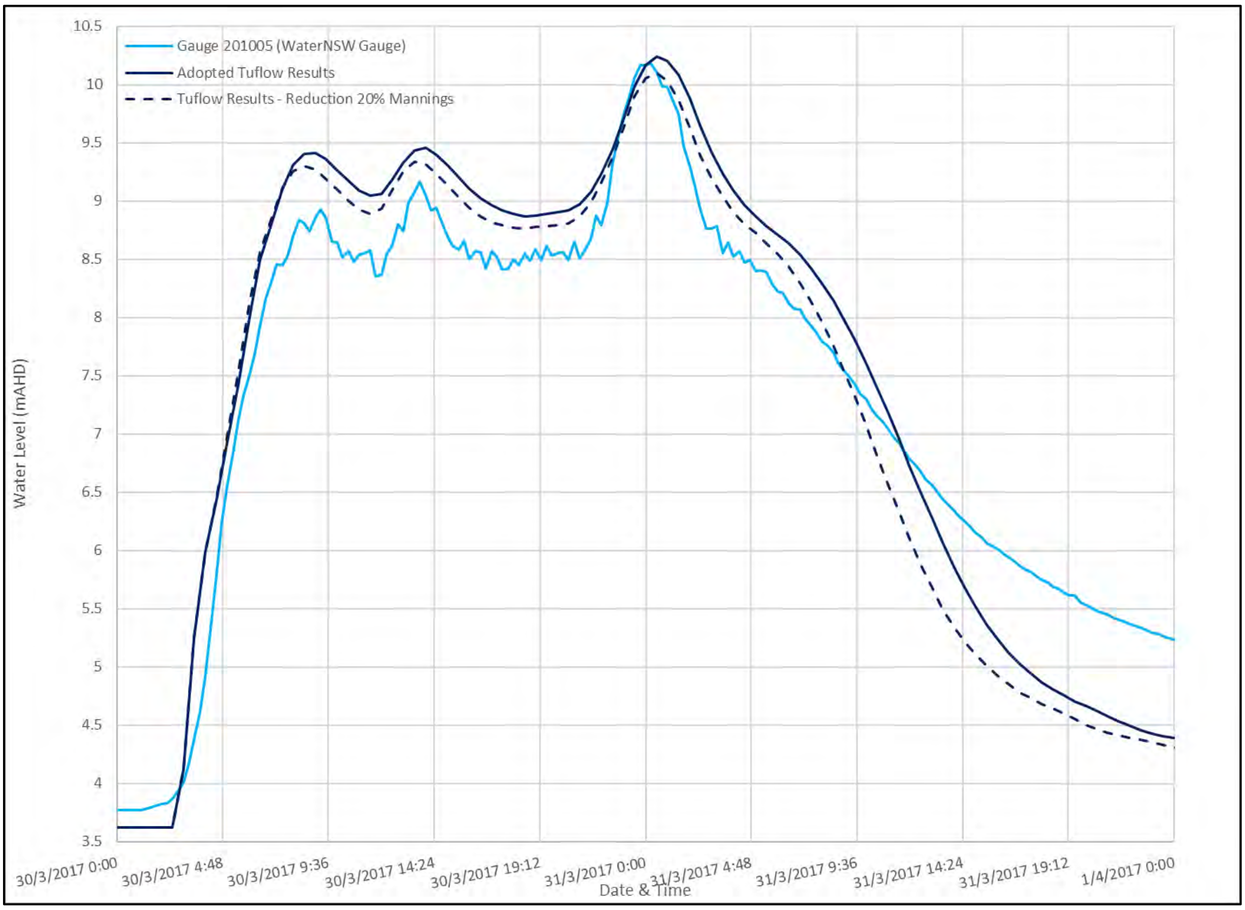



Diagram 34: 2017 Event – Boat Harbour Gauge Flood Level – Reduction 20% Manning's

Purely based on gauge inspection, Murwillumbah Bridge Gauge peak is better matched using a lower Manning's than just altering the viscosity coefficient. However, inspecting the flood survey points demonstrates that using a lower Manning's cause higher differences between the recorded and modelled flood levels to the east of Murwillumbah. The difference in the Murwillumbah Bridge Gauge is illustrated in Diagram 35, with the survey comparison demonstrated in Figure 27. The impact of using a lower Manning's is reinforced in Table 34, where the average and median differences for the area between Bray Park and Tumbulgum increases with a lower roughness condition selected compared to the adopted parameters.

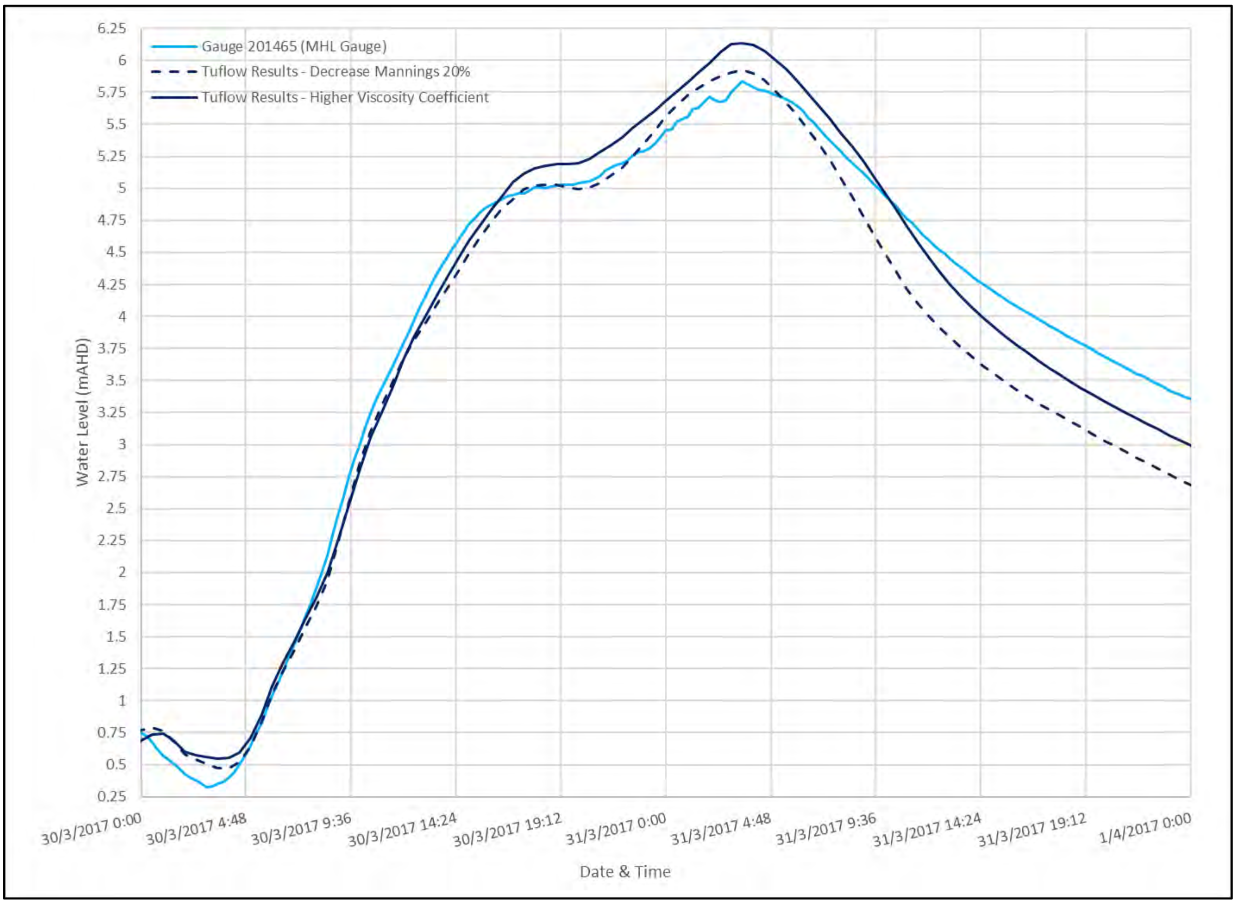



Diagram 35: 2017 Event – Murwillumbah Bridge Gauge – Reduction in Manning’s

Using lower Manning’s downstream of the Tumbulgum gauge reduces levels at the Tumbulgum gauge, therefore the lower Manning’s is not recommended for the bottom extent of the model (see Diagram 36).

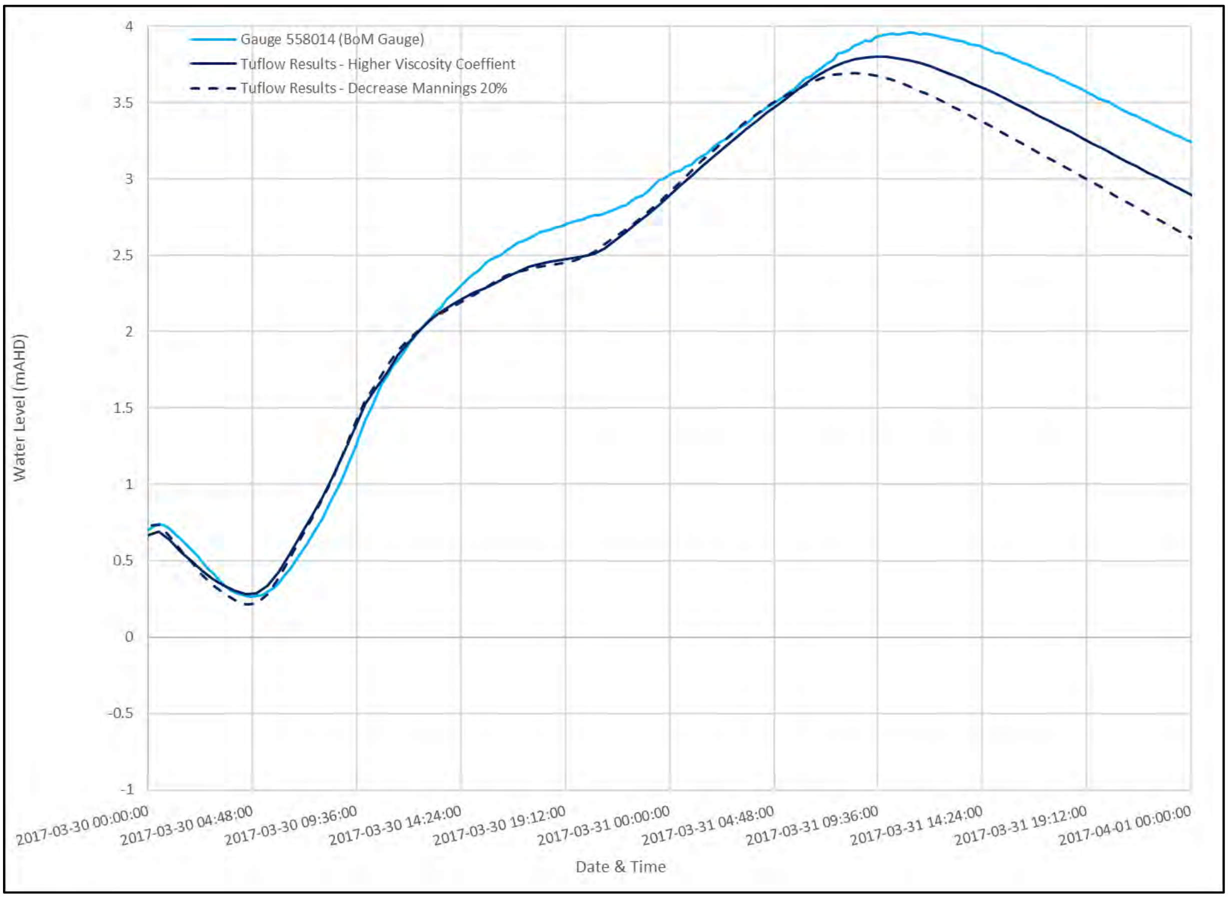



Diagram 36: 2017 Event - Tumbulgum Gauge – Reduction in Manning's

Table 35 outlines the statistics in key regions between Manning's sensitivity. Flood survey levels agreement for Murwillumbah and the whole Tweed catchment is Hydraulic Model – Murwillumbah Flood Levels - 2017 Event Viscosity Sensitivity
Figure 24, Figure 25, Figure 26 and Figure 27.

From a whole model perspective, the high Wu adopted offered the best calibration over the whole of the model but looking at different regions demonstrated different results. Downstream of Tumbulgum lowering the Manning provided the best calibration results.

Between Bray Park and Tumbulgum, the high Wu coefficient achieved modelled flood levels that were in better agreement than the modelled flood levels achieved using the lower or higher manning coefficient.

Initial sensitivity runs (not reported) indicated that the Uki and Rous reaches of the catchment achieved better calibration using the lower Manning values. It was determined based on this information that that upper reaches of the catchment could receive a local lowering of Manning to achieve better calibration. Based on this information localised lowering of the Manning values in flood events in the upper reaches on the catchment upstream of Bray Park was undertaken to achieve a better fit.

Table 35: 2017 Statistical Analysis of Model Effectives – Manning's Variation

| | Adopted | | | -20% Manning's | | | +20% Manning's | | |
|---|---|---|---|---|---|---|---|---|---|
| Assessment | Median | Average | Standard Deviation | Median | Average | Standard Deviation | Median | Average | Standard Deviation |
| Whole Model Extent | 0.04 | 0.09 | 0.47 | -0.18 | -0.10 | 1.01 | 0.24 | 0.36 | 0.67 |
| Catchment downstream of Tumbulgum | 0.15 | 0.17 | 0.22 | 0.04 | 0.06 | 0.28 | 0.16 | 0.23 | 0.39 |
| Catchment between Bray Park and Tumbulgum | 0.04 | 0.02 | 0.29 | -0.22 | -0.23 | 0.43 | 0.24 | 0.28 | 0.42 |
| Eungella | 0.34 | 0.26 | 0.19 | 0.67 | 0.66 | 0.33 | 0.17 | 0.07 | 0.29 |
| Uki | 0.00 | 0.24 | 0.95 | -0.09 | 0.05 | 0.85 | 0.63 | 0.69 | 0.84 |
| Rous | 0.13 | 0.24 | 0.32 | -0.05 | -0.02 | 0.27 | 0.36 | 0.51 | 0.36 |

### 9.2.3. Sensitivity Conclusion

Based on the sensitivities undertaken, the following became the adopted model:

- No modification of the hydrologic lag parameter was undertaken;
- Adopted Wu (10) was used in the hydraulic model for all events; and
- There was localised modification of Manning's in the upper reaches to achieve better calibration of the flood events without compromising the calibration at the floodplain section of the model.

# 10. HYDRAULIC RATING CURVE CHECKS

Given the reliance on rating curves to convert recorded water levels into flow for the calibration of the hydrologic model and the understanding of how the flood wave propagated through the catchment, a check of key rating curves was undertaken. The hydraulic rating curves have been based on the 2022 model results. It should be noted that at Palmers Road and Uki, given the number of changes that can occur during a flood event, the rating curve at these locations can change in each flood event depending on the amount of scour that occurs during the event.

## 10.1. Palmers Road Gauge

WaterNSW provides a synthetic rating curve for Palmers Road gauge, this information was compared to the hydraulic model rating curve. There was no bathymetry information available for the river at this location. Diagram 37 demonstrates the WaterNSW and the hydraulic model rating curves for Palmers Road gauge. The maximum gauged level for Palmers Road is 33 mAHD which occurred in 2012. This is significantly lower than the level observed in the 2022 event (38.63 mAHD). The WaterNSW rating curve is not quality controlled. The rating curve for Palmers Road gauge is illustrated in Diagram 37.

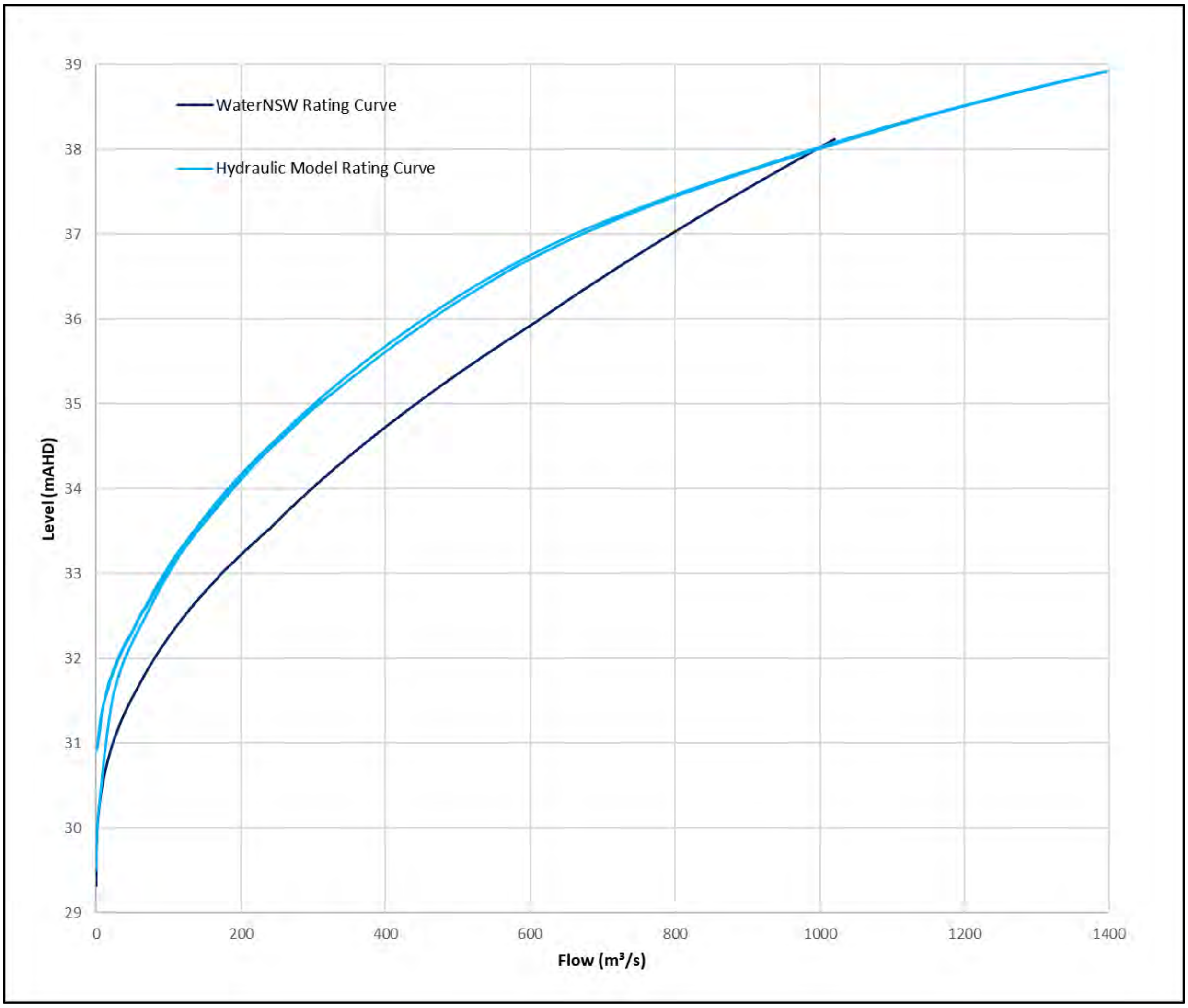



Diagram 37: Palmers Road Gauge Rating Curves

The hydraulic model rating curve demonstrates that less flow can pass at the same water level on the WaterNSW rating curve. For low flow scenarios this is likely due to the lack of bathymetric data available at the site. At approximately 38 mAHD the hydraulic model rating curve is much more efficient than the WaterNSW rating curve. This elevation is likely the point when the overbank section of Palmers Road gets initiated.

Given the WaterNSW rating curve is not quality controlled, the hydraulic model rating curve has been adopted in this study for this location.

## 10.2. Uki Gauge

BoM provides a synthetic rating curve for Uki gauge (Reference 20), this information was compared to the hydraulic model rating curve. It was generally found that the terrain at the gauge location could be located within 0.5 m of the gauge zero. There was no bathymetry information available for the river at this location. The hydraulic model terrain was higher than the gauge zero from the BoM information with the water surface likely present in the LiDAR at this location.

The maximum gauge level for Uki is 13.27 mAHD which occurred in 1990. This is significantly lower than the level observed in the 2022 event (22.42 mAHD). The BoM rating curve is not quality controlled. The rating curve for Uki gauge is illustrated in Diagram 38.

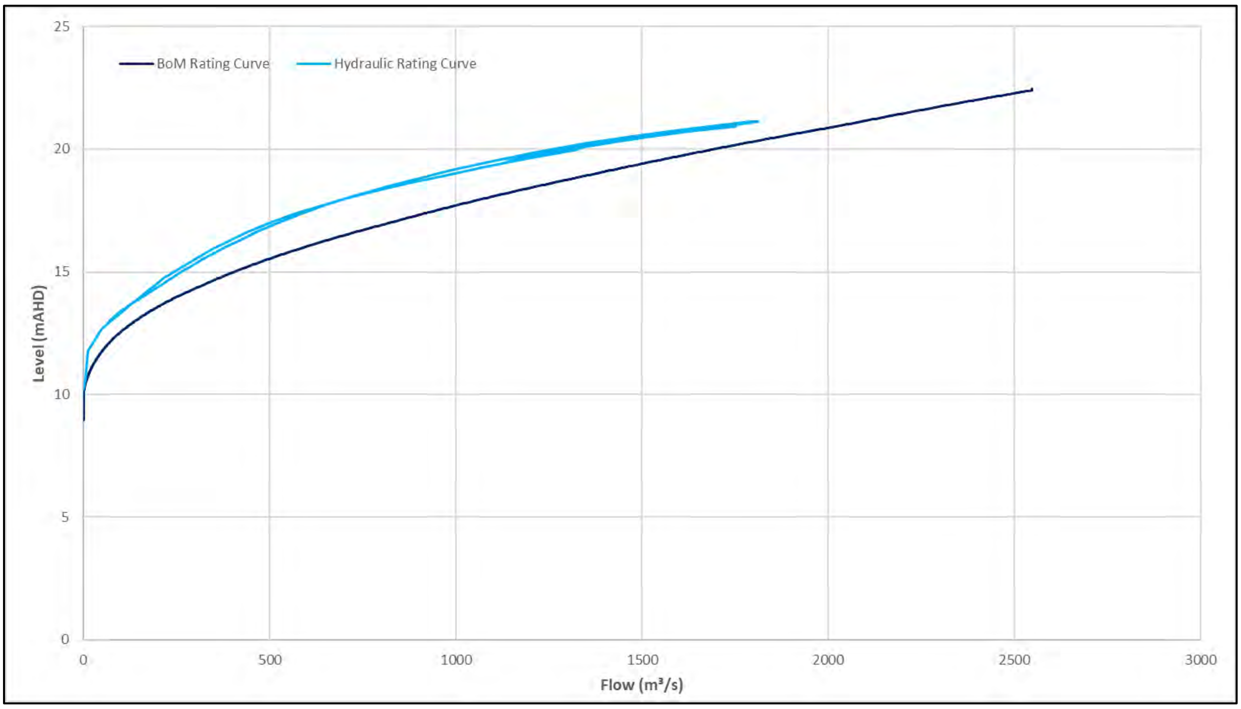



Diagram 38: Uki Gauge Rating Curves

The hydraulic model rating curve demonstrates that less flow can pass at the same water level on the BoM rating curve. At low flows (<500 $m^3/s$) it is likely that this is a function of the reduced conveyance present due to the channel below the normal water surface not being appropriately represented. At moderate flows the higher levels are likely derived due to local friction variances. At the higher flows the curves reconverge.

Noting the variance in the rating curves is primarily present in low to moderate events, a conservative approach to rating curve utilisation has been used. This results in the BoM rating curve, which provides higher flows for lower levels to be utilised when developing design event flow rates.

## 10.3. Eungella

WaterNSW provides a synthetic rating curve for Eungella gauge (Reference 20), this information was compared to the hydraulic model rating curve. It was generally found that the terrain at the gauge location could be located within 0.3 m of the gauge zero. There was no bathymetry information available for the river at this location.

The maximum gauge level for Eungella is 19.33 mAHD which occurred in 2013. This is much lower than the level observed in the 2017 event (23.13 mAHD). The WaterNSW rating curve is not quality controlled. The rating curve for Eungella gauge is illustrated in Diagram 39.

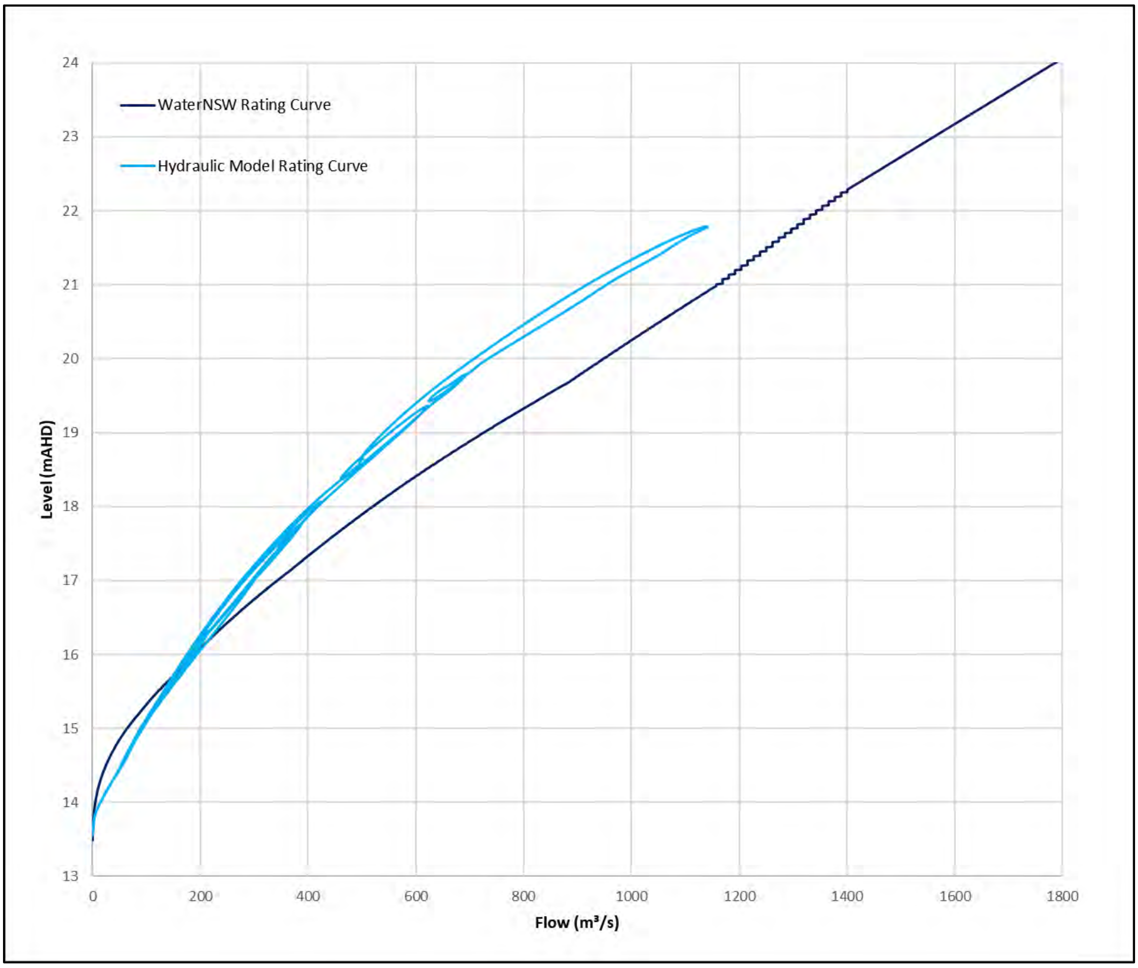



Diagram 39: Eungella Gauge Rating Curves

The hydraulic model rating curve demonstrates that more flow can pass at the same water level on the WaterNSW rating curve below 15.5 mAHD. Above this elevation less flow can pass at the same water level as the WaterNSW rating curve. Given the WaterNSW rating curve is not quality controlled, the hydraulic model rating curve has been adopted in this study for this location.

## 10.4. Boat Harbour 3

WaterNSW provides a synthetic rating curve for Boat Harbour 3 gauge (Reference 20), this information was compared to the hydraulic model rating curve. It was generally found that the terrain at the gauge location could be located within 0.5 m of the gauge zero. There was no bathymetry information available for the river at this location.

The rating curve for Boat Harbour 3 gauge is illustrated in Diagram 40. The hydraulic model rating curve demonstrates that below 8.5 mAHD less flow can pass at the same water level on the WaterNSW rating curve. Above 8.5mAHD, the river is more efficient than the WaterNSW rating curve. It was noted in BMT's Post Event Flood Behaviour Analysis and Review of Flood Intelligence – Tweed River (Reference 11) that the flows at Boat Harbour using the WaterNSW rating curve were too low for the 2017 flood event. This reinforces the belief that Boat Harbour gauge flows were incorrect during the 2017 calibration event.

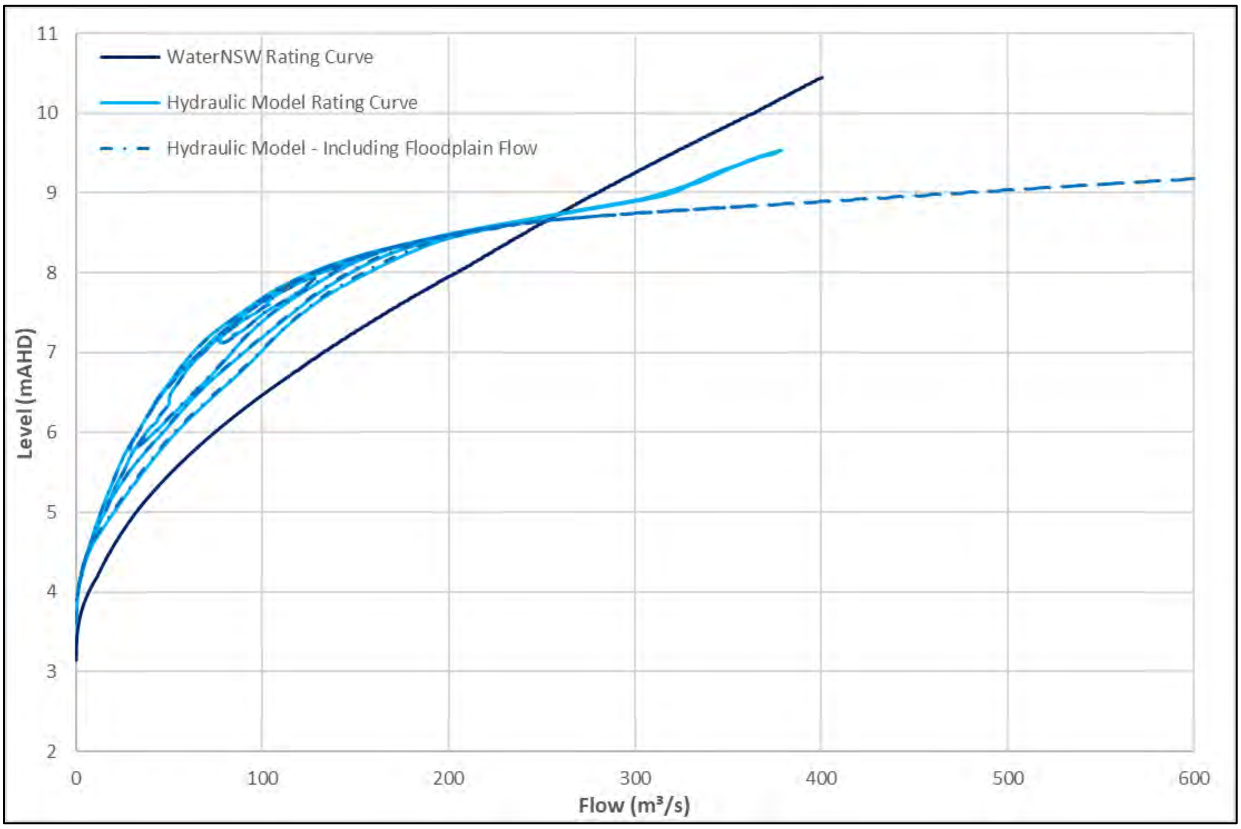



Diagram 40: Boat Harbour 3 Gauge Rating Curves

Given the WaterNSW rating curve is not quality controlled, the hydraulic model rating curve has been adopted in this study for this location.

## 10.5. Cobaki Creek

WaterNSW provides a synthetic rating curve for Cobaki Creek gauge (Reference 20), this information was compared to the hydraulic model rating curve. It was generally found that the terrain at the gauge location could be located within 0.1 m of the gauge zero. There was no bathymetry information available for the river at this location.

The rating curve for Cobaki Creek gauge is illustrated in Diagram 41. The hydraulic model rating curve demonstrates that below 6 mAHD less flow can pass at the same water level on the WaterNSW rating curve. Above 6 mAHD, the river is more efficient than the WaterNSW rating curve. This lower efficiency at low flows may be due to the hydraulic terrain not capturing the low flow channel. This has resulted in issues in 2020 calibration as flows were only 40 $m^3/s$ and the hydraulic model struggles to replicate this relationship.

It is likely that the WaterNSW rating curve is appropriate below 6 mAHD with the hydraulic model rating curve more suitable above this level.

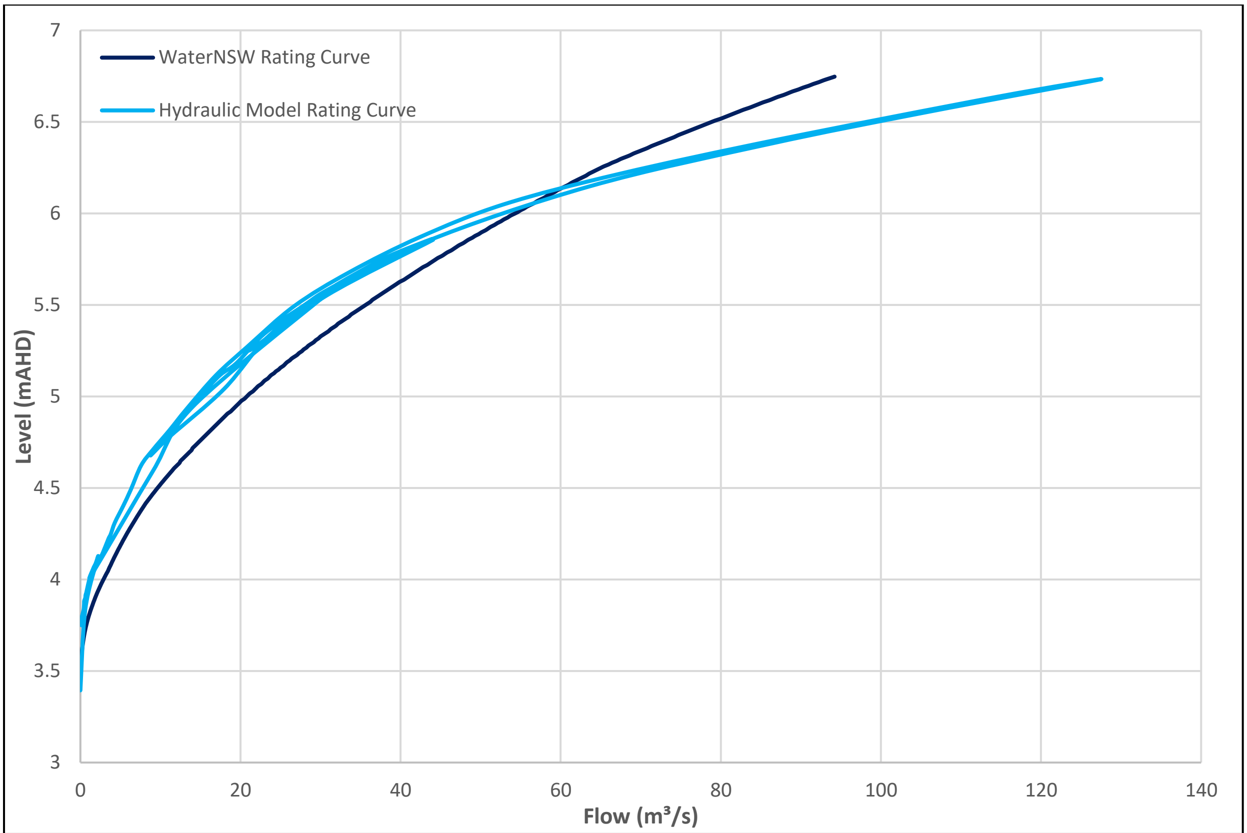



Diagram 41: Cobaki Creek Gauge Rating Curves

## 10.6. Adopted Rating Curves

Upon completion of the rating curve review, the results of the calibration at these gauges were reviewed and updated. Generally, there is better agreements between the recorded and modelled flows at all locations. In the 2022 event, Boat Harbour has better agreement between the recorded and modelled flows by the inclusion of the breakout flows. It is likely that the hydraulic model Boat Harbour rating curve is high as the gauge zero has not been adequately included in the model. This is due to no bathymetry survey being included at the gauge location.

During low flow floods events the hydraulic rating curves struggles to provide agreement between the modelled and recorded flows as the hydraulic model is unlikely to have fully captured the low flow channel at these cross-sections.
It is noted that during flood events the vegetation near Palmers Road, Uki and Eungella gauges

can alter during the event. Therefore, it is hard to determine a representative rating curve at these locations due to the constant changes in bed elevation and vegetation, which impact on the derived rating curve.

# 11. FLOOD FREQUENCY ANALYSIS

As part of this study Flood Frequency Analysis (FFA) has been undertaken in accordance with the current best practice guidelines (Reference 1). FFA is a critical tool for quantifying at-site flood risk. This analysis can provide significantly improved confidence in rainfall-based flood modelling techniques by closing the loop between multiple processes with associated unknowns, such as rainfall losses, spatial and temporal rainfall variability over large catchments, and joint probability with backwater flow mechanisms where these exist. In the design modelling component of this study the FFA analysis undertaken will be compared to design flows at each location to ensure the flows are of a magnitude that is representative of historic records.

FFA uses the statistical analysis of recorded data to estimate the magnitude of an event with a particular exceedance probability. Ideally, this analysis should be applied at a site where streamflow records are at least 10-15 years long. For this assessment, the Annual Maximum Series of depth was extracted from each of the gauges with a long enough record and associated rating curve to convert the depth into flow. The TUFLOW Flike software was then used to assign a plotting position to each event, assigning an AEP to a given flow.

FFA was performed on the gauges listed in Table 36

Table 36: FFA Gauge Durations

| Gauge | Duration of data (years) |
|---|---|
| Murwillumbah Bridge | 107 |
| Tumbulgum | 37 |
| Tweed River at Uki (201900) | 55 |
| Tweed River at d/s Palmers Road (201015) | 14 |
| Rous River at Boat Harbour No. 3 (201005) | 67 |
| Oxley River at Eungella (201001) | 76 |
| Cobaki Creek (201012) | 42 |

## 11.1. Annual Maxima series

An Annual Maxima Series (AMS) of flow for the period of data available is used in a probabilistic assessment as the sample data. The AMS is comprised of the highest instantaneous value for flow in each year of record. This information was collected for each gauges using the calendar year as the wet season in the region is generally January to March. Therefore, the calendar year largely aligns with the water year and is suitable for use in the AMS.

## 11.2. Data Fit

The Log-Pearson III (LP3) distribution was used to fit the data within Flike. This was identified as the preferred flood frequency in ARR2019. As this distribution is sensitive to the presence of low outliers, low flow values were censored using the multiple Grubbs-Beck test for outlier detection. The LP3 distribution is a three parameter probability distribution related to the standard Gamma probability distribution. The three parameters are the mean, standard deviation and skew of the data sample.

## 11.3. Locations with Previous FFA's

The 2005 Tweed flood study developed FFA's for Murwillumbah and Tumbulgum through the development of synthetic rating curves from the developed hydraulic models. These synthetic rating curves were then updated as part of the South Murwillumbah FPRMS, and the total length of record extended. The rating curves from the FPRMS were adopted, and the length of record updated as part of this study.

### 11.3.1. Murwillumbah

In the 2005 study, Murwillumbah had a level record of 118 years, and was constructed from level measurements from multiple gauges, including the current Murwillumbah bridge gauge. This record was extended using the current gauging from the Murwillumbah bridge gauge as part of the South Murwillumbah FPRMS, and an updated rating curve was adopted.

The updated rating curve was utilised for this study and the length of record was extended again using the Murwillumbah bridge level record. A similar censoring regime was adopted as part of this study, removing 51 records below the 850 $m^3/s$, as this was used as an infill value in the AMS series, and is better represented as a censored flow in a Bayesian fit. Diagram 42 shows the probability distribution plot for the LP3 model with the low flows censored.

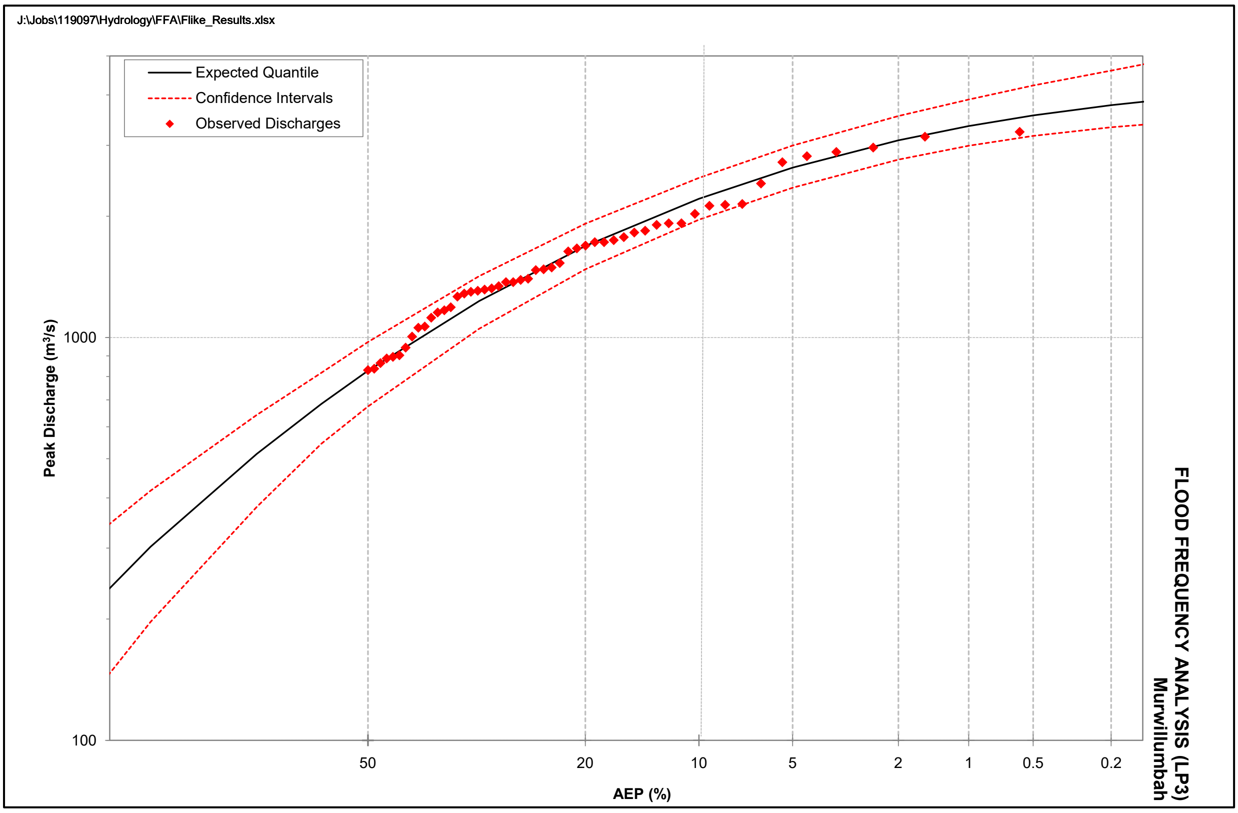



Diagram 42: Flood Frequency Analysis at Murwillumbah

Table 37 below show a comparison between the current fitted FFA and those developed as part of the previously mentioned flood studies. It shows a good level of agreement with the South Murwillumbah FPRMS.

Table 37: Comparison of Peak Flows at Murwillumbah

| AEP | Current Study Peak Flow | 2005 Study Peak Flow | 2017 Study Peak Flow |
|---|---|---|---|
| 20% | 1,702 | 1,700 | 1,728 |
| 10% | 2,258 | 2,070 | 2,258 |
| 5% | 2,717 | 2,430 | 2,683 |
| 1% | 3,484 | 3,240 | 3,357 |
| 0.2% | 3,713 | 4,070 | 3,739 |

### 11.3.2. Tumbulgum

An FFA was also created for Tumbulgum as part of the South Murwillumbah FPRMS. This was undertaken utilising 33 years of recorded level at Tumbulgum and a synthetic rating curve. The record for this location was updated to include up to 2022, and the FFA was redeveloped. 17 low flows were censored as part of the multiple Grubs Beck test for this location, removing flows below approximately 550 $m^3$/sec. Diagram 43 shows the probability distribution plot for the LP3 model with the low flows censored.

Given this gauge is tidally influenced the FFA based on flow is dependent on the rating curve. This rating curve is complex due to the interaction of tides on the level, flow relationship. There are also hysteresis effects where the rating curve is completely different on the rising and falling limb of the event.

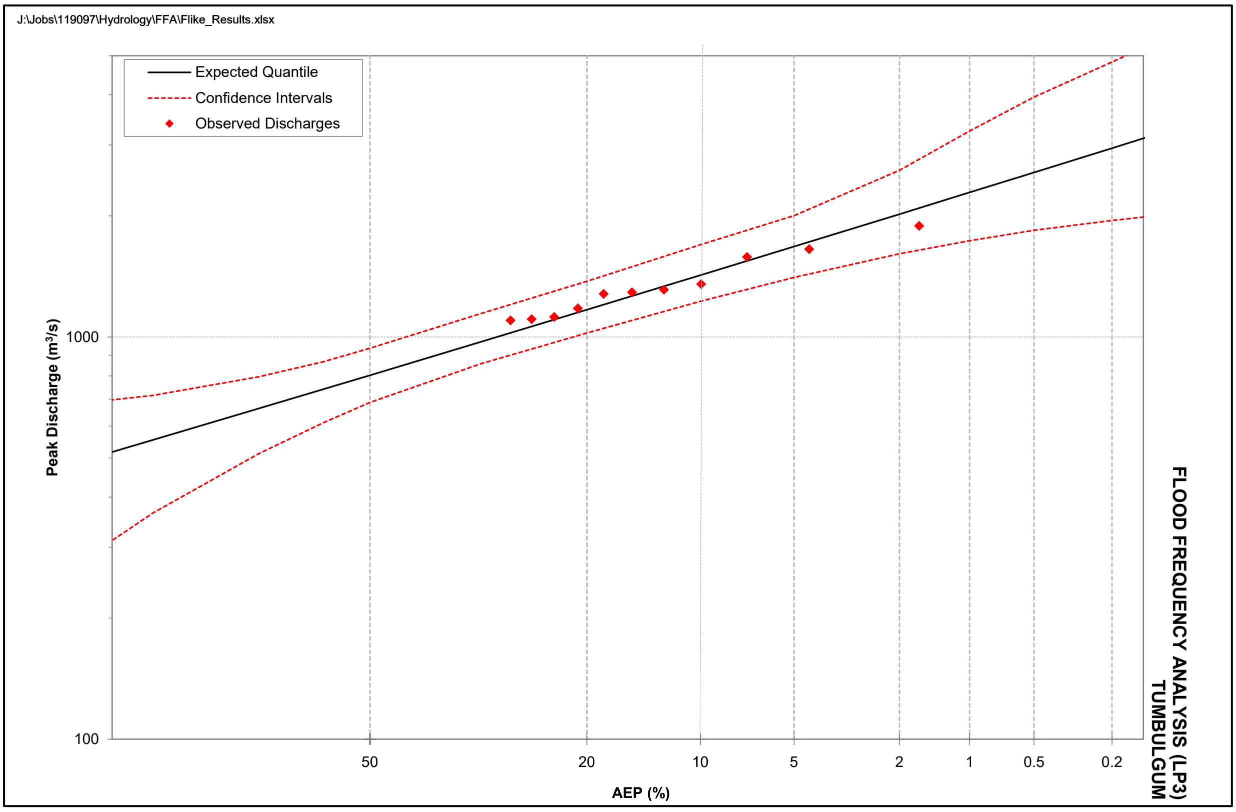



Diagram 43: Flood Frequency Analysis at Tumbulgum

Multiple probability fits were applied as part of the FPRMS, and the results of all included. These have been compared to the updated LP3 fit undertaken for this study.

Table 38: Comparison of Peak Flows at Tumbulgum

| AEP | Current Study Peak Flow ($m^3$/sec) | 2017 Study Peak Flow ($m^3$/sec) | | | |
|---|---|---|---|---|---|
| | | Gumbel | Log Normal | LP3 | GEV |
| 20 % | 1,245 | 1,201 | 1,196 | 1,208 | 1,217 |
| 5% | 2,065 | 1,678 | 1,678 | 1,776 | 1,705 |
| 1% | 3,447 | 2,207 | 2,238 | 2,491 | 2,206 |
| 0.2% | 4,241 | 2,731 | 2,824 | 3,302 | 2,666 |

The updated LP3 fit generated as part of this study has a higher level of agreement with the other methods of the previous flood study, bringing down its estimate of flow by 300 $m^3$/sec compared to the 2017 LP3 fit. Noting the length of the dataset it is likely the low frequency flows will continue to vary until a sufficiently long period of data is available.

## 11.4. New FFA locations

In addition to the above 2 existing FFA locations, 5 additional locations have gauges and measured rating curves where FFA can be developed. These are the Tweed d/s Palmers Road (Palmers Road), Uki, Eungella, Rous River at Boat Harbour no.3, and Cobaki Creek. FFAs were developed at each of these locations to enable regional checks on the design modelling throughout the system. There is no previous FFA data at each of these locations to compare against for these locations.

### 11.4.1. Uki

The FFA at Uki was originally developed from 46 years of record, with 18 years censored as low flow, with values censored below 370 $m^3$/sec. The rating curve adopted was from the hydraulic model given the discrepancy noted in Section 10.2 regarding the WaterNSW rating curve at this location. Using this information, identified that the 2022 event was plotting in a frequent AEP range but based on town flood history, this event has not been seen in over 100 years.

Additional gauge information was identified that enabled the record at the gauge to be extended from 46 years of record to 102 years of data. This record has flows censored 500 $m^3$/s. The fit adopted was the LP3 distribution, as shown on Diagram 44, and summarised in Table 39. The extended FFA graph with the longer history of events enables a better statistical plotting position for the 1% AEP event.

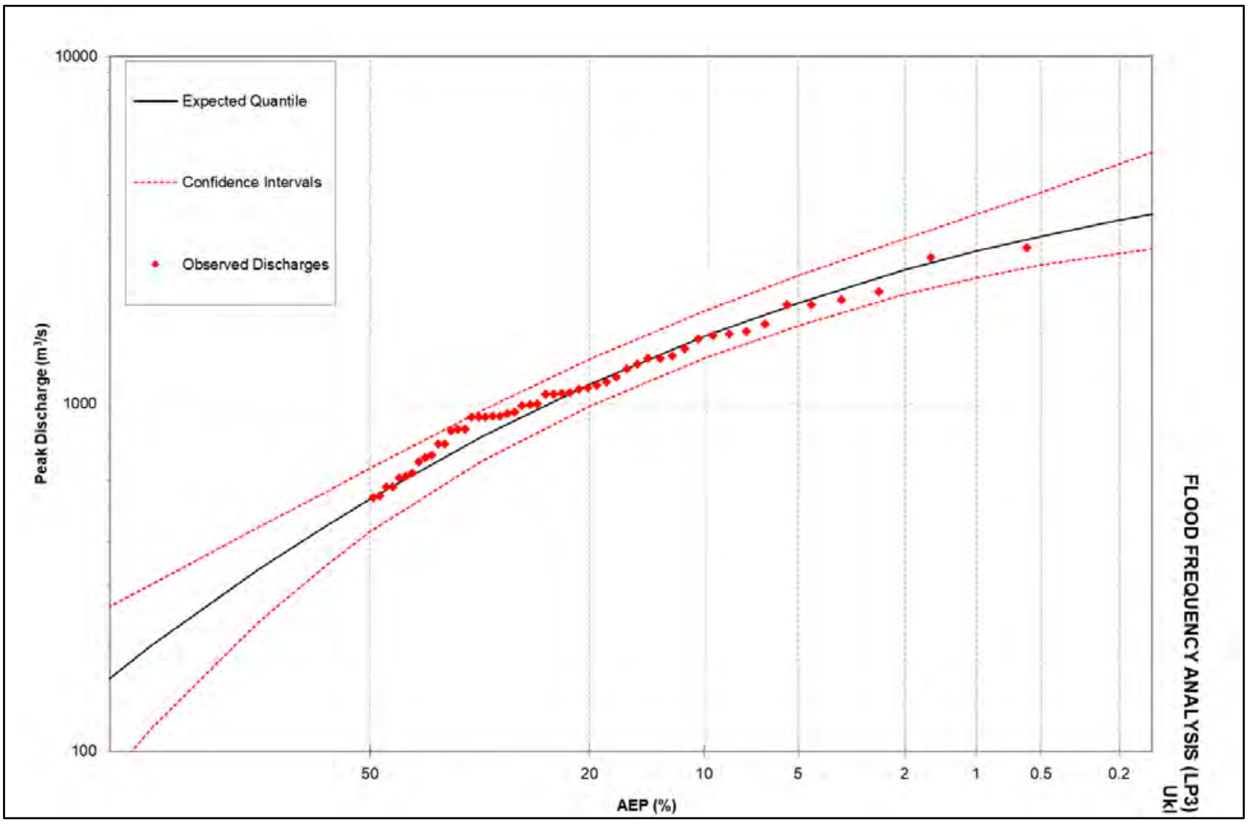



Diagram 44: Flood Frequency Analysis at Uki

Table 39: Expected Quantile Flows at Uki

| AEP | FFA Estimated Peak Flow ($m^3$/sec) |
|---|---|
| 20% | 1,136 |
| 10% | 1,561 |
| 5% | 1,957 |
| 2% | 2,430 |
| 1% | 2,752 |
| 0.5% | 3,043 |

### 11.4.2. Palmers Road

Palmers Road has the shortest gauge of record and thus the highest level of uncertainty in the 1 in 100 estimation. Additionally, it had a high skew, that caused the 1 in 100 estimation higher than that expected at Uki, which is downstream of Palmers Road and should likely have a higher flow. Initially two (2) values were censored as low flows, removing all flows below 180 $m^3$/s. The statistical fit at Palmers Road was then modified using the prior gaussian distribution from Uki. This has led to the 1 in 100 estimate for Palmers Road to be approximately half the peak flow at Uki, which is similar to the ratio of peak flows identified during the large calibration events. The fit is illustrated on Diagram 45, and summarised in Table 40

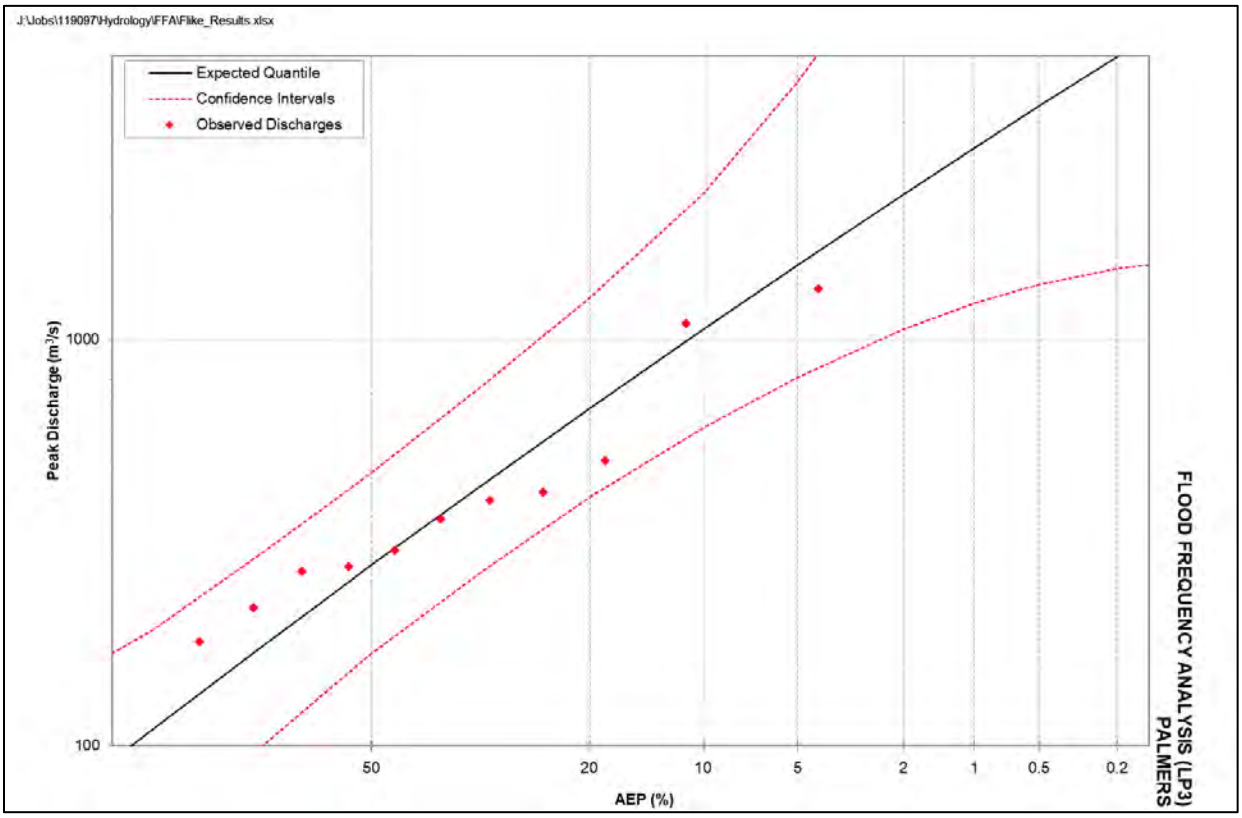



Diagram 45: Flood Frequency Analysis at Palmers Road

Table 40: Expected Quantile Flows at Palmers Road

| AEP | FFA Estimated Peak Flow ($m^3$/sec) |
|---|---|
| 20% | 678 |
| 10% | 1,063 |
| 5% | 1,529 |
| 2% | 2,283 |
| 1% | 2,969 |
| 0.5% | 3,764 |

### 11.4.3. Eungella

The Eungella FFA was developed from 68 years of record. The hydraulic model rating curve established in Section 10.3 has been used for this assessment noting the deficiencies in the WaterNSW rating. A multiple Grubbs Beck test for low flow outliers identified 20 records which unduly affected the fit, and these values were censored. This censored all flows below 238 $m^3$/s and resulted in a good model fit with reasonable 90% confidence interval. The fit is illustrated in Diagram 46, with the expected Quantile flows in Table 41.

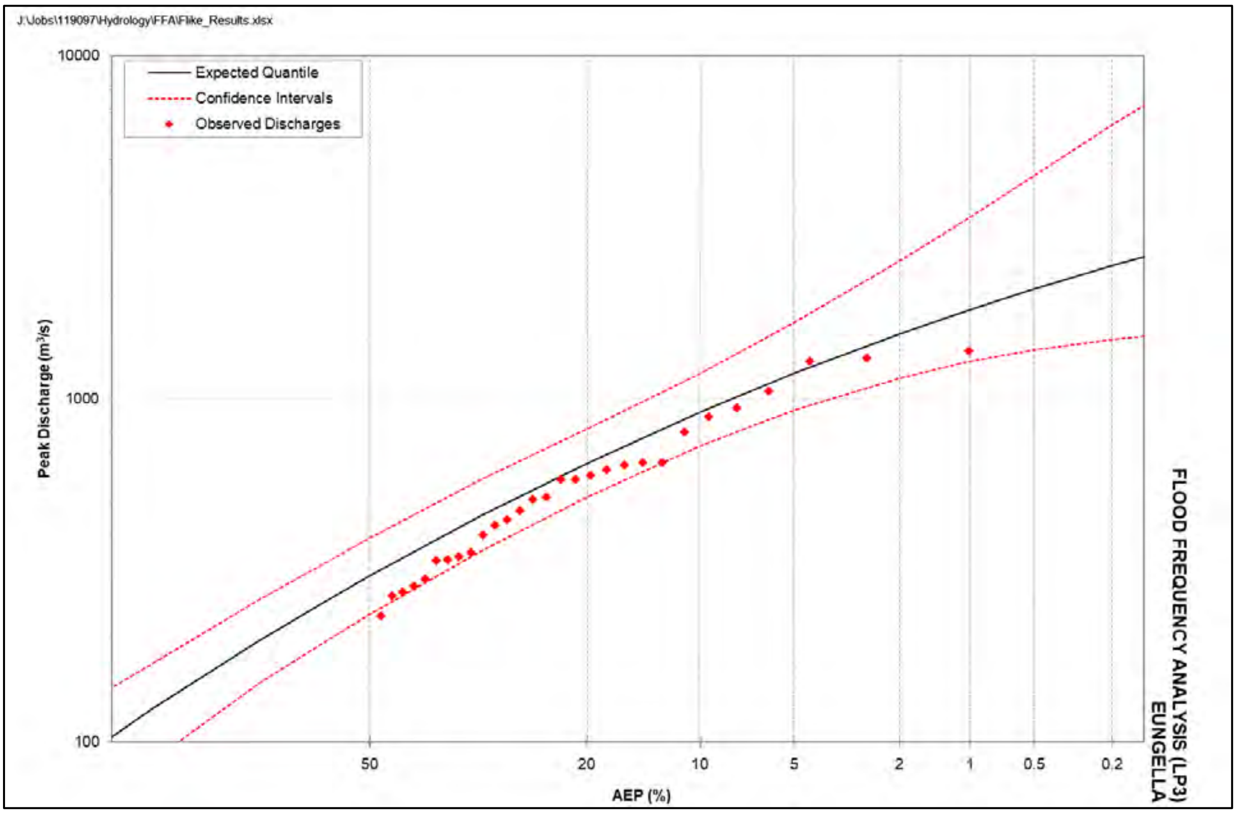



Diagram 46: Flood Frequency Analysis at Eungella

Table 41: Expected Quantile Flows at Eungella

| AEP | FFA Estimated Peak Flow (m$^3$/sec) |
|---|---|
| 20% | 651 |
| 10% | 918 |
| 5% | 1,190 |
| 2% | 1,552 |
| 1% | 1,825 |
| 0.5% | 2,096 |

### 11.4.4. Cobaki Creek

The Cobaki Creek FFA was developed from 41 years of record, and the rating curve as available from the BoM. A multiple Grubbs Beck test for low outliers identified 11 records which unduly affected the fit, and these values were censored. This censored all flows below 28 m$^3$/sec. This fit is similar to that found at Tumbulgum and may be indicative of the skew seen more towards the bottom of the catchment. It was noted from the calibrations that there is a significant difference between typical rainfall conditions at the top and the bottom of the catchment. This fit could be informed with gaussian priors to improve the confidence interval above one percent, but there are no FFA's with significantly longer records in its imminent vicinity. The fit is illustrated in Diagram 47 and summarised in
Table 42.

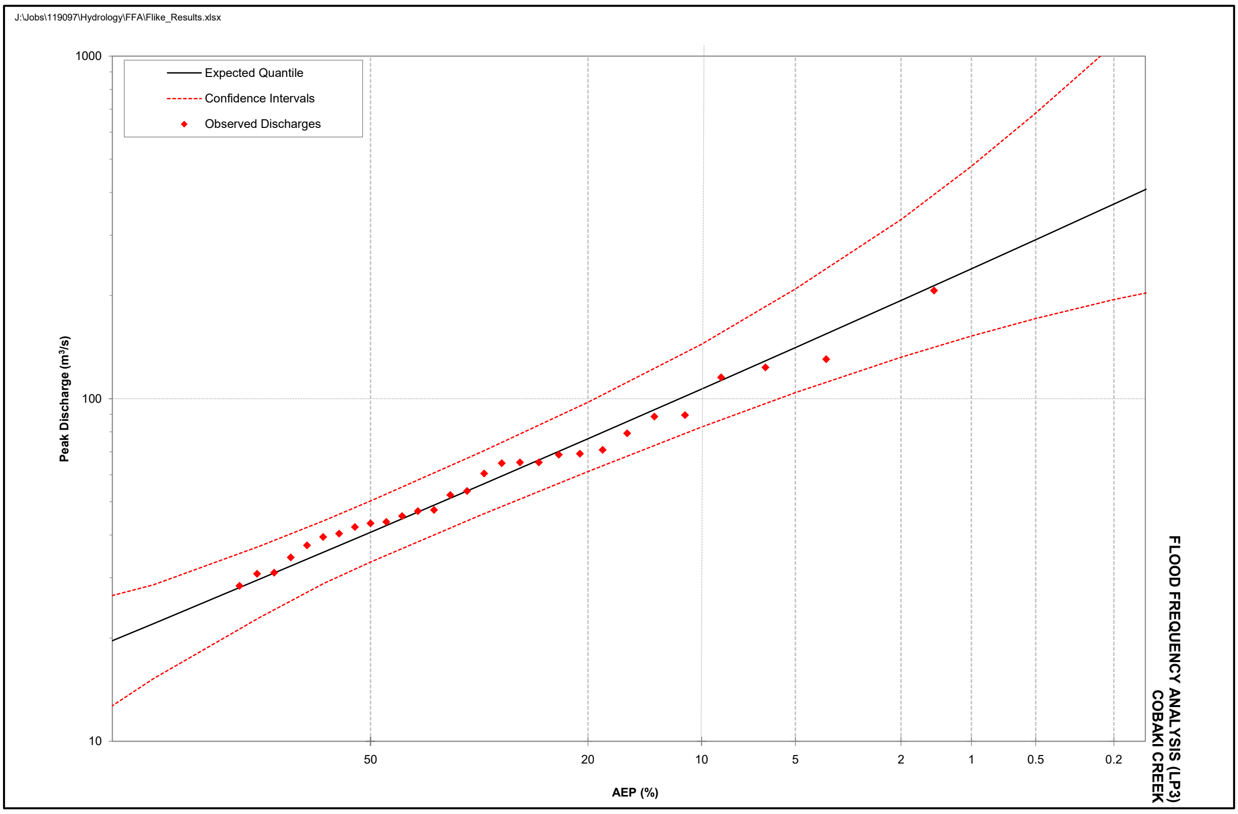



Diagram 47: Flood Frequency Analysis at Cobaki Creek

Table 42: Expected Quantile Flows at Cobaki Creek

| AEP | FFA Estimated Peak Flow ($m^3/s$) |
|---|---|
| 20% | 76 |
| 10% | 106 |
| 5% | 140 |
| 2% | 193 |
| 1% | 239 |
| 0.5% | 291 |

### 11.4.5. Boat Harbor No. 3

The Boat Harbor FFA was developed from 65 years of partial record. It has been identified that the location of this gauge doesn't capture a significant bypass which flows above approximately 150 $m^3$/sec. The rating curve supplied from the WaterNSW with this gauge also doesn't include this bypass. The hydraulic rating curve derived from the model for the complete flow (including the bypass) at this location has been used for the assessment.

A multiple Grubbs Beck test for low outliers identified 14 records which unduly affected the fit, and these values were censored. This censored all flows below 326 $m^3$/s and resulted in a good model fit with reasonable 90% confidence interval. The fit for boat Harbor No. 3 based on the hydraulic model rating is illustrated in Diagram 40 and summarised in Section 10.4. Given the large storage change when breakouts occur it may be preferable to have a dual FFA, one modelling low flows, and a second modelling less frequent events.

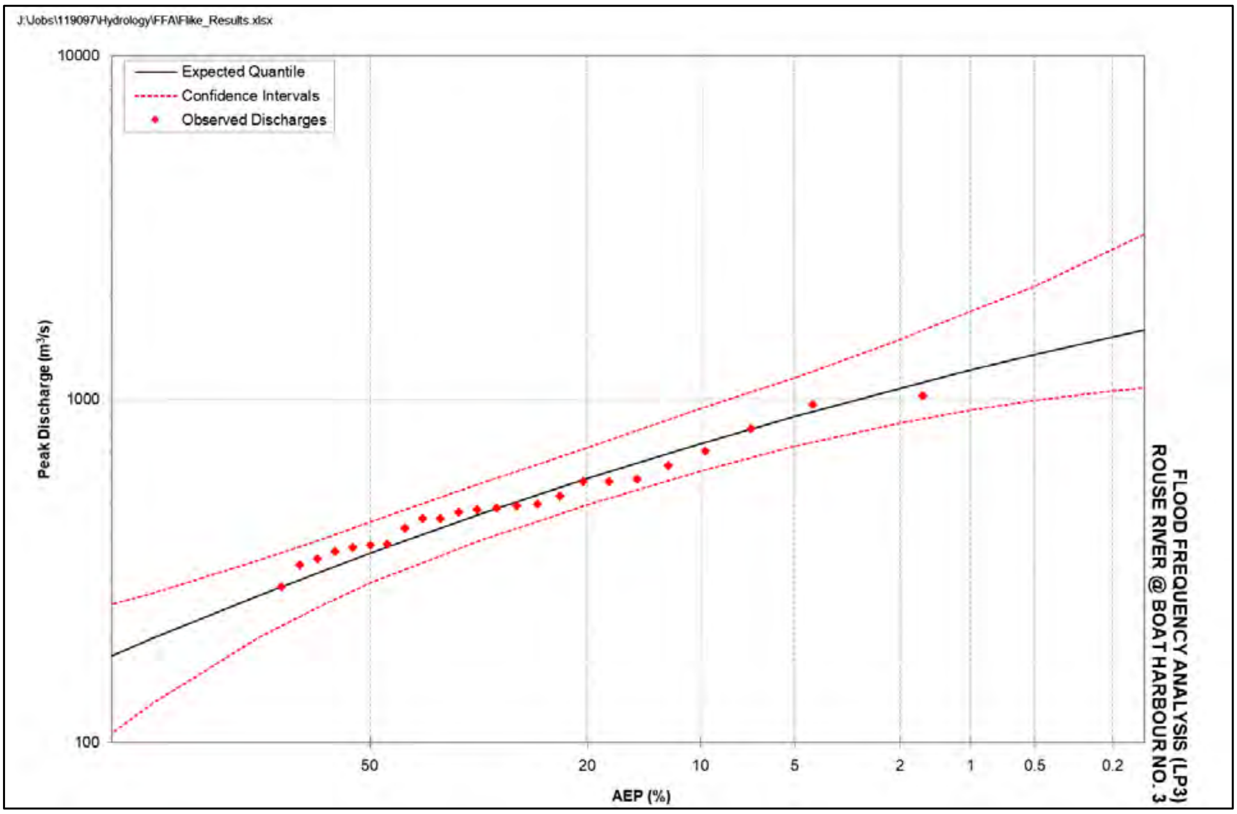



Diagram 48: Flood Frequency Analysis at Boat Harbour No. 3

Table 43: Expected Quantile Flows at Boat Harbour No. 3

| AEP | FFA Estimated Peak Flow ($m^3/s$) |
|---|---|
| 20% | 588 |
| 10% | 744 |
| 5% | 892 |
| 2% | 1,079 |
| 1% | 1,216 |
| 0.2% | 1,520 |

# 12. DESIGN IFD COMPARISON

ARR 2019 guidelines for design flood modelling were adopted for this study, including the use of ARR 2019 design information for all IFD. A comparison was undertaken between the IFD estimation provided by the BoM and the three longest continuous rainfall records available in the catchment.

## 12.1. ARR 2019 IFD

ARR 2019 IFD information was obtained from the BoM. IFD information was sourced for each sub catchment individually from the BoM's gridded IFD data and applied in the WBNM hydrologic model. A summary of the average design rainfall depths across the catchment are provided in Table 44.

Table 44: Catchment Average IFDs Depth (mm)

| (min) | 20% | 10% | 5% | 2% | 1% | 0.5% | 0.2% |
|---|---|---|---|---|---|---|---|
| 30 | 40 | 47 | 54 | 63 | 70 | 74 | 83 |
| 45 | 47 | 56 | 65 | 77 | 86 | 92 | 103 |
| 60 | 53 | 64 | 74 | 88 | 100 | 107 | 120 |
| 90 | 64 | 76 | 89 | 108 | 124 | 132 | 149 |
| 120 | 72 | 87 | 103 | 126 | 144 | 154 | 173 |
| 180 | 87 | 106 | 126 | 156 | 180 | 192 | 215 |
| 270 | 106 | 131 | 157 | 194 | 225 | 238 | 267 |
| 360 | 122 | 152 | 183 | 226 | 262 | 277 | 310 |
| 540 | 151 | 188 | 228 | 281 | 324 | 341 | 382 |
| 720 | 176 | 219 | 265 | 325 | 374 | 394 | 441 |
| 1080 | 217 | 269 | 324 | 395 | 450 | 476 | 534 |
| 1440 | 249 | 309 | 370 | 447 | 507 | 540 | 606 |
| 1800 | 276 | 340 | 406 | 488 | 551 | 599 | 674 |
| 2160 | 298 | 367 | 436 | 522 | 587 | 645 | 727 |
| 2880 | 332 | 407 | 481 | 573 | 641 | 711 | 803 |
| 4320 | 377 | 459 | 539 | 639 | 713 | 793 | 895 |
| 5760 | 404 | 491 | 576 | 681 | 759 | 844 | 950 |
| 7200 | 422 | 514 | 603 | 713 | 795 | 881 | 991 |
| 8640 | 435 | 530 | 624 | 739 | 826 | 911 | 1,023 |

## 12.2. Comparison with At-Site IFD

The design IFDs provided by BoM are derived from the pooling of data across the region from a number of gauges. These values were compared against the IFD data derived from at-site analysis of several gauges throughout the catchment to analyse how well they compare. Table 45 provides further information on the gauges used including supplier and record duration.

Table 45: Gauges Used for At-site IFD Comparison

| Gauge | Station ID | Supplier | Record Length |
|---|---|---|---|
| Morning View | 58113 | BoM | 1965-Current |
| Bray Park | 58158 | BoM | 1971-Current |
| Kunghur | 58129 | BoM | 1966-Current |
| Upper Rous | 558080 | MHL | 2010-Current |
| Doon Doon | 58019 | BoM | 1952- Current |

Springbrook Upper gauge was additionally included as part of this analysis as it covers a region of note across the QLD border in the Gold Coast City council region. The City of the Gold Coast has recently undertaken a review and update of the IFD information for its catchments. A request was made for this information to ensure a smooth transition across the border and to ensure that the IFD was consistent in the areas of overlapping information. The City of the Gold Coast IFD have been reviewed and it is noted there is a discrepancy between the Design IFD and BoM IFD.

The AMS was derived from the recorded rainfall data at each gauge location. To do this the rainfall was disaggregated from a variable timestep in the raw data to a series of one minute periods by averaging the rainfall since the last record. This approach can underestimate event rainfall for shorter durations as the rainfall is smoother, however this effect will be very minor for durations greater than 10 minutes, particularly for larger events (which AMS events will be) where on a small proportion of the total rain will fall in the first time step. For each duration of interest, a rolling window sum was used to calculate the annual maximum rainfalls from the one minute data.

The Cunnane plotting position was derived for each AMS event for each duration. This is recommended for plotting unbiased quantile estimations for annual maximum flood data series in ARR (Reference 1). The same method was used here for plotting annual maximum rainfall depths rather than flow. The BoM 2019 IFD rainfalls were selected at the nearest grid cell to the gauge and plotted to compare with the at-site AMS values.

Table 46 and Table 47 are a percentage comparison between the BoM IFD and at-site IFD, for Morning View and Bray Park. The values are calculated by subtracting the at-site value from the BoM IFD value and divided by the IFD value. This means positive values are the percentage that the BoM IFD is overestimating the IFD at the location, and negative values are an underestimation. The complete graphs associated with these tables are included in Appendix N.

Table 46: Morning View IFD Comparison

| Dur \AEP | Percentage difference from IFD (IFD – at site) / IFD (%) | | | |
|---|---|---|---|---|
| | 10% | 5% | 2% | 1% |
| 0.5 hr | 15.7 | 17.9 | 24.7 | 23.3 |
| 2 hr | 11.1 | 19.9 | 18.2 | -2.4 |
| 6 hr | -18.8 | -5.7 | 10.9 | 20.5 |
| 9 hr | -12.1 | -2.7 | 14 | 21.1 |
| 12 hr | -13.7 | 4.3 | 17.1 | 17.5 |
| 24 hr | -6.7 | 3.10% | 15 | 20.1 |

Table 47: Bray Park IFD Comparison

| Dur\AEP | Percentage difference from IFD (IFD – at site) / IFD (%) | | | |
|---|---|---|---|---|
| | 10% | 5% | 2% | 1% |
| 0.5 hr | 4.8 | -0.7 | 8.2 | 13.4 |
| 2 hr | -8.3 | 4.6 | 10.3 | 8.9 |
| 6 hr | -7.3 | 5.5 | 19.7 | 26.8 |
| 9 hr | -0.7 | 9.2 | 22.6 | 28.9 |
| 12 hr | -5.3 | 4.6 | 13.6 | 20.9 |
| 24 hr | 3.5 | 8.3 | 15.8 | 17.5 |

Morning View and Bray Park show a close agreement between the IFD calculated at the gauge and that retrieved from BoM. Most durations are either very similar or slightly higher in the IFD representation at that point, and there is a fairly even distribution of values higher and lower than the BoM IFD estimate. As such, the BoM data is considered a reasonable representation of the rainfall at this location.

The next location considered was Kunghur in Table 48.

Table 48: Kunghur IFD Comparison

| Dur\AEP | Percentage difference from IFD (IFD – at site) / IFD (%) | | | |
|---|---|---|---|---|
| | 10% | 5% | 2% | 1% |
| 0.5 hr | 12.01 | 17.46 | 22.59 | 23.74 |
| 2 hr | 15.68 | 15.75 | 10.73 | -1.79 |
| 6 hr | 9.96 | 6.05 | -0.23 | -12.86 |
| 9 hr | 1.59 | 7.94 | 11.97 | 6.15 |
| 12 hr | 4.1 | 6.86 | 13.48 | 14.96 |
| 24 hr | 10.35 | 12.23 | 22.97 | 28.24 |

The Kunghur BoM IFD data includes a small systematic over estimation for all durations and all AEPs. Almost all values are positive at almost all durations. As such the BoM IFD estimate in this area is larger than that measured at the site. However, the size of this systematic bias is considered relatively small and will not have a marked impact on the design flood process.

A further IFD comparison was undertaken at the Upper Rous River alert gauge, as shown in Table 49. The Upper Rous gauge is an alert gauge with only 10 years of record. The shorter record means that the plotting positions of the recorded depths only extend out to the 5% AEP, as reflected in the table provided.

Table 49: Upper Rous IFD Comparison

| Dur\AEP | Percentage difference from IFD (IFD – at site) / IFD (%) | | | |
|---|---|---|---|---|
| | 50% | 20% | 10% | 5% |
| 0.5 hr | 19.73 | 34.18 | 30.96 | 27.59 |
| 2 hr | 15.55 | 31.6 | 32.5 | 32.78 |
| 6 hr | 19.73 | 34.18 | 30.96 | 27.59 |
| 9 hr | 11.82 | 16.8 | 19.52 | 32.55 |
| 12 hr | 10 | 16.75 | 15.4 | 25.96 |
| 24 hr | 10.99 | 0.75 | 2.46 | 19.15 |

It is important to note that there was only 10 years of record to make use of in this location which could skew the analysis. The result of the analysis shows that there was an over estimation of depth for the shorter durations for the IFD, with a good comparison occurring at longer durations.

An IFD comparison was undertaken at the Doon Doon gauge, as show in Table 50. Doon Doon gauge is an alert gauge with only 15 years of record (2005-2020) sub daily information and 60 years of daily data for this gauge (1953-2022).

Table 50: Doon Doon IFD Comparison

| Dur\AEP | Percentage difference from IFD (IFD – at site) / IFD (%) | | | |
|---|---|---|---|---|
| | 10% | 5% | 2% | 1% |
| 0.5 hr | -35 | -59 | -65 | -46 |
| 2 hr | -14 | -12 | 4 | 11 |
| 6 hr | -9 | -2 | 11 | 10 |
| 9 hr | -27 | 1 | 18 | 13 |
| 12 hr | -19 | 10 | 22 | 7 |
| 24 hr | 7 | 1 | 11 | -8 |

The analysis at Springbrook gauge, as shown in Table 51, showed a systematic underestimation in IFD in this region, and this could be influencing the headwaters of the Rous.

Table 51: Springbrook Upper IFD Comparison

| Dur\AEP | Percentage difference from IFD (IFD – at site) / IFD (%) | | | |
|---|---|---|---|---|
| | 10% | 5% | 2% | 1% |
| 0.5 hr | 6.4 | 14 | 4.4 | 7 |
| 2 hr | -21.6 | -5.6 | -2.1 | 7 |
| 6 hr | -30.8 | -13 | -15.4 | -6.1 |
| 9 hr | -33.6 | -10 | 10.1 | 22 |
| 12 hr | -30.8 | -14.5 | -28.8 | -22 |
| 24 hr | -53.8 | -34.1 | -48.7 | -41.8 |

The Springbrook Upper gauge demonstrates a reasonable agreement for all shorter duration storms, up until approximately the 12hr burst. From then on there appears to be a bias to underestimation in IFD. This could have an impact on local area flooding in the northern part of the Rous catchments and will be explored further during the design simulation process through a comparison between the FFA and design flows on the Rous River at Boat Harbour 3 to validate this data.

The Lockyer, Ipswich and Moreton Bay IFD dataset (Reference 18) was developed as an update to the 2016 IFD information available for that region. The outcomes of that report indicated that generally the sub daily IFD grid was oversmoothed in the 2016 IFD, particularly in areas with an orographic enhancement due to elevated terrain. The same behaviour can be seen in the pluviograph records for the Tweed region, with a good match achieved for gauges on the floodplain, an overestimation at the base of the range in the Upper Rous and an underestimation at the Springbrook Park gauge. The Tweed catchment is characterised by areas with large height variations, which would be expected to cause similar orographic enhancements in rainfall on each of the major tributaries to the Tweed catchment, including the Tweed and Rous rivers, and Oxley River. The FFA's developed in the upper reaches of the catchment for this flood study will be used to validate the rainfall depths in these regions, with the potential to modify the design rainfall to account for these effects.

While there is some discrepancy between the at-site IFD and BoM IFD depths, the implications will be further assessed during design event analysis. There are a number of hydrologic mechanisms in the design event estimation process that may result in the variances presented being inconsequential to the outcomes of the assessment, such as of initial and continuing losses.

# 13. DESIGN EVENT ESTIMATION

As this is a regional study, several key focus locations (refer Section 13.1) were assessed heading down the catchment to incorporate the effects of the Areal Reduction Factor (ARF) and areal temporal patterns on the design flows generated for each location. Local focus locations, some utilising point temporal patterns, were also considered to represent the upper reaches of the catchment.

The WBNM models were used to estimate design flood discharges throughout the study, using design rainfall Intensity-Frequency-Duration (IFD) data from BoM and applying model parameters based on the results of the joint calibration undertaken in Stage 2: Calibration report (WMAwater, 2023). The critical duration and temporal pattern selections are in accordance with ARR2019 guidelines (refer Section 13.6). Frequent to rare design event results are presented in Section 13.7 and the incorporation of Climate Change is covered in Section 13.3. The PMF assessment and results are covered in Section 13.9.

## 13.1. Focus Locations and Areal Reduction Factor (ARF)

The selection of a focal point in the study affects hydrologic model parameters, including ARF and temporal pattern selection (point or temporal). The focus locations in this study were selected based on populated zones in the catchment, or at areas of interest such as at key gauges in the system, to ensure analysis is completed for a representative cross-section of the catchment. A map showing the local focus locations assessed in the hydrologic models is provided in Figure 28. The contributing area to each focus location and its placement within the hydraulic model extents is shown in Figure 28.

An Areal Reduction Factor (ARF) is a correction factor to adjust the mean of the point rainfall depth to the catchment rainfall depth. It is a function of the total catchment area, the duration of the design rainfall event and its AEP. Thus, ARF varies with the selection of a focus location in WBNM. Both point and areal temporal patterns were applied to several of the focal locations. Both concepts were included in the hydrologic modelling; the details and model parameters adopted at each focus location are summarised in Table 52.

Table 52: Details of Focus Locations Assessed

| Focus ID | Location | Area ($km^2$) | Areal Temporal Pattern | Point Temporal Pattern | WBNM Model |
|---|---|---|---|---|---|
| Pal | Palmers Road | 154 | ECS 200 $km^2$ | Yes | Palmers |
| Uki | Uki | 231 | ECS 200 $km^2$ | Yes | Uki |
| Eun | Eungella | 214 | ECS 200 $km^2$ | Yes | Eungella |
| Mur | Murwillumbah | 649 | ECS 500 $km^2$ | Yes | Murwillumbah |
| Boat | Boat Harbour | 130 | ECS 100 $km^2$ | Yes | Boat Harbour |
| Tum | Tumbulgum | 916 | ECS 1,000 $km^2$ | Yes | Tumbulgum |
| Cob | Cobaki | 10 | None (point) | Yes | Cobaki |

## 13.2. Design Event Parameters and Losses

The WBNM model parameters nominated for design event modelling were adopted based on the results of the joint calibration, which fit a routing and lag parameter value to the four historic events for each model. Design rainfall losses were selected through reconciliation to the FFA at Uki, Eungella, Boat Harbour, Murwillumbah and Cobaki.

ARR2019 guidance for loss selection is to use an average of the calibrated losses where sufficient data exists, otherwise to apply the Data Hub losses. Both the average calibrated losses and average Data Hub loses were tested in the hydrologic models, as well as various iterations of varying the initial loss. Ultimately, zero initial and continuing losses were applied in all models to better fit the curves shown in the FFA across all gauges.

## 13.3. Design Event Rainfall

As part of the revision to ARR2019, the BoM updated the Intensity-Frequency-Duration (IFD) design rainfalls from those previously derived for ARR1987; these are referred to as the BoM 2016 IFDs. The update included more than 30 years of additional rainfall and data from rainfall stations, use of updated statistical methods and extension of the IFD estimates to include rare events, all of which generally resulted in significant improvements as compared to the 1987 estimates.

Since this update, some of the local Councils discovered inconsistencies between their own rain gauge records and the 2016 IFDs, and that spatial behaviour noted through their extensive pluviograph networks was not present in the updated IFDs. Due to these concerns, design IFD comparisons were conducted at key gauges within the Tweed catchment to understand the associated differences between at-site IFDs and BoM IFDS.

### 13.3.1. Design IFD Comparison

ARR 2019 guidelines for design flood modelling were adopted for this study, including the use of ARR 2019 design information for all IFD. A comparison was undertaken between the IFD estimation provided by the BoM and the three longest continuous rainfall records available in the catchment. The analysis was inconclusive as the BoM design IFD values were too long in comparison to the at-site IFD information given the short record of information. Given the inconclusive nature of the analysis it was established that the BoM IFD values would be adopted for the study. Further details of this comparison are provided in Section 12.2.

To ensure that the design IFDs utilised flows with a good correlation to historical flow (recorded at key flow gauges throughout the catchment), the full suite of design event models were run, with the peak flows then compared with the gauging locations. Table 53 shows the results of the analysis utilising the selected design event losses (zero losses).

In general, there is a good match to FFA flows and the design event flows modelled. The primary variances are occurring in Uki and Cobaki however it is noted that the period of length at Cobaki limits its functionality for events greater than the 1% AEP. At Uki large scale events are highly sensitive to catchment conditions, with small changes in roughness resulting in large changes in water level at the location. It is considered the flow outcomes at the site are within the tolerances of the certainty of the model given the dynamic response that occurs in the area.

Table 53: Comparison of Hydrologic Model - Hydraulic Model Results to FFA Results

| Gauge | Results | Years of Data | Estimated Discharge ($m^3/s$) | | | |
|---|---|---|---|---|---|---|
| | | | 20% | 5% | 1% | 0.20% |
| Uki | FFA | 102* | 1100 | 1816 | 2875 | 3278 |
| | Modelled | | 1033 | 1809 | 2270 | 2534 |
| | *Diff (%)* | | -6% | 0% | -21% | -23% |
| Eungella | FFA | 76 | 651 | 1190 | 1825 | 2449 |
| | Modelled | | 848 | 1591 | 1897 | 2125 |
| | *Diff (%)* | | 30% | 34% | 4% | -13% |
| Murwillumbah | FFA | 107 | 1700 | 2631 | 3419 | 4006 |
| | Modelled | | 2000 | 2646 | 3200 | 3626 |
| | *Diff (%)* | | 18% | 1% | -6% | -9% |
| Boat Harbour | FFA | 67 | 588 | 892 | 1216 | 1520 |
| | Modelled | | 535 | 850 | 1329 | 1539 |
| | *Diff (%)* | | -9% | -5% | 9% | 1% |
| Cobaki | FFA | 42 | 76 | 140 | 239 | 370 |
| | Modelled | | 83 | 114 | 209 | 255 |
| | *Diff (%)* | | 9% | -19% | -13% | -31% |

## 13.4. Scour

It was determined that the scour that was identified in the 2022 flood event would likely occur in the 1% AEP, 0.2% AEP and PMP events, with all smaller events i.e. the 20% AEP and 5% AEP, to assume that the Tweed entrance was not scoured. With and without scour in the 1% AEP has very little impact on the results at Murwillumbah, but as was evident in the 2022 event modelling, the scouring of the entrance enabled a different flow behaviour downstream of Barney's Point bridge.

## 13.5. Climate Change Analysis

The design rainfalls used to generate design discharge estimates are based on observed rainfall data and that primarily represents the climate of the 20$^{th}$ century. A climate change assessment is important in understanding the impact of future climates on the study area.

A Climate Change (CC) projection was run for the 5 % AEP and 1% AEP event using a low and high greenhouse gas emission scenario, which assumes a horizon (year) of 2090. The high emission scenario uses a Representative Concentration Pathway (RCP) of 8.5. These conditions equate to an increase in rainfall of 19.7%. The sea level conditions outlined in *Tweed Estuary Tidal Inundation Assessment and Mapping* report for sea level rises were adopted as the boundary conditions in the climate change scenario. The RCP 8.5 2090 sea level rise of 0.91 m has been adopted for this climate change scenario.

The low emission scenario uses a Representative Concentration Pathway (RCP) of 4.5. These conditions equate to an increase in rainfall of 9.5%. The sea level conditions outlined in *Tweed Estuary Tidal Inundation Assessment and Mapping* report for sea level rises were adopted as the boundary conditions in the climate change scenario. The RCP 4.5 2090 sea level rise of 0.71 m has been adopted for this climate change scenario.

The critical events nominated for the 5% AEP and 1% AEP event were run with this scenario; the resulting extents and levels are provided in Appendix R.

## 13.6. Critical Durations

The critical duration is the duration and temporal pattern that best represents the mean or median flood behaviour for a specific design event. The selection of critical durations and temporal patterns was completed at a series of regional focus locations progressing down the Tweed River and at additional local focus locations in the headwaters of the catchment. The aim of this assessment was to ensure that an appropriate envelope of design flows was assessed across the full extent of the catchment, such that the system was not dominated by a singular duration and/or temporal pattern. Without accounting for this, durations/temporal patterns deemed critical in the upper reaches of the catchment were noted to be overpowered by those deemed critical at locations further downstream in the system.

The initial critical duration and temporal selection was made based on the WBNM output, as discussed below, and then refined using the hydraulic model results. In some cases, multiple durations were assessed where predicted peak flows from the hydrologic model were similar.

The WBNM results, represented as box and whisker plots generated by the Python tool, were used to assess the critical durations and temporal patterns. Both the temporal pattern one above mean and temporal pattern one above median were considered in the temporal pattern selection, with the one above mean preferred if the visual result was reasonable.

Whilst selection of the median pattern (R6) removes the influence of potential outliers, the selection of one above the mean accounts for all ten data points. In many cases it is difficult to ascertain if potential outliers should be included or excluded, so assessing both options provides the fullest picture of the data. The spread of the box and whisker plot was also considered and occasionally led to the exclusion of long durations which appeared to be critical at face value. If neighbouring peak flows were similar across multiple durations, these were tested in the hydraulic model.

Areal Temporal Patterns were adopted in the study but when those patterns were run through the hydraulic model, there was insufficient volume within the storm to provide peak water levels that were comparable to the 2009 study. Looking at the history of how the Tweed catchment floods, an event is usually preceded by a smaller event before the main storm system, which often “primes” the system. To combat this issue, point temporal patterns were run through the hydrologic model. Point temporal patterns are recommended for smaller catchments however often have more reasonable temporal shapes than areal temporal patterns on the east coast. This is due to the fact that there were more datasets available to inform the point temporal pattern datasets in ARR2019.

Events with a similar peak flow to the critical areal temporal pattern were chosen for similar or longer durations to understand the impact on the hydraulic peak water level results. It was established that the point temporal patterns were critical in the hydraulic model as they had increased volume in the network, that enabled a more representative peak water level to be achieved in the lower end of the Tweed catchment given that the system is volume driven, not peak flow rate driven.

Table 54 provides a summary of the critical duration and temporal patterns at focal locations tested in the hydraulic model. Table 55 provides a summary of the peak flows produced by the hydrologic model for each AEP event at each focus location. In addition to the below, a 60 minute short duration event has been run for each AEP to enable consideration of short duration events at the headwater zones of the catchment.

Table 54: Critical Events Run in the Hydraulic Model

| Focus | Rationalised Critical Event Selection | | | |
|---|---|---|---|---|
| | **20%** | **5%** | **1%** | **0.2%** |
| Pal | 720 TP4805<br>**1080 TP4836** | 540 TP4760<br>720 TP4800<br>1080 TP4824<br>1440 TP4680 | 540 TP4746<br>**1080 TP4748** | 540 TP4746<br>720 TP4787<br>**1080 TP4824**<br>1440 TP4655 |
| Uki | 540 TP4771<br>720 TP4807<br>1080 TP4836<br>1440 TP4883<br>**2160 TP4936** | 720 TP4703<br>1080 TP4828<br>1440 TP4871<br>2160 TP4916 | 540 TP4743<br>**720 TP4751**<br>1080 TP4727<br>1440 T4655 | 540 TP4745<br>**720 TP4786**<br>1080 TP4816<br>1440 TP4655 |
| Eun | 540 TP4774<br>720 TP4809<br>1080 TP4833<br>**1440 TP4847** | 720 TP4703<br>1080 TP4828<br>1440 TP4871<br>2160 TP4914 | 540 TP4745<br>720 TP4787<br>1080 TP4727<br>**1440 TP4655** | 540 TP4745<br>**720 TP4787**<br>1080 TP4816<br>1440 TP4817 |
| Mur | 1080 TP4833<br>1440 TP4883<br>2160 TP4936<br>**2880 TP4957** | 1080 TP4826<br>1440 TP4835<br>2160 TP4914<br>**2880 TP4947** | 1080 TP4816<br>1440 TP4856<br>2160 TP4912<br>**2880 TP4858** | 1080 TP4816<br>**1440 TP4817**<br>2160 TP4908<br>2880 TP4858 |
| Boat | 540 TP4773<br>720 TP4809<br>1080 TP4833<br>1440 TP4847<br>**2160 TP4933**<br>2880 TP4957 | 720 TP4703<br>1080 TP4826<br>1440 TP4873<br>2160 TP4921<br>2880 TP4812 | 540 TP4746<br>720 TP4747<br>**1080 TP4748**<br>1440 TP4749<br>2160 TP4912<br>2880 TP4939 | 540 TP4746<br>**720 TP4787**<br>1080 TP4748<br>1440 TP4749<br>2160 TP4753<br>2880 TP4939 |
| Cob | 270 TP4709<br>360 TP4739<br>540 TP4776<br>**720 TP4804** | 270 TP4704<br>360 TP4696<br>540 TP4760<br>**720 TP4800** | 270 TP4693<br>360 TP4694<br>540 TP4442<br>**720 TP4785** | 270 TP4693<br>360 TP4596<br>540 TP4442<br>**720 TP4785** |
| Tum | **1440 TP 4883** | **1440 TP 4871** | **2160 TP4912** | **2160 TP4908** |

Table 55: WBNM Peak Flows for the Critical Events Selected at Focus Locations

| Focus | Peak Flows at Focus Locations ($m^3/s$) | | | |
|---|---|---|---|---|
| | 20% | 5% | 1% | 0.2% |
| Pal | 670 | 1020 | 1550 | 1810 |
| Uki | 1200 | 1840 | 2730 | 3220 |
| Eun | 820 | 1240 | 1840 | 2180 |
| Mur* | 2270 | 3470 | 4830 | 5780 |
| Boat | 530 | 790 | 1220 | 1450 |
| Cob | 60 | 100 | 150 | 180 |
| Tum* | 2734 | 4174 | 6207 | 7502 |

*Due to the location of the Gauge and the bypass that occurs the hydrologic model overestimates flow relative to the FFA analysis undertaken

## 13.7. Design Event Inflows

Each focal location has a certain amount of the catchment contributing, which is used to inform the ARF upstream of this location. In order to ensure that areas that use a smaller ARF do not unintentionally result in higher flows downstream only flows upstream of the focal location are input into the hydraulic model. Figure 30 to Figure 35 illustrated the inflows used for each focal location within hydraulic model.

## 13.8. Design Event Tidal Scenario

Design events produced for the Tweed Flood Study are made up of an envelope of catchment flood events and coincident oceanic inundation. The scenarios used for each design flood event are outlined in Table 56 below based on guidance provided in Reference 26.

Table 56: Oceanic Scenarios and Catchment Scenarios Used for Each Design Flood Event

| Design Event | Ocean Inundation | Catchment Inundation | Outlet Condition | Results |
|---|---|---|---|---|
| 20% AEP | HHWS* | 20% AEP | No Scour | 20% AEP results |
| 5% AEP | 5% AEP ocean level | Nil | No Scour | 5% AEP results |
| | HHWS* | 5% AEP | No Scour | |
| 1% AEP | 5% AEP ocean level | 1% AEP | 2022 Scour | Enveloped results for maximum water level and depth for the 1% AEP event |
| | 1% ocean level | 5% AEP | 2022 Scour | |
| | ISLW** | 1% AEP | 2022 Scour | Peak velocity results for 1% AEP event |
| 0.2% AEP | 1% AEP ocean level | 0.2% | 2022 Scour | 0.2% AEP results |
| PMF | 1% AEP ocean level | PMF | 2022 Scour | PMF results |

* HHWS – High Water Springs (Solstice Spring)

** ISWL - Indian Spring Low Water

## 13.9. Probable Maximum Flood Event

An assessment of the reasonable upper limit of flooding, referred as the Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF), was completed for Tweed River within the study area. The World Meteorological Organization defines the PMP as *'the greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of year'*. Estimating the PMP and PMF comes with significant uncertainty, as there is limited physical evidence or data for such extreme floods. To obtain such estimates requires significant extrapolation from observed events or physical reasoning.

### 13.9.1. Methodology

The different methods of estimating the PMP are tailored to different catchment characteristics and locations. For this study, the applicable methods include the Generalised Short Duration Method (GSDM) which is relevant for durations less than six hours and smaller catchments up to 1,000 km$^2$, and the Generalised Tropical Storm Method (GTSMR) for longer durations up to 120 hours and larger catchments up to 150,000 km$^2$ in the region of Australia where tropical storms result in the greatest depths of rainfall. Both methodologies were developed by BoM and have associated guidance for completing the assessments (References 24 and 25).

Once the preliminary GSDM and GTSMR estimated depths were determined, the results were charted and GTSMR results were tweaked where necessary to best marry up the two datasets. The 9-hour and 18-hour events rainfall depths were then interpolated from the curve.

Table 57 provides a summary of the PMP assessments completed for this study. Note that the estimated AEP is based on ARR2019 (Reference 2, Book 8 Chapter 3). The parameters and assumptions used in generating the PMP depth estimates are detailed in the following sections, and the results are presented in Section 13.9.7.

Table 57: Summary of PMP Assessments within the Study Area

| Location | Area (km$^2$) | Estimated AEP | Method of Assessment |
|---|---|---|---|
| Tweed River – Murwillumbah | 649 | 1 in 5,000,000 | GTSMR |
| Oxley River – Eungella | 214 | 1 in 8,500,000 | GSDM |
| Tweed River – Uki | 231 | 1 in 8,500,000 | GSDM |
| Rous River – Boat Harbour | 130 | 1 in 9,500,000 | GSDM |
| Cobaki Creek – Cobaki | 10 | 1 in 10,000,000 | GSDM |

### 13.9.2. Parameters

The GSDM parameters adopted in the assessment are provided in Table 58, and the parameters used in the GTSMR assessed are provided in Table 59.

Table 58: GSDM Rainfall Parameters Adopted

| Parameter | Murwillumbah | Eungella | Uki | Boat Harbour | Cobaki |
|---|---|---|---|---|---|
| Catchment area ($km^2$) | 649 | 214 | 231 | 130 | 10 |
| Elevation Adjustment Factor, EAF | 1 | 1 | 1 | 1 | 1 |
| Moisture Adjustment Factor, MAF | 0.8 | 0.82 | 0.82 | | |
| Terrain Factor | 1 (rough) | 1 (rough) | 1 (rough) | 1 (rough) | 1 (rough) |

Table 59: GTSMR Rainfall Parameters Adopted

| Parameter | Murwillumbah |
|---|---|
| Catchment area | 649 |
| GTSMR zone | Coastal |
| Average Topographical Adjustment Factor, TAF | 1.71 |
| Average Decay Amplitude Factor, DAF | 0.95 |
| Average EPW (Annual) | 85.87 |
| Average Moisture Adjustment Factor (Annual), MAF | 0.72 |

### 13.9.3. Temporal Patterns

The GSDM utilises a singular design temporal distribution detailed in the guidance from BoM. The GTSMR utilises an ensemble approach with ten areal temporal patterns based on the ten largest storms in the storm database, also provided by BoM.

In addition to this, ARR2019 guidance specifies that the Average Variability Method (AVM) and its temporal pattern (also provided by BoM) should also be considered. This is further discussed in Section 13.9.6.

### 13.9.4. Spatial Distribution

The design spatial distribution of rainfall across the catchment used in the GSDM assessment is based on fitting a series of ellipses to the catchment, ensuring the best fit to the catchment by the smallest ellipse. The distribution assumes a stationary, convective storm. The GSDM spatial distribution is illustrated in Diagram 49.

There is limited knowledge about the spatial distribution of GTSMR style events, so this is inferred from the most probable distribution of the topographic component of rainfall within the catchment. In the GTSMR assessment, this is accounted for through the TAF (topographic adjustment factor) grid. The TAF grid represents the average ratio between the 72-hour 50-year IFD to flat-land IFD. The TAF applied in the assessment is determined at a sub-catchment level for greater spatial resolution.

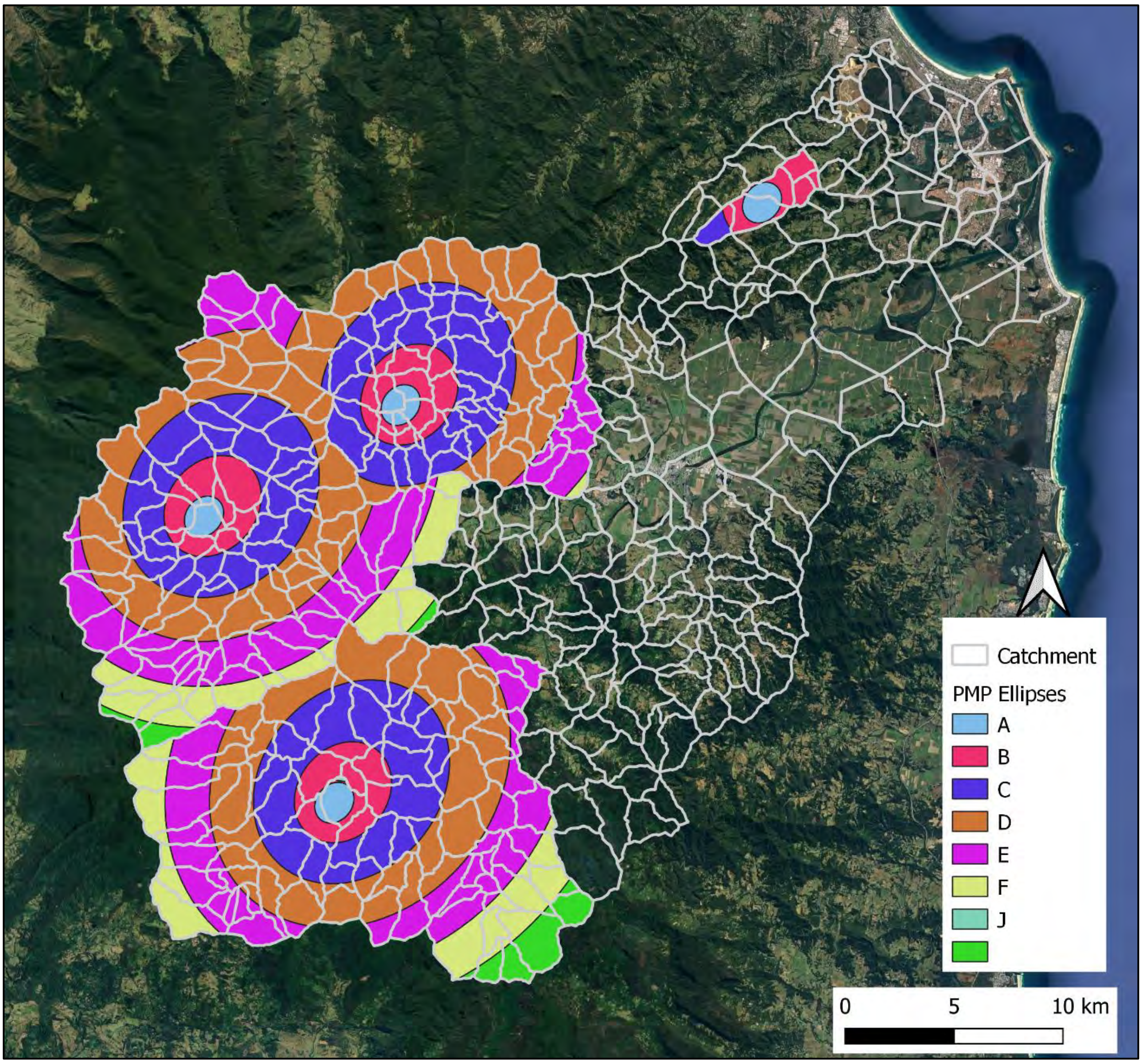



Diagram 49: GSDM Spatial Distribution

### 13.9.5. Losses

In extreme events, a much greater proportion of the catchment may become saturated during the event. The catchment may also experience stripping of vegetation, resulting in an increase in the volume and speed of the overland flow.

The initial and continuing loss design event approach was maintained, with losses selected for each PMP assessment based on ARR2019 guidelines and considering the losses used in the rare design event modelling. An initial loss of 0 mm and a continuing loss of 0 mm/h were selected for each assessment.

### 13.9.6. Average Variability Method

ARR2019 guidance recommends checking the GTSMR ensemble results against those generated by the Average Variability Method (AVM) pattern for the durations modelled. The AVM pattern represents an AEP-neutral event and generally falls close to the mean for each duration modelled. This was used to verify that reasonable PMP estimates were developed.

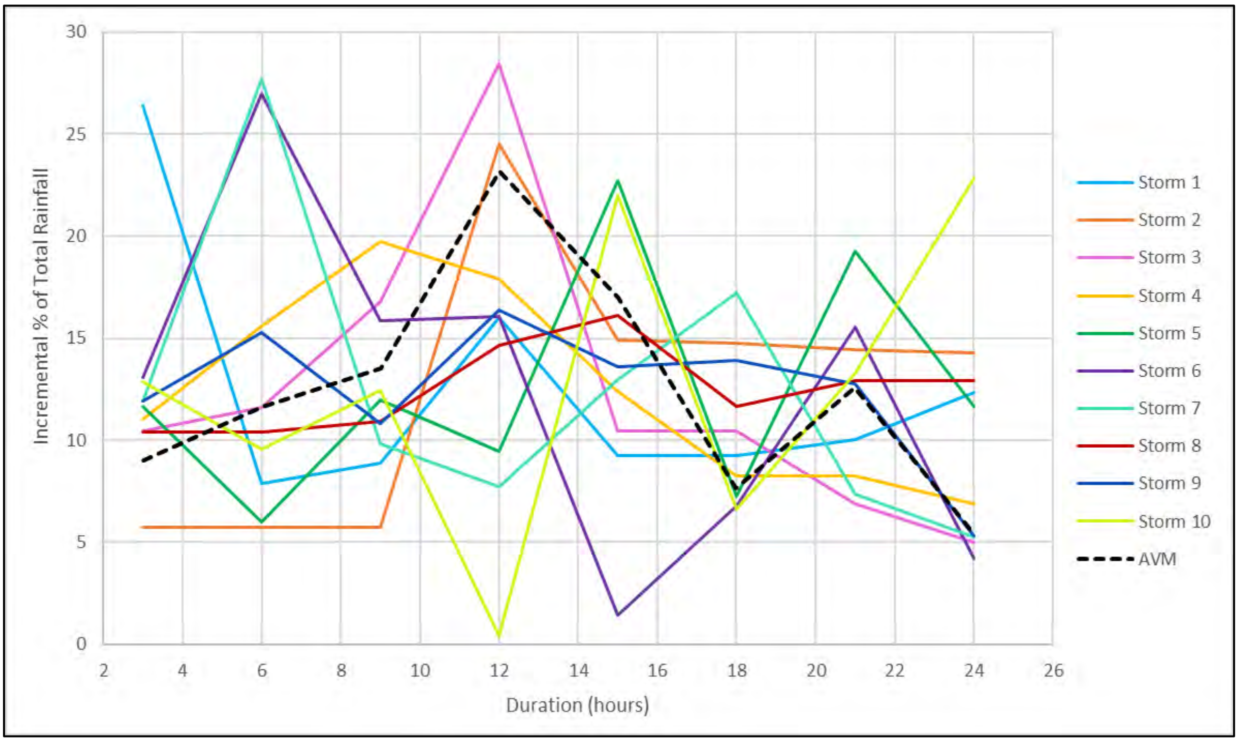



Diagram 50: Comparison of Ensemble Temporal Patterns to AVM Pattern for a 24-hour Duration Storm and 2,500 km$^2$ Spatial Extent in the Coastal Zone

For the example of the 24-hour duration patterns, the largest increment in the AVM pattern is 23% as compared to the ensemble patterns, which have maximum increments ranging from 16% to 28.5%. This translates to a difference of 900 m$^3$/s between methods for the 24-hour duration, as presented in Table 60. The AVM check was run for the 24-hour to 120-hour duration storms but did not exceed the maximums of the ensemble patterns chosen as critical events.

Table 60: Comparison of Ensemble Temporal Pattern Discharges to AVM Pattern Discharges

| Location | Murwillumbah | | |
|---|---|---|---|
| Duration (h) | 24 | 36 | 48 |
| Ensemble mean discharge (m$^3$/s) | 14,608 | 9,097 | 7,766 |
| Ensemble max discharge (m$^3$/s) | 18,840 | 15,865 | 11,630 |
| AVM max discharge (m$^3$/s) | 16,774 | 12,668 | 9,572 |
| Difference to mean | 15% | 39% | 23% |
| Difference to max | -11% | -20% | -18% |

### 13.9.7. Results

The critical durations for the GSDM were selected based on the duration resulting in the highest peak flow as per ARR2019 guidance. The selection of critical events for the GTSMR method followed this same process, and additionally considered the spread of the temporal patterns in the box and whisker plot to determine the temporal pattern resulting in the highest reasonable peak flow for the nominated duration. The box and whisker plot for the GTSMR assessment is shown in Diagram 51. Peak flow results and critical events nominated for each of the assessments are provided in Table 61. The critical events naming convention refer to the real rainfall event that is defined within the GTSMR guidance that is used to determine the rainfall temporal pattern.

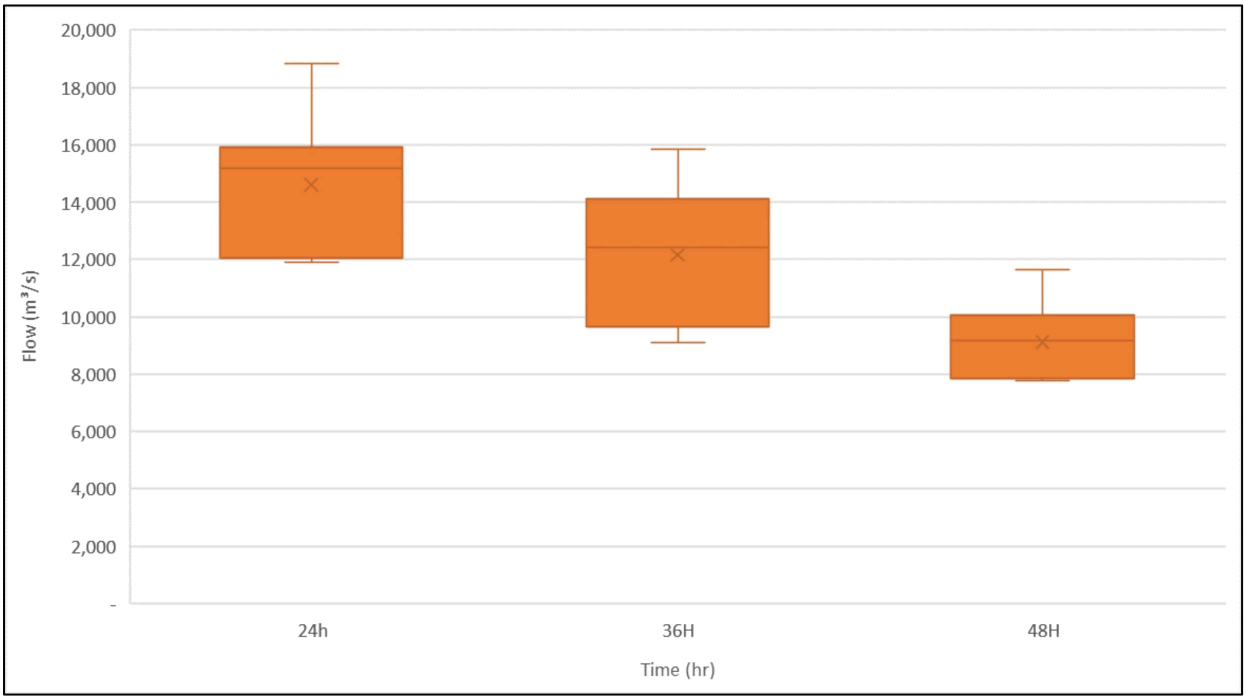



Diagram 51: Box Plot of GTSMR Results at Murwillumbah – PMF Event

Table 61: Critical Events and Maximum Discharges – PMF Event

| Location | Critical Events | Maximum Discharge ($m^3/s$) |
|---|---|---|
| Murwillumbah | 24h 1954 Feb 21 | 18,840 |
| Uki | 4h | 7,732 |
| Palmer | 4h | 5,892 |
| Eungella | 4h | 6,536 |
| Boat Harbour | 4h | 4,635 |
| Tumbulgum | 24h 1954 Feb21 | 25,426 |
| Cobaki | 4h | 645 |

# 14. DESIGN EVENT RESULTS

The design event modelling in the hydrologic and hydraulic model is a complex and interactive process that requires the investigation of multiple combinations of design parameters to establish an adequate representation of a design flood event for the catchment.

The design event results for the Tweed hydrology model focused on the seven (7) key gauges which cover key areas within the catchment. These gauges are; Eungella, Palmers Road, Uki, Boat Harbour, Murwillumbah, Tumbulgum and Cobaki Creek. The Palmers Road gauge has the shortest recorded therefore more confidence was placed on matching at Uki then Palmers Road.

Both Murwillumbah and Tumbulgum have flows that bypass the gauging location in large events leading to differences between bank flow and full-flood flow. Also, both of these gauges are tidally influenced leading to different water levels for the same flow.

The hydraulic model focused on ten (10) key level gauges that cover both the upper reaches of the catchment and the lower tidal reaches of the Tweed River. These gauges are:

- Bray Park weir;
- Murwillumbah Bridge (except 1989);
- North Murwillumbah;
- Tumbulgum;
- Barney’s Point;
- Tyalgum Bridge;
- Chillingham;
- Terranora; and
- Dry Dock.

## 14.1. Flow Assessment

Verification of the WBNM model peak flows and TUFLOW hydraulic peak flows against the FFA was undertaken at the six gauged locations investigated in this study. A summary of the results is presented visually in Appendix O and given in Table 62.

Table 62: Comparison of Hydrologic Model - Hydraulic Model Results to FFA Results

| Focus | Results | Estimated Discharge (m$^3$/s) | | | |
|---|---|---|---|---|---|
| | | **20%** | **5%** | **1%** | **0.20%** |
| Pal | FFA | 678 | 1529 | 2969 | 2969 |
| | WBNM | 632 | 974 | 1371 | 1613 |
| | TUFLOW | 600 | 1160 | 1600 | 1800 |
| | *Diff (%) FFA WBNM* | -7% | -36% | -54% | -46% |
| | *Diff (%) FFA TUFLOW* | -11% | -24% | -53% | -48% |
| Uki | FFA | 1100 | 1816 | 2875 | 3278 |
| | WBNM | 1198 | 1842 | 2586 | 3035 |
| | TUFLOW | 1033 | 1809 | 2270 | 2534 |
| | *Diff (%) FFA WBNM* | 9% | 1% | -10% | -7% |
| | *Diff (%) FFA TUFLOW* | -6% | 0% | -21% | -23% |
| Eun | FFA | 651 | 1190 | 1825 | 2449 |
| | WBNM | 797 | 1240 | 1759 | 2095 |
| | TUFLOW | 848 | 1591 | 1897 | 2125 |
| | *Diff (%) FFA WBNM* | 22% | 4% | -4% | -14% |
| | *Diff (%) FFA TUFLOW* | 30% | 34% | 4% | -13% |
| Mur | FFA | 1700 | 2631 | 3419 | 4006 |
| | WBNM | 2265 | 3470 | 4873 | 5769 |
| | TUFLOW | 2000 | 2646 | 3200 | 3626 |
| | *Diff (%) FFA WBNM* | 33% | 32% | 43% | 44% |
| | *Diff (%) FFA TUFLOW* | 18% | 1% | -6% | -9% |
| Boat | FFA | 588 | 892 | 1216 | 1520 |
| | WBNM | 525 | 788 | 1222 | 1452 |
| | TUFLOW | 535 | 850 | 1329 | 1539 |
| | *Diff (%) FFA WBNM* | -11% | -12% | 0% | -4% |
| | *Diff (%) FFA TUFLOW* | -9% | -5% | 9% | 1% |
| Cob | FFA | 76 | 193 | 239 | 370 |
| | WBNM | 61 | 102 | 146 | 176 |
| | TUFLOW | 83 | 114 | 175 | 194 |
| | *Diff (%) FFA WBNM* | -20% | -47% | -39% | -52% |
| | *Diff (%) FFA TUFLOW* | 9% | -41% | -27% | -48% |
| Tum | FFA | 1355 | 2537 | 4553 | 7580 |
| | WBNM | 2743 | 4294 | 6035 | 7119 |
| | TUFLOW | 2000 | 3000 | 3500 | 4800 |
| | *Diff (%) FFA WBNM* | 102% | 69% | 33% | -6% |
| | *Diff (%) FFA TUFLOW* | 48% | 18% | -23% | -37% |

There is generally good agreement between the WBNM and TUFLOW flows at gauge locations with the exception of Murwillumbah and Tumbulgum which has a significant breakout flow that does not pass through the gauge location.

At Boat Harbour and Eungella there was good agreement between the FFA and the WBNM and TUFLOWS over the whole range of events. The Murwillumbah model flows were critical at these locations within hydraulic model.

At Uki and Palmers Road, the hydrologic and hydraulic models illustrated less flows than the FFA predicted for the 1% AEP and 0.2% AEP flows. Better fit was achieved for the 20% AEP and 5% AEP with a higher deviation identified for the 1% AEP and 0.2% AEP. The rating curve at both Uki and Palmers Road constantly changes as scouring of the creek occurs and trees along the riverbank are ripped up during events. Between the two gauges Uki has a longer period of data and has been relied upon to ensure the design hydrology matches as closely to the FFA as possible. Hydraulic peak flows for Uki illustrated in Diagram 135 (Appendix O) demonstrates peak flows just outside the lower error bounds. While at Palmers Road which has a shorter period, hydraulic and hydrologic peak flows are within the error bounds.

These two locations were difficult to calibrate in the hydraulic model for the historical floods, so it is not surprising that during the design event modelling those same troubles and discrepancies that were identified during the calibrations stage are still evident during the design event modelling. Although the peak flows at Uki and Palmers Road are lower than the expected FFA peak flow, the current hydrologic model assumes no losses meaning that increased flows would likely require the design rainfall to increase. Based on the current IFD information, there was not sufficient information to alter the adopted design rainfall. It is likely as further rainfall events occur in this section of the catchment further information can be gathered to inform this decision.

The hydraulic model peak flows at Cobaki sits within the error bounds of the FFA with the hydrologic model peak flows just outside the lower confidence limits. The catchment that sits upstream of Cobaki is extremely small in comparison to the larger hydrologic and hydraulic model.

At Tumbulgum, which is tidally influenced, there is a poor agreement between the FFA, WBNM and TUFLOW. The FFA for this location cannot be relied upon as, at different flows that same water level can be achieved due to the hysteresis effect at the gauging location. There is very little ability to verify the design flows at the location given this. However, the hydraulic and hydrologic peak flows are within the error bounds of the assessment.

## 14.2. Level Assessment

Peak water levels within the model at key locations is presented visually in Appendix P and given in Table 63. The report locations are illustrated in Figure 36.

Table 63: Peak Water Levels

| River Location | ID | Name | Peak Water Level (mAHD) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 20% | 5% | 1% | 0.20% | PMF |
| Lower Tweed | 1 | 558041 Gauge-Letitia2A | 1.03 | 2.06 | 2.61 | 2.66 | 4.87 |
| | 2 | 558029 Gauge-Dry_Dock | 1.03 | 2.07 | 2.61 | 2. 66 | 4.94 |
| | 3 | 558056 Gauge-Terranora | 1.03 | 2.08 | 2.61 | 2.68 | 4.94 |
| | 4 | 558045 Gauge-Cobaki | 1.03 | 2.03 | 2.61 | 2.85 | 4.94 |
| | 5 | Cobaki Ck | 6.31 | 6.62 | 7.08 | 7.24 | 9.16 |
| Mid Tweed | 6 | Barneys Point | 1.27 | 2.03 | 2.66 | 3.24 | 6.45 |
| | 7 | 558102 Gauge_BarneysPt | 1.31 | 2.03 | 2.67 | 3.41 | 7.00 |
| | 8 | 558010 Flood_Gauge_Chinderah | 1.36 | 2.03 | 2.72 | 3.50 | 7.12 |
| | 9 | 558014 Tumbulgum | 2.72 | 3.32 | 4.02 | 4.54 | 8.53 |
| | 10 | Tygalgah (Smiths) (Reader) | 3.16 | 3.57 | 4.19 | 4.68 | 8.69 |
| Rous | 11 | Kynn Bridge No.3 (Reader) | 4.10 | 4.50 | 4.83 | 5.13 | 9.22 |
| | 12 | Boat Harbour (Rous River) (2) | 6.22 | 6.72 | 7.12 | 7.41 | 9.54 |
| | 13 | Boat Harbour (Rous River) | 6.29 | 6.90 | 7.34 | 7.65 | 9.96 |
| | 14 | 58204 Rous @ Boat Harbour 3 | 9.22 | 9.72 | 10.00 | 10.31 | 13.15 |
| | 15 | 58011 Chillingham_Bridge | 30.26 | 31.35 | 31.62 | 32.22 | 36.41 |
| Oxley River | 16 | 58193 Eungella | 21.01 | 22.94 | 23.78 | 24.08 | 27.20 |
| | 17 | 558088 Tyalgum_Bridge | 51.56 | 53.36 | 54.31 | 54.74 | 60.35 |
| Upper Tweed | 28 | 58186 North Murwillumbah | 4.87 | 5.41 | 6.01 | 6.41 | 10.37 |
| | 18 | 558067 Murwillumbah Bridge | 4.80 | 5.30 | 5.89 | 6.29 | 10.36 |
| | 19 | US_Murwillumbah Bridge | 4.88 | 5.44 | 6.06 | 6.46 | 10.46 |
| | 20 | Murwillumbah Lavender Ck | 4.99 | 5.63 | 6.29 | 6.65 | 10.53 |
| | 21 | Commercial Road (Reader) | 5.11 | 5.76 | 6.43 | 6.75 | 10.59 |
| | 22 | 558065 Bray Park Weir | 6.96 | 8.55 | 9.50 | 9.93 | 14.94 |
| | 23 | Bakers Byangum (Reader) | 8.51 | 9.87 | 10.69 | 11.09 | 15.99 |
| | 24 | 58167 Tweed @ Uki | 19.09 | 20.94 | 21.59 | 22.08 | 29.17 |
| | 25 | 558009 Clarrie Hall Dam Rd | 25.54 | 27.67 | 28.55 | 29.19 | 34.39 |
| | 26 | 558018 Tweed R @ D/s Palmer | 37.01 | 38.38 | 39.16 | 39.75 | 43.97 |
| | 27 | 558028 Clarrie Hall Dam | 64.68 | 65.62 | 66.50 | 66.86 | 68.77 |

## 14.3. Annual Exceedance Probability of 2017 and 2022 Floods

Based on the design flood levels, the Annual Exceedance Probability (AEP) of the 2017 and 2022 floods can be assessed. This is outlined in Table 64. Most of the events in 2017 and 2022 are within the same AEP range. Uki, Tumbulgum, and Barneys Point were estimated to have an AEP between 0.2% to PMF in 2022, which is different from the event in 2017. The differences between the peak levels in 2017 and 2022 can be attributed to the different dynamics of the rainfall events in the two years. For example, in 2022 at Uki, the main event followed a smaller event that occurred a couple of days before, such that the initial water level at the start of the main rainfall event was larger in 2022 (Diagram 81) compared to 2017 (Diagram 65). This resulted in a very high volume compared to 2017, resulting in disproportionately higher peaks in the mid-floodplain storage areas. A similar reason applies to Tumbulgum (Diagram 72 and Diagram 89) and Barneys Point (Diagram 74 and Diagram 91), with Barneys Point also affected by the tide.

Table 64: AEP of 2017 and 2022 Floods Based on Design Results

| Gauge | 2022 Recorded Peak Level (mAHD) | AEP of 2022 Flood | 2017 Recorded Peak Level (mAHD) | AEP of 2017 Flood |
|---|---|---|---|---|
| 58193 Eungella | 21.11 | 20% to 5% | 23.13 | 5% to 1% |
| Palmers Road | 38.63 | 20% to 5% | 38.08 | 5% to 1% |
| 58167 Uki | 22.42 | 0.2% to PMF | 21.89 | 1% to 0.2% |
| 58204 Boat Harbour at Rous River | 9.20 | 20% to 5% | 10.18 | ~0.2% |
| Cobaki Creek | 6.83 | 5% to 1% | 6.87 | 5% to 1% |
| 558065 Bray Park Weir | 9.26 | 5% to 1% | 9.25 | ~1.0% |
| 58186 Murwillumbah Bridge | 6.23 | 1% to 0.2% | 5.89 | 1% to 0.2% |
| 558014 Tumbulgum | 4.78 | > 0.2% | 3.96 | ~1.0% |
| 558102 Barneys Point | 2.91 | 1% to 0.2% | 2.22 | 5% to 1% |
| 558045 Cobaki | 1.95 | 5% to 1% | 1.52 | 5% to 1% |
| 558056 Terranora | 1.94 | 5% to 1% | 1.58 | 5% to 1% |
| 558029 Dry Dock | 1.74 | 5% to 1% | 1.39 | 5% to 1% |
| 558088 Tyalgum Bridge | 52.01 | 20% to 5% | 53.71* | 5% to 1% |

* Estimated

## 14.4. Flood Behaviour

The flood behaviour of the catchment is summarised in the following sections.

### 14.4.1. Murwillumbah

In Murwillumbah, the effects of flooding are varied. The Murwillumbah Township is protected by flooding from a river levee, which provides immunity up to the 1% AEP event, but is overtopped in the 0.2% AEP event from riverine flooding.

At the peak of the 1% AEP flood event, inundation in Murwillumbah CBD is minimal with small patches near Prince Street, Princes Lane and King Street. There is some inundation near the Dorothy Street levee near the Murwillumbah Leagues Club. Near the northern end of the East Murwillumbah levee near Mayal Creek there is a small pocket of inundation behind the levee on Tumbulgum Road.

In a 0.2% AEP event the Dorothy Street Levee, East Murwillumbah and the Murwillumbah CBD levees are completely overtopped leading to widespread flooding.

A detailed overtopping assessment of the levee and flooding in the Murwillumbah Township was undertaken in 2018 by Catchment Simulation Solutions. The local study is of a higher detail than this study and should be used to inform flood knowledge in the Murwillumbah Township.

### 14.4.2. South Murwillumbah

South Murwillumbah is affected by flooding in small events with depths up to 4 m in some low-lying areas (between Wardrop Street and Tweed Valley Way, and River Street) in the 20% AEP event. The South Murwillumbah levee provides some protection but begins to overtop when levels at the Murwillumbah Bridge reach approximately 4.8 mAHD.

South Murwillumbah is predicted to be fully inundated during the 1% AEP event from both Tweed River breakout and local runoff. Peak depths are up to 5 m in low lying areas, and up to 1.5 m over Tweed Valley Way.

The airfield acts as the major flow path from South Murwillumbah to Condong Creek during flood events velocity-depth products are greater than 0.3 $m^2/s$ across much of South Murwillumbah during the 1% AEP flood event.

### 14.4.3. Condong

Some areas of Condong are predicted to be inundated in small events including the 20% AEP flood. In the 1% AEP flood, most of Condong is inundated apart from a small, isolated area at the northern end of town (Maria and Carmen Place). Peak depths are up to 2 m in low lying areas, and up to approximately 1 m over Tweed Valley Way in the 1% AEP flood. Most buildings are located on the higher ground along Tweed Valley Way where depths are lower.

### 14.4.4. Tumbulgum

Tumbulgum is also predicted to be inundated by small flood events including the 20% AEP flood. At the peak of the 20% AEP flood event, most of the town is inundated apart from small areas of higher ground, with depths up to 1.5 m in low lying areas. During the 1% AEP flood event, the whole town is inundated, with depths up to 3 m in low lying areas. Velocities through town are small. In events larger than the 1% AEP flood event, Tweed Valley Way and the floodplain to the south become high flow areas with velocity-depth products above 0.3 $m^2/s$.

Within the design event assessment, it is noted the hydraulic grade was seemingly different to the grades present in the calibrated flood events between the river mouth (Entrance) and Tumbulgum. A review of the mechanism of this was undertaken. What is immediately identified is the ocean boundary conditions of the design events are significantly higher than the calibration events in the 1% and 0.2% AEP. This is a requirement of design flood modelling, set by NSW Flood Risk Management Manual guidance, and is to ensure that a conservative approach to ocean/tidal and riverine flood interactions is considered. This tailwater condition affects the levels in the design events up to approximately the western end of Dodds Island.

Once around the sharp bend near the Tweed Broadwater, there is a level change which starts to significantly reduce the tidal influence. At this location the 0.2% AEP and the 2022 event start to diverge, with the 2022 event becoming higher. This indicates that downstream of this location the tidal condition set was influencing the 0.2% AEP flood levels. Similar divergence in flood results are observed when comparing the 1% AEP and 2017 events. Downstream of this the higher tailwater present in the 1% AEP was affecting the design flood levels. Upstream of this location the water level grade between the modelled events is very similar. Based on the review it is considered that the majority of differences present in water level gradient are driven by the ocean tailwater condition applied to the design event simulations.

Review of historic event outputs from previous studies (Tweed Valley Flood Study, 2005, WBM Oceanics Australia) indicates similar behaviour has been present for all previous calibrated events, including the 1974 and 1989 events.

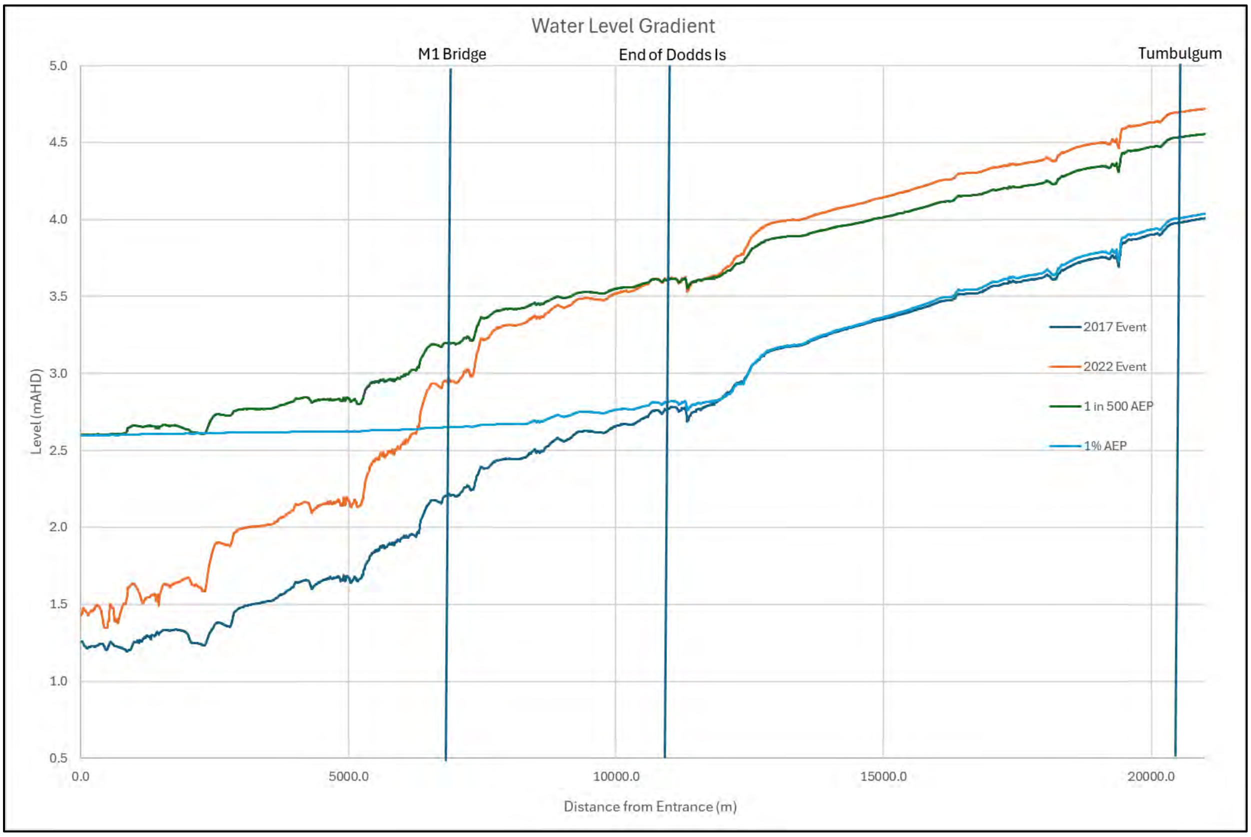



Diagram 52 – Water Level Gradient

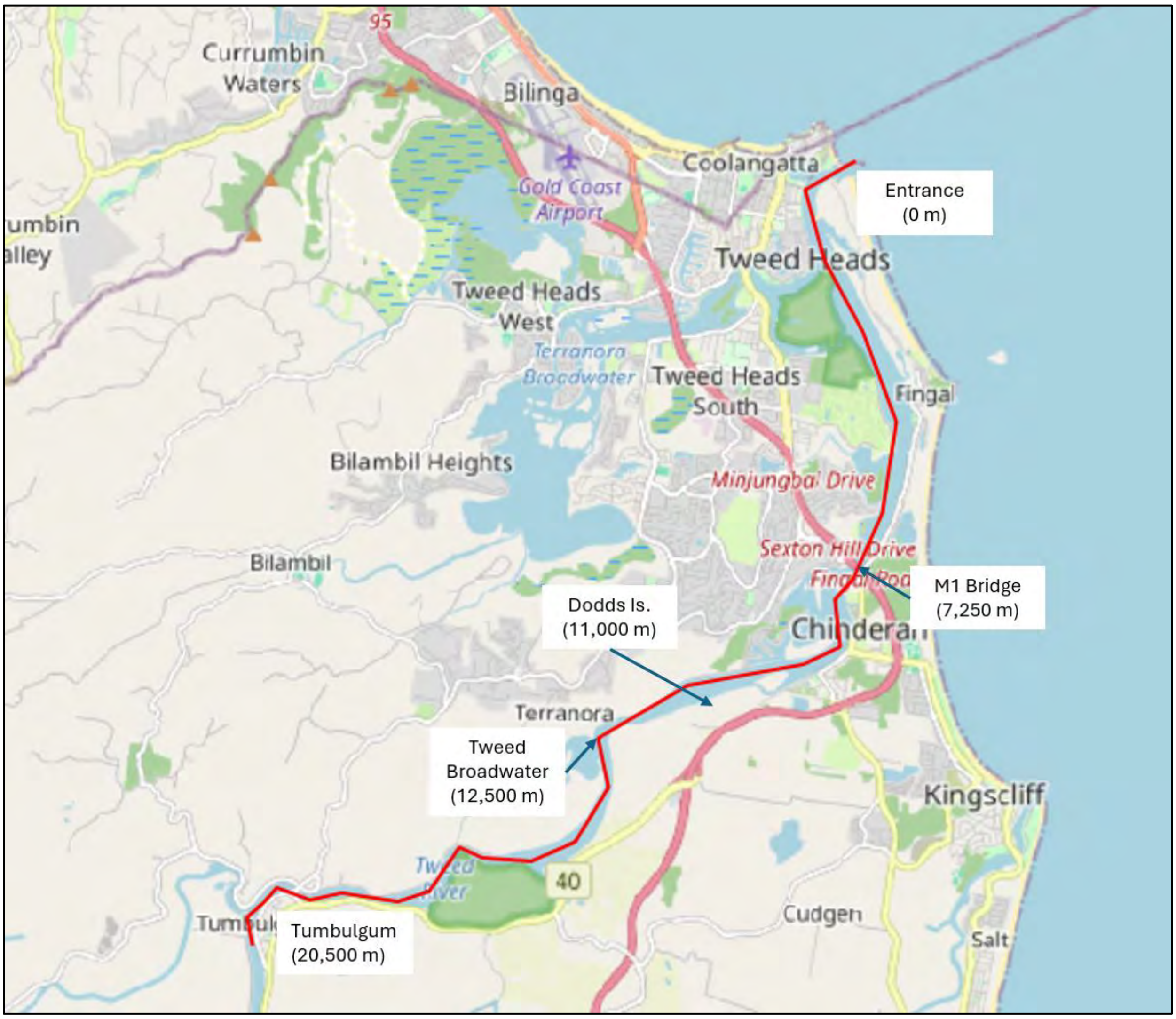



Diagram 53 – Long Section Profile Details

### 14.4.5. Chinderah

Large areas of Chinderah experience flooding in the 5% AEP event with depths up to 1.5 m in low lying areas adjacent to the Kingscliff drain. In the 1% AEP event, most of Chinderah is inundated with depths up to 2.5 m. Velocities are generally low (less than 0.1 m/s in most areas), and velocity-depth products are also generally low (less than 0.3 $m^2$/s) in the 1% AEP flood event.

### 14.4.6. Kingscliff

The northwestern edge of Kingscliff, extending approximately halfway from Sand Street to Kingscliff Street, is inundated in the 1% AEP flood event, with depths up to approximately 1 m within properties, and 1.5 m in the streets. Velocities are generally less than 0.5 m/s and velocity-depth products are less than 0.1 $m^2$/s in the 1% AEP event in this area. Residential streets inundated include Sand Street, Ozone Street, Kindee Street, Ocean Street, Surf Street, Terrace Street and Eddy Avenue.

Properties within the southern area of Kingscliff are generally free of flooding in the 1% AEP flood event. However, in the 0.2% AEP and greater, low-lying properties are inundated, with majority of residential streets inundated, west of Kingscliff Street, with depths of up to approximately 1 m along Elrond Drive.

### 14.4.7. Fingal Head

The main centre of Fingal Head is not affected by flooding up to the 0.2% AEP flood event. However, Letitia Road to the north (including some adjacent properties) and Fingal Road leading into Fingal Head from the south (also including some adjacent properties) are predicted to be inundated in the 5% AEP event. The depth of inundation over Fingal Road is up to 1.5 m near Wommin Lake in the 1% AEP flood event.

### 14.4.8. Banora Point

Banora Point is expected to be mostly flood free in the 1% AEP flood (see Figure 6-11) with the exception of the Kirkwood Road area which is inundated from Terranora Creek in the 5% AEP flood and larger. Velocity-depth products are less than 0.3 $m^2/s$ in the 1% AEP event. The Banora Point Golf Course provides flood storage in events larger than the 20% AEP, with depths between 1.5 m and 2 m in the 1% AEP event.

No inundation of developed areas is expected in Flame Tree Park in the 1% AEP event with the exception of some streets. Note however, that this is only based on flooding from either storm surge or a catchment flood. It does not include areas inundated by stormwater flooding, usually caused by shorter-duration, higher-intensity local rainfall events, such as that which occurred in June 2005. There is currently a Tweed Heads South Levee and Drainage Study being undertaken which will provide further local flooding conditions for this region.

### 14.4.9. Tweed Heads South

The Tweed Heads South levee was designed to provide immunity for the 1954 flood levels. Based on the survey of the levee, there are some sections of the levee that are overtopping in the 5% AEP event, including several locations along both the Dry Dock Road and Minjungbal Drive sections of the levee. The levee is overtopped by up to 0.3 m near the South Tweed Bowls Club. Depth of inundation in the northern residential areas are mostly between 0.5 m and 1 m in the 1% AEP event. Velocity-depth products are less than 0.3 $m^2/s$ in the 1% AEP event. Most of the southern commercial area is flood free in the 1% AEP event with the exception of some of the northern streets including Minjungbal Drive north of Machinery Drive. There is currently a Tweed Heads South Levee and Drainage Study being undertaken which will provide further local flooding conditions for this region.

### 14.4.10. Tweed Heads

Most of the developed areas of Tweed Heads are flood free in the 1% AEP event with the exception of a few properties along Endeavour Parade in the north and Margaret Street near the canals. Some streets are also inundated in this event, including sections of Kennedy Drive up to 1 m, Ducat Street up to 1 m and Keith Compton Drive up to 0.5 m near the old Tweed Heads District Hospital.

### 14.4.11. Tweed Heads West

Low lying areas of Tweed Heads West are expected to be inundated in the 5% AEP event and larger. Widespread inundation occurs in the 1% AEP event including most properties along Kennedy Drive, Gray Street, Rose Street, Blue Waters Crescent and Wyuna Road. Depths are typically 1 m to 1.5 m in this event. Approximately two-thirds of Seagulls Estate and all of the streets are inundated in the 1% AEP flood, with depths up to 1.5 m along Sunset Boulevard.

The shopping centre experiences inundation from the rear of the property. In the 1% AEP event the depths present onsite are up to 300 mm.

### 14.4.12. Uki

Low lying areas and properties of Uki are expected to be inundated in the 5% AEP event and larger. Inundation of Kyogle Road occurs as a result of the convergence of Rowlands Creek with the Tweed River. The majority of properties within Uki are flood free in the 1% AEP event, with the exception of some properties along Kyogle Road, with depths up to approximately 2 m, and some properties along Smiths Creek Road, with depths up to approximately 2.5 m.

# 15. COMPARISON TO PREVIOUS STUDIES

The previous flood study, completed in 2009, was undertaken using best available information and the limits of computation.

Since its completion there have been a number of advancements in hydrologic and hydraulic modelling approaches as well as a number of significant flood events occurring. During the more recent events many observed flood levels were recorded which enables far more confidence in model calibration to be achieved.

The key changes within the modelling which affect the levels which are achieved within the design model are:

- Improved representation of the Tweed and Rous River Channels
    - o The representation of the channel has changed from 1-dimension to a 2-dimension representation. Also, additional bathymetry information is included in this study compared to the 2009 study.
- Improved topographic data.
- Improved understanding of flood mechanics
- Improved calibration data
- Updated hydrologic modelling approaches (ARR2019 guidance)

Verification of the hydrologic and hydraulic modelling was also made through comparison of flows and levels to the hydraulic results from previous studies.

## 15.1. Level Estimates

### 15.1.1. 1 % AEP Review

Verification of the hydrologic and hydraulic modelling was also made through comparison of flows, levels and impacted properties from previous studies. A comparison of the estimated design water levels between this study, the Tweed Flood Study (2009) and Murwillumbah CBD Levee and Drainage Study (2018) is provided in Table 65 and Table 66.

Table 65: Comparison of Predicted Flood Heights at Gauges to Previous Studies (mAHD)

| Focus location | WMA (2023) | | CatchmentSim (2018) | | BMT (2009) | |
|---|---|---|---|---|---|---|
| | 1% AEP | 5% AEP | 1% AEP | 5% AEP | 1% AEP | 5% AEP |
| Murwillumbah Bridge | 5.89 | 5.30 | 5.94 | 5.36 | 6.91 | 5.84 |
| Boat Harbour* | 7.14 | 6.67 | - | - | 6.05 | 5.57 |
| Tumbulgum | 4.02 | 3.32 | - | - | 3.82 | 2.92 |
| Cobaki | 2.61 | 1.39 | - | - | 2.29 | 2.14 |

*North Arm inspection point used from the 2009 study

In addition, detail comparison at a range of points has been completed between this study and the Tweed Flood Study (2009). The reporting locations are shown on Figure 36.

Table 66: Comparison of Predicted Flood Heights at a Range of Locations (mAHD)

| Name | Peak Water Level | | |
|---|---|---|---|
| | 1% (2023) | 1% (2009) | Difference (m) |
| Barneys Point | 2.66 | 2.79 | -0.13 |
| Bilambil | 3.49 | 3.02 | 0.47 |
| Boat Harbour (Rous River) | 7.34 | 6.40 | 0.94 |
| Boat Harbour (Rous River) (2) | 7.12 | 6.38 | 0.74 |
| Bray Park Weir | 9.50 | 9.20 | 0.30 |
| Cobaki Lakes | 3.09 | 2.31 | 0.78 |
| Commercial Road (Reader) | 6.43 | 7.24 | -0.81 |
| Fingal | 2.62 | 2.38 | 0.24 |
| Flood_Gauge_Chinderah | 2.72 | 3.01 | -0.29 |
| Gauge_BarneysPt | 2.67 | 2.92 | -0.25 |
| Gauge-Cobaki | 2.61 | 2.29 | 0.32 |
| Gauge-Dry_Dock | 2.61 | 2.30 | 0.31 |
| Gauge-Letitia2A | 2.61 | 2.39 | 0.22 |
| Gauge-Terranora | 2.61 | 2.32 | 0.29 |
| Kingscliff | 2.80 | 3.21 | -0.41 |
| Kynn Bridge No.3 (Reader) | 4.83 | 4.52 | 0.31 |
| Murwillumbah Bridge | 5.89 | 6.92 | -1.03 |
| Murwillumbah Lavender Ck | 6.29 | 7.10 | -0.81 |
| Tumbulgum | 4.02 | 3.90 | 0.12 |
| Tygalgah (Smiths) (Reader) | 4.19 | 4.00 | 0.19 |
| US_Murwillumbah Bridge | 6.06 | 6.93 | -0.87 |

Generally, the results from the current study are similar (within 300 mm) to the results from the 2009 study except at Murwillumbah, Boat Harbour, Cobaki Lakes and near Kingscliff. Diagram 54 provides a map showing the differences in the 1% AEP event.

At Murwillumbah the 2009 study was a 1D representation of the Tweed River which may not have adequately modelled the breakout flow that occurs within the system. The current study Murwillumbah water levels are similar to the Murwillumbah CBD Levee and Drainage Study (2018), which was modelled in a similar manner. It should be noted that the reduced water levels are only present to the west of the Tweed Valley Way in this section, with water levels to the east of Tweed Valley Way being similar or higher than the 2009 model 1% AEP water levels.

At Boat Harbour the inspected locations are right at the upstream boundary of the area assessed within the 2009 flood model. The modelling of the flood levels in the 2009 model was somewhat simplified through this section to ensure model stability. As a result, it is considered the new model, with the Rous River well defined, is a more appropriate representation of flooding.

At Cobaki Lakes, this area in the previous model was used primarily to ensure the inflows into the Tweed River were appropriate. Within this study flows that are relevant to the local catchment have also been assessed, resulting in higher water levels.

At Kingscliff, peak water level is strongly influenced by the rate at which floodwaters can flow to the ocean through Barneys Point and the river mouth. In the 2009 model there was no good information regarding the function of the entrance in high flow events. Bathymetric survey from before and after the 2022 event identified that significant scour of the Tweed River Entrance occurred during each event, resulting in a more efficient entrance condition. Therefore, the new model has included a scour profile within the bathymetry in the area, consistent with the scour observed, for all design events above the 5% AEP. The new model also includes improved representation of the area around Barneys Point which results in a relative increase in conveyance and subsequent reduction in peak flood level in the Chinderah/Kingscliff area

In areas not previously mapped, DCP-A3 (development of flood liable land) provides advice as to the Highest Recorded Flood Level at a range of locations. Table 67 shows the differences between this advice and the modelled 1% AEP. In Chillingham the level in the 1% AEP is significantly higher than the current advice while Uki and Tyalgum are lower.

Table 67: Comparison of 1% AEP Modelled Levels vs DCP-A3 Advice

| Name | Peak Water Level (mAHD) | | |
|---|---|---|---|
| | 1% (2023) | Highest Recorded Flood Level (DCP-A3) | Difference (m) |
| Bilambil | 3.49 | 3.48 | 0.01 |
| Chillingham | 31.62 | 29.90 | 1.72 |
| Uki | 21.59 | 22.40 | -0.81 |
| Tyalgum | 54.31 | 55.11 | -0.80 |

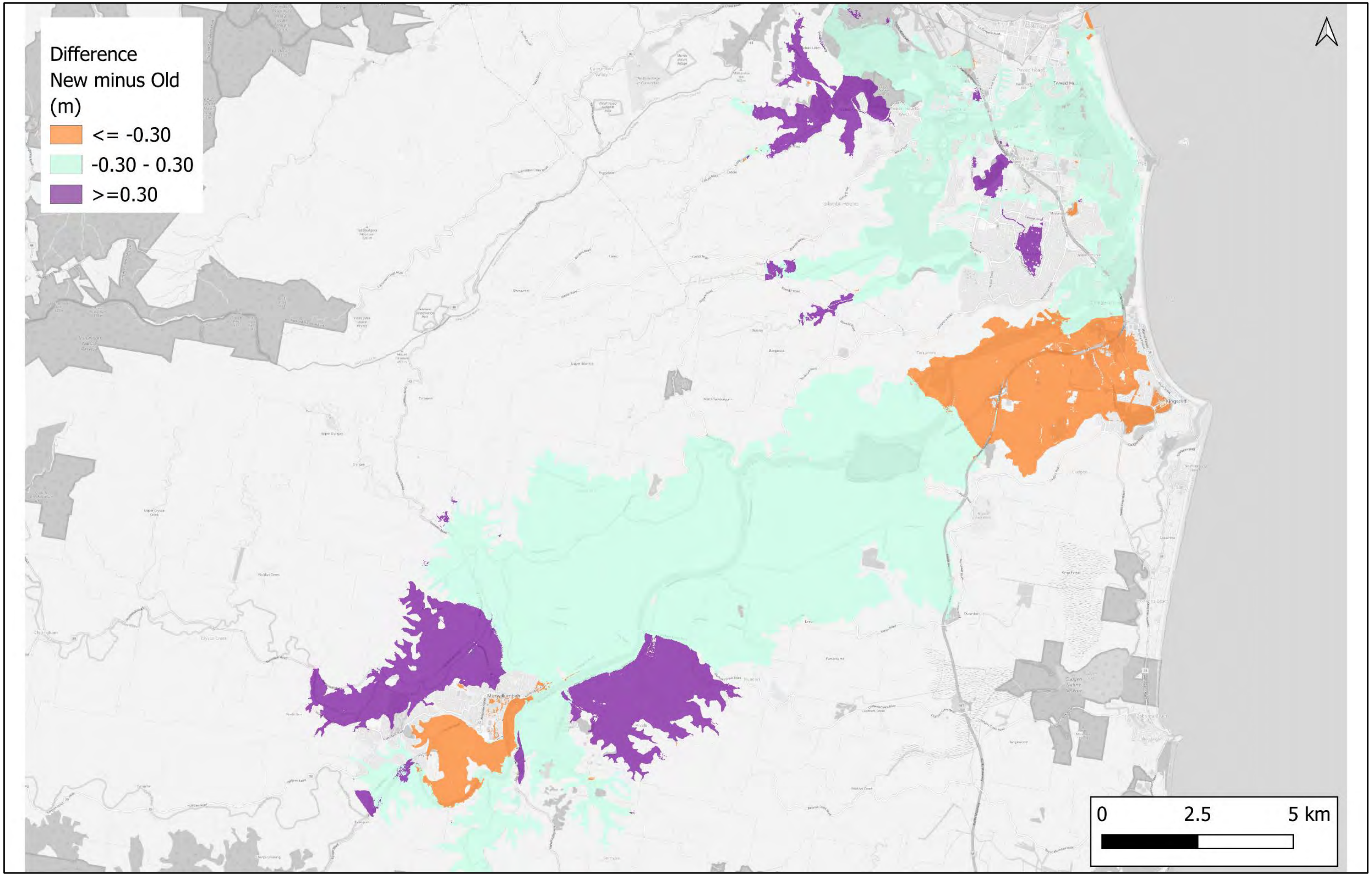



Diagram 54 – 1% AEP Flood Level Difference – New Modelling Minus Old Modeling

### 15.1.2. PMF Event Review

Diagram 55 shows the long section of water level between the Motorway and the ocean entrance. In the 2009 model the entrance condition results in a significant bottlenecking of flow at the entrance, which results in a generally static water level between the Motorway and the entrance, with a 2 m head drop present once out of the river. In the current version of the model the flow is less constrained, resulting in the presence of some hydraulic grade within the estimated flood levels.

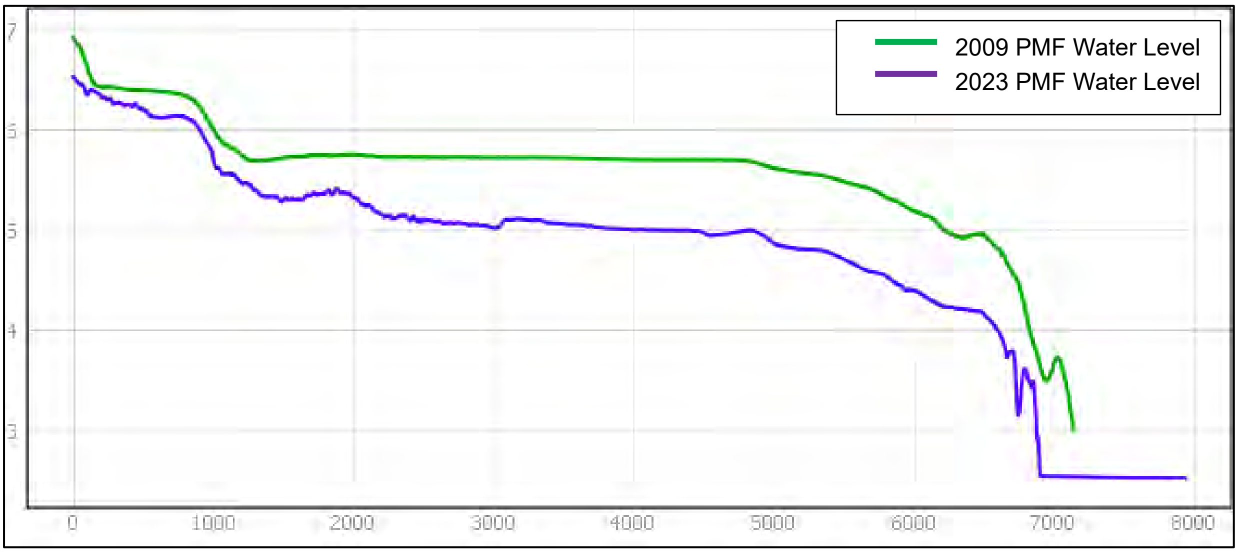



Diagram 55 – PMF Event Long Section Between Motorway and Ocean

Diagram 56 provides a map showing the differences in the PMF event. In the PMF event there are significant reductions to flood levels for the majority of areas from Tumbulgum downstream to the ocean entrance. This is due to the revised entrance condition which results in a system which can more efficiently discharge flow during major events. The levels used to develop this entrance condition were based off survey undertaken after the 2022 flood event.

Reductions are present to the south of Murwillumbah. This reduction is consistent with the observed reductions in the 1% AEP event. This is due to the change in the representation of the channel from 1D to 2D.

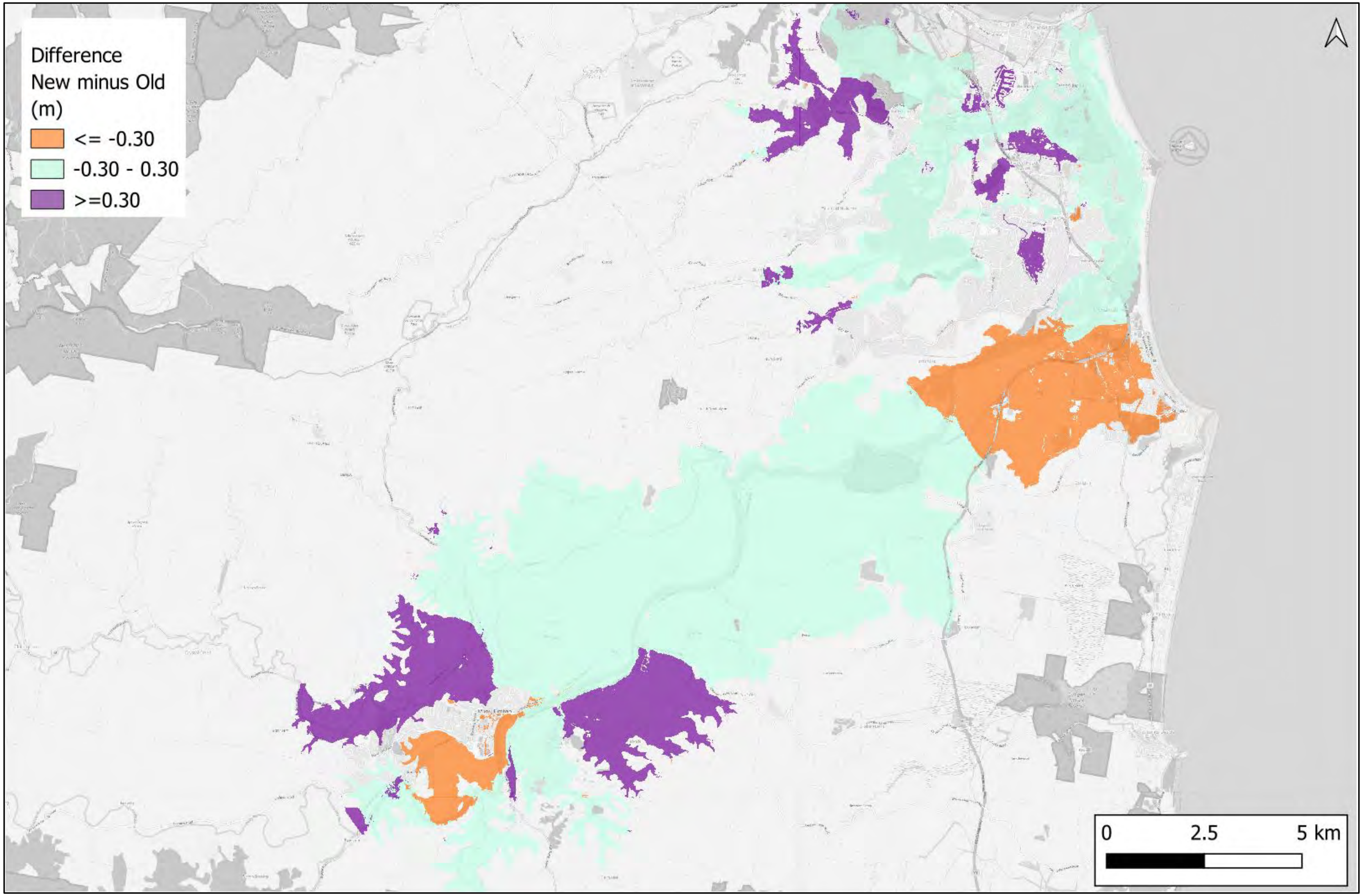



Diagram 56 – PMF Flood Level Difference – New Modelling minus Old Modeling

## 15.2. Flow Estimates

A comparison of the estimated design discharges between this study, the Tweed Flood Study (2009) and Murwillumbah CBD Levee and Drainage Study (2018) has also been undertaken. This is presented in Table 68.

Table 68: Comparison of design discharges at gauges to previous studies – 1% AEP ($m^3/s$)

| Location | WMA (2023) | | | CatchmentSim (2018) | | | BMT (2009) | | |
|---|---|---|---|---|---|---|---|---|---|
| | FFA | WBNM | TUFLOW | FFA | WBNM | TUFLOW | FFA | WBNM | TUFLOW |
| Boat Harbour | 1,216 | 1,222 | 1,329 | - | | | | | 1,140 |
| Cobaki | 239 | 146 | 175 | - | | | | 110 | - |
| Murwillumbah Bridge | 3,484 | 4,830 | 3,200 | 3,379 | | | 3,240 | | 3,937 |

There is good agreement between the three studies for the peak flows at Murwillumbah Bridge. Both the 2009 BMT and the current study confirm similar peak flows at Boat Harbour and Cobaki in the 1% AEP event.

A review of the PMF flows was also undertaken. Note this was completed within the hydrologic model given the large flows that are being recorded. Table 69 shows the variance in flow at three locations. Along the main branch the variation is within 10%, noting only a minor change to PMF approach is present in this assessment this is expected. At Cobaki the flows have increased significantly. This is due to the assessment modelling the local event as well as the regional event at this location, substantially increasing the flow estimates.

Table 69: Comparison of Design Discharges at Gauges to Previous Studies – PMF ($m^3/s$)

| Location | WMA (2023) | BMT (2009) |
|---|---|---|
| Boat Harbour | 21,470 | 19,960 |
| Cobaki | 1,200 | 312 |
| Murwillumbah Bridge | 16,041 | 14,615 |

## 15.3. Properties Affected

With regards to the number of floor levels affected within the extent of the previous hydraulic model, the revised model results in significantly lower numbers of floor levels impacted. A review of the 0.2% AEP results indicate a significant portion of the variance occurs in the Tweed Heads, Chinderah and Kingscliff region, with 3,271 floor levels affected in the 2009 0.2% AEP study in this area, versus 1,732 in the revised study.

Murwillumbah and Murwillumbah South also show a reduced number of floor levels affected, consistent with the lower levels identified in the 1% AEP flood event. A check of the flows and volume in the 0.2% AEP event show that at the Motorway (Barneys Point) the flows and volumes between the 2009 flood model and the current model are within 5%.

For the effectively same flow however, the level at this location is 800 mm lower than the 2009 study. This is primarily due to the altered entrance condition assumptions as discussed in Section 15.1. In the 5% AEP event the Tweed Heads area is affected by an elevated tide level, which is not consistent with levels in the current study.

Table 70: Floor Levels Impacted (total) – Current Study

| Property Type | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Residential | 12 | 66 | 1433 | 1904 | 7503 |
| Commercial | 10 | 42 | 284 | 375 | 784 |
| Industrial | 5 | 19 | 64 | 72 | 106 |
| **Total** | **27** | **127** | **1781** | **2351** | **8393** |

Table 71: Floor Levels Impacted (total) – 2009 Study

| Property Type | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Residential | 16 | 349 | 960 | 3,837 | 7,614 |
| Commercial | 27 | 67 | 275 | 566 | 812 |
| Industrial | 8 | 15 | 55 | 82 | 106 |
| **Total** | **51** | **431** | **1290** | **4,485** | **8,532** |

## 15.4. Summary

The review of the current study against previously modelled outcomes indicates that the updated modelling approaches utilised result in large changes to previously developed outcomes in a number of locations.

As part of the new project, significant time and effort has gone into the development of a robust and defendable flood model, with good calibration being achieved to a number of flood events. The flows derived as part of the study have also been validated against long term flow information in the catchment to ensure the estimates are appropriate and within the certainty bounds of the datasets available.

Ultimately the variances that have been identified between the two modelling projects are explainable and are a consequence of improved data and improved modelling approaches. While some uncertainty still exists with regards to the appropriate scour condition that should be present at the river entrance it is considered that the approach utilised within the revised study, based on the observations recorded in the 2022 flood event, have a higher likelihood than the no scour scenario utilised previously.

# 16. CONSEQUENCE OF FLOODING ON THE COMMUNITY

Impacts of flooding has been undertaken to provide a quantification of the impacted properties within the Tweed River. Table 72 summarises the number of impacted properties in each AEP event. Table 73 shows the number of ground levels impacted within the catchment. This analysis has been undertaken as there is no floor level survey outside the extent of the previous FRMS, meaning none of the floor levels within Uki, Eungella, Boat Harbour and other key locations are known. Table 74 shows the number of properties that may experience above floor flooding in each AEP event. Note this floor level analysis is only limited to the extent of the previous flood risk management study, which surveyed floor levels within its extent.

The analysis of exposure for buildings reveals the following:

- Over 9,000 properties have some level of flood affectation in a 1% AEP event.
- Over 1,100 properties have the floor level impacted in a 1% AEP event;
- Over 15,000 properties have some level of flood affectation in a PMF.
- Over 8,400 properties have their floors impacted in the PMF event.

Table 72: Floor Levels Impacted (total)

| Property Type | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Residential | 12 | 344 | 1,435 | 1,904 | 7,503 |
| Commercial | 10 | 74 | 284 | 375 | 784 |
| Industrial | 5 | 19 | 64 | 72 | 106 |
| **Total** | **27** | **437** | **1,783** | **2,351** | **8,393** |

Table 73: Ground Level at Property Impacted (total)

| Locality | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Back Creek | 27 | 27 | 27 | 27 | 27 |
| Banora Point | 266 | 434 | 718 | 957 | 2,159 |
| Bilambil | 94 | 99 | 106 | 104 | 116 |
| Bilambil Heights | 34 | 47 | 55 | 62 | 113 |
| Bray Park | 19 | 114 | 124 | 132 | 190 |
| Brays Creek | 21 | 22 | 22 | 22 | 23 |
| Bungalora | 23 | 24 | 24 | 24 | 25 |
| Burringbar | 1 | 1 | 1 | 1 | 1 |
| Byangum | 78 | 85 | 86 | 88 | 102 |
| Byrrill Creek | 45 | 47 | 48 | 48 | 52 |
| Carool | 39 | 40 | 41 | 41 | 43 |
| Cedar Creek | 6 | 6 | 6 | 6 | 6 |
| Chillingham | 72 | 87 | 94 | 95 | 122 |
| Chinderah | 120 | 360 | 460 | 473 | 473 |
| Chowan Creek | 29 | 29 | 29 | 29 | 31 |
| Clothiers Creek | 1 | 1 | 1 | 1 | 3 |
| Cobaki | 61 | 63 | 63 | 64 | 77 |
| Cobaki Lakes | 28 | 30 | 34 | 35 | 45 |
| Commissioners Creek | 29 | 29 | 29 | 29 | 32 |

| Locality | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Condong | 123 | 143 | 175 | 179 | 179 |
| Crystal Creek | 64 | 68 | 72 | 74 | 98 |
| Cudgen | 36 | 38 | 50 | 81 | 92 |
| Doon Doon | 84 | 87 | 89 | 90 | 100 |
| Dulguigan | 74 | 80 | 83 | 84 | 98 |
| Dum Dum | 28 | 37 | 38 | 38 | 41 |
| Dunbible | 115 | 122 | 128 | 130 | 148 |
| Dungay | 60 | 62 | 63 | 63 | 74 |
| Duranbah | 14 | 14 | 16 | 17 | 17 |
| Duroby | 30 | 30 | 30 | 30 | 30 |
| Eungella | 106 | 124 | 133 | 137 | 144 |
| Eviron | 122 | 124 | 125 | 125 | 128 |
| Farrants Hill | 4 | 4 | 4 | 4 | 5 |
| Fernvale | 43 | 44 | 51 | 52 | 69 |
| Fingal Head | 60 | 162 | 196 | 214 | 280 |
| Glengarrie | 3 | 3 | 3 | 3 | 3 |
| Hopkins Creek | 32 | 32 | 32 | 32 | 35 |
| Kielvale | 39 | 45 | 50 | 55 | 86 |
| Kingscliff | 24 | 61 | 205 | 688 | 1,012 |
| Kunghur | 76 | 78 | 78 | 78 | 81 |
| Kunghur Creek | 28 | 28 | 30 | 30 | 33 |
| Kynnumboon | 48 | 49 | 50 | 50 | 57 |
| Limpinwood | 77 | 80 | 83 | 83 | 86 |
| Mebbin | 16 | 17 | 17 | 17 | 17 |
| Midginbil | 34 | 35 | 38 | 38 | 40 |
| Mount Burrell | 48 | 51 | 53 | 55 | 57 |
| Mount Warning | 51 | 54 | 54 | 55 | 57 |
| Murwillumbah | 244 | 447 | 672 | 1,067 | 1,736 |
| Nobbys Creek | 65 | 73 | 76 | 78 | 96 |
| North Arm | 35 | 40 | 42 | 46 | 52 |
| North Tumbulgum | 73 | 81 | 85 | 85 | 97 |
| Numinbah | 46 | 46 | 46 | 46 | 49 |
| Nunderi | 52 | 70 | 91 | 97 | 145 |
| Piggabeen | 62 | 65 | 72 | 74 | 90 |
| Pumpenbil | 79 | 82 | 82 | 83 | 88 |
| Reserve Creek | | | | | 1 |
| Rowlands Creek | 58 | 60 | 62 | 62 | 66 |
| Smiths Creek | 56 | 60 | 66 | 72 | 90 |
| South Murwillumbah | 700 | 894 | 940 | 942 | 976 |
| Stokers Siding | 116 | 117 | 121 | 123 | 143 |
| Stotts Creek | 38 | 38 | 39 | 39 | 39 |
| Terragon | 57 | 58 | 60 | 60 | 67 |
| Terranora | 39 | 49 | 53 | 56 | 86 |
| Tomewin | 8 | 8 | 8 | 8 | 8 |
| Tumbulgum | 346 | 352 | 352 | 352 | 352 |

| Locality | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Tweed Heads | 404 | 657 | 789 | 1,120 | 1,610 |
| Tweed Heads South | 102 | 1,016 | 1,215 | 1,450 | 1,866 |
| Tweed Heads West | 326 | 975 | 1,097 | 1,156 | 1,232 |
| Tyalgum | 117 | 161 | 188 | 190 | 252 |
| Tyalgum Creek | 57 | 57 | 58 | 58 | 62 |
| Tygalgah | 82 | 82 | 82 | 82 | 82 |
| Uki | 154 | 217 | 230 | 238 | 302 |
| Upper Burringbar | 1 | 1 | 1 | 1 | 1 |
| Upper Crystal Creek | 75 | 76 | 76 | 76 | 86 |
| Upper Duroby | 34 | 34 | 34 | 34 | 37 |
| Urliup | 65 | 66 | 67 | 68 | 74 |
| Wardrop Valley | 11 | 11 | 13 | 14 | 20 |
| Zara | 35 | 36 | 40 | 42 | 46 |
| **Grand Total** | **5,969** | **9,146** | **10,671** | **12,559** | **16,558** |

Table 74: Floor Levels Impacted (by locality)

| Locality | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Banora Point | 0 | 0 | 0 | 5 | 1534 |
| Bilambil | 0 | 0 | 1 | 1 | 10 |
| Bilambil Heights | 0 | 0 | 0 | 0 | 4 |
| Bray Park | 0 | 8 | 9 | 10 | 83 |
| Byangum | 0 | 1 | 2 | 3 | 6 |
| Chinderah | 1 | 42 | 158 | 227 | 248 |
| Cobaki | 0 | 0 | 0 | 0 | 2 |
| Cobaki Lakes | 0 | 0 | 0 | 1 | 1 |
| Condong | 1 | 2 | 18 | 40 | 117 |
| Cudgen | 0 | 0 | 0 | 0 | 8 |
| Dulguigan | 1 | 3 | 6 | 8 | 13 |
| Dunbible | 0 | 0 | 0 | 0 | 8 |
| Dungay | 0 | 0 | 0 | 0 | 12 |
| Duranbah | 0 | 0 | 0 | 0 | 1 |
| Eviron | 0 | 1 | 9 | 14 | 29 |
| Fernvale | 0 | 0 | 0 | 0 | 0 |
| Fingal Head | 0 | 26 | 68 | 83 | 176 |
| Kielvale | 0 | 0 | 0 | 0 | 18 |
| Kingscliff | 0 | 0 | 26 | 115 | 781 |
| Kynnumboon | 1 | 2 | 5 | 5 | 19 |
| Murwillumbah | 6 | 6 | 13 | 131 | 908 |
| Nobbys Creek | 0 | 0 | 0 | 0 | 2 |
| North Arm | 0 | 0 | 1 | 1 | 5 |
| North Tumbulgum | 0 | 1 | 3 | 6 | 17 |
| Nunderi | 0 | 1 | 2 | 4 | 56 |
| South Murwillumbah | 7 | 54 | 175 | 220 | 480 |
| Stotts Creek | 0 | 0 | 0 | 0 | 3 |
| Terranora | 0 | 0 | 0 | 0 | 13 |

| Locality | 20% AEP | 5% AEP | 1% AEP | 0.2% AEP | PMF |
|---|---|---|---|---|---|
| Tumbulgum | 9 | 17 | 36 | 67 | 181 |
| Tweed Heads | 0 | 5 | 122 | 183 | 1,210 |
| Tweed Heads South | 1 | 144 | 566 | 598 | 1,395 |
| Tweed Heads West | 0 | 119 | 552 | 609 | 992 |
| Tygalgah | 0 | 5 | 11 | 20 | 55 |
| Urliup | 0 | 0 | 0 | 0 | 4 |
| **Total** | **27** | 437 | **1,783** | **2,351** | **8,391** |

# 17. IMPACTS OF CLIMATE CHANGE

The impact of Climate Change on flooding within the catchment is outlined in Table 75 to Table 76 for the 5% AEP and 1% AEP events. Climate Change will result in a significant number of additional properties floors being inundated in the 5% AEP event. These properties are predominately residential structures. The analysis of exposure for buildings reveals the following:

- Low Climate Change Scenario
  - An additional 1,185 residential buildings will be impacted in the 5% AEP with Climate Change compared to the current 5% AEP inundation.
  - There are significant increases in the number of industrial and commercial properties that will be impacted in the 5% AEP with Climate Change.
  - Residential properties consist of 85% of the total properties impacted in the 5% AEP with Climate Change compared to only 70% in the current 5% AEP flood level.
  - An additional 1,798 residential buildings will be impacted in the 1% AEP with climate change compared to the current 1% AEP inundation.
  - An additional 110 commercial buildings will be impacted in the 1% AEP with Climate Change compared to the current 1% AEP inundation.
  - There are minor increases in the number of industrial properties that will be impacted in the 1% AEP with Climate Change.
  - Residential properties consist of 87% of the total properties impacted in the 1% AEP with Climate Change compared to only 80% in the current 1% AEP inundation.
  - Commercial properties consist of 11% of the total properties impacted in the 1% AEP with Climate Change compared to only 16% in the current 1% AEP inundation.
- High Climate Change Scenario
  - An additional 1,521 residential buildings will be impacted in the 5% AEP with Climate Change compared to the current 5% AEP inundation,
  - There are significant increases in the number of industrial and commercial properties that will be impacted in the 5% AEP with Climate Change.
  - Residential properties consist of 85% of the total properties impacted in the 5% AEP with Climate Change compared to 79% in the current 5% AEP flood level.
  - An additional 2,639 residential buildings will be impacted in the 1% AEP with Climate Change compared to the current 1% AEP inundation,
  - An additional 291 commercial buildings will be impacted in the 1% AEP with Climate Change compared to the current 1% AEP inundation,
  - There are minor increases in the number of industrial properties that will be impacted in the 1% AEP with Climate Change.
  - Residential properties consist of 86% of the total properties impacted in the 1% AEP with Climate Change compared to only 80% in the current 1% AEP inundation.
  - Commercial properties consist of 12% of the total properties impacted in the 1% AEP with Climate Change compared to only 14% in the current 1% AEP inundation.

Climate Change is impacting more residential properties than commercial and industrial properties. In the 1% AEP event, the Murwillumbah CBD levee is not currently overtopped but with Climate Change this levee is overtopped resulting in a significant number of residential properties being impacted behind the levee.

The majority of changes are identified in Chinderah, Murwillumbah, Tweed Heads, Tweed Heads West, Tweeds Head South and Fingal. These localities are all impacted more than another other locality within the Tweed catchment as they are located within the tidal zone that is impacted by both the increase in rainfall and tidal levels.

Table 75: Floor Levels Impacted (total) – Climate Change

| Property Type | 5% AEP | 5% AEP + LCC | 5% AEP + HCC | 1% AEP | 1% AEP + LCC | 1% AEP + HCC |
|---|---|---|---|---|---|---|
| Residential | 344 | 1,529 | 1,865 | 1,435 | 3,233 | 4,074 |
| Commercial | 74 | 261 | 301 | 284 | 394 | 575 |
| Industrial | 19 | 29 | 29 | 64 | 68 | 73 |
| **Total** | **437** | **1,819** | **2,195** | **1,783** | **3,695** | **4,722** |

Table 76: Floor Levels Impacted (by locality) – Climate Change

| Locality | 5% AEP | 5% AEP + LCC | 5% AEP + HCC | 1% AEP | 1% AEP + LCC | 1% AEP + HCC |
|---|---|---|---|---|---|---|
| Banora Point | 0 | 0 | 0 | 0 | 146 | 538 |
| Bilambil | 0 | 0 | 0 | 1 | 1 | 1 |
| Bray Park | 8 | **9** | **9** | 9 | **10** | **11** |
| Byangum | 1 | **2** | **2** | 2 | 3 | 3 |
| Chinderah | 42 | **129** | **142** | 158 | **211** | **227** |
| Cobaki | 0 | 0 | 0 | 0 | 1 | 1 |
| Cobaki Lakes | 0 | 0 | 0 | 0 | 1 | 1 |
| Condong | 2 | **3** | **7** | 18 | **31** | **41** |
| Dulguigan | 3 | **4** | **4** | 6 | 6 | **8** |
| Eviron | 1 | **3** | **8** | 9 | **12** | **14** |
| Fingal Head | 26 | **67** | **71** | 68 | **109** | **117** |
| Kingscliff | 0 | **3** | **18** | 26 | **52** | **103** |
| Kynnumboon | 2 | **3** | **3** | 5 | 5 | 5 |
| Murwillumbah | 6 | **8** | **10** | 13 | **60** | **291** |
| North Arm | 0 | 0 | 0 | 1 | 1 | 1 |
| North Tumbulgum | 1 | 1 | **2** | 3 | **4** | **6** |
| Nunderi | 1 | **2** | **2** | 2 | **3** | **4** |
| South Murwillumbah | 54 | **82** | **131** | 175 | **206** | **232** |
| Stotts Creek | 0 | 0 | 0 | 0 | 0 | 0 |
| Tumbulgum | 17 | **19** | **22** | 36 | **43** | **65** |
| Tweed Heads | 5 | **237** | **415** | 122 | **852** | **959** |
| Tweed Heads South | 144 | **609** | **669** | 566 | **1,028** | **1,136** |
| Tweed Heads West | 119 | **632** | **687** | 552 | **897** | **936** |
| Tygalgah | 5 | **6** | **10** | 11 | **13** | **21** |
| **Total** | **437** | **1,819** | **2,212** | **1,783** | **3,695** | **4,722** |
| **Total Increase** | | **1,382** | **1,775** | | **1,912** | **2,939** |

Peak water levels within the model at key locations is presented visually in Appendix R and given in Table 77. The report locations are illustrated in Figure 36.

Table 77: Peak Water Levels Climate Change

| River Location | Name | Peak Water Level (mAHD) | | | |
|---|---|---|---|---|---|
| | | High CC Scenario | | Low CC Scenario | |
| | | 5% AEP | 1% AEP | 5% AEP | 1% |
| Lower Tweed | Gauge-Letitia2A | 2.84 | 3.50 | 2.68 | 3.29 |
| | Gauge-Dry_Dock | 2.88 | 3.48 | 2.71 | 3.28 |
| | Gauge-Terranora | 2.89 | 3.49 | 2.71 | 3.28 |
| | Gauge-Cobaki | 2.89 | 3.49 | 2.71 | 3.28 |
| | Cobaki Ck | 6.81 | 7.19 | 6.71 | 7.09 |
| Mid Tweed | Barneys Point | 2.62 | 3.52 | 2.50 | 3.31 |
| | Gauge_BarneysPt | 2.62 | 3.52 | 2.49 | 3.32 |
| | Flood_Gauge_Chinderah | 2.59 | 3.53 | 2.46 | 3.32 |
| | Tumbulgum | 3.76 | 4.50 | 3.54 | 4.22 |
| | Tygalgah (Smiths) (Reader) | 3.92 | 4.66 | 3.73 | 4.39 |
| Rous | Kynn Bridge No.3 (Reader) | 4.73 | 5.21 | 4.61 | 5.00 |
| | Boat Harbour (Rous River) (2) | 7.00 | 7.44 | 6.85 | 7.28 |
| | Boat Harbour (Rous River) | 7.21 | 7.70 | 7.06 | 7.51 |
| | Rous @ Boat Harbour 3 | 9.98 | 10.38 | 9.86 | 10.13 |
| Oxley River | Eungella | 23.54 | 24.24 | 23.27 | 24.03 |
| | Chillingham_Bridge | 31.80 | 32.46 | 31.59 | 31.85 |
| | Tyalgum_Bridge | 54.01 | 54.94 | 53.70 | 54.64 |
| Upper Tweed | North Murwillumbah | 5.76 | 6.55 | 5..60 | 6.30 |
| | Murwillumbah Bridge | 5.63 | 6.43 | 5.48 | 6.18 |
| | US_Murwillumbah Bridge | 5.80 | 6.60 | 5.63 | 6.35 |
| | Murwillumbah Lavender Ck | 6.04 | 6.79 | 5.85 | 6.56 |
| | Commercial Road (Reader) | 6.18 | 6.87 | 5.99 | 6.66 |
| | Bakers Byangum (Reader) | 10.41 | 11.34 | 10.14 | 11.02 |
| | Bray Park Weir | 9.18 | 10.17 | 8.87 | 9.84 |
| | Tweed @ Uki | 21.56 | 22.46 | 21.28 | 22.16 |
| | 558009 Clarrie Hall Dam Rd | 28.40 | 29.33 | 28.09 | 28.94 |
| | Tweed R @ D/s Palmer | 38.90 | 39.77 | 38.66 | 39.48 |
| | 558028 Clarrie Hall Dam | 66.22 | 67.00 | 65.92 | 66.79 |

# 18. POST PROCESSING OF MODEL RESULTS

Floods can be hazardous to people, property and infrastructure. However, this flood risk only exists when the community and the built environment interact with hazardous flood behaviour. Floodplain management aims to support management of flood risk by supporting land use planning, emergency management and flood risk management. Understanding flood risk and how it can impact on existing and future development is essential to the management of flood risk.

Mapping of design flood extents alone does not provide a full picture of the varying degrees of flood risk across the floodplain. Breaking down the floodplain into varying degrees of flood function (hydraulic categories) or hazard assists in building this picture of flood risk and allows the development of appropriately targeted management measures.

## 18.1. Hydraulic and Hazard Classification

For the purposes of floodplain risk management in NSW, floodplains can be divided into hydraulic and hazard categories. Details of this process are provided in the NSW Governments Floodplain Development Manual (2005, Appendix L) (Reference 26) and *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 27), as well as briefly described below.

### 18.1.1. Flood Function

Hydraulic categories describe the flood behaviour by categorising areas depending on their function during the flood event, specifically, whether they transmit large quantities of water (floodway), store a significant volume of water (flood storage) or do not play a significant role in either storing or conveying water (flood fringe). The floodway represents areas of the floodplain that typically have high velocities and high flood flows. Development or changes to topography in these areas can have significant impact on flood behaviour. Flood storage areas of the floodplain are usually subject to relatively low velocities and high depths. While these areas are not used to convey large volumes of water, topographical changes that remove storage area can have impacts on flood behaviour. Understanding the flood function across the floodplain is important to ensure appropriate future planning decisions are made.

Although the three categories of hydraulic function are described in the Floodplain Development Manual (The Manual) (Reference 26), their definitions are largely qualitative, and the manual does not prescribe a method to determine each area. The manual gives one indication of how to quantitatively differentiate floodway and flood storage, when it states that flood storage areas, when completely filled with solid material, will not raise peak flood levels by “more than 0.1 m and/or would cause the peak discharge anywhere downstream to increase by more than 10%”.

Ultimately, at this stage in the flood study process the level of sensitivity testing to achieve a robust flood function categorisation is not achievable. This should occur at the Flood Risk Management Study phase, when cumulative impacts and the impact of development on the floodplain is considered. These assessments provide a context to review the parameters and ensure the most appropriate outcome for the catchment. For this study the parameters utilised in the Tweed Valley

Floodplain Risk Management Study (2014) have been adopted. The hydraulic categories used in the Murwillumbah CBD Levee and Drainage Study (2018) have been also tested in the current study, they are outlined in Table 79.

Table 78: Flood Function Definition Parameters – Tweed Valley Floodplain Risk Management Study

| Waterway | Floodway Definition Parameters |
|---|---|
| Floodway | Velocity x depth > 0.3 $m^2/s$ |
| Flood Storage | Velocity x depth > 0.0025 $m^2/s$ and not defined as Floodway |
| Flood Fringe | Areas that are not floodway or flood storage |

Table 79: Flood Function Definition Parameters – Murwillumbah CBD Study

| Waterway | Floodway Definition Parameters |
|---|---|
| Floodway | Velocity x depth >= 1 |
| Flood Storage | Depth > 0.15m and not defined as Floodway |
| Flood Fringe | Areas that are not floodway or flood storage |

Hydraulic categories have been defined by considering detailed assessment of flood behaviour, the available topographic information and interpretation of the hydraulic model results and knowledge of the catchment. Mapping of the flood function for the 5% AEP, 1% AEP and 0.2% AEP is presented in Appendix Q.

### 18.1.2. Flood Hazard

As with hydraulic categories, hazard classification plays an important role in informing floodplain risk management in an area. Previously, hazard classifications were binary – either Low or High Hazard as described in the Manual. However, in recent years there has been a number of developments in the classification of hazard. Reference 27 provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. The classification is divided into six categories (Reference 27) which 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 people or vehicles. All buildings types considered vulnerable to failure.

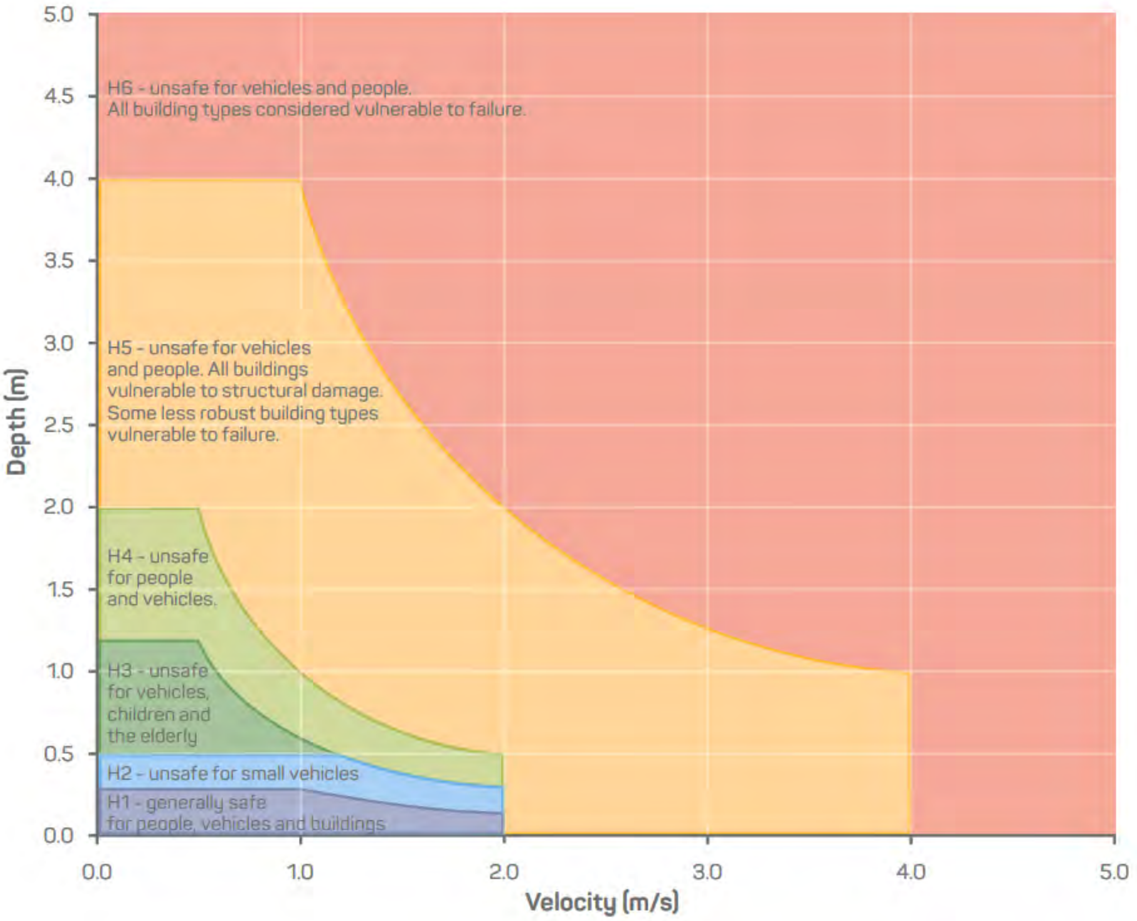



Diagram 57 Hazard Classifications

H5 and H6 represent areas of the floodplain that are most hazardous, and these areas are considered unsafe for all people, cars and buildings. H3 and H4, while less hazardous are generally both considered to be unsafe for all vehicles and most people and therefore the consequences should people be in these areas are still high. H1 and H2 are the lease hazardous areas of the floodplain and while considered generally safe for people, some smaller vehicles may be at risk. Mapping of the flood hazard for the 5% AEP, 1% AEP and 0.2% AEP is presented in Appendix Q.

# 19. FLOOD EMERGENCY RESPONSE CLASSIFICATIONS FOR COMMUNITIES

To assist in the planning and implementation of response strategies the SES classifies communities according to the impact flooding has on them. Flood affected communities are those in which the normal functioning of services is altered either directly or indirectly because a flood results in the need for external assistance. This impact relates directly to the operational issues of evacuation, resupply and rescue. The classifications defined in Diagram 58.

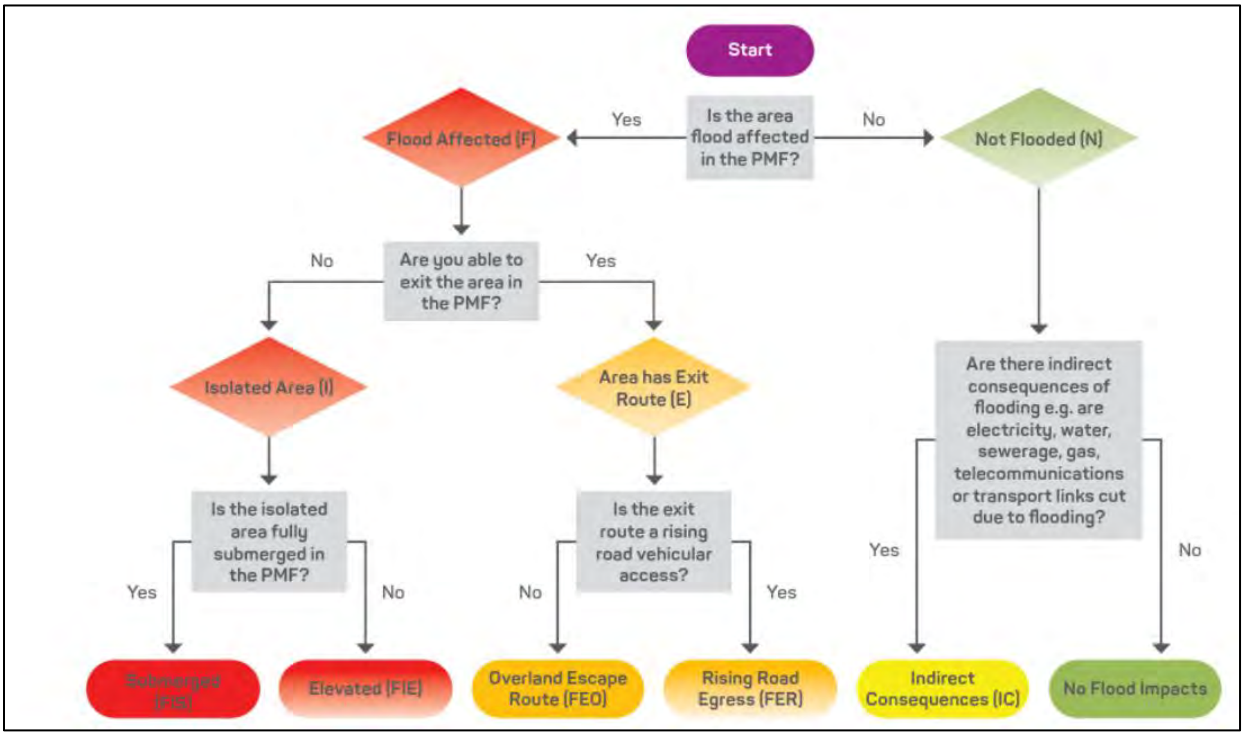



Diagram 58 Flood Emergency Repsonse Classification Flow Chart

Key descriptions about townships is outlined below:

- Upper Tweed (Eungella, Tyalgum, Palmers, Uki and Boat Harbour)
    - o All have Rising Road Egress (FER) out of the PMF extent into the hinterland
    - o There is a large number of roads submerged in the PMF (FIS), that are the only connection road between Murwillumbah and Upper Tweed.
    - o Small pockets of PMF high flood islands meaning properties that will be surrounded by water but not inundated in a PMF event. These small pockets have elevated roads (FIE) that are surrounded by the PMF.
- Murwillumbah
    - o CBD is inundated in a PMF event but has rising road egress (FER) to the west. The issue is that once people evacuate to the west, there is no connection to other townships, and they become stranded.
    - o There is a portion of Murwillumbah, north of Wollumbin Street bridge that are not impacted in a PMF event but surrounded by water. This region is fully isolated as the road out of the area are fully submerged (FIS). Roads within the PMF high flood island are classified as FIE. The connection between the FIE and FER roads in Murwillumbah are surrounded by submerged roads.

- South Murwillumbah and Tumbulgum
    - Both are fully impacted in the PMF event but have rising road egress to the south/south-east towards the border of the Tweed catchment.
    - All roads near the Tweed River as classified as FIS as they are submerged in the PMF event. There are few evacuation routes for South Murwillumbah it sits well within the floodplain zone of the catchment.
    - There are even less available rising road egress options in Tumbulgum compared to South Murwillumbah as the PMF extent impacts a significant portion of the zone surrounding the town. The majority of the roads within Tumbulgum are classified as FIS. People on the southern side of the Tweed River have very limited evacuation options while people on the northern side of the river have some rising road options.
- Chinderah and Fingal Road
    - There are no evacuation options as the whole area is impacted in a PMF event with all roads submerged, roads are classified as FIS.
- Banora Point
    - Area is not isolated in the PMF event but has both rising road and overland escape routes to enable residents to evacuate towards Terranora.
- Tweed Head South
    - Majority of it is within the PMF extent but some is isolated during the PMF event.
    - There are rising egress roads between Tweed Heads South and Banora Point (FER).
    - The portion of Tweed Heads South that is surrounded by the PMF has elevated roads (FIE).

The figures in Appendix S illustrate these concepts.

# 20. CONCLUSIONS

Following the review of existing material an update to the hydrology and hydraulic models that represent the Tweed catchment were undertaken.

The hydraulic model was updated to include modifications in the catchment since the previous model build and included an update of the complete geometry of the model based on the latest LiDAR. Bathymetric data was used to represent the main channel up to Bray Park Weir, and up to Cobaki Creek. Calibration of the roughness in this model was then undertaken, with good matches to observed levels recorded throughout the model. Sensitivities were explored for the 2017 calibration model and demonstrated that the model is representing the flood behaviour well. Based on the sensitivity analysis, localised modifications to model roughness were undertaken in the upper reaches of the catchment to achieve appropriate calibration results. The 2022 hydraulic model adopted hydraulic roughness was used for the design models as it accounts for the current scour conditions in the catchment.

Design event modelling, climate change analysis and post processing of model results has also been completed. A comparison of the flood levels observed, compared to the previous study indicate that while some variances are present, the variances are within the bounds of expected changes. Cross checking of the areas with the largest changes confirm that observed flood level information present in the areas align well with the modelled levels in both the 2017 and 2022 flood events.

This study has used the best available data, incorporated recent flood experiences and utilised best practice industry guidance to provide a representation of flooding in the Tweed Valley.

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# Figures

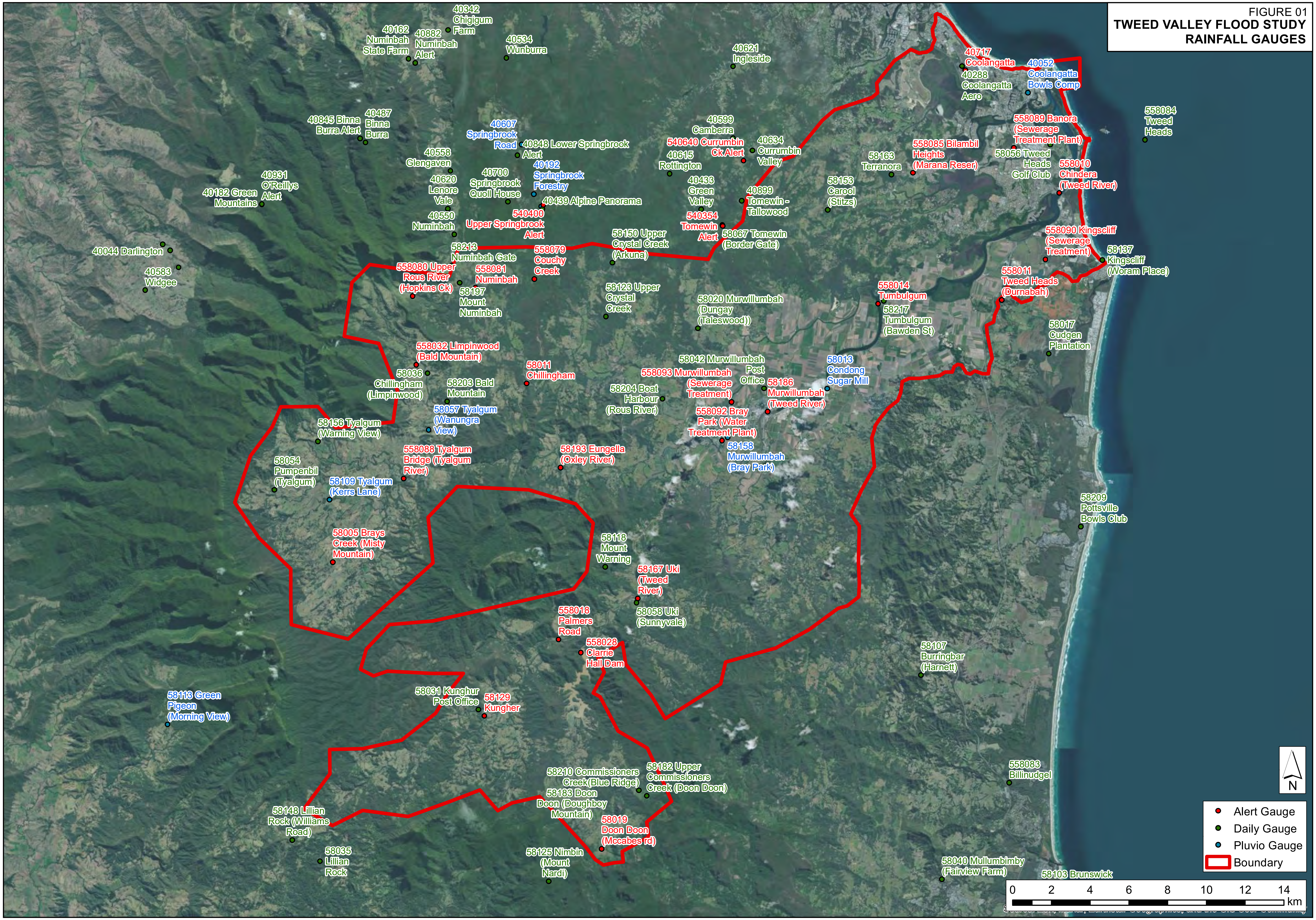


FIGURE 01
TWEED VALLEY FLOOD STUDY
RAINFALL GAUGES

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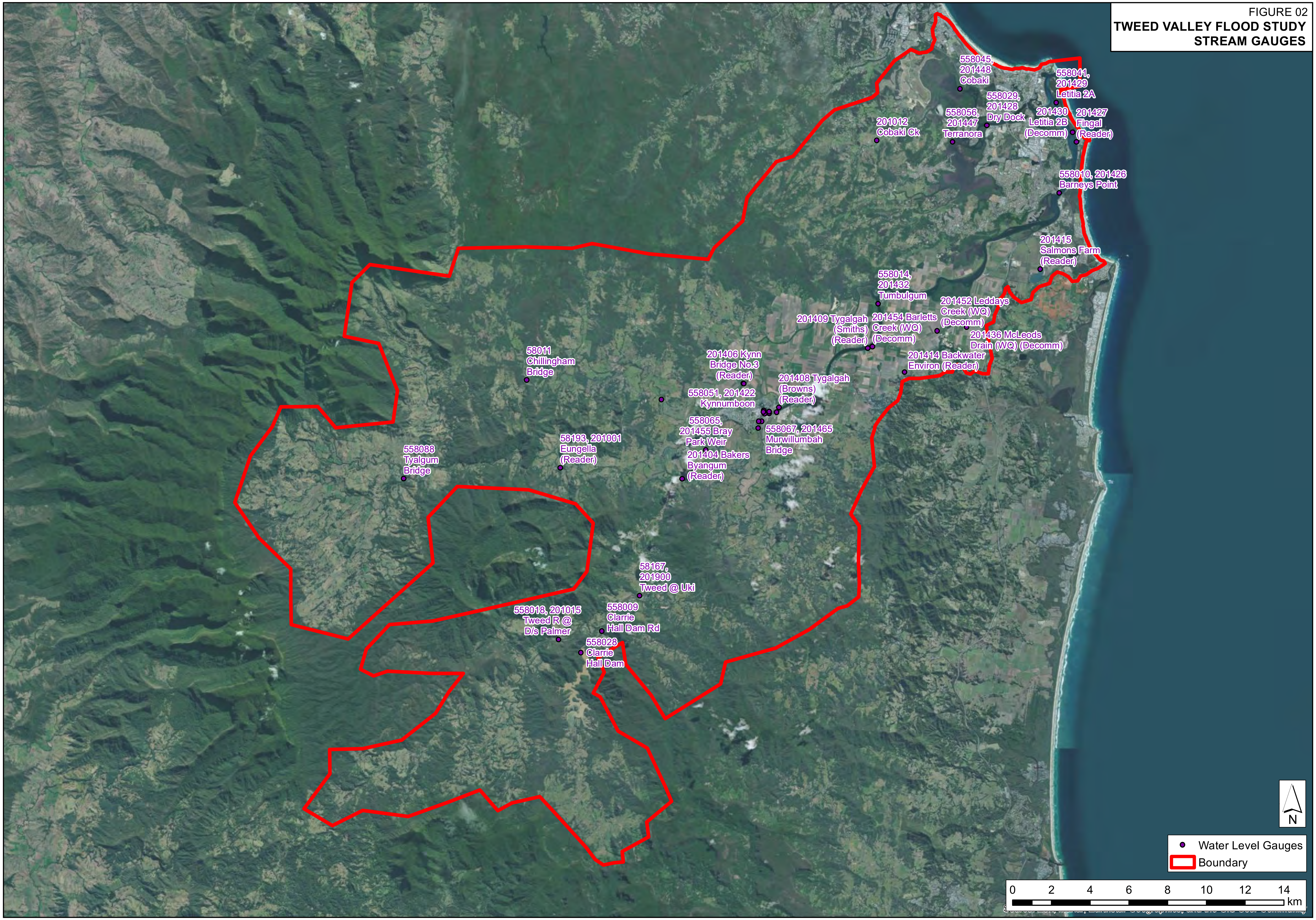


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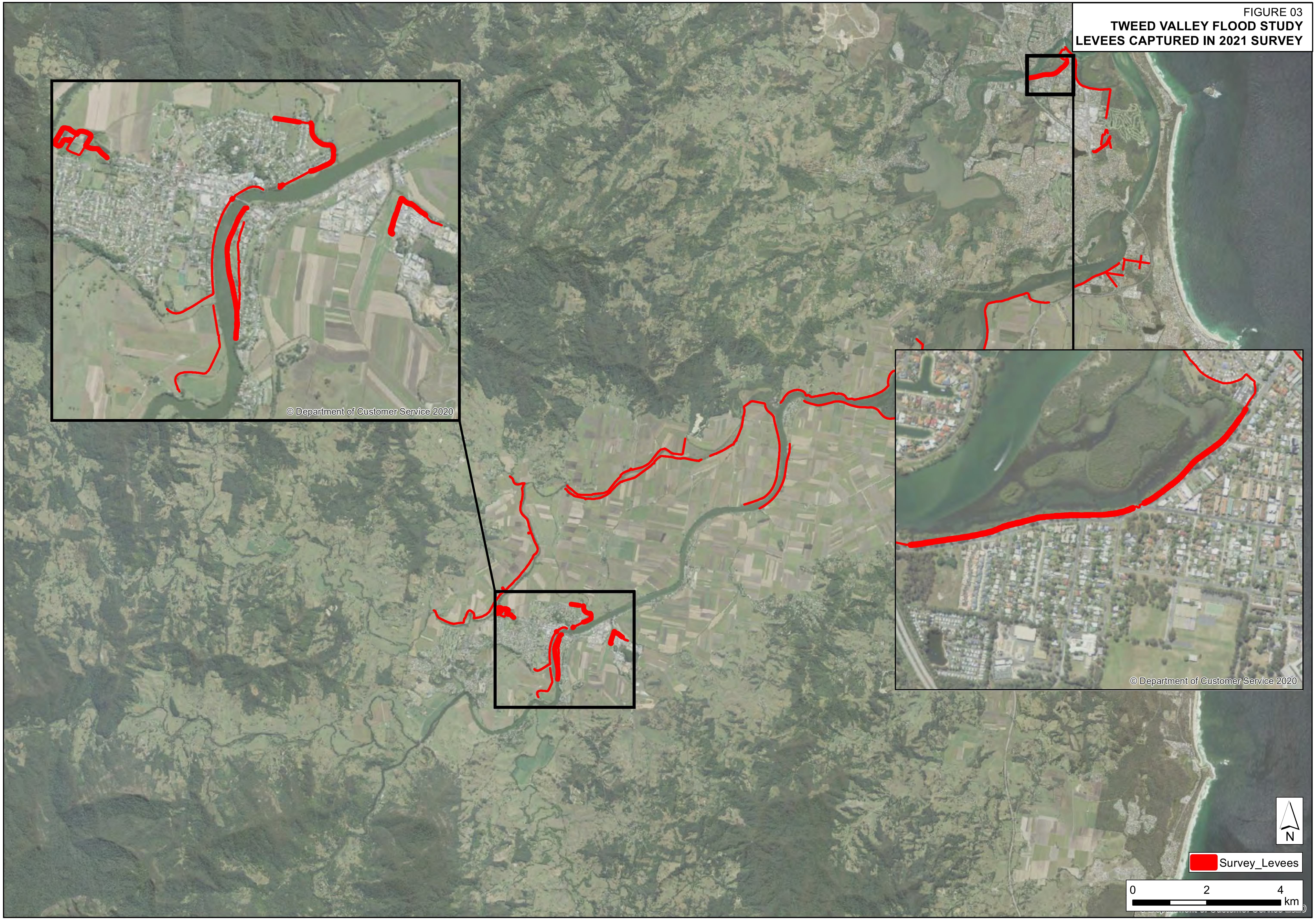


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FIGURE 04
**TWEED VALLEY FLOOD STUDY**
**DIGITAL ELEVATION MODEL**

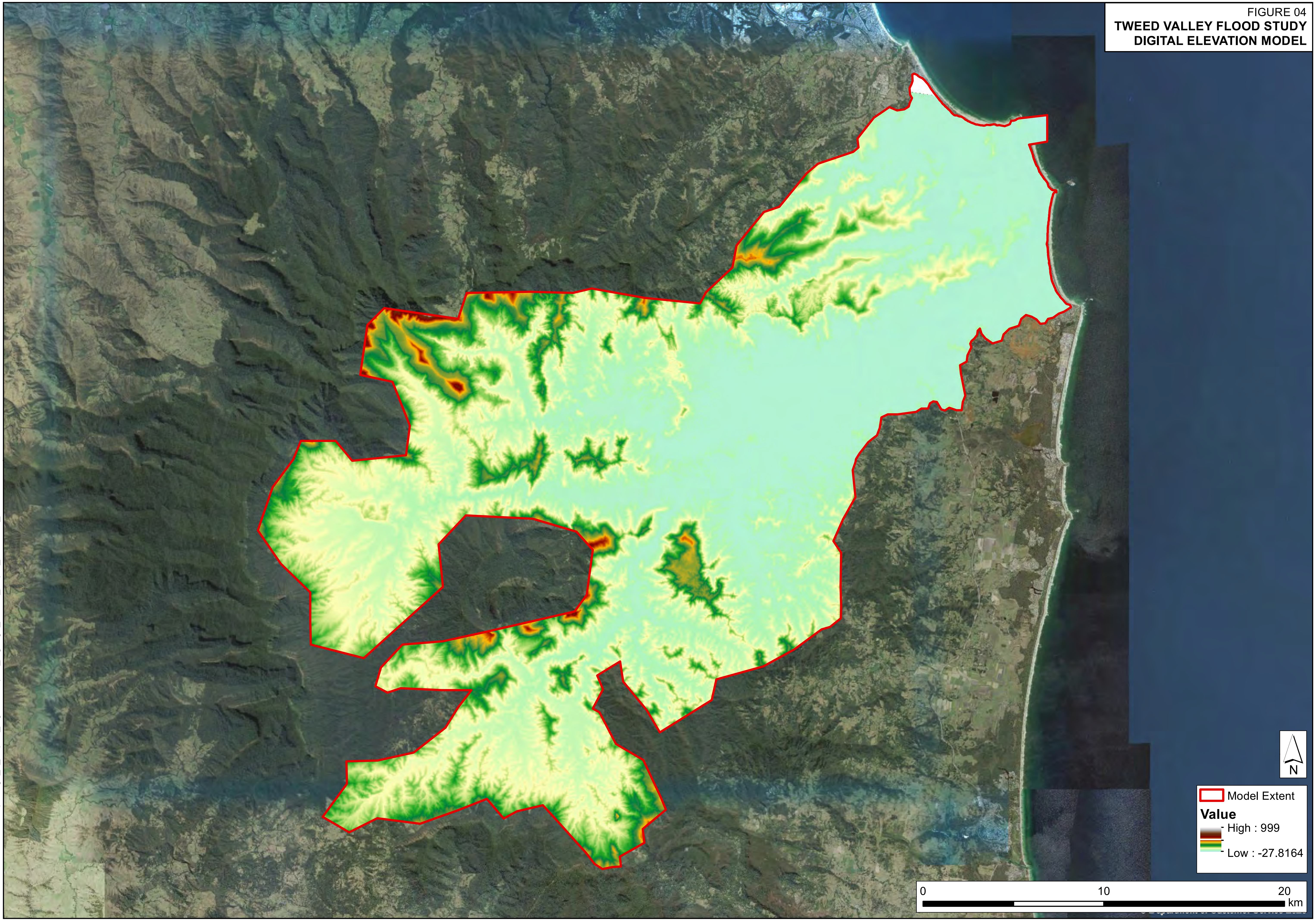


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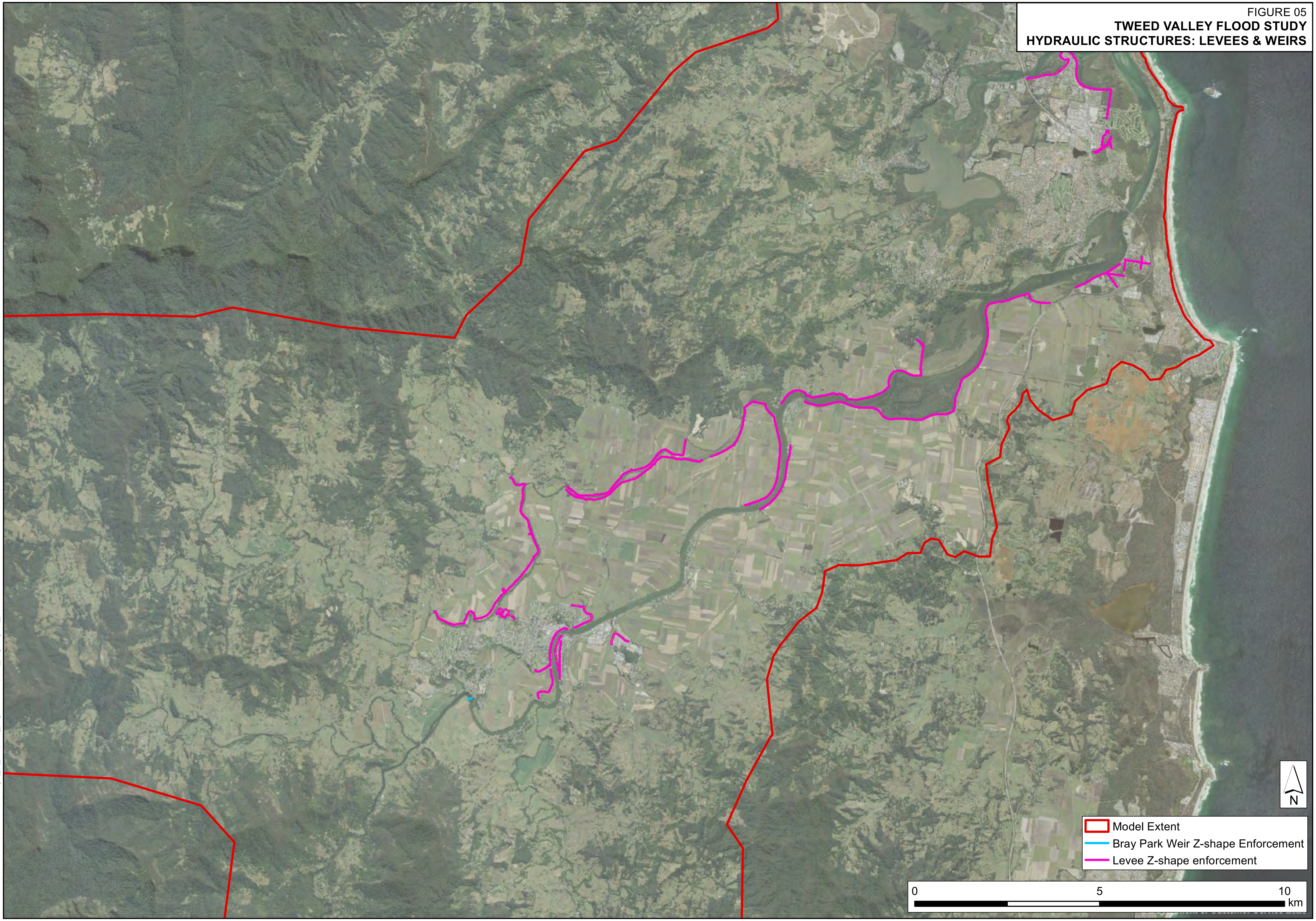
FIGURE 05
**TWEED VALLEY FLOOD STUDY**
**HYDRAULIC STRUCTURES: LEVEES & WEIRS**

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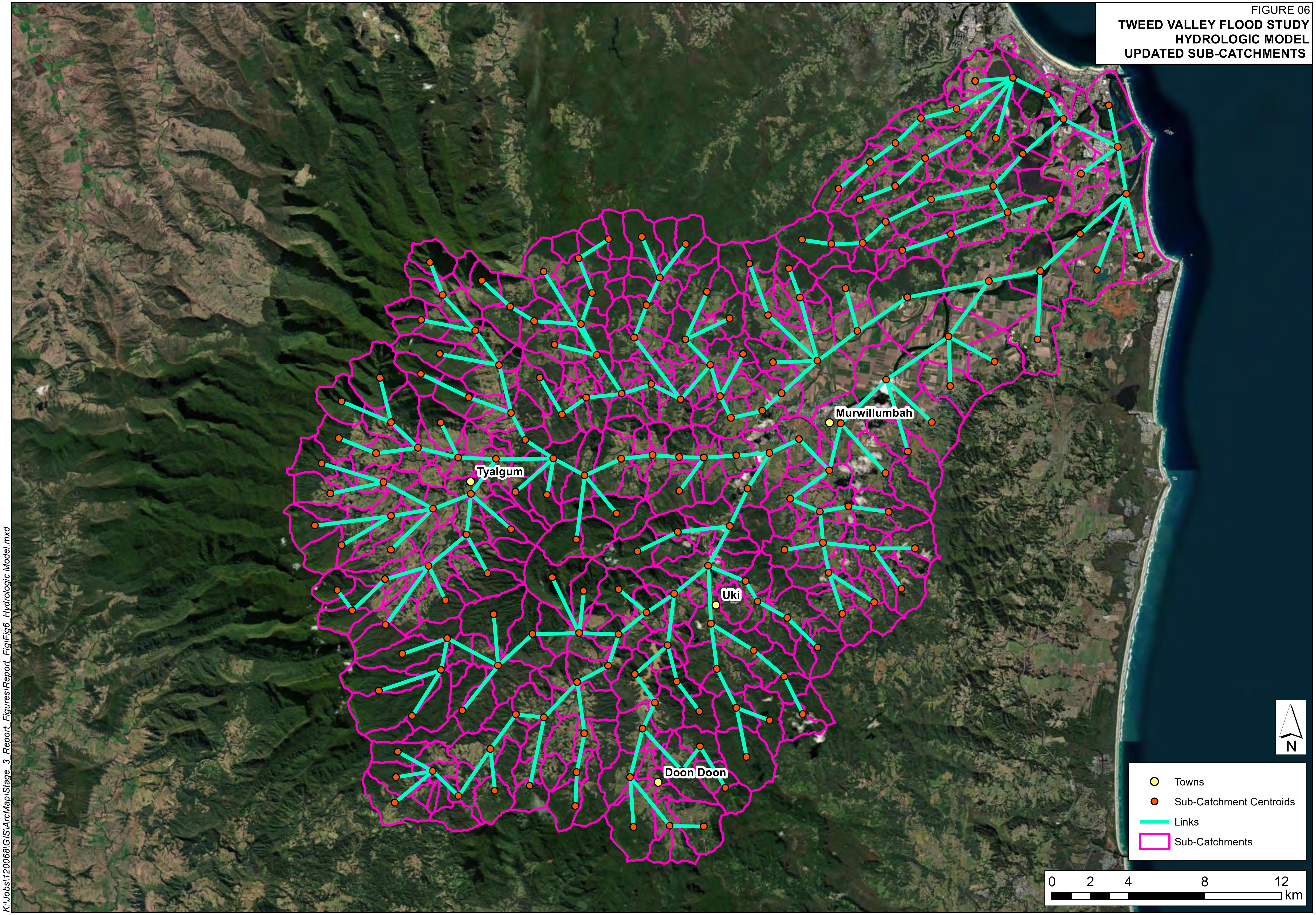


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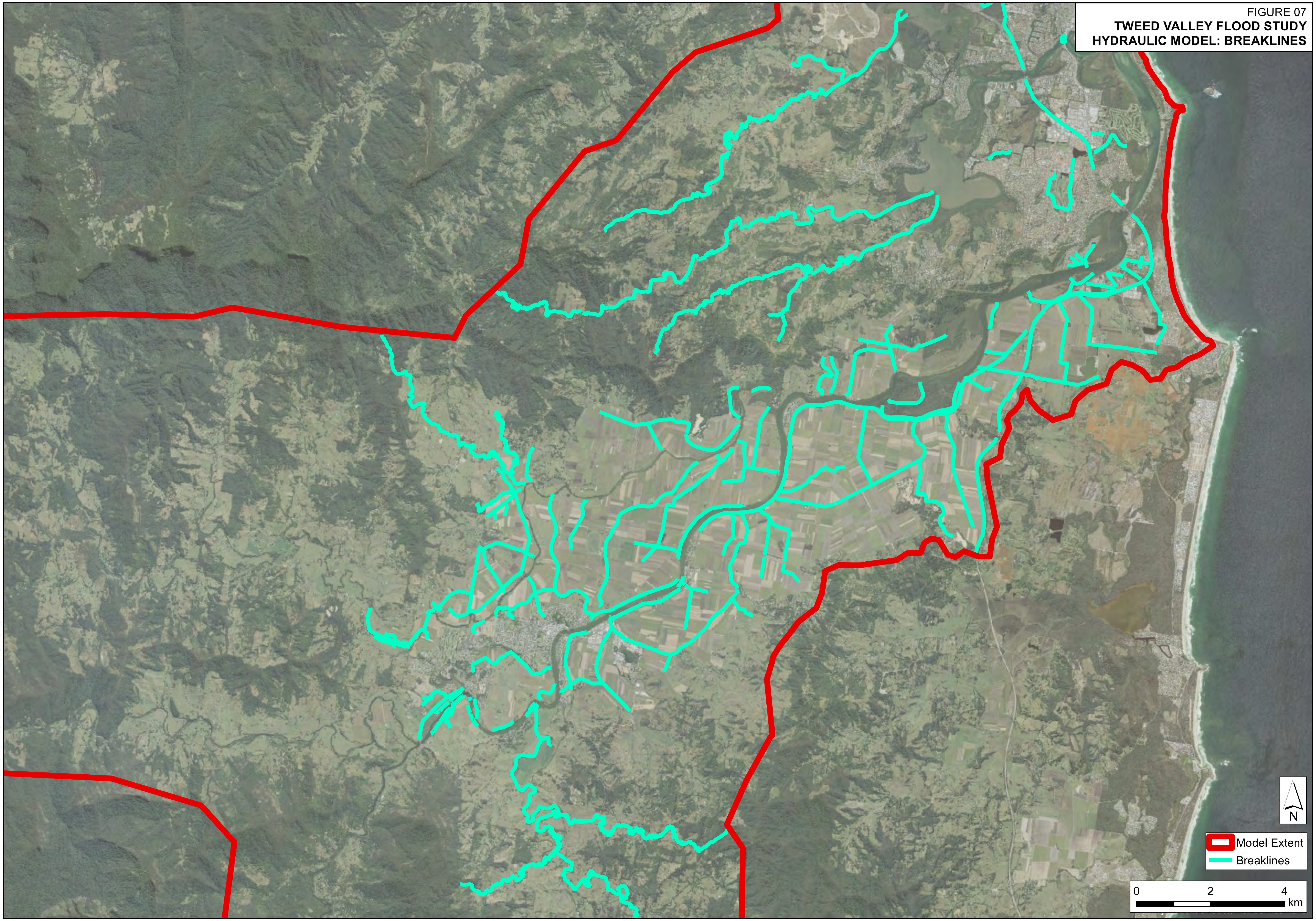
FIGURE 07
**TWEED VALLEY FLOOD STUDY**
**HYDRAULIC MODEL: BREAKLINES**

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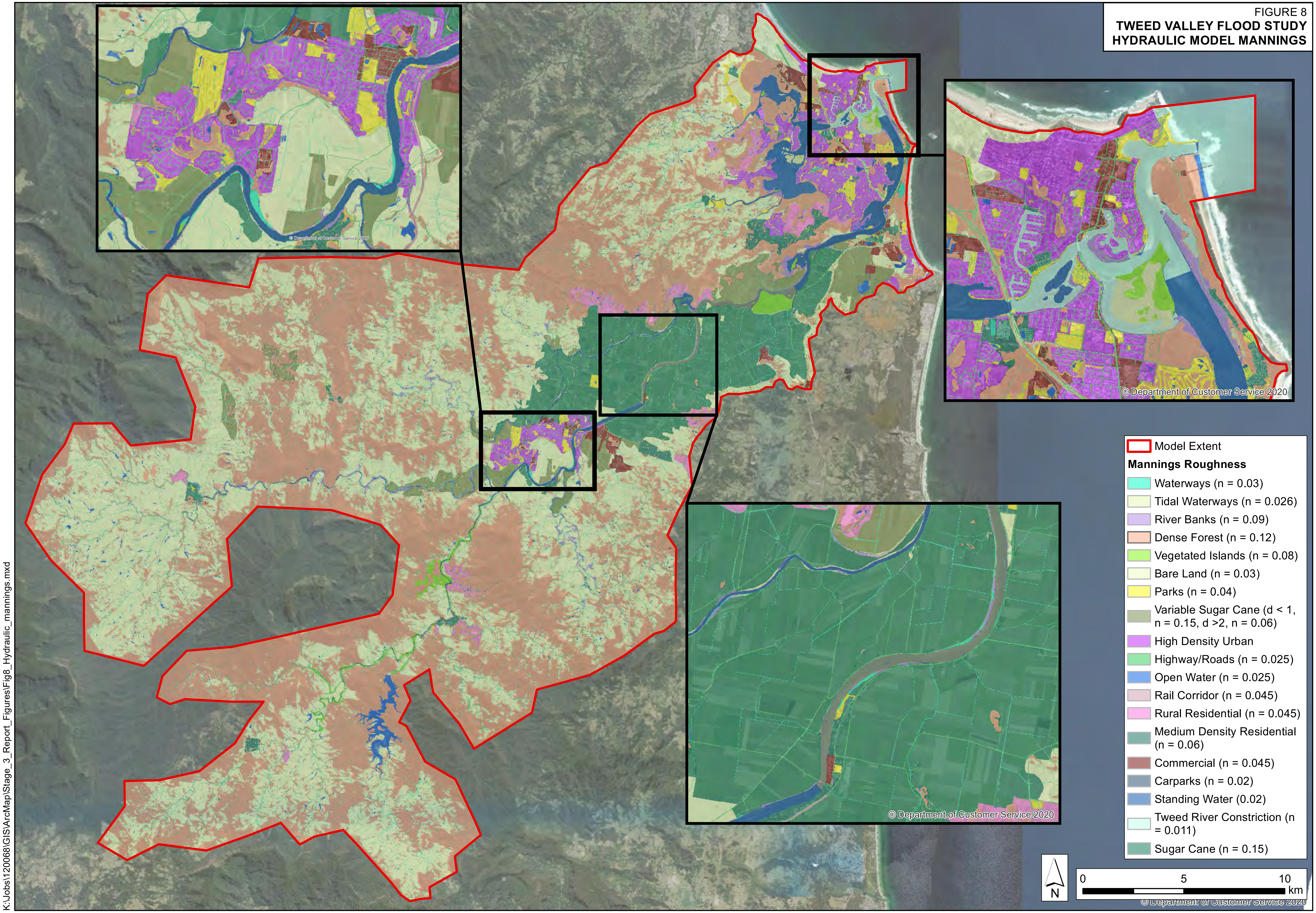

FIGURE 8
TWEED VALLEY FLOOD STUDY
HYDRAULIC MODEL MANNINGS
Model Extent
Mannings Roughness
Waterways (n = 0.03)
Tidal Waterways (n = 0.026)
River Banks (n = 0.09)
Dense Forest (n = 0.12)
Vegetated Islands (n = 0.08)
Bare Land (n = 0.03)
Parks (n = 0.04)
Variable Sugar Cane (d < 1, n = 0.15, d >2, n = 0.06)
High Density Urban
Highway/Roads (n = 0.025)
Open Water (n = 0.025)
Rail Corridor (n = 0.045)
Rural Residential (n = 0.045)
Medium Density Residential (n = 0.06)
Commercial (n = 0.045)
Carparks (n = 0.02)
Standing Water (0.02)
Tweed River Constriction (n = 0.011)
Sugar Cane (n = 0.15)
N
0
5
10
km
© Department of Customer Service 2020
© Department of Customer Service 2020
© Department of Customer Service 2020
© Department of Customer Service 2020
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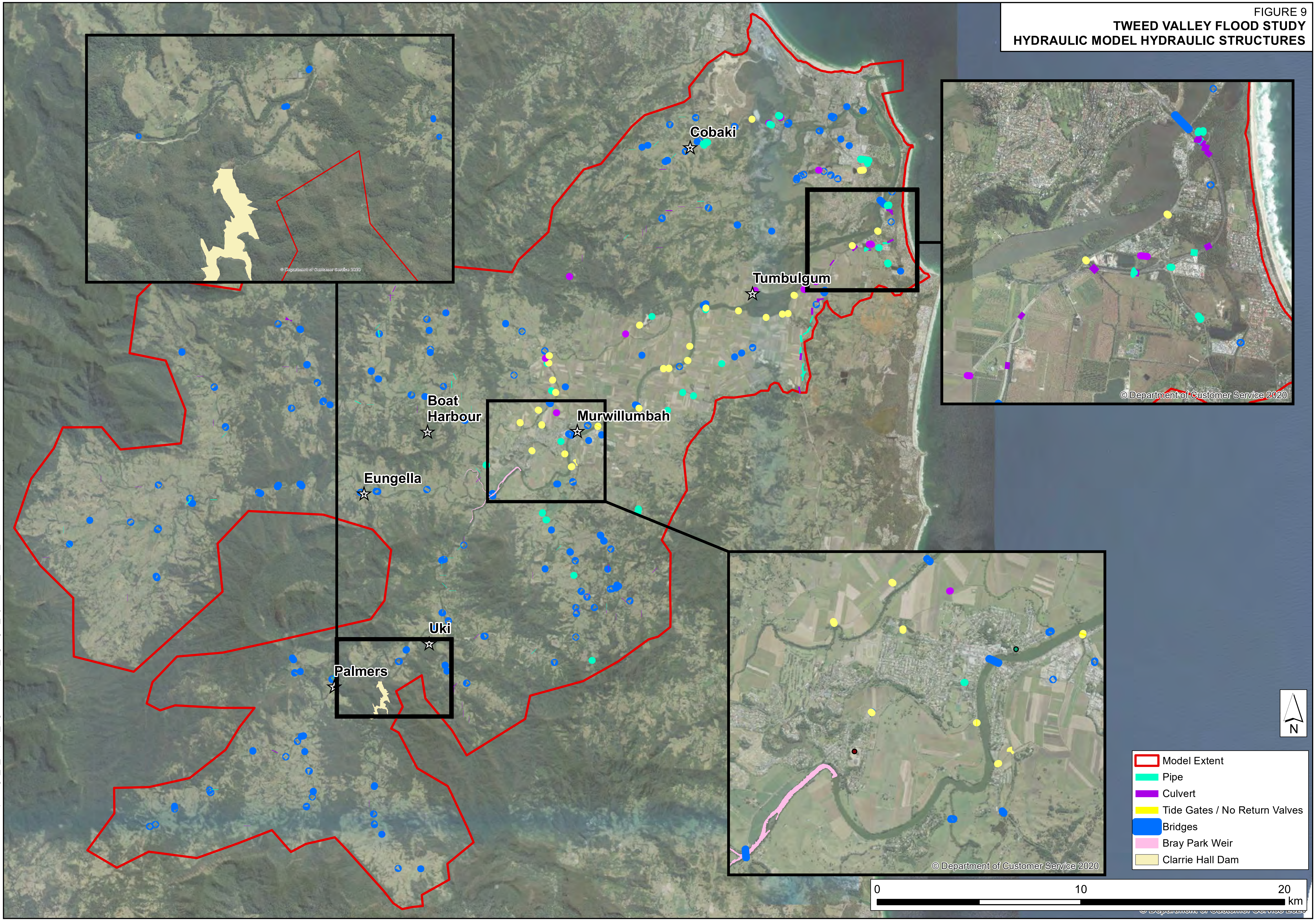


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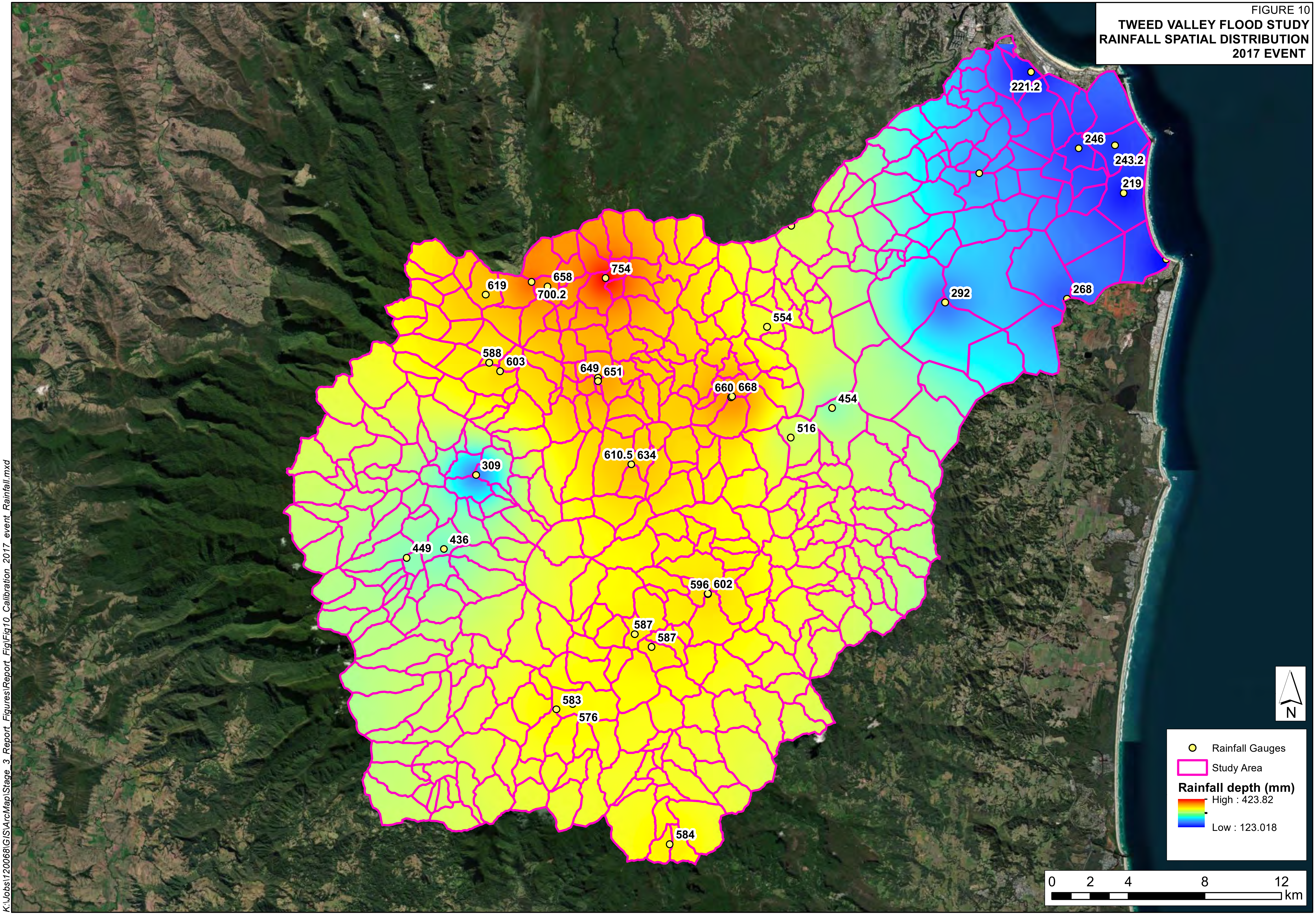

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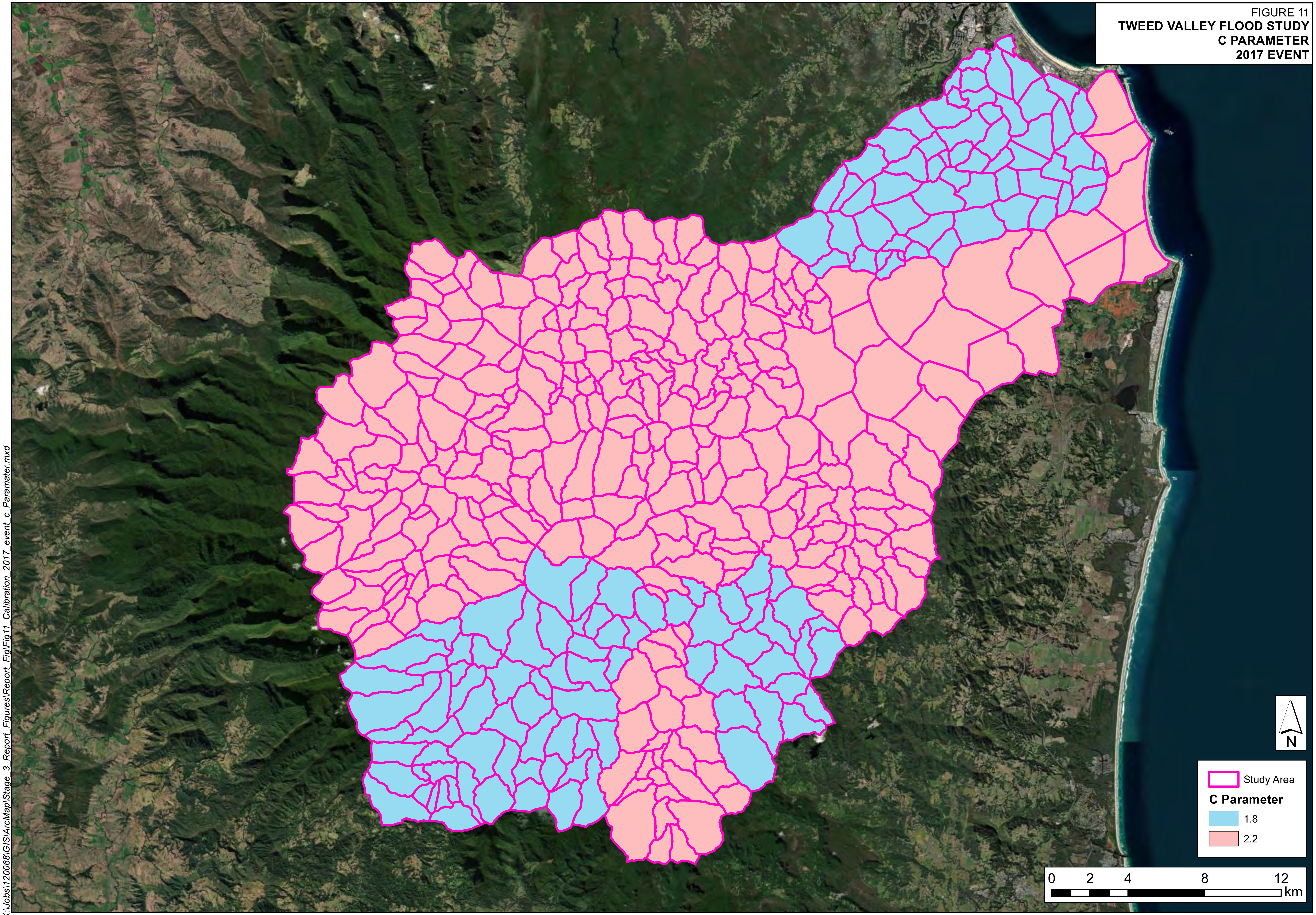


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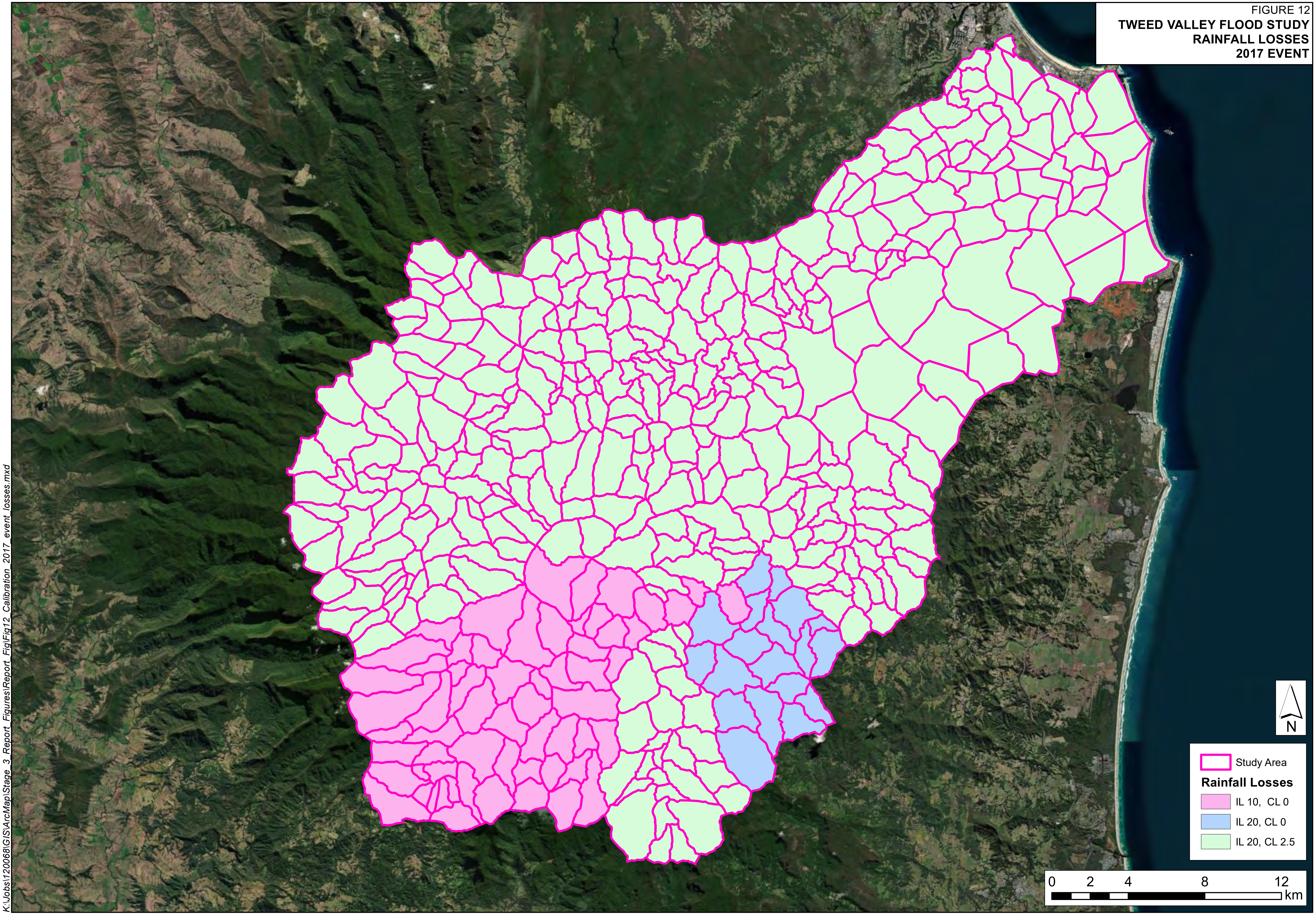


FIGURE 12
**TWEED VALLEY FLOOD STUDY**
**RAINFALL LOSSES**
**2017 EVENT**

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FIGURE 13

**TWEED VALLEY FLOOD STUDY**
**RAINFALL SPATIAL DISTRIBUTION**
**2022 EVENT**

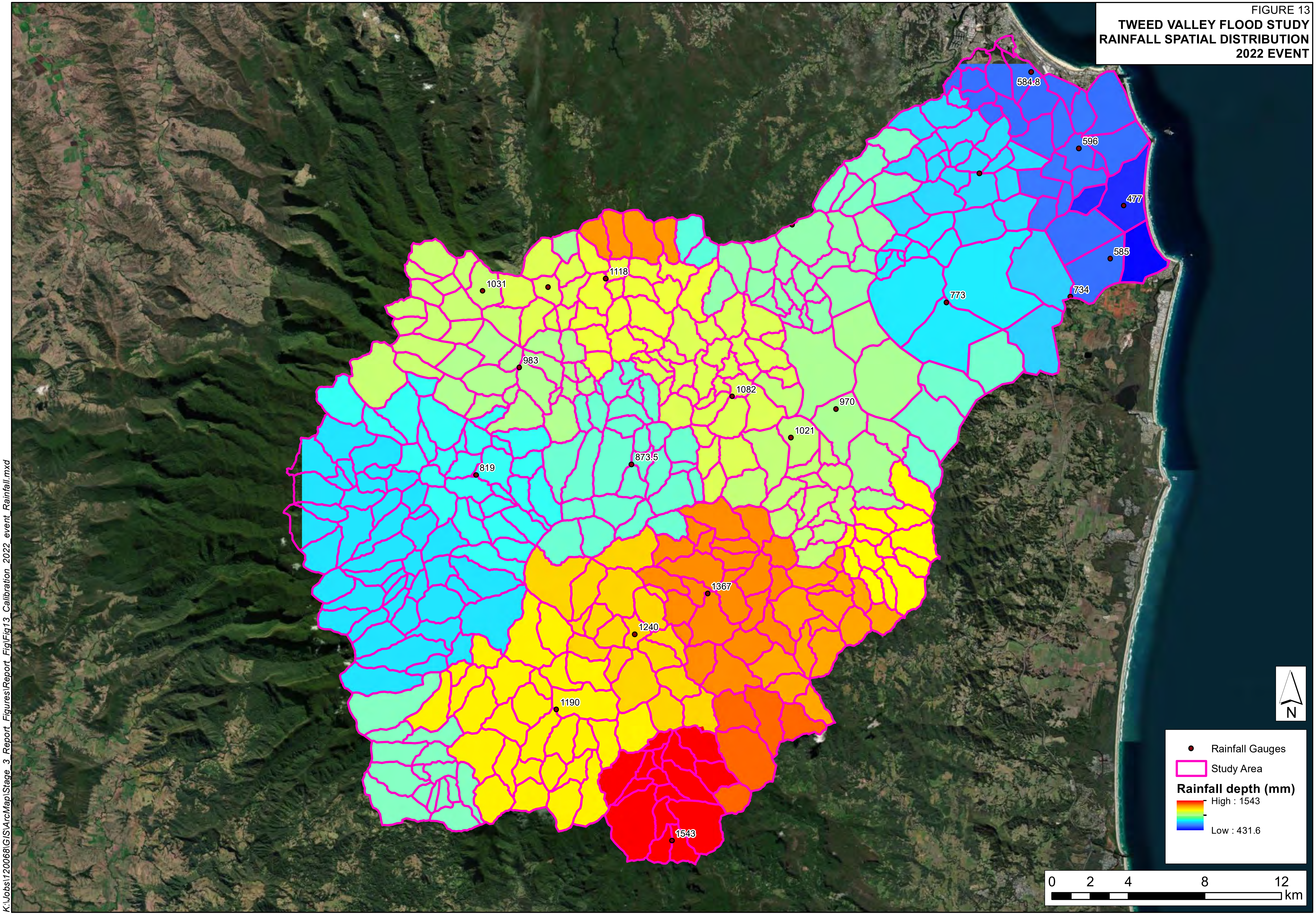


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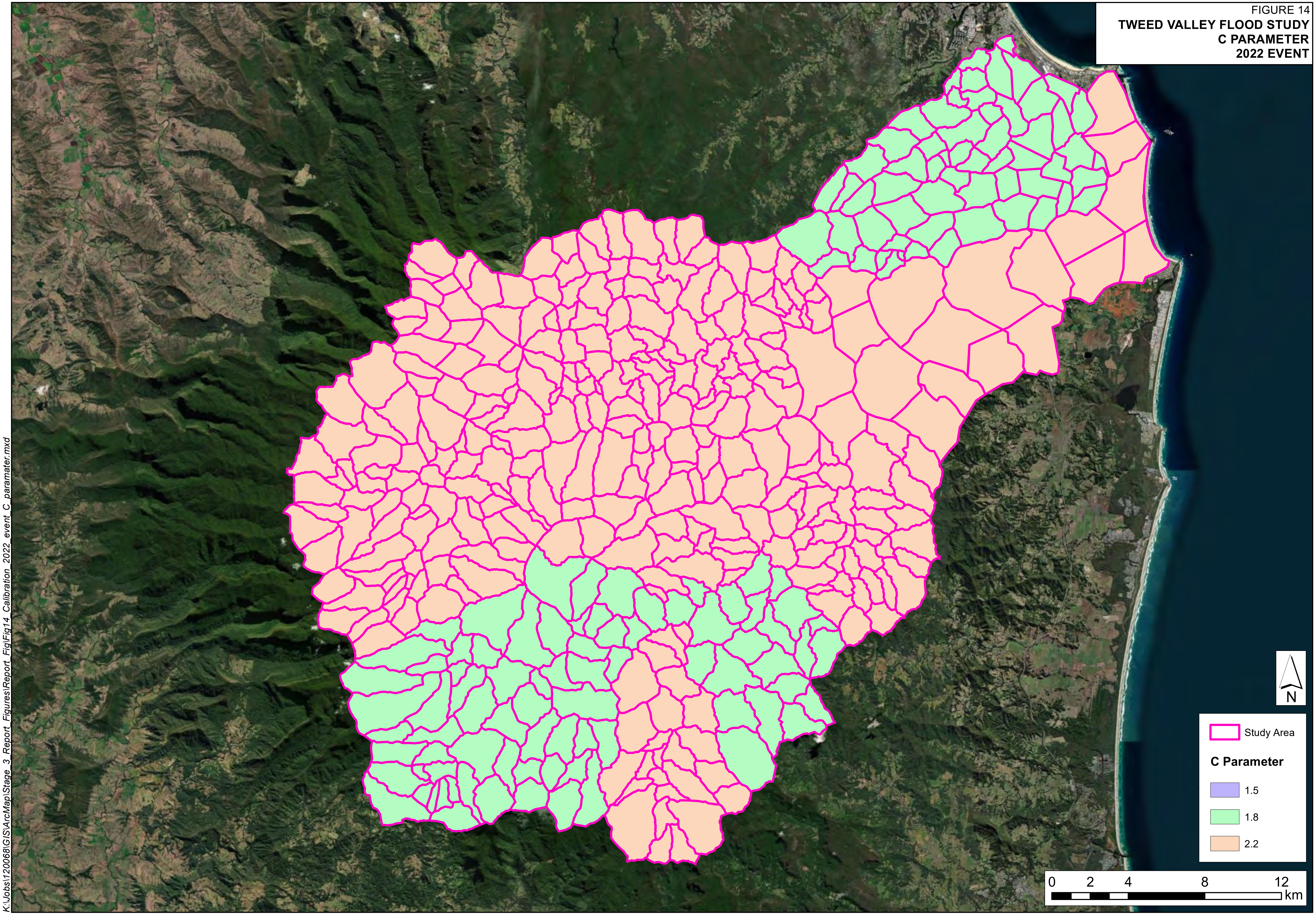
FIGURE 14
**TWEED VALLEY FLOOD STUDY**
**C PARAMETER**
**2022 EVENT**



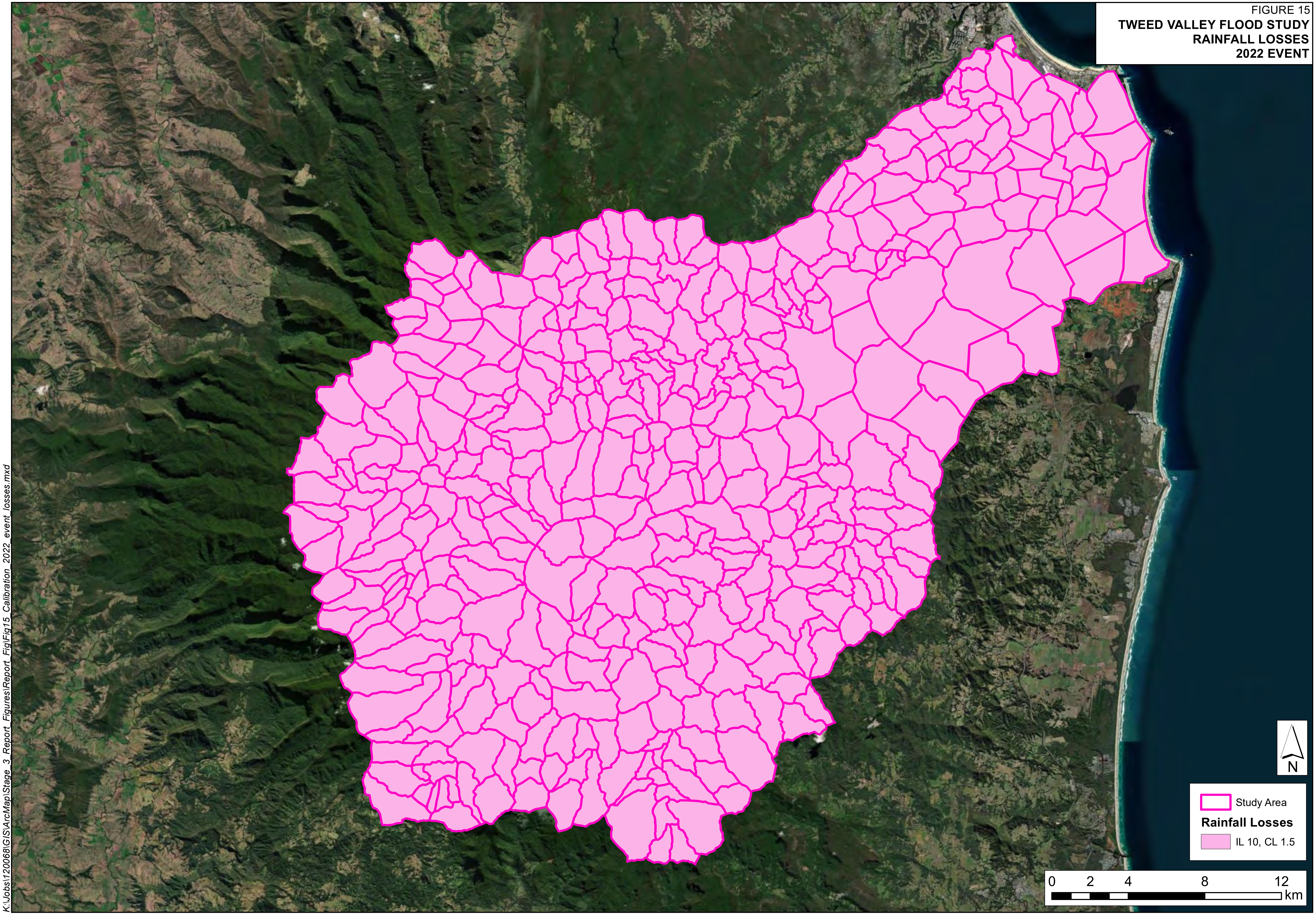



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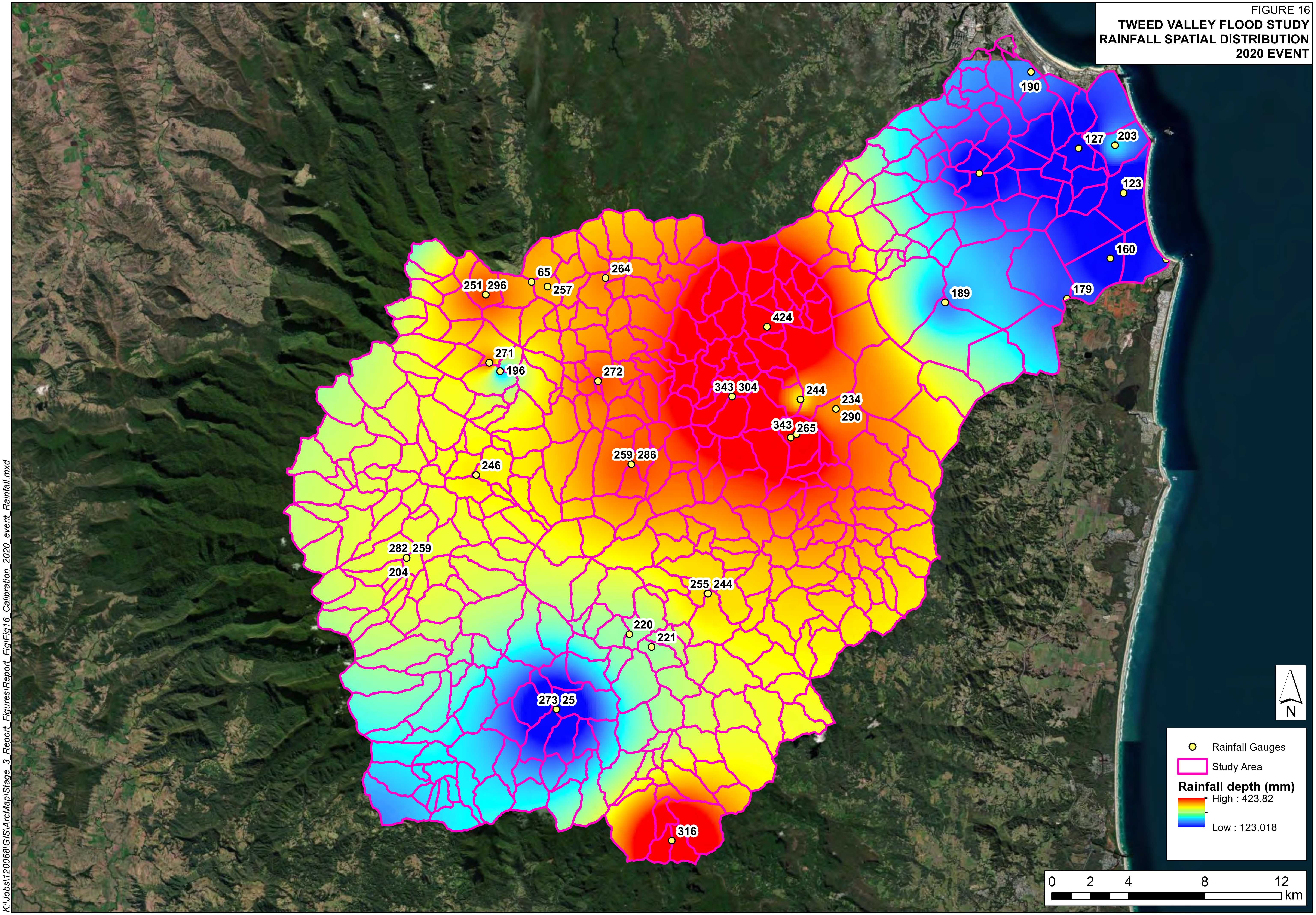
FIGURE 16
**TWEED VALLEY FLOOD STUDY**
**RAINFALL SPATIAL DISTRIBUTION**
**2020 EVENT**

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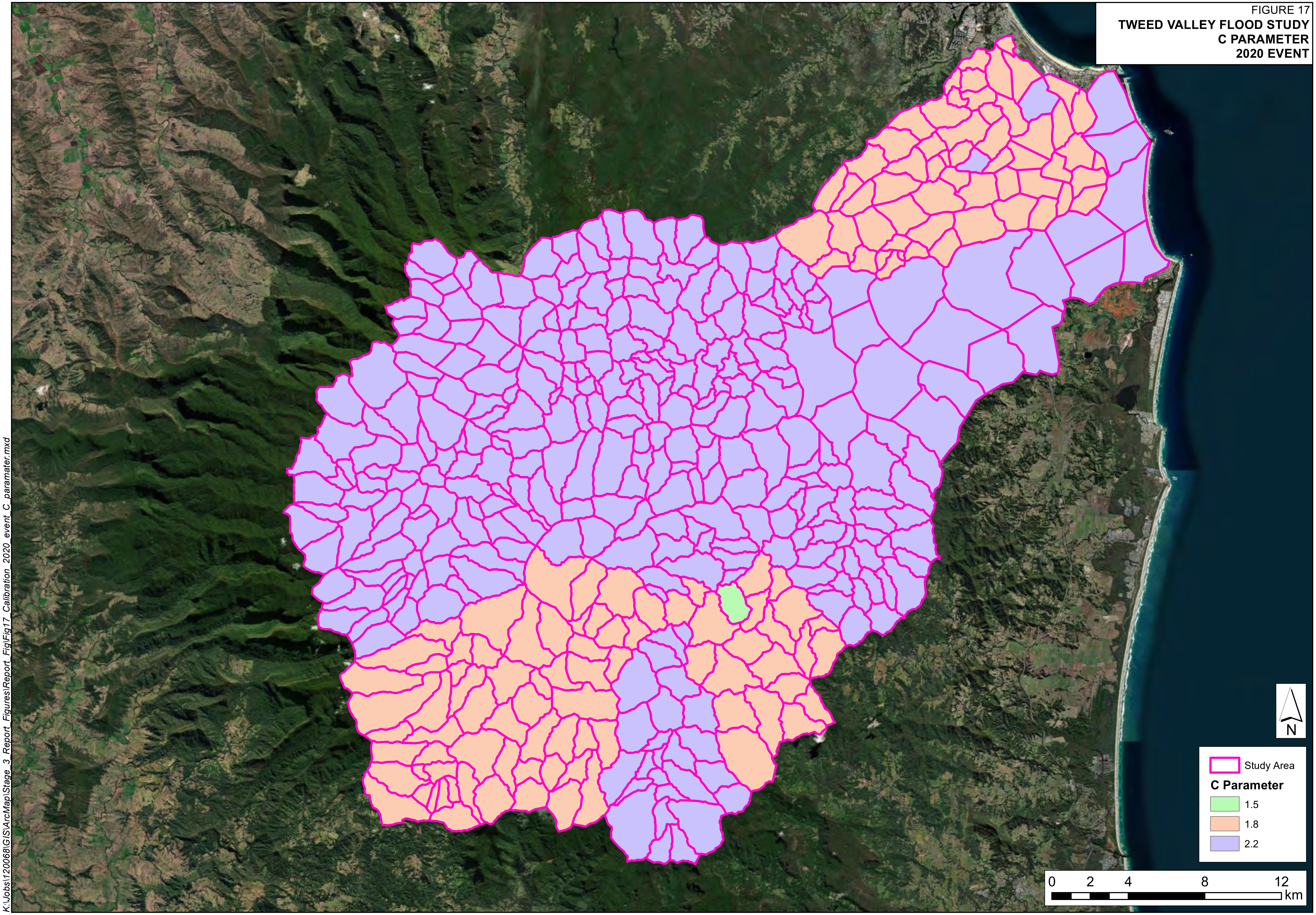


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FIGURE 18
**TWEED VALLEY FLOOD STUDY**
**RAINFALL LOSSES**
**2020 EVENT**

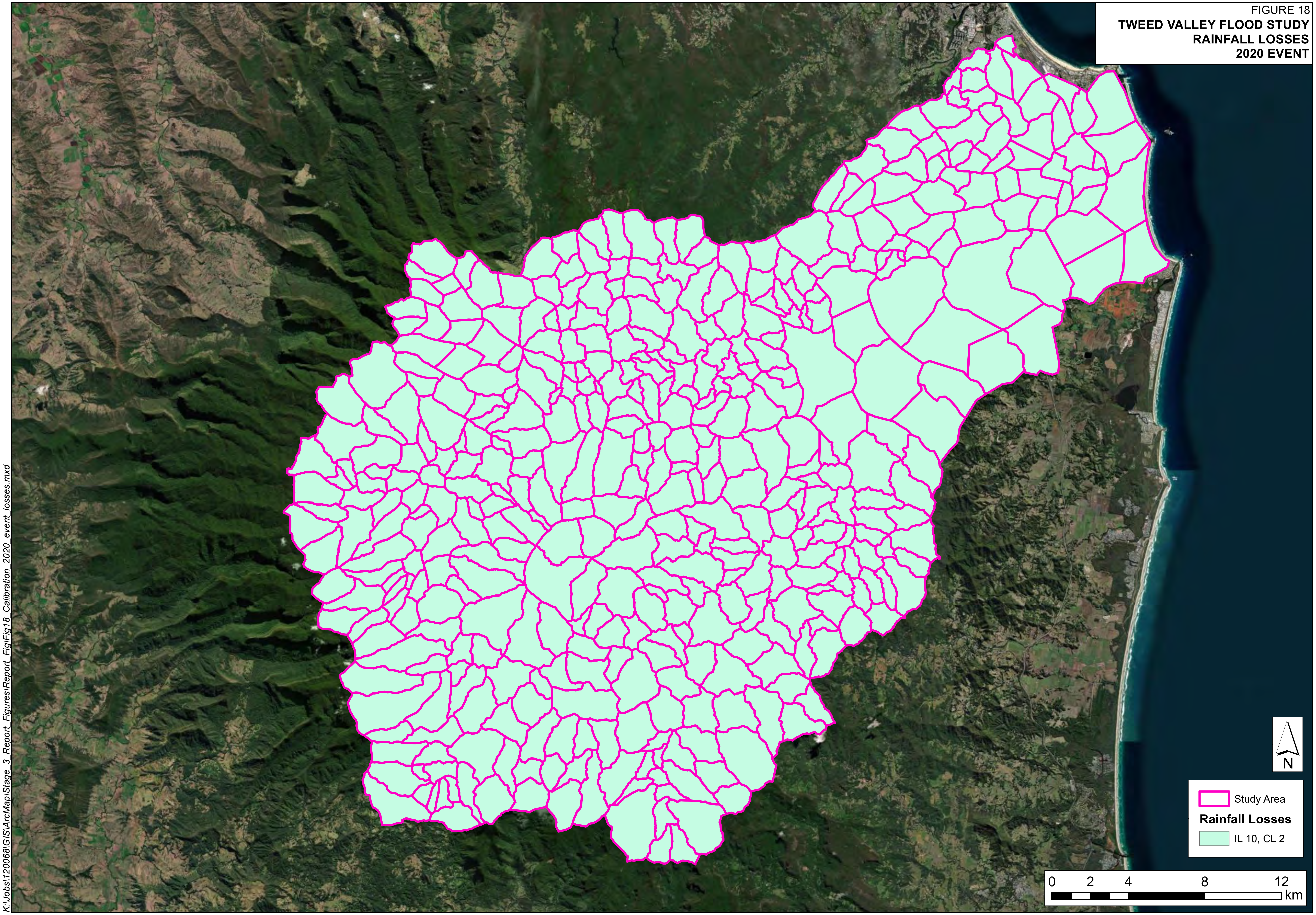


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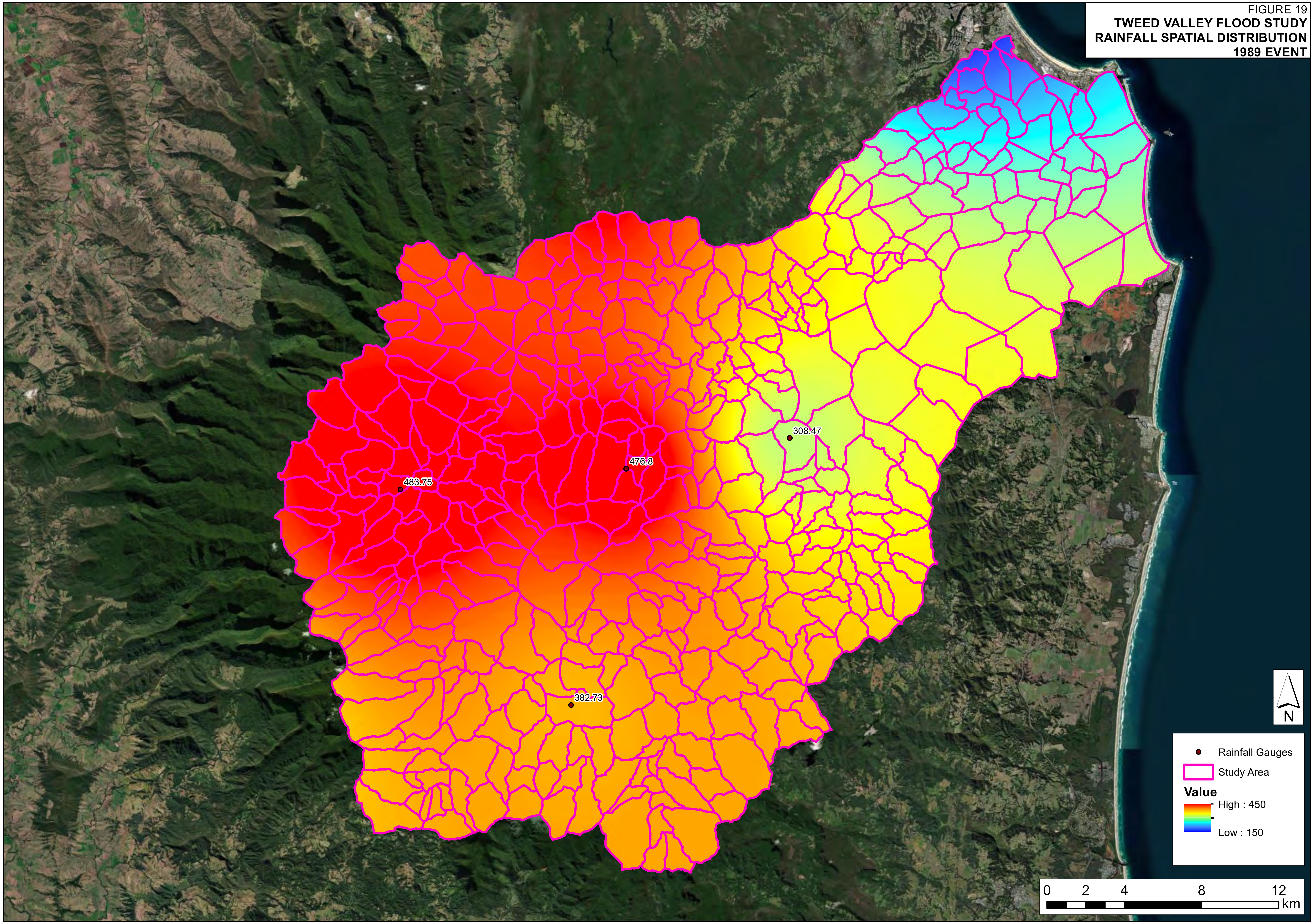
FIGURE 19
**TWEED VALLEY FLOOD STUDY**
**RAINFALL SPATIAL DISTRIBUTION**
**1989 EVENT**

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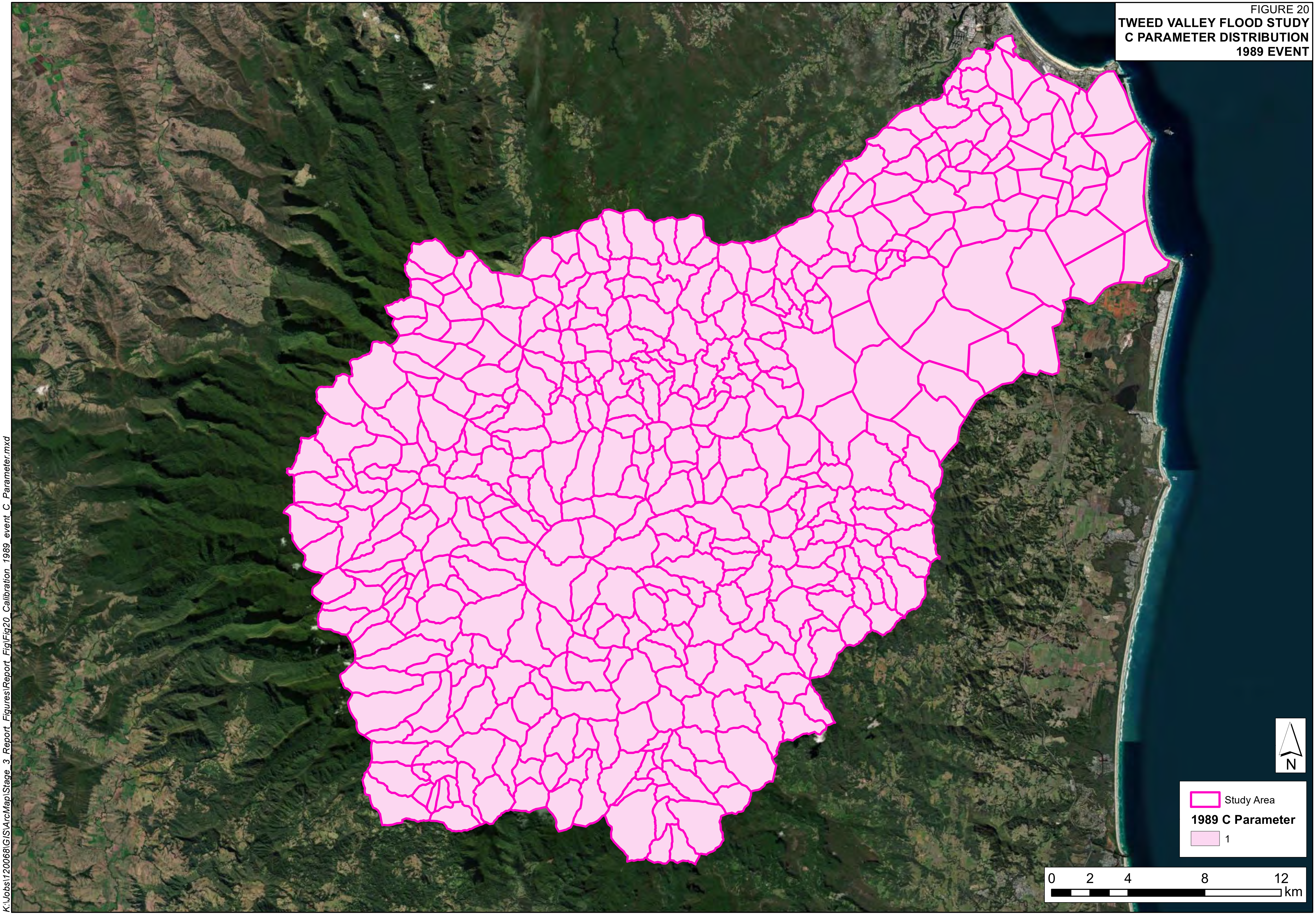
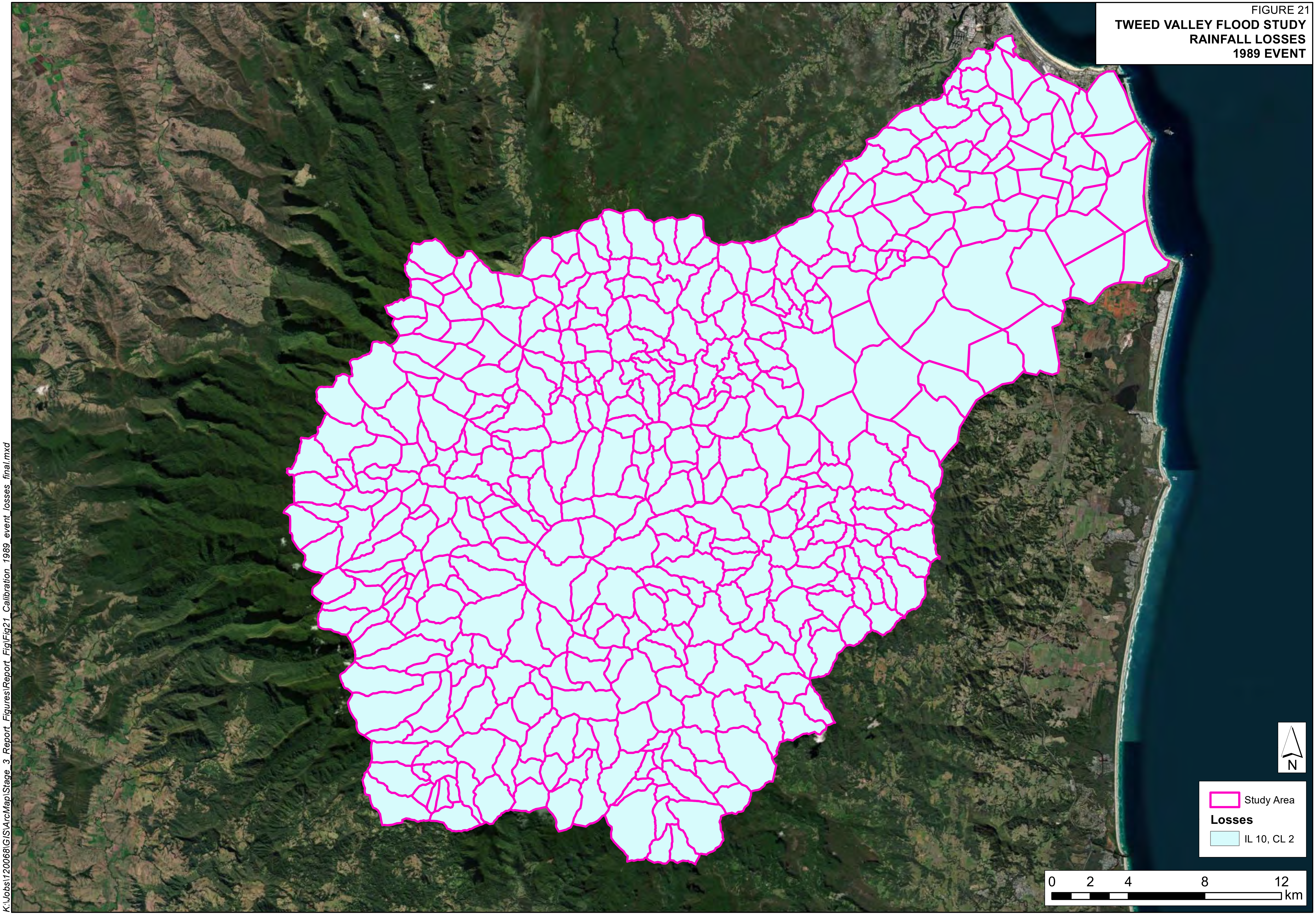


FIGURE 20
TWEED VALLEY FLOOD STUDY
C PARAMETER DISTRIBUTION
1989 EVENT
N
Study Area
1989 C Parameter
1
0
2
4
8
12
km
K:\Jobs\120068\GIS\ArcMap\Stage_3_Report_Figures\Report_Fig\Fig20_Calibration_1989_event_C_Parameter.mxd

FIGURE 21
**TWEED VALLEY FLOOD STUDY**
**RAINFALL LOSSES**
**1989 EVENT**

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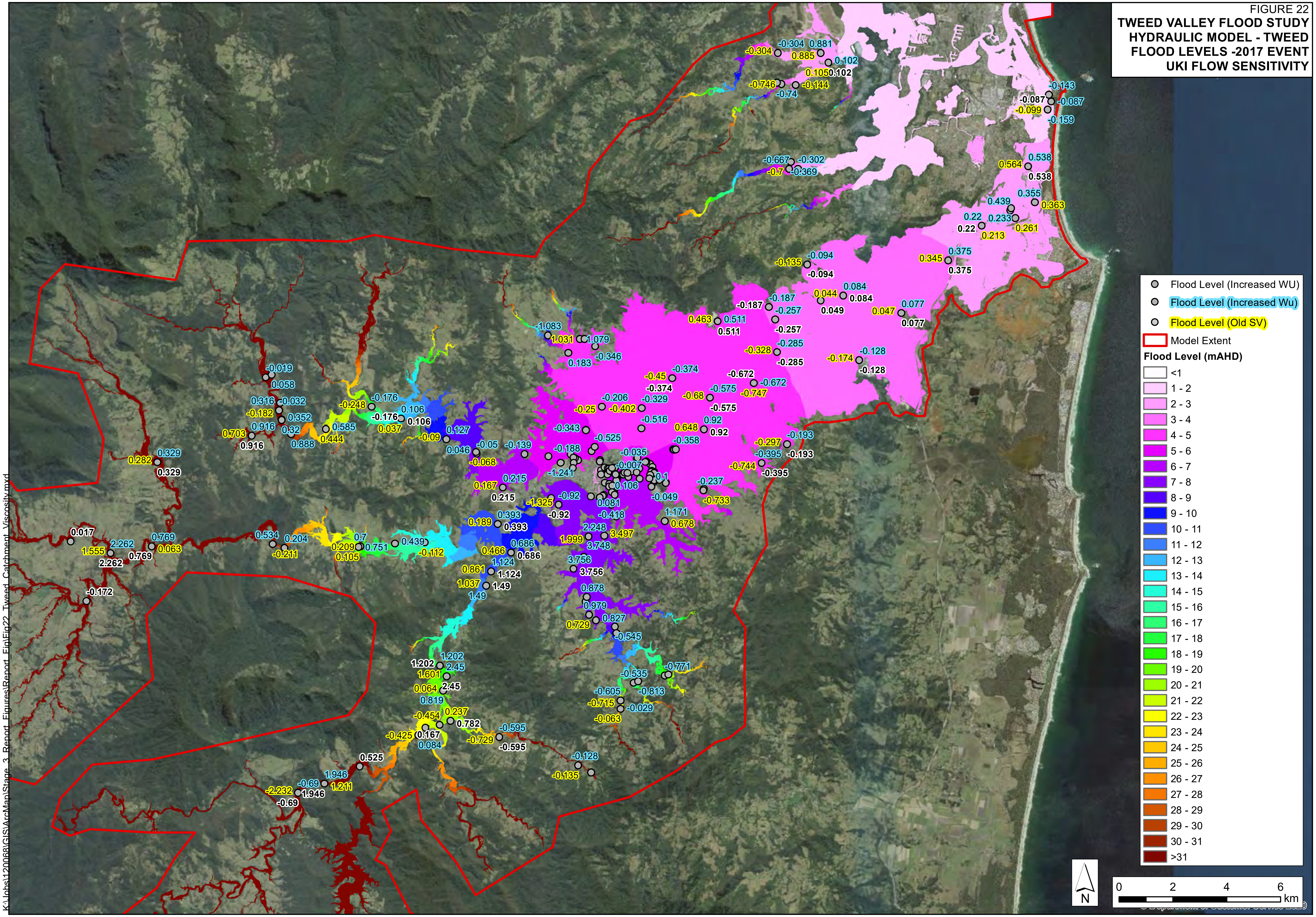

FIGURE 22
TWEED VALLEY FLOOD STUDY
HYDRAULIC MODEL - TWEED
FLOOD LEVELS -2017 EVENT
UKI FLOW SENSITIVITY
Flood Level (Increased WU)
Flood Level (Increased Wu)
Flood Level (Old SV)
Model Extent
Flood Level (mAHD)
<1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
20 - 21
21 - 22
22 - 23
23 - 24
24 - 25
25 - 26
26 - 27
27 - 28
28 - 29
29 - 30
30 - 31
>31
N
0 2 4 6 km
K:\Jobs\120068\GIS\ArcMap\Stage_3_Report_Figures\Report_Fig\Fig22_Tweed_Catchment_Viscosity.mxd

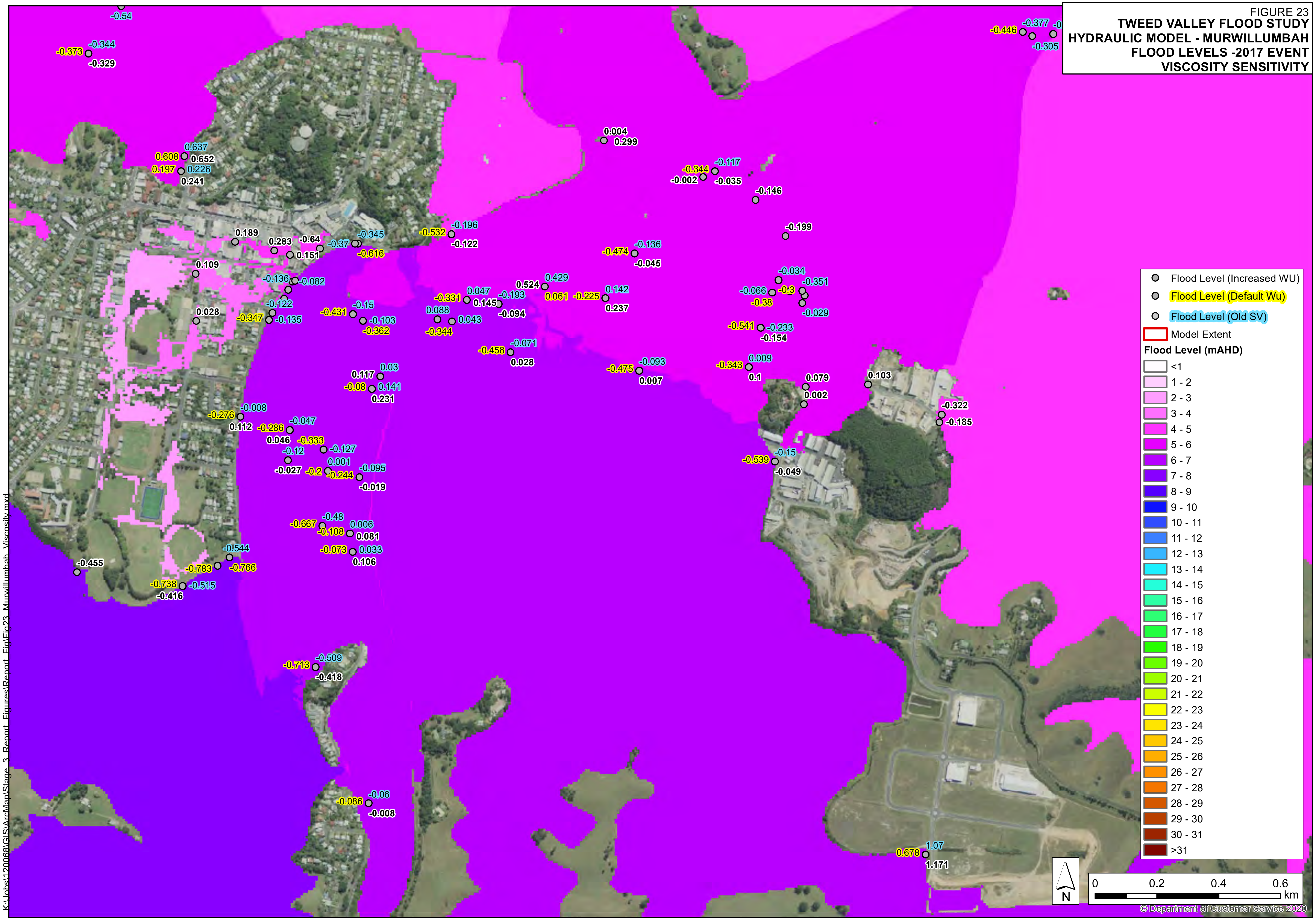


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FIGURE 24
**TWEED VALLEY FLOOD STUDY**
**HYDRAULIC MODEL - TWEED**
**FLOOD LEVELS -2017 EVENT**
**INCREASE MANNING SENSITIVITY**

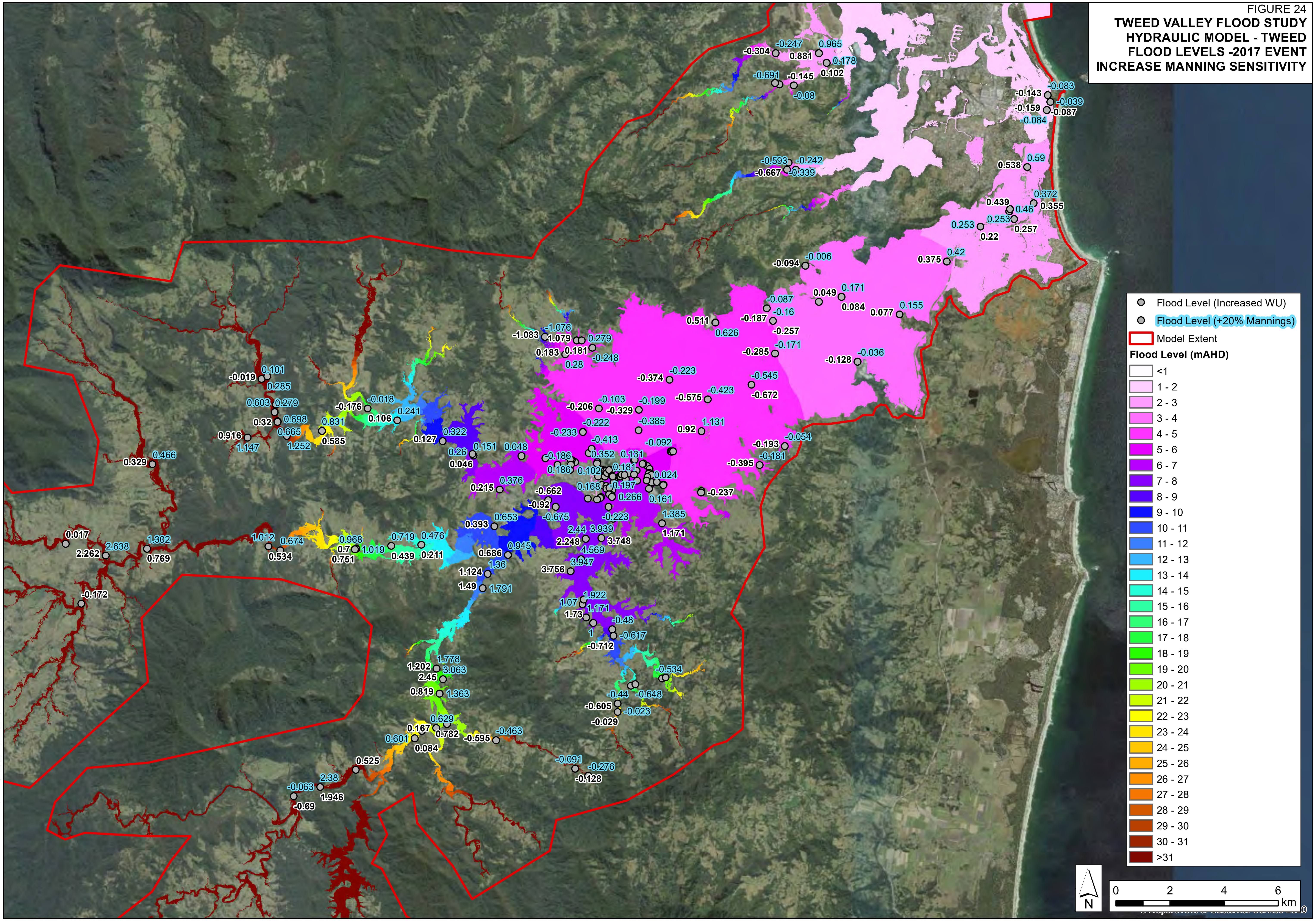


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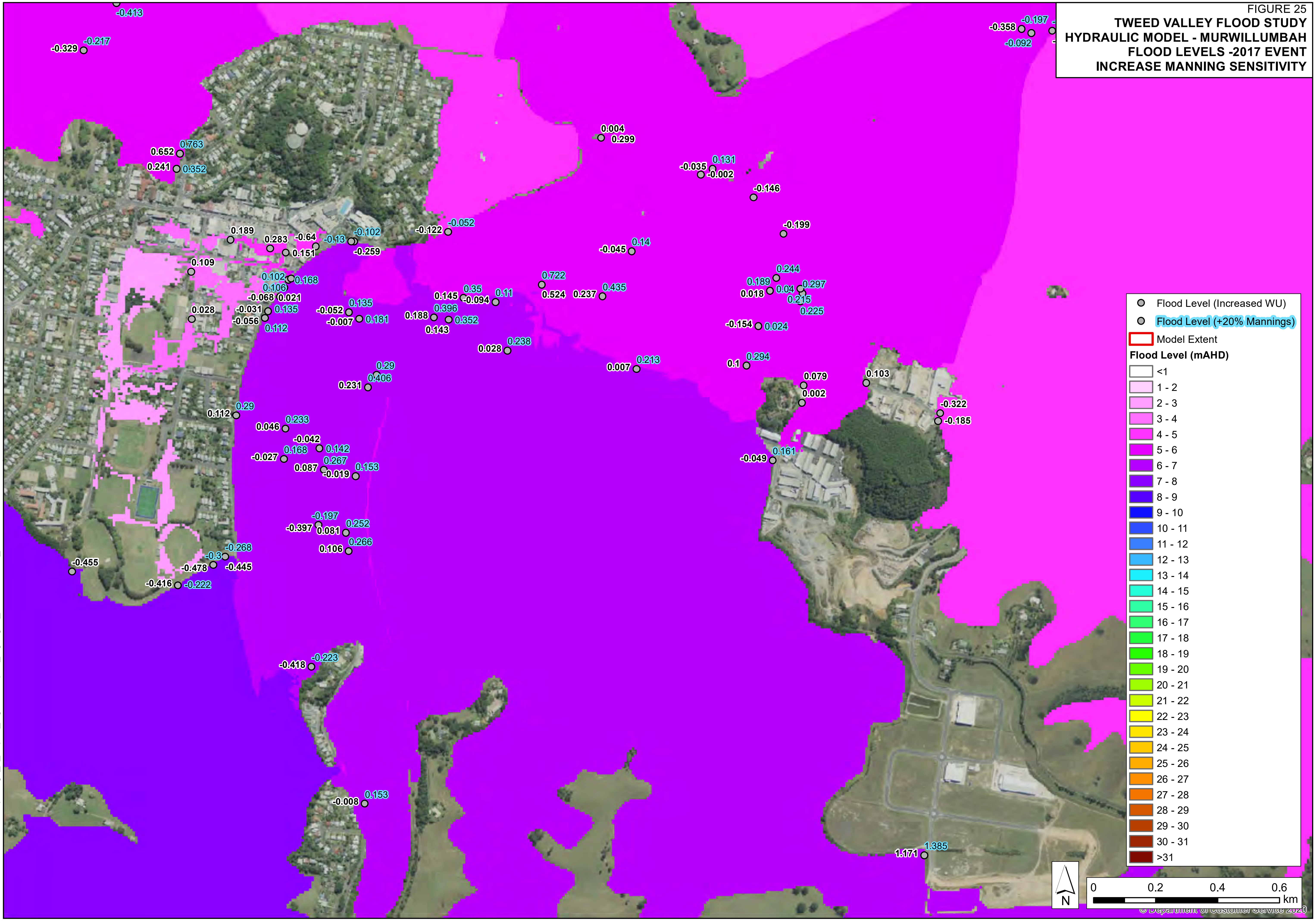
FIGURE 25

# TWEED VALLEY FLOOD STUDY
## HYDRAULIC MODEL - MURWILLUMBAH
## FLOOD LEVELS -2017 EVENT
## INCREASE MANNING SENSITIVITY



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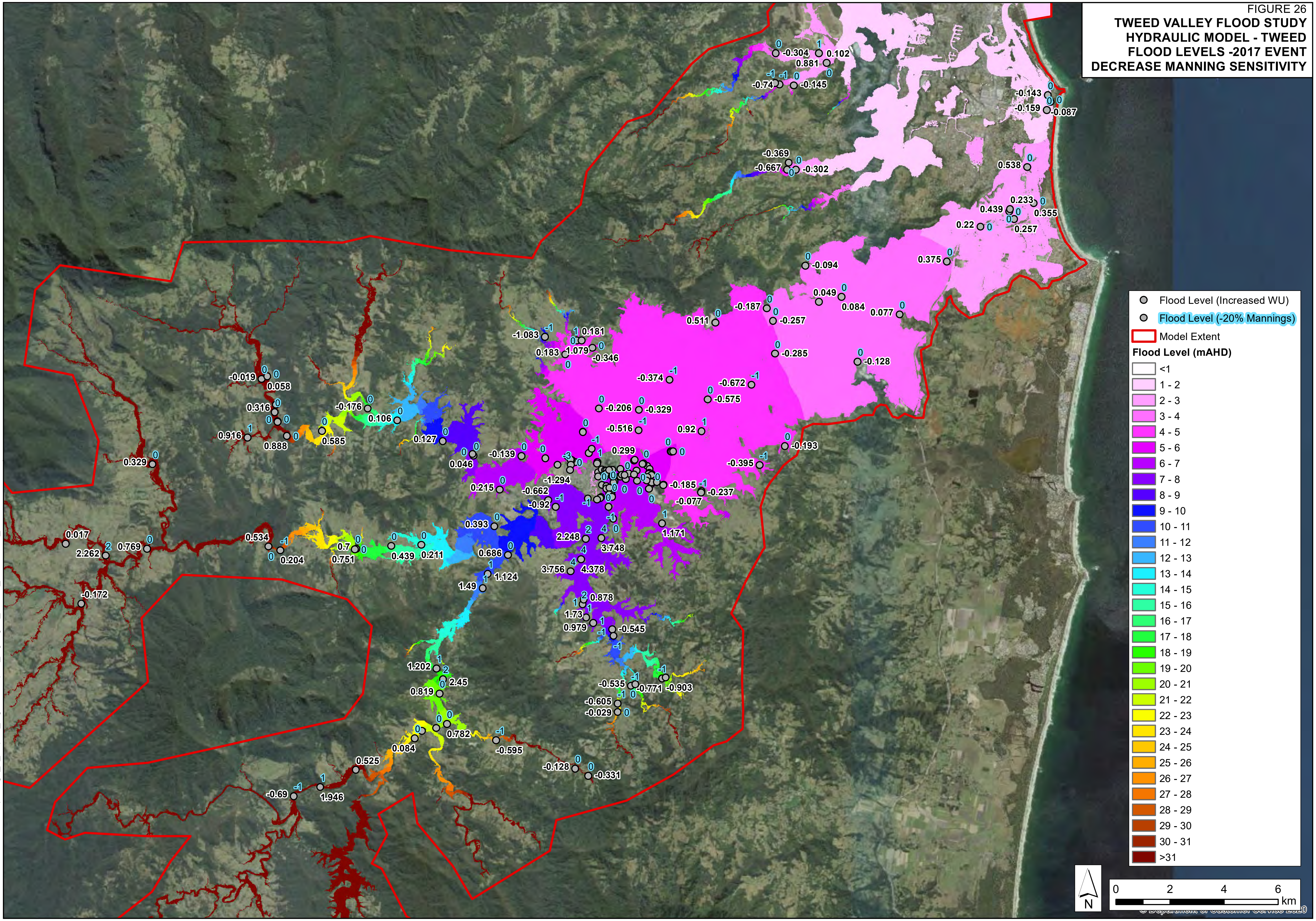
FIGURE 26
TWEED VALLEY FLOOD STUDY
HYDRAULIC MODEL - TWEED
FLOOD LEVELS -2017 EVENT
DECREASE MANNING SENSITIVITY
Flood Level (Increased WU)
Flood Level (-20% Mannings)
Model Extent
Flood Level (mAHD)
<1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
6 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
20 - 21
21 - 22
22 - 23
23 - 24
24 - 25
25 - 26
26 - 27
27 - 28
28 - 29
29 - 30
30 - 31
>31
N
0 2 4 6 km
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K:\Jobs\120068\GIS\ArcMap\Stage_3_Report_Fig\Report_Figures\Fig26_Tweed_Catchment_MM.mxd

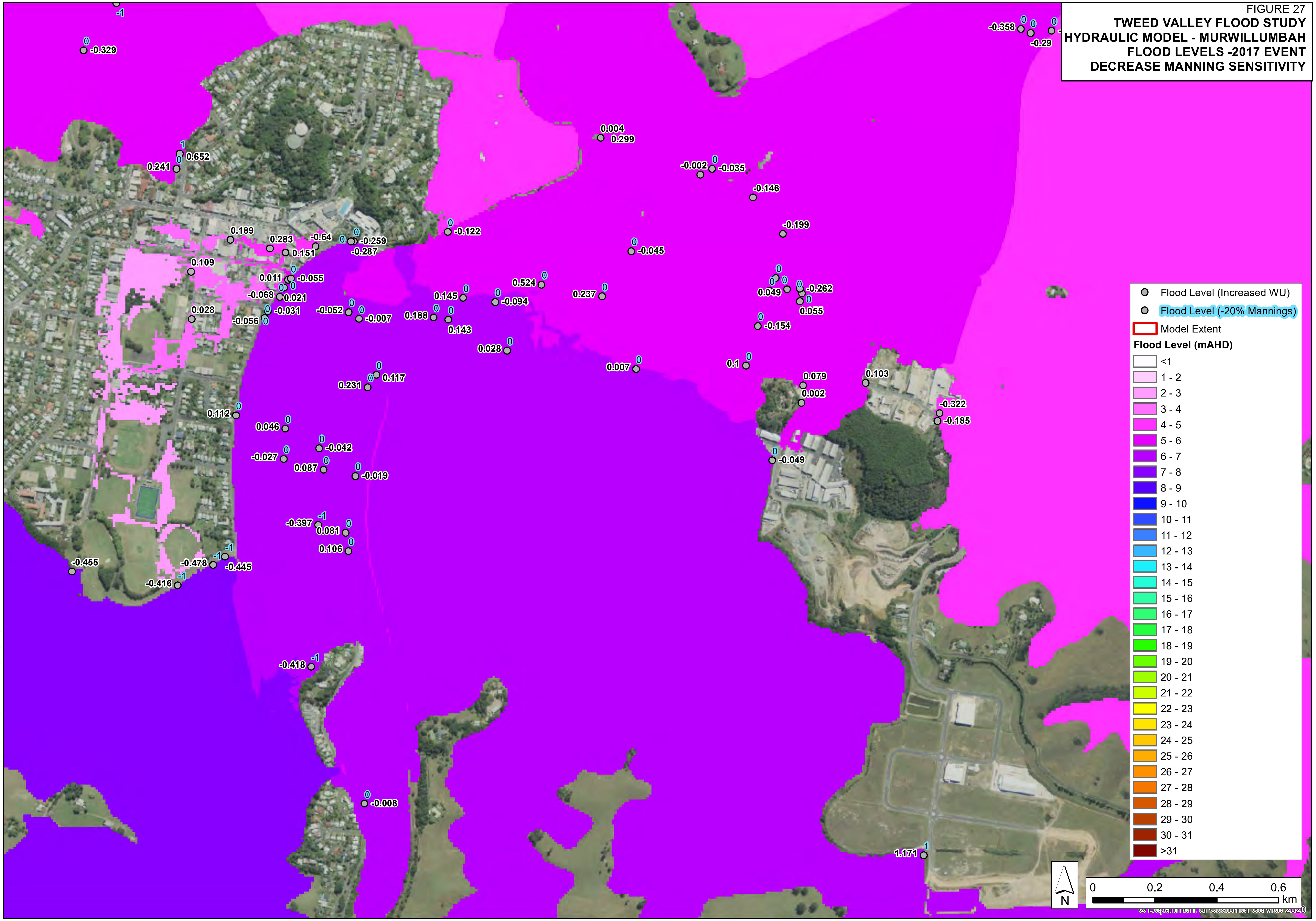


FIGURE 27
**TWEED VALLEY FLOOD STUDY
HYDRAULIC MODEL - MURWILLUMBAH
FLOOD LEVELS -2017 EVENT
DECREASE MANNING SENSITIVITY**

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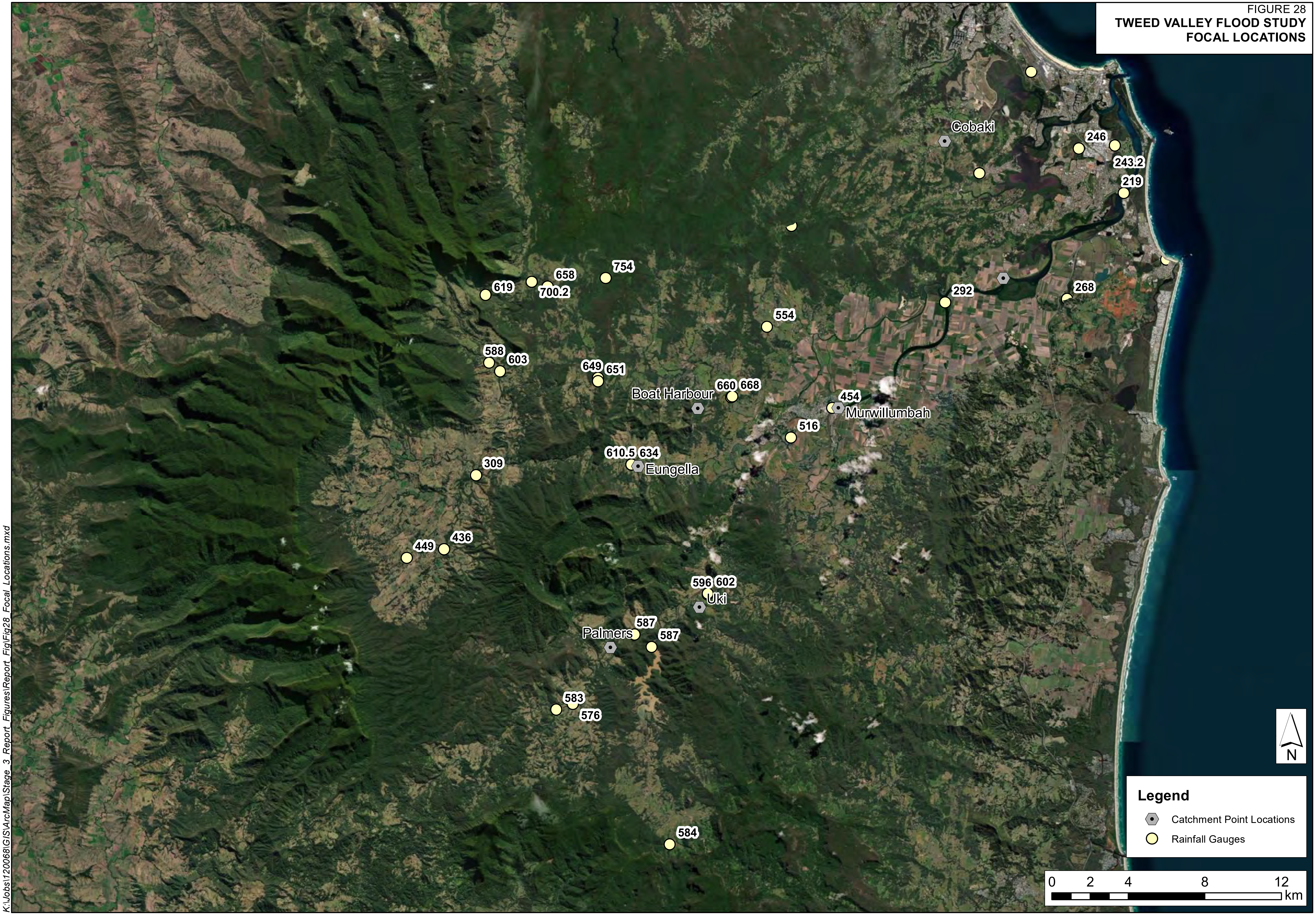


FIGURE 28
**TWEED VALLEY FLOOD STUDY**
**FOCAL LOCATIONS**

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FIGURE 29
**TWEED VALLEY FLOOD STUDY**
**ARF ZONES**

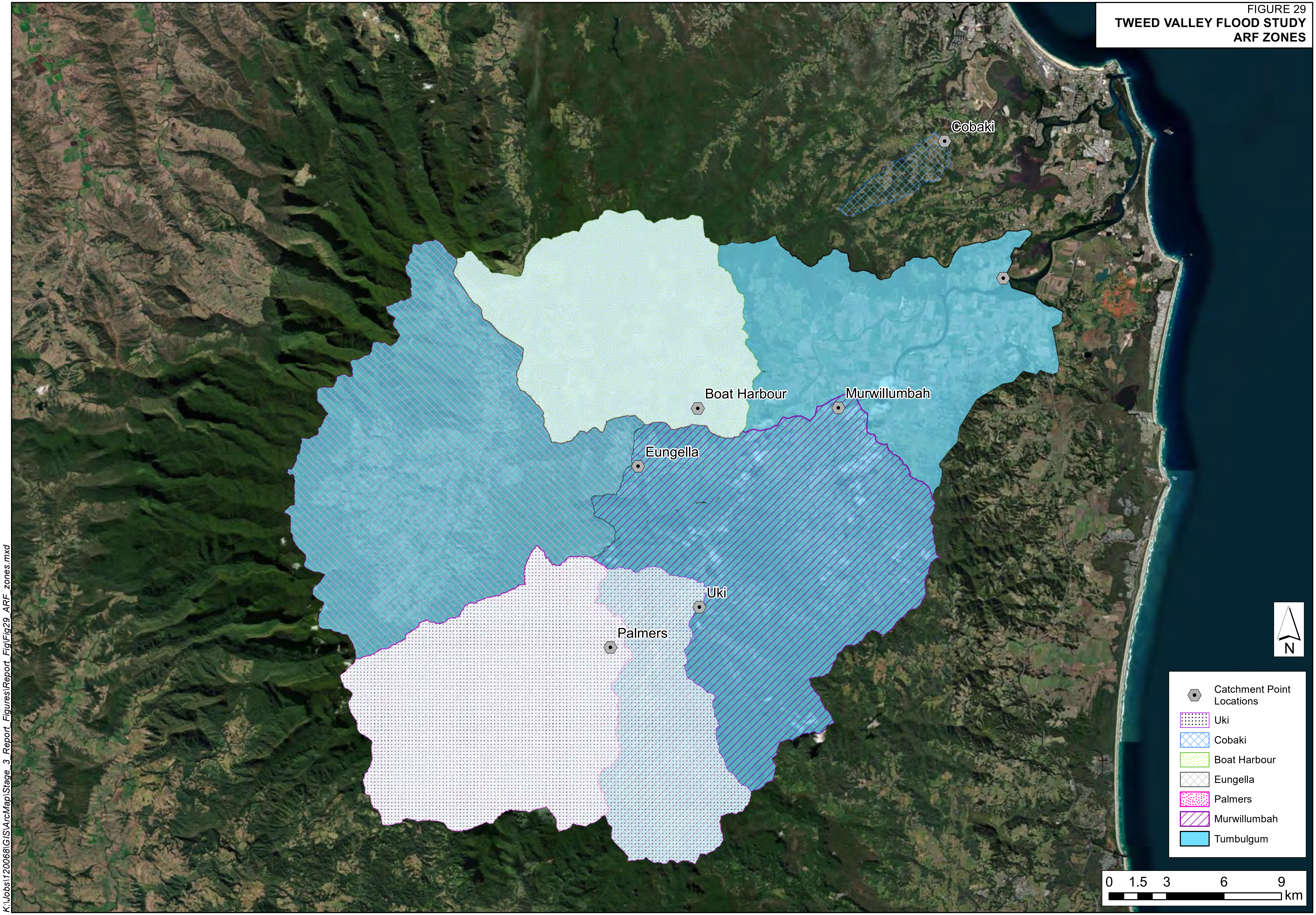


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FIGURE 30
**TWEED VALLEY FLOOD STUDY**
**MURWILLUMBAH INFLOWS**

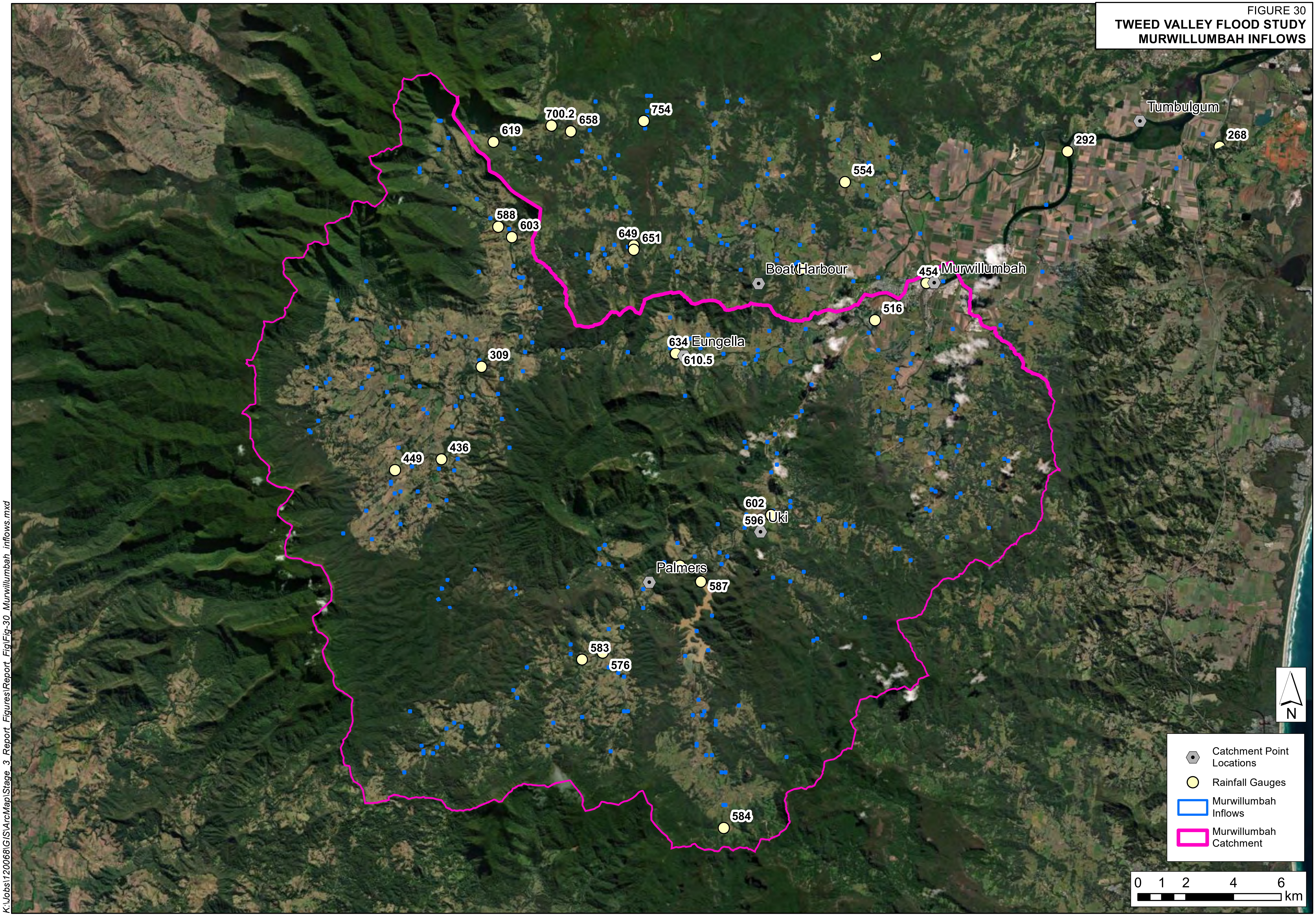


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FIGURE 31
**TWEED VALLEY FLOOD STUDY**
**PALMERS ROAD INFLOWS**

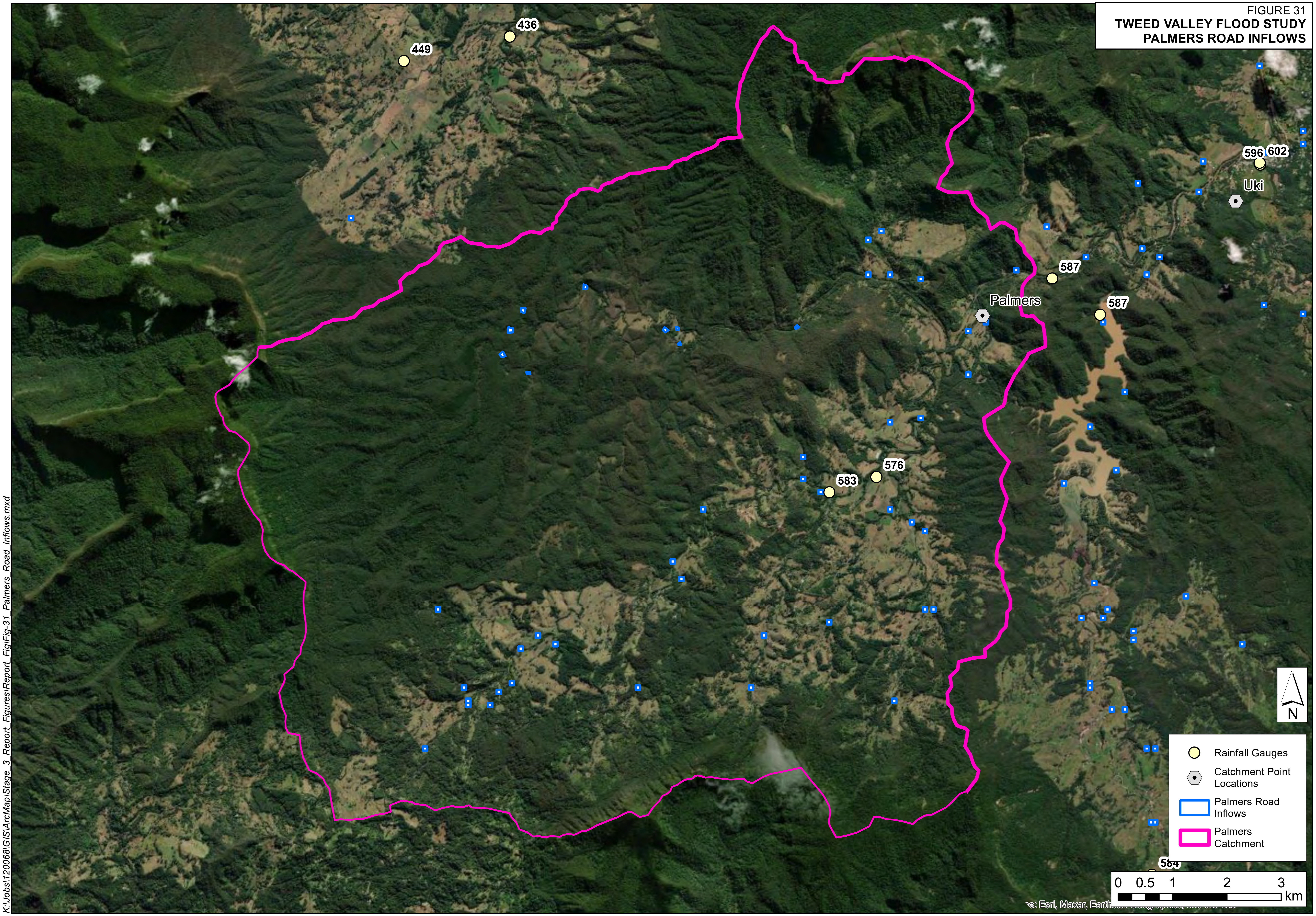


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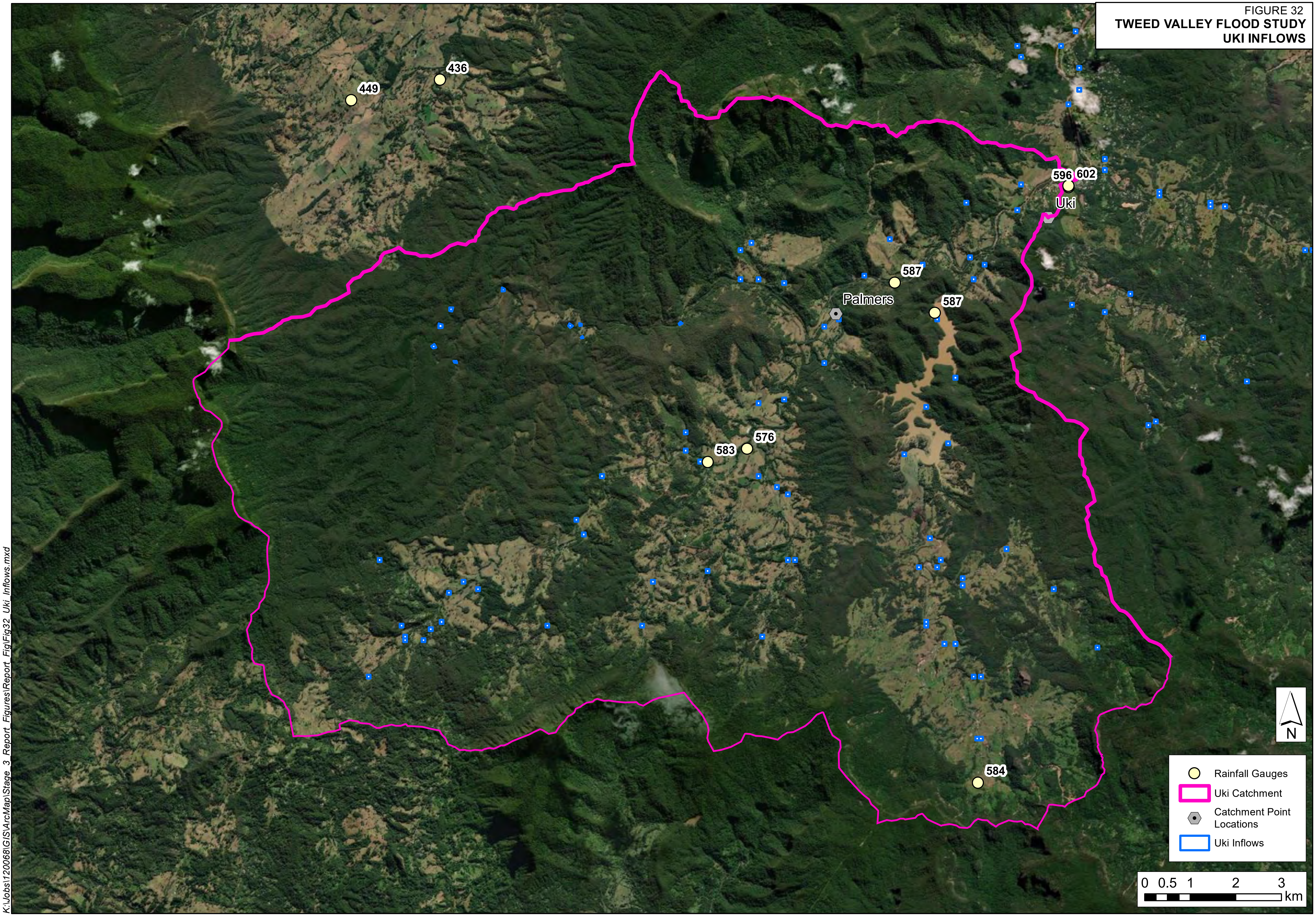
FIGURE 32
**TWEED VALLEY FLOOD STUDY**
**UKI INFLOWS**

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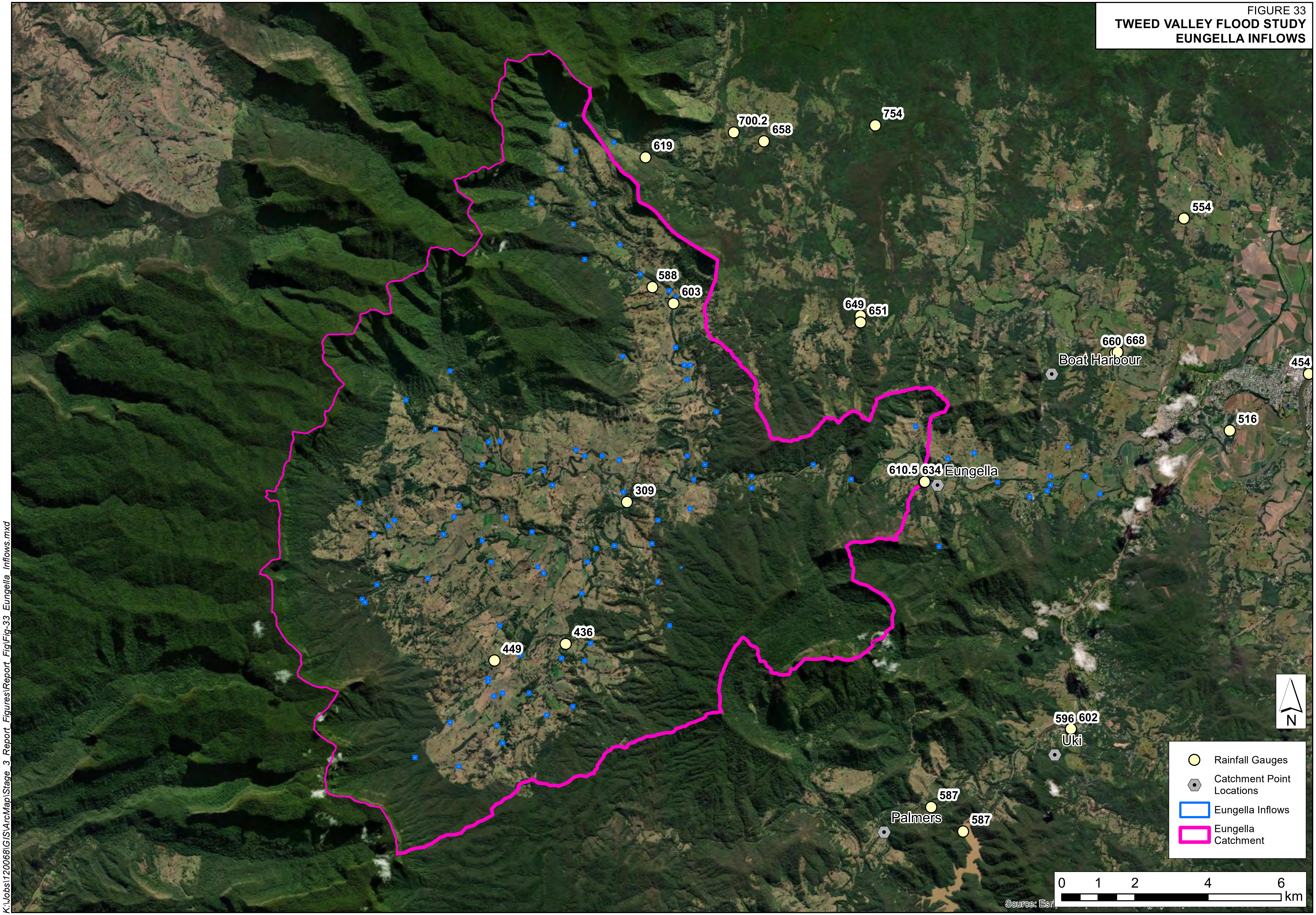
FIGURE 33
TWEED VALLEY FLOOD STUDY
EUNGELLA INFLOWS
700.2
658
754
619
554
588
603
649
651
660
668
Boat Harbour
454
516
610.5
634
Eungella
309
436
449
596
602
Uki
587
Palmers
587
N
Rainfall Gauges
Catchment Point Locations
Eungella Inflows
Eungella Catchment
0
1
2
4
6
km
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FIGURE 34
TWEED VALLEY FLOOD STUDY
BOAT HARBOUR INFLOWS

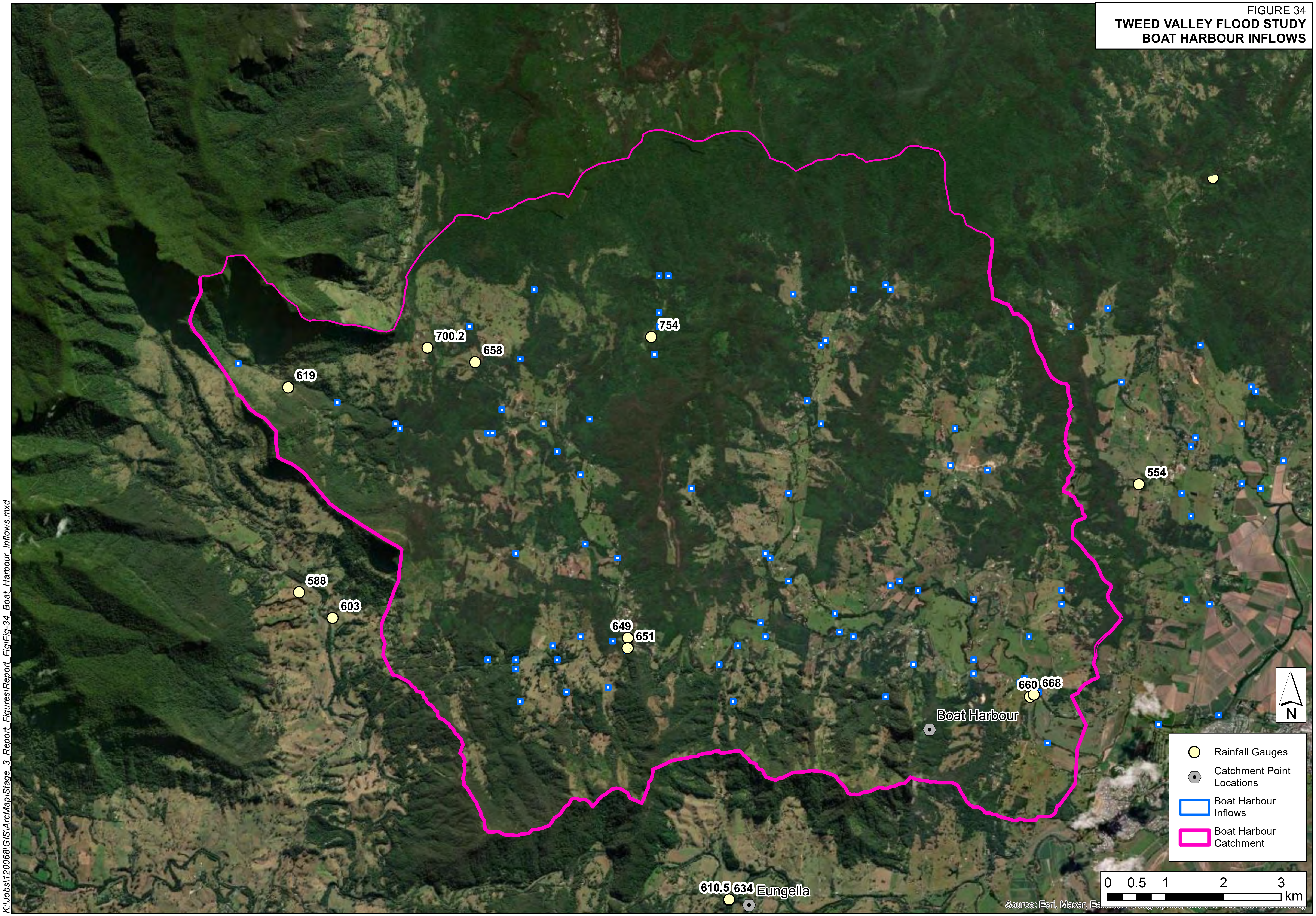


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FIGURE 35
**TWEED VALLEY FLOOD STUDY**
**COBAKI INFLOWS**

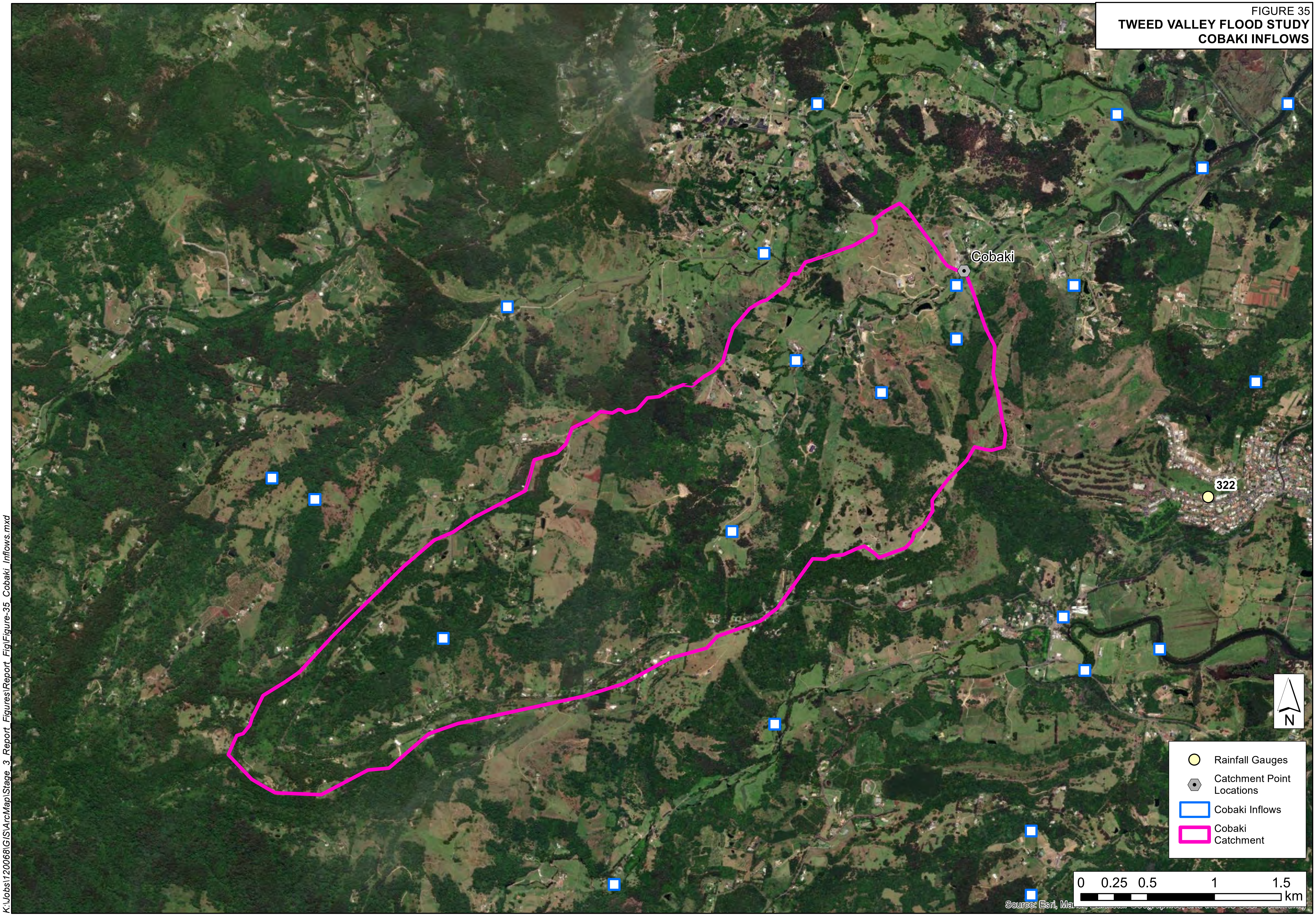
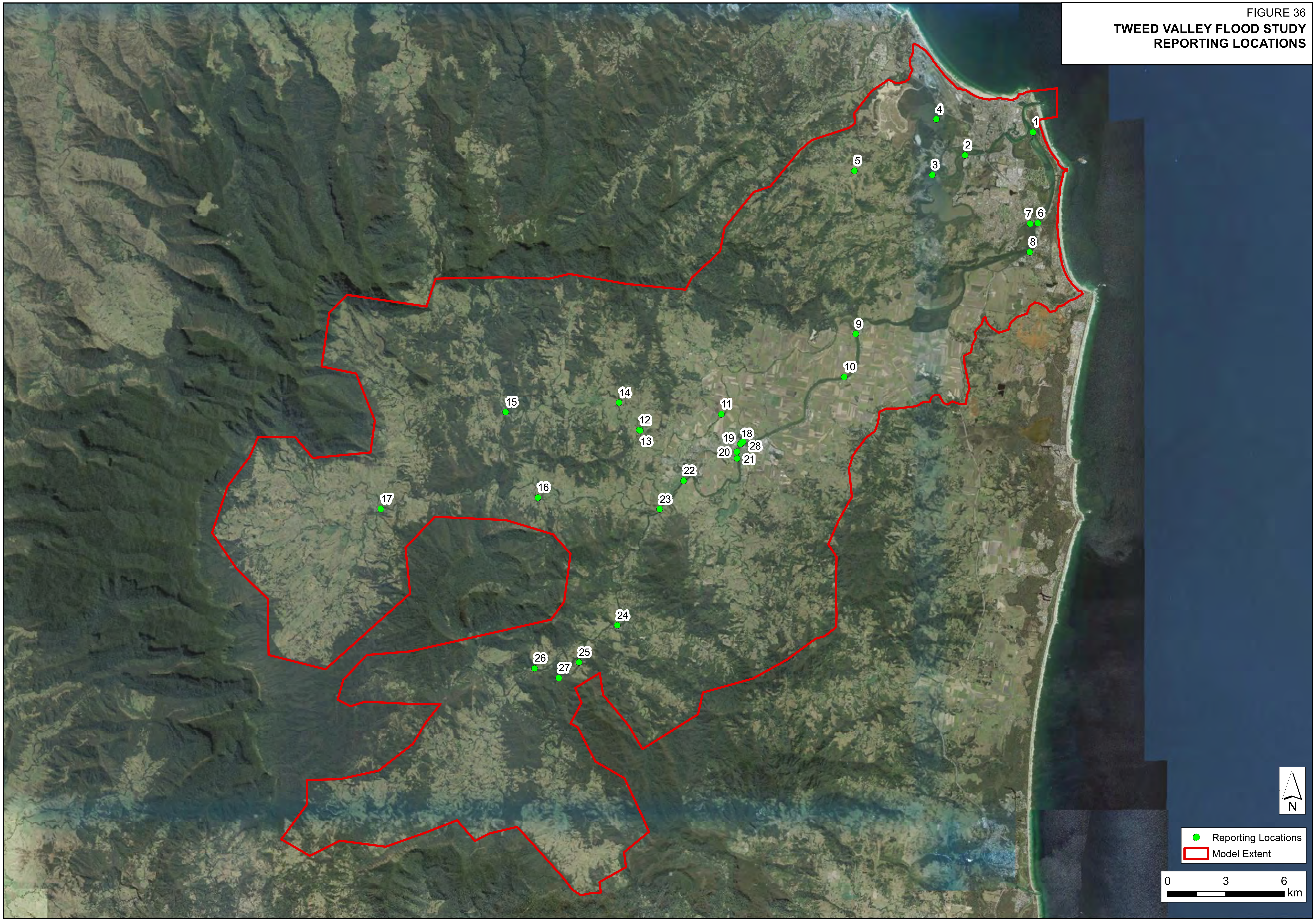


FIGURE 36
**TWEED VALLEY FLOOD STUDY**
**REPORTING LOCATIONS**

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