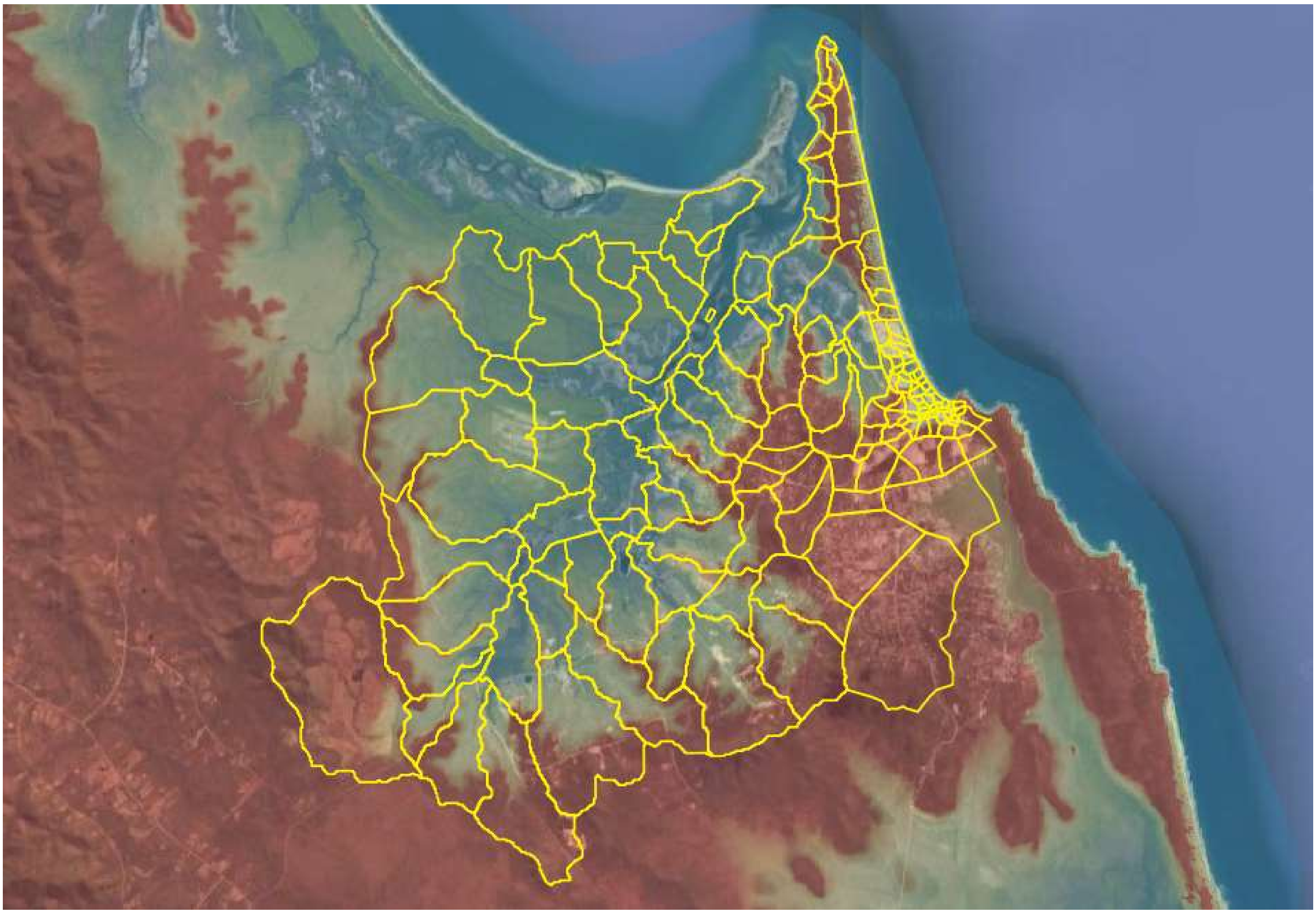
GLADSTONE REGIONAL COUNCIL

AGNES WATER DRAINAGE STUDY

DRAFT REPORT



JUNE 2025

Document Set ID: 6405165
Version: 1, Version Date: 30/06/2025

Level 7, 87 Wickham Terrace
Spring Hill, QLD, 4000

Tel: (07) 3151 2660
Fax: (02) 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

AGNES WATER DRAINAGE STUDY

DRAFT REPORT

JUNE 2025

Project Agnes Water Drainage Study	**Project Number** 124028
Client Gladstone Regional Council	**Client's Representative** Jacinta Giles
Project Manager Michael Reeves RPEQ 34715	

Revision History

Revision	Description	Distribution	Authors	Reviewed by	Verified by	Date
0	Draft Stage 1 Report	GRC	Eliza Towndrow	Daniel Wood RPEQ	Daniel Wood RPEQ	OCT 2024
1	Final Stage 1 Report	GRC	Eliza Towndrow	Daniel Wood RPEQ	Daniel Wood RPEQ	JAN 2024
2	Draft Stage 2 Report	GRC	Reinier Koster, Eliza Towndrow	Daniel Wood RPEQ	Daniel Wood RPEQ	MAR 2025
3	Final Stage 2 Report	GRC	Reinier Koster, Fiona Haynes	Michael Reeves RPEQ	Michael Reeves RPEQ	JUN 2025
4	Draft Stage 3 Report	GRC	Reinier Koster, Fiona Haynes	Michael Reeves RPEQ	Michael Reeves RPEQ	JUN 2025
5	Final Stage 3 Report	GRC	Reinier Koster, Fiona Haynes	Michael Reeves RPEQ	Michael Reeves RPEQ	JUN 2025

AGNES WATER DRAINAGE STUDY

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF PHOTOGRAPHS

LIST OF DIAGRAMS

LIST OF FIGURES

LIST OF ACRONYMS

1D	One-dimensional
2D	Two dimensional
AEP	Annual Exceedance Probability
ARF	Areal Reduction Factor
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
CHAS	Coastal Hazard Adaptation Study
DEM	Digital Elevation Model
GRC	Gladstone Regional Council
GSDM	Generalised Short Duration Method (PMP Estimation)
HAT	Highest Astronomical Tide
HHWS(SS)	High High Water Springs (Solstice Spring)
IFD	Intensity, Frequency and Duration (Rainfall)
LiDAR	Light Detection and Ranging (aerial survey technique)
mAHD	Metres above Australian Height Datum
MHWS	Mean High Water Springs
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
QUDM	Queensland Urban Drainage Manual
RFFE	Regional Flood Frequency Estimation
SGS	Sub-Grid Sampling
SSP	Shared Socio-economic Pathway
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WBNM	Watershed Bounded Network Model (hydrologic model)
WMS	Web Map Service
XP-RAFTS	Runoff Analysis and Flow Training Simulation developed by XP solutions (hydrologic model)

ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2019) 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 2019 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	

EXECUTIVE SUMMARY

WMA Water was commissioned by Gladstone Regional Council to undertake a drainage study for Agnes Water. The purpose of the drainage study is to develop a set of updated Flood Hazard Overlay mapping in the Planning Scheme and provide updated information on riverine flood affected properties in the urban areas of the Agnes Water township and surrounding catchments.

The study area consists of the Agnes Creek and Round Hill Creek catchments, with the focus being on the urban area of Agnes Water, located within the Agnes Creek catchment. A range of data were collected and reviewed including previous reports and models, rainfall data, topographic data, land use data and stormwater infrastructure data. A site inspection was also conducted.

A flood model of the study area was developed, consisting of a hydrologic model, simulating the runoff that occurs from rainfall, and a hydraulic model, simulating how floodwaters move through the catchment. A WBNM hydrologic model was developed for the two catchments, covering an area of approximately 110 km^2 and consisting of 154 sub-catchments. A TUFLOW hydraulic model was developed for the study area consisting of a variable grid size (16 m to 2 m), with topography based on available LiDAR and bathymetry information. The model includes hydraulic structures such as the stormwater network and culverts. Inflows were sourced from the WBNM model and using the direct rainfall approach. Tidal boundaries were adopted at the ocean outlets.

There are limited records of historic flood events which have occurred in the vicinity of the Agnes Water study area. Therefore, hydrological and hydraulic models developed for the Agnes Water Drainage Study were not subject to a rigorous calibration exercise.

Design rainfall events were simulated in the WBNM and TUFLOW models using Australian Rainfall and Runoff 2019 (version 4.2) guidelines. This includes the use of 2016 design rainfall data, factoring of rainfalls for climate change, application of areal reduction factors, design storm losses, pre-burst rainfall, and the ensemble approach. Coincident tailwater levels were adopted consisting of various tide scenarios. Design flood events simulated include the 1 Exceedance per Year, 50%, 20%, 10%, 5%, 2%, 1%, 1 in 200, 1 in 500, 1 in 2000 Annual Exceedance Probability events and the Probable Maximum Flood.

The WBNM and TUFLOW models were validated through a comparison with previous studies, the rational method, regional flood frequency analysis and photographs of flooding within Anges Water. Given the absence of data to calibrate the models, it was concluded that a reasonable validation result was achieved.

Design flood results were produced for the full range of events and tide scenarios. A future climate scenario (2100 horizon) was also simulated for selected events and a sensitivity analysis was undertaken for structure blockage and Manning's roughness. Flood results were mapped, including peak flood depth, peak flood level, peak velocity, peak velocity-depth product, peak hydraulic hazard and peak hydraulic risk. A classification of 'riverine' versus 'overland' flooding was undertaken for the 1% AEP event. These outputs inform the flood component of Gladstone Regional Council's planning scheme.

1. INTRODUCTION

1.1. Scope

WMA Water was commissioned by Gladstone Regional Council (GRC) to undertake a drainage study for Agnes Water. The purpose of the drainage study is to develop a set of updated Flood Hazard Overlay mapping in the Planning Scheme and provide updated information on riverine flood affected properties in the urban areas of the Agnes Water township and surrounding catchments. The project involves:

- Review of previous studies,
- Review of data, both provided by GRC and sourced by WMA Water, for the purposes of undertaking the drainage study,
- Developing a modelling methodology including modelling and review of model validation cases,
- Design event modelling and mapping,
- Sensitivity analysis, and
- Modelling of mitigation scenarios.

This report documents the above scope of work.

1.2. Study Area

The study area consists of the Agnes Creek and Round Hill Creek catchments. There are two urban areas within these catchments – Seventeen Seventy and Agnes Water. The focus of this study is on Agnes Water. Agnes Water is located within the Gladstone Regional Council area, approximately 80 km south of Gladstone. Agnes Water lies generally within the Agnes Creek catchment. Agnes Creek is a relatively small coastal estuary with a catchment area of approximately 20 ha. Elevations in the upper catchment reach 50 mAHD to 80 mAHD, however the catchment elevations drop to below 10 mAHD within a few hundred metres from the top of the catchment. A significant part of the lower floodplain (including the town centre) is below 6 mAHD. Agnes Creek and its associated minor drainage lines are generally conveyed within engineered drainage channels (both open and covered) until reaching the ornamental pond adjacent to Agnes Street. From this point until the creek mouth, Agnes Creek generally exists in a natural state. The Creek in this area generally has a flat grade, is thickly vegetated and is spanned by numerous pedestrian and vehicle crossings. Land use within the catchment is made up of mostly low-density residential and open space reserves, with significant areas of urban development within Agnes Water.

The Round Hill Creek catchment is largely rural with areas of bushland and grassland/paddocks The catchment reaches elevations just over 200 mAHD. The majority of the catchment is zoned rural with some areas of low density residential mainly in lower elevations. The lower portion of Round Hill Creek is a wide estuary.

The study area for the project is shown in Figure 1.

1.2.1. Site Inspection

A site inspection of the Agnes Creek catchment was undertaken on 25 July 2024, by a representative from WMA Water. The purpose of the inspection was to ground-truth key structures and to improve WMA Water's understanding of the catchment and key hotspots, as identified by GRC.

2. AVAILABLE DATA

A data review of existing studies and datasets was undertaken to improve WMA Water's understanding of the catchment and to identify data gaps that may need to be resolved to improve the outcomes of the drainage study. Table 1 summarises the studies and datasets that have been provided by GRC or sourced by WMA Water, in addition to the site inspection that was undertaken by WMA Water in July 2024.

Table 1: Available Data

Data	Description	Sourced By	Report Section
Existing studies	Agnes Water Flood Mitigation Project (Engeny, 2015)	GRC	3.1
Rainfall	Station rainfall data	WMA Water	4.2
	BoM IFDs	WMA Water	4.2.1
Topography	2009, 2023, intertidal LiDAR and bathymetry	WMA Water/ GRC	4.5
Land use	Aerial imagery	GRC	4.6.1
	Cadastre	GRC	4.6.2
Structures	Culverts	GRC	4.7
	Stormwater network	GRC	
Site inspection	Findings	WMA Water	
Existing models	2015 Agnes Water Flood Mitigation Project	GRC	3.2

3. PREVIOUS STUDIES

3.1. Agnes Water Flood Mitigation Project (Engeny, 2015)

GRC engaged Engeny Water Management to undertake an updated flood study of the Agnes Creek catchment (Engeny, 2015, Reference 1). The updated flood study involved a review of previous drainage studies completed within the Agnes Creek catchment and the establishment of updated hydrological and hydraulic models to assess flood behaviour. Once the flood behaviour within the catchment was assessed, a range of flood mitigation measures were identified, and recommendations were provided.

3.1.1. Hydrologic & Hydraulic Modelling

A hydrological model was established with XP-RAFTS and a hydraulic model was developed using a 1D/2D TUFLOW model. Due to the lack of available historic flood information within the Agnes Creek catchment, these models were not fully calibrated (Engeny, 2015). Table 2 below details the design flood events that were considered by Engeny (2015).

Table 2: Engeny (2015) Design Flood Events

Design Flood Event	Hydrologic Inflows	Tailwater Conditions
20% AEP	20% AEP	MHWS (1.18 mAHD)
10% AEP	10% AEP	MHWS (1.18 mAHD)
5% AEP	5% AEP	MHWS (1.18 mAHD)
2% AEP	2% AEP	MHWS (1.18 mAHD)
1% AEP, MHWS	1% AEP	MHWS (1.18 mAHD)
1% AEP, HAT	1% AEP	HAT (1.97 mAHD)
1% AEP, Storm Surge	1% AEP	1% AEP Storm Surge (2.3 mAHD)
1% AEP, 2100 Climate Change	1% AEP + 20%	MHWS + 0.5 m (1.68 mAHD)
PMF	PMF	HAT (1.97 mAHD)

Note: MHWS = Mean High Water Springs
HAT = Highest Astronomical Tide

The hydraulic modelling results showed inundation upstream of the main Agnes Creek channel, during all modelled flood events. Flooding is generally due to overland flow towards Agnes Creek. The hydraulic modelling identified the following inundated areas (Engeny, 2015):

- Upstream of the Heights Entrance, bounded by Starfish Street and Round Hill Road.
- Central Agnes Water, including the area around the shopping centre, Graham Colyer Drive and the area surrounding the ornamental pond.
- The Jeffery Court housing estate.
- The area bounded by Captain Cook Drive, Lady Musgrave Court and Agnes Creek.

3.1.2. Flood Mitigation Options

Three concept options were considered potentially viable flood mitigation options to reduce flood levels. The options and associated cost are detailed in the table below.

Table 3: Engeny (2015) Mitigation Options

Mitigation Option	Cost ($ million)
Construction of a detention basin upstream of Jeffery Court.	2.1
Increased stormwater/flooding conveyance beneath Jeffery Court.	2.5
Additional Agnes Creek flood relief pipes.	1.2

However, Engeny (2015) concluded that at this level of investigation, it is not considered that any of the flood mitigation options represent value for money, without further investigation and a more detailed cost benefit analysis.

3.1.3. Recommendations

Engeny (2015) provided the following recommendations based on the outcomes of the study:

- Historic flood data (peak flood level survey) should be collected during any future flooding event.
- An investigation into the feasibility of raising the immunity of waterway crossings in the Agnes Creek catchment should be undertaken.
- A more detailed cost benefit assessment based on a flood damages analysis be undertaken.
- Non-structural measures such as voluntary house raising, or house purchase be investigated.
- The considered mitigations options be subjected to a more detailed cost estimation exercise.
- Council adopts the flood study (Engeny, 2015) and associated outputs for land use planning, development control and emergency planning purposes.

3.2. Review of Engeny Model

The hydrologic and hydraulic models developed as part of the Agnes Water Flood Mitigation Project (Engeny, 2015) were provided by GRC. A review of these models was undertaken and is detailed in the sections below.

3.2.1. Hydrologic Model

Table 4 and Table 5 summarise the outcomes of the hydrologic model review. Noting the significant difference in the study area and scope of the current project, the supplied XP-RAFTS model was utilised as a reference and was not adapted for use in the current study. A new hydrologic model that covers the full study area was developed.

Table 4: Engeny (2015) Hydrologic Model Review

Item	Description
Sub-catchment delineation	24 small sub-areas ranging between approximately 1 hectare to 16 hectares.
Fraction impervious	The fraction impervious was calculated by assigning a percentage impervious area to each land use type within the supplied cadastre data. These areas were then intersected with the delineated sub-catchments to define the fraction impervious for each sub-catchment. Urban areas, including roads were assumed to be 50% impervious. Open space areas were assumed to be 5% impervious.
Routing	The lag routing approach was adopted. Lag time was calculated based on an assumed average velocity (0.9 m/s), using catchment slope and values from Queensland Urban Drainage Manual (QUDM, 2007, Reference 2).
Rainfall	Design rainfall depths were generated using the internal IFD calculation tool within XP-RAFTS. No areal reduction factors (ARFs) were applied to the generated design rainfall depths. ARR (1987, Reference 3) temporal patterns for Zone 3 were applied to all design storms.
Losses	Table 5 shows the losses that are used in the hydrological model.

Table 5: Losses Used in the Engeny (2015) Hydrological Model

Initial Loss (mm)	Continuing Loss (mm/h)
25	2.5

3.2.2. Hydraulic Model

Table 6 and Table 7 summarise the outcomes of the hydraulic model review. Noting the significant difference in the study area and scope of the current project, the supplied TUFLOW model was used as a reference for validation (refer to Section 8.3) but was not adapted for use in the current study. A new model that covers the full study area was developed for this project.

Table 6: Hydraulic Model Review

Item	Description
Model engine and version	TUFLOW classic (version 2013-12-AE).
Model extent and grid size	The model extent includes Agnes Creek, with a grid size of 4 m.
Inflows	For all areas, the sub-catchment hydrographs generated from the hydrologic model were applied directly into the model.
Boundaries	The 2D downstream boundary is located just downstream of the NRMA Agnes Water Holiday Park on Agnes Water Beach.
DEM	The DEM of the model includes the 2010 1 m LiDAR and a 2014 detailed Agnes Creek survey.
Roughness	The roughness layer for the model was derived using supplied cadastral data, aerial photography and photography associated with field surveys. Adopted Manning's 'n' values were based on industry standard values consistent with ARR (1987) and QUDM (2007).

Item	Description
Structures	Culverts modelled as 1D elements linked to the 2D domain. Bridges are modelled in the 2D domain as 2d_lfcsh layers. Weirs are modelled in the 2D domain using a breakline approach.
Stormwater	Stormwater network modelled as 1D elements linked to the 2D domain. Stormwater drainage infrastructure has been incorporated into the model where representation of trunk drainage was critical to correctly represent flooding behaviour.
Reporting locations	The model includes reporting locations of flood levels at 16 points across the catchment. The model includes three flow lines in key locations across the catchment.

Table 7: Manning's 'n' for Lumped Land Use (sourced from the .tmf file)

ID	Land Use	Manning's 'n'
1	Roads	0.025
2	Maintained Grass	0.040
3	Residential (lawns and gardens)	0.060
4	Moderate Vegetation	0.070
5	Dense Vegetation	0.080
7	Creek Vegetation	0.100
8	Buildings	0.300
9	Downstream Creek Channel	0.040

4. DATA REVIEW

4.1. Historic Events

There are limited records of historic flood events which have occurred in the vicinity of the Agnes Water study area. Therefore, hydrological and hydraulic models developed for the Agnes Water Drainage Study were not subject to a rigorous calibration exercise.

The modelling methodology, including the validation of the hydrologic and hydraulic models is further discussed in Sections 5.

4.2. Rainfall Station Data

The Seventeen Seventy (gauge 039314) rainfall station is the closest rainfall station to the study area. The gauge is operated by the Bureau of Meteorology (BoM) and has daily rainfall observations over a 38-year period. The gauge is located approximately 500 m south-east of the township of Seventeen Seventy and 6 km north north-west of Agnes Water, as shown in Diagram 1. Table 8 provides the details of the Seventeen Seventy rainfall gauge.

Table 8: Bureau of Meteorology Rainfall Stations Near to Agnes Water Study Area

Station ID	Station Name	Station Start	Station End	Temporal Resolution	Data Accessible
039314	Seventeen Seventy	1986	Current	Daily	Yes

Diagram 2 shows the daily rainfall recorded at the Seventeen Seventy (gauge 039314) rainfall station between 1986 to 2024.

Diagram 1: Seventeen Seventy (Gauge 039314) Rainfall Station

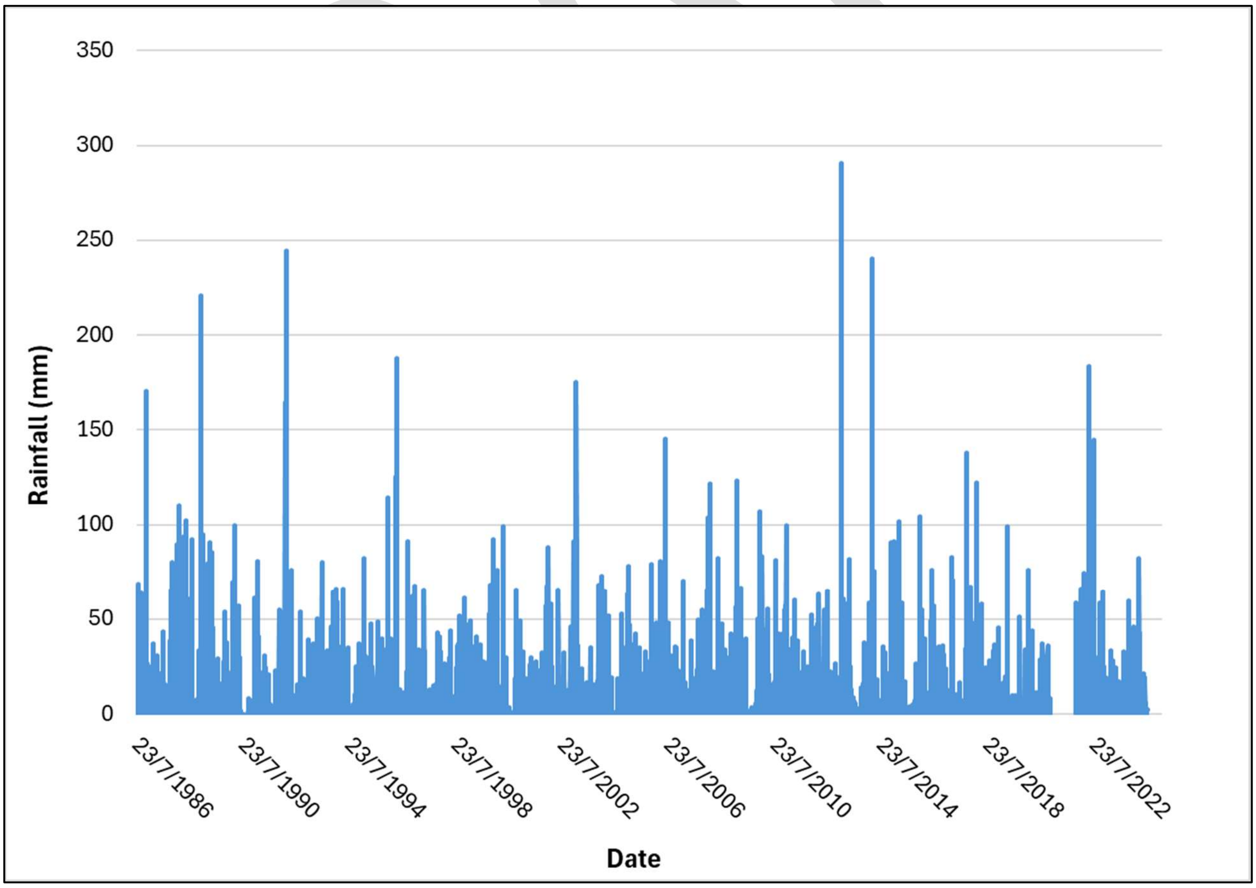


Diagram 2: Seventeen Seventy (Gauge 039314) Rainfall Station Data

4.2.1. Design Rainfall

Design rainfall events will be used in the development of the hydrologic and hydraulic models to represent the likely rainfall within the Agnes Water study area for a variety of events. Design rainfall depths were obtained from the BoM (Reference 4). This comes in the form of intensity-frequency-duration (IFD) data. Table 9 shows the BoM IFD design rainfall across the catchment for a range of Annual Exceedance Probabilities (AEPs) and durations for the Agnes Water region. For each event frequency (for example the 1% AEP event), rainfall intensity is provided for a range of durations. The information currently available was released in 2016. Rainfall estimates for the PMP are estimated using the Generalised Short Duration Method (GSDM, Reference 5).

It was expected, based on the previous study (Engeny, 2015), that the critical durations within the Agnes Water study area are relatively short, ranging between an hour to a couple of hours. Longer events were also considered as part of design event modelling (refer Section 9).

Table 9: Design Rainfall Depth (mm) - BoM IFDs

AEP (%) / Duration (min)	30	60	90	120	180	270	360	720	1440
63.2 (1EY)	29.4	38.4	43.9	48.0	54.3	61.5	67.3	84.8	108
50	32.7	42.8	49	53.7	61	69.5	76.5	97.5	126
20	42.9	56.4	65	71.7	82.5	95.3	106	139	185
10	49.7	65.6	75.9	84.1	97.3	113	127	170	227
5	56.3	74.5	86.6	96.2	112	132	148	200	272
2	64.9	86.3	101	113	132	156	177	243	333
1	71.4	95.3	112	125	148	176	200	276	382
0.5 (1 in 200)	80.2	107	126	141	166	197	224	310	428
0.2 (1 in 500)	93	124	146	163	192	228	259	358	497
0.05 (1 in 2000)	114	152	179	200	235	279	317	437	608

4.3. Stream Level Data

There is no stream level gauge within the Agnes Creek catchment, Round Hill Creek catchment or surrounding study area. Standard parameters will be adopted in the development of the hydrologic and hydraulic models, consistent with ARR2019 v4.2 (Reference 6).

4.4. Tailwater Conditions

The Agnes Creek and Round Hill Creek catchments are tidally influenced and therefore tailwater condition scenarios will be included in the hydraulic model. This information will be derived from the GRC Coastal Hazard Adaptation Strategy (CHAS, Reference 7) that was recently completed and supplied by GRC.

4.5. Topography Data

Topography data was used in the development of the hydraulic model to provide an accurate representation of the landform of the study area. Due to the diversity of topographical features within the study area, a variety of datasets were used to create the Digital Elevation Model (DEM). Table 10 lists the datasets and relevant sources, with the datasets described in the following sections.

Table 10: Topography Data to be Used in Model Development

Dataset	Resolution (m)	Source
2023 LiDAR – Agnes Water	1	Gladstone Regional Council
Bathymetry	30	
Intertidal LiDAR	10	
2009 LiDAR	1	Queensland Government (Elvis (fsdf.org.au))
Bathymetry – Agnes Creek	3	Aquamap Pty Ltd
Bathymetry – Round Hill	1	

4.5.1. Agnes Water LiDAR

GRC provided the following topography data:

- 2023 LiDAR of Agnes Water with a grid resolution of 1 m. This LiDAR dataset covers the main township of Agnes Water but does not cover the entire study area.
- Bathymetry covering the mouth of Round Hill Creek, with a 30 m resolution.
- Intertidal LiDAR for Agnes Water, with a 10 m resolution.

The LiDAR provided by GRC does not cover the entire study area and therefore 2009 LiDAR, with a 1 m resolution, has been sourced from the Queensland Government (Elvis (fsdf.org.au)) to cover the remaining topography.

A comparison between the data supplied by GRC and sourced from the Queensland Government shows that the mean difference in the vertical direction between the 2023 LiDAR and the 2009 LiDAR where the two datasets overlap (excluding the ocean) is approximately -0.11m. The two datasets are relatively consistent horizontally across key features within the study area, such as watercourses and drainage lines.

4.5.2. Intertidal – 10 m

GRC provided a 10 m resolution intertidal LiDAR which covers the regions of the study area that are affected by the tide. These areas include along the Agnes Water Beach and within the Round Hill Creek channel. The 1 m bathymetry of Round Hill Creek (described below) was used instead of the intertidal LiDAR where available.

4.5.3. Bathymetry – 30 m

GRC provided 30 m resolution bathymetry covering an area of approximately 14 km^2 at the outlet of Round Hill Creek. Given the low resolution of this dataset, it was not used in the hydraulic model.

4.5.4. Bathymetry – 1 m

Aquamap Pty Ltd provided 1 m bathymetry covering the channel of Round Hill Creek, from the mouth to 10 km upstream. The 1 m bathymetry data was applied instead of the 30 m bathymetry in the hydraulic model.

4.5.5. Agnes Creek – 3 m

Aquamap Pty Ltd provided a small section of 3 m resolution bathymetry covering Agnes Creek, an area of approximately 2 ha, located relatively parallel to Agnes Water Beach. This dataset was used to enforce the creek bottom in hydraulic model. A comparison between the 3 m Agnes Creek LiDAR and the GRC suppled 1 m Agnes Water LiDAR shows a vertical difference of approximately 0.4 m, where the two datasets meet. The channel of Agnes Creek in the 3 m LiDAR is not aligned with the 1 m LiDAR near Ocean Beach Drive. Comparing with aerial imagery, it appears that the 3 m LiDAR is out of alignment, in the upstream section of the LiDAR.

Once each of the datasets are combined into the DEM, this will be incorporated into the hydraulic model. The extents of each of the datasets are shown in Figure 3.

4.6. Land Use

4.6.1. Aerial Imagery

GRC provided high resolution aerial imagery of the Agnes Water area. The aerial imagery was sourced from a Web Map Service (WMS) and was considered in the identification of key features within the study area, such as vegetation and urban areas.

4.6.2. Cadastre

GRC provided a cadastre dataset, which was used in this study to assign land use and appropriate Manning's 'n' values in the hydraulic model.

4.7. Hydraulic Structures

GRC provided a hydraulic structure database that contains data for culverts, gross pollutant traps, and stormwater pipes and pits within the study area. No bridges are included in the data package supplied by GRC.

A culverts dataset was provided for the study area. All culverts within this dataset are owned by GRC and includes information for each culvert, including asset ID, dimensions and construction date. The upstream and downstream inverts are not provided. Table 11 provides an overview of the culvert dataset completeness within the study area.

GRC provided a structure database containing the stormwater network within the study area, including Agnes Water, Round Hill and Seventeen Seventy. Table 11 details each component of the stormwater network data, as provided GRC. Figure 4 shows the stormwater network features within the study area.

Table 11: Details of the Stormwater Network in the Provided Data

Feature	Number of	Length	Size	Invert US	Invert DS
Culverts	321	321	321	0 (0%)	0 (0%)
Pipes (total)	**452**	**437**	**437**	**245**	**245**
< 375 mm	62	62	62	41 (66%)	41 (66%)
375 – 600 mm	301	301	301	154 (51%)	151 (50%)
600 – 900 mm	66	66	66	44 (66%)	44 (66%)
> 900 mm	13	13	13	8 (61%)	9 (69%)
Pits (total)	**451**	**354**	**405**	**55**	**-**
Field Gully	4	3	4	4 (100%)	-
Side Entry	268	263	267	-	-
Single Side Entry	8	-	-	-	-
Manholes	73	27	69	17 (23%)	-
Roof water	1	-	-	-	-
Gross Pollutant Traps	2	-	-	-	-
Detention Basin	1	1	1	-	-
Open Drains	30	30	-	-	-

4.7.1. Stormwater Network Processing

A review of the GRC database was undertaken to gain an understanding of the steps that would be required to incorporate the data into the hydraulic model. This review identified:

- The digitisation of the GRC database is generally good (that is, the stormwater pipes are digitised from upstream to downstream and are snapped to the stormwater pits and manholes). However, some instances were identified where this was not the case and was manually rectified.
- Missing pipe sizes and inverts were inferred from the surrounding network and DEM, and to use the TUFLOW tools available in QGIS to check the pipe network to make sure the pipe network is fit for purpose (pipes in the right direction, invert levels US/DS etc.).
- For pits, missing sizes and inverts are inferred from the surrounding network.

4.8. Developments

4.8.1. Recent Notable Developments

Recent development within the study area has been undertaken south-west of central Agnes Water and covers an area of approximately 6 ha. This development is included in the 2023 Agnes Water LiDAR, as supplied by GRC, and will therefore be incorporated in the DEM in the hydraulic Model.

Discussions with GRC indicate that while there are some proposed future developments, they are not to be considered part of the base case scenario.

4.9. Site Inspection

A site inspection was undertaken on 25 July 2024. The following features were observed:

- Agnes Creek and the surrounds are predominantly low-lying, with some higher elevations to the west. In general, the creek system at the downstream end is mostly flat with minimal grade.
- Agnes Creek is significantly overgrown in large sections and the flow conveyance is likely impacted due to the presence of vegetation.
- During the site visit the outlet to the ocean was closed. It is assumed this is the general condition of the creek, however, it was assumed to be closed for the purpose of the flood modelling (based on the levels in the relevant topographic data).
- Agnes Creek, through the urban footprint of Agnes Water, is subject to significant modification including substantial areas where the channel has been built over.
- The township of Seventeen Seventy has limited drainage infrastructure.
- The populated region of Round Hill Creek catchment is substantially different from Agnes Creek. The area is very hilly with significant elevation variation. The stormwater system in the area is sparse and often consists only of small outlet drains connected to road / kerb.

Key features of the Agnes Water stormwater network and Round Hill Drainage area, as observed during the site inspection, are shown in Photo 1 to Photo 9.

Photo 1: Agnes Creek at Heights Entrance Road

Photo 2: Culvert Crossing along Captain Cook Drive from Agnes Water Park

Photo 3: Agnes Creek Outlet

Photo 4: Inlet to Agnes Creek under Agnes Street

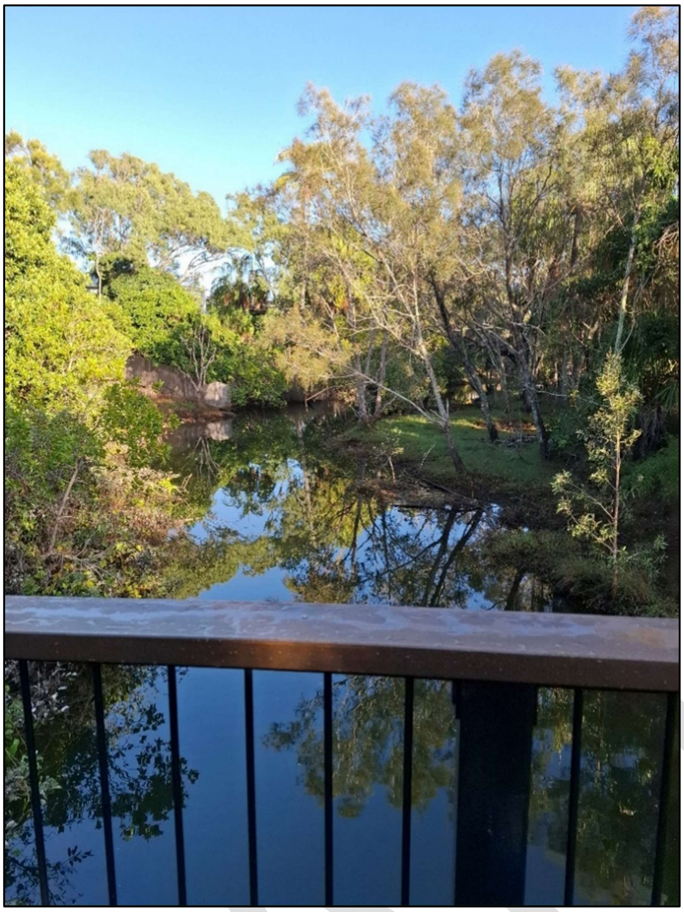


Photo 5: Agnes Creek – Looking Upstream

Photo 6: Open Drain at Agnes Water Park

Photo 7: Agnes Creek under Endeavour Plaza (*Source: Google Street View*)

Photo 8: Agnes Creek Upstream of Captain Cook Drive (*Source: Google Street View*)

Photo 9: Round Hill – Typical Drainage System

5. OVERALL MODELLING METHODOLOGY

5.1. Hydrologic Model

A hydrological model is a computer-based software tool for estimating the amount of runoff that flows from a catchment for a given amount of rainfall, and the timing of this runoff flow. Using a computer-based hydrologic model is the best practice method for determining how much runoff is generated from rainfall information (which is available from rain gauges). This type of hydrologic model is referred to as a runoff-routing model. Flow hydrographs are generated by a hydrological model, which is then used as inputs at the boundaries of the hydraulic model to provide details about flood levels and velocities within a catchment.

For the Agnes Water Drainage Study, the Watershed Bounded Network Model (WBNM) package was selected as the hydrological model. WBNM is widely used throughout Australia to estimate runoff from both rural and urban areas. The WBNM has a relatively simple but well supported method, where the routing behaviour of the catchment is primarily assumed to be correlated with the catchment area. WMA Water developed a WBNM covering the entire study area, including Agnes Creek catchment and Round Hill catchment.

Due to the absence of historic flood information available for the study area, the validation of the hydrologic model is limited. Therefore, industry standard parameters, including initial loss and continuing loss values as described in ARR 2019 (Reference 6), were used in the development of the model. The hydrological model results were reviewed against the previous hydrologic models developed for Agnes Creek catchment and Round Hill catchment.

5.2. Hydraulic Model

A hydraulic model can estimate the flood levels, depths, velocities and extents across the floodplain. It can also provide information about how the flooding changes over time. The hydraulic model can simulate floodwater both within the creek banks, and when it breaks out and flows overland, including flows through structures (such as culverts), over roads and around buildings. The TUFLOW package was adopted for this study as it meets requirements for best practice and is currently the most widely used model of this type in Australia for flood modelling.

WMA Water developed a TUFLOW model covering the entire study area, including the Agnes Creek catchment and Round Hill catchment. The model was developed using the HPC engine. The HPC engine has a benefit over the Classic engine in the ability to be parallelised and run on a graphics card, significantly reducing run times. The model adopts the 'Quadtree' feature of TUFLOW, with the ability to vary the grid size across the model domain. This allows a larger grid size for the rural floodplain and smaller grid size for the urban areas. The model also utilises 'Sub-grid sampling' (SGS), to provide topographic details at a scale smaller than the grid size.

Due to the absence of historic flood information available for the study area, the validation of the hydraulic model is limited. Therefore, industry standard parameters, including Manning's roughness values as described in ARR 2019 (Reference 6), were used in the development of the model. The hydraulic model results were reviewed against the previous hydraulic models developed for Agnes Creek catchment and Round Hill catchment.

5.3. Model Approach

Areas outside of Agnes Water have been modelled using a direct rainfall hydraulic model (TUFLOW) as well as the hydrology model (WBNM). The direct rainfall method applies the rainfall directly within the hydraulic model and it simulates the runoff that occurs and routes this flow through the catchment hydraulically. This method was selected due to the relatively undefined nature of flow paths through the rural areas of the Round Hill Creek catchment. Within Agnes Waters, catchment inflows have been obtained from the hydrology model and applied to inflow surface areas. The 1D pit and pipe network has been linked to the 2D surface to allow transfer of flows between the 2D and 1D environments. Tidal levels have been added to both the direct rainfall portion of the model and the Agnes Water portion with initial water levels in the Round Hill Estuary set at the tide level.

5.4. Validation

Due to the absence of available historic flood information for the Agnes Creek and Round Hill catchments, validation of the hydrologic model was undertaken through comparisons of design event results with Regional Flood Frequency Estimation (RFFE) and the Rational Method. A comparison with previous modelling undertaken for the catchments was also undertaken. Validation of the hydraulic model was undertaken by again comparing peak flows with estimates from alternate methods and previous modelling. Peak flood levels were compared with previous modelling and a visual verification was undertaken using photographs supplied of inundation at several areas within the study area.

5.5. Design Events

Design event flood modelling was undertaken for the following events:

- 1 EY (63.2% AEP)
- 50% AEP
- 20% AEP
- 10% AEP
- 5% AEP
- 2% AEP
- 1% AEP
- 1 in 200 (0.5%) AEP
- 1 in 500 (0.2%) AEP
- 1 in 2000 (0.05%) AEP
- Probable Maximum Flood (PMF)

Representative storms were selected for each event and simulated in the hydrologic and hydraulic models. All design events were simulated with a variety of tailwater (ocean) conditions, including Mean High Water Springs (MHWS), Highest Astronomical Tide (HAT) and Storm Surge conditions. Design flood mapping was produced to display the results of the modelling.

Table 12: Rainfall and tide event probability for storm surge conditions

Design AEP	Catchment Flood Scenario	Ocean Water Boundary Scenario
50% AEP	50% AEP	HHWS(SS)
20% AEP	20% AEP	HHWS(SS)
10% AEP	10% AEP	HHWS(SS)
5% AEP	5% AEP	HHWS(SS)
2% AEP	2% AEP	5% AEP
1% AEP (enveloped)	1% AEP	5% AEP
	5% AEP	1% AEP
0.5% AEP	0.5% AEP	1% AEP
0.2% AEP	0.2% AEP	1% AEP
0.05% AEP	0.05% AEP	1% AEP
PMF	PMF	1% AEP

5.6. Climate Change

New guidance on how to include the effect of climate change on design rainfall depths have been developed and the final version has been released to the industry (Reference 6). The climate change guidance recommends that design rainfall depths from the IFDs available from the BoM (developed in 2016) should be adjusted to account for increases in temperature for both the current period and future projected periods. The shared socio-economic pathway (SSP) 3-7.0 was adopted for this study. The 2030 horizon (near-term) was adopted as the 'current day' conditions and a 2100 horizon for the 'future' conditions.

5.7. Sensitivity Analysis

A sensitivity analysis was undertaken to gain an understanding of the tolerances and sensitivity of the hydraulic model to certain parameters. The following sensitivity assessments were undertaken:

- Manning's 'n' roughness (+/-20%); and
- Hydraulic structure blockage (+50%).

6. HYDROLOGIC MODEL

6.1. Model Extent

The hydrologic model covers approximately 110 km^2, encompassing the localities of Agnes Water, Round Hill and Seventeen Seventy. The extent includes the catchments of Round Hill Creek, which discharges at Seventeen Seventy, and Agnes Creek, which discharges at Agnes Water Main Beach. The hydrology model extent is shown in Figure 4, noting that portions of this model were not used to derive inflows to the TUFLOW model as the direct rainfall method was used instead.

6.2. Sub-Catchments

The hydrological model consists of 154 sub-catchments. Sub-catchments were delineated based on the topography of the 1 m 2009 LiDAR for majority of the extent, with the Agnes Water township delineated using the 1 m 2023 LiDAR. The sub-catchments in areas of increased residential density have a higher level of detail and are relatively small, whereas the sub-catchments are larger in the upper reaches of the catchment. Figure 2 shows the sub-catchment delineation.

6.3. Rainfall

6.3.1. Design Rainfall

Design rainfall depths were sourced from the BoM and were used in the development of the hydrology model to represent the likely rainfall within the Agnes Water study area, for a variety of design events. The hydrology model was run for the 1 Exceedance per Year (EY), 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP 1 in 200 AEP, 1 in 500 AEP and 1 in 2000 AEP events. Table 14 details the IFD design rainfall used in the development of the model.

Intensity-frequency-duration (IFD) data at various locations were checked to ensure that the variation in rainfall is limited. The variation for a 12 hour 1% AEP storm was approximately 2 mm for a rainfall depth of 278 mm, which is negligible. Similarly, for the 1hr 1% AEP storm, the depth varied less than 2 mm across all sub-catchments with a maximum depth of 95.3 mm and minimum 93.6 mm. Therefore, as there is no significant variation across the study area, the selected IFD at the centroid of the catchment is representative for the entire study area. This statistical assessment of IFD included all sub-catchments within the study area.

The design rainfalls for the PMP were derived using the BoM's GSDM (Reference). The catchment terrain was estimated to be 'rough' with an elevation adjustment factor of 1 and a moisture adjustment factor of 0.91. The PMPs were divided into two zones to give more accurate estimations of PMP depths on individual parts of the catchment as the flooding within Agnes Water is not directly impacted by the flow on Round Hill Creek. A PMP area of 54.8 km^2 was used for the Round HIll Creek catchment. The GSDM requires rainfall to be distributed spatially using ellipses. The ellipses were centred over the centroid of the Round Hill Creek catchment (at a latitude and longitude of -24.25°S, 151.84°E), with the largest ellipse being 'D'. For the coastal area the PMP area was set to 1 km^2 as this was the approximate catchment area at key locations of interest for the study and gives a conservative estimate across the area. As 1 km^2 is smaller than the smallest PMP ellipse ('A'), a fixed PMP depth was applied across this area.

6.3.2. Areal Reduction Factor

Various options for aerial reduction factors (ARFs) have been considered including areal reduction factor based on:

- the entire study area (109 km^2);
- local Agnes Water township area (4.4 km^2); and
- no reduction.

In order to best represent the rainfall and runoff across the entire study area while not underestimating depths in areas with only localised catchments contributing, the areal reduction factor was adopted for half the study area (i.e. 54 km^2).

6.3.3. Climate Adjustment Factors

Updated climate change guidelines in Australian Rainfall and Runoff (Book 1, Chapter 6 in Reference 6) advise to adjust the 2016 BoM IFDs for climate change that has already occurred, since the date of the underlying rainfall data in the IFDs. Therefore, to adhere to best practice, the IFDs that were sourced from the BoM were adjusted for 2030 climate change scenario SSP3-7.0 by multiplying the IFDs by the recommended climate change factors. The climate change factors are available on the ARR datahub for different event durations. Table 13 details the rainfall increase factors for each duration used to account for 2030 climate change in the development of the model and Table 2 details the adjusted IFDs for the region.

Table 13: Climate Change Rainfall Factors – 2030 SSP3-7.0

Duration (hours)	Climate Change Rainfall Factor
<1	1.18
1.5	1.17
2	1.16
3	1.14
4.5	1.13
6	1.12
9	1.12
12	1.11
18	1.10
>24	1.10

Table 14. Design Rainfall Depth (mm) - BoM IFDs adjusted for Climate Change up to 2030

AEP (%) / Duration (min)	30	60	90	120	180	270	360	720	1440
63.2 (1EY)	34.7	45.3	51.4	55.7	61.9	69.5	75.4	95.0	118.8
50	38.6	50.5	57.3	62.3	69.5	78.5	85.7	109.2	138.6
20	50.6	66.6	76.1	83.2	94.1	107.7	118.7	155.7	203.5
10	58.6	77.4	88.8	97.6	110.9	127.7	142.2	190.4	249.7
5	66.4	87.9	101.3	111.6	127.7	149.2	165.8	224.0	299.2
2	76.6	101.8	118.2	131.1	150.5	176.3	198.2	272.2	366.3
1	84.3	112.5	131.0	145.0	168.7	198.9	224.0	309.1	420.2
0.5 (1 in 200)	94.6	126.3	147.4	163.6	189.2	222.6	250.9	347.2	470.8
0.2 (1 in 500)	109.7	146.3	170.8	189.1	218.9	257.6	290.1	401.0	546.7
0.05 (1 in 2000)	134.5	179.4	209.4	232.0	267.9	315.3	355.0	489.4	668.8

6.4. Losses

Initial and continuing losses were sourced from the ARR Datahub. Losses were also adjusted for 2030 climate conditions (SSP3-7.0). Table 15 details the original and climate change losses used in the development of the model.

Table 15: Design and Climate Change Losses

	Initial Storm Loss (mm)	Continuing Loss (mm/h)
Original	24.0	3.6
Adjusted for Climate Change	24.48	3.7

Compared to previous studies, the continuing loss is higher than what was used previously. All previous studies used a continuing loss of 2.5 mm/h. Given that the critical durations are relatively short, it is expected that the impact of a higher continuing loss is relatively small.

The initial loss was similar to previous studies, with 25 mm used in the study by Cox Andrews (2003, Reference 8) and Engeny (2015, Reference 1). However, the URS Flood mitigation study (2008, Reference 9) used an initial loss of only 10 mm. The guidelines applicable to each of the previous studies did not consider initial storm loss and initial burst loss separately (Reference 3). This is relevant when comparing initial loss values under the older guidelines and the present guidelines (Reference 6). Refer to Section 6.5 for a further discussion of initial losses.

6.5. Pre-burst Rainfall

Current best practice includes using pre-burst rainfall in the hydrological modelling. Using a pre-burst rainfall assumes that the soil is more saturated before the storm burst starts and therefore the initial loss is lower. The median pre-burst rainfall values, as provided by the ARR Datahub, were applied to the model. The median pre-burst rainfall is provided in Table 16 for the 1% and 10% AEP events together with the resulting initial burst loss (Initial Storm Loss – Pre-burst Rainfall).

Table 16: Median Pre-burst rainfall impact on losses in 10% and 1% AEP Events (2030)

Duration	10% AEP (mm)		1% AEP (mm)	
	Pre-burst depth	Burst Initial Loss	Pre-burst depth	Burst Initial Loss
60	2.8	21.7	8.4	16.1
90	3.4	21.1	15.5	9.0
120	4.4	20.1	16.3	8.2

As noted above, the previous studies had initial loss values varying from 25 – 10 mm. The comparable initial burst loss similarly varies from 22 – 8 mm depending on event probability and duration. While the losses cannot be directly compared due to the differences in approach (noted above), and differing design rainfall depths, the range of losses is shown as relatively consistent. Further consideration of losses is recommended should calibration data become available.

6.6. Fraction Impervious

Fraction impervious values were assigned within the hydrology model based on the land use zones, as determined from spatial data provided by GRC. Land use zone spatial data was available for majority of the model extent, however, where land use zone data was not available, fraction impervious values were determined based on aerial imagery. The fraction impervious values are detailed in Table 17.

Table 17: Fraction Impervious Values for Land Use Types

GIS BaseParcel	Assumed Landuse	Fraction Impervious
Centre (level 1 Zone)	Commercial	0.80
Character Residential	Residential	0.55
Community Facility	Commercial	0.80
Conservation	100% pervious	0.00
Emerging Communities	100% pervious	0.00
Industry Investigation Area	Commercial	0.80
Low Density Residential	Low Density Residential	0.40
Low-Medium Density Residential	Residential	0.55
Medium Density Residential	Residential	0.80
Minor Tourism	Commercial	0.80
Mixed Use	Commercial	0.80
Neighbourhood Centre	Commercial	0.80
Open Space	100% pervious	0.00
Rural	100% pervious	0.00
Rural Residential	Rural Residential	0.05
Special Purpose	Commercial	0.80
Sport & Recreation	100% pervious	0.00

6.7. WBNM Parameters

The model input parameters to represent each sub-catchment in WBNM are:

- A lag factor (termed ‘C’), which can be used to accelerate or delay the runoff response to rainfall;

- A stream flow routing factor, which can accelerate or decelerate in-channel flows occurring through each sub-catchment;
- An impervious area lag factor.

The ‘C’ lag factor was set to a value of 1.6, which is the recommended default for an ungauged catchment. There was not sufficient information available to justify deviating from this value. The stream routing factor was set to 1.0, representing a natural channel, and the default impervious lag factor of 0.1 was adopted.

7. HYDRAULIC MODEL

7.1. Hydraulic Model Overview

details the hydraulic model approach for the Agnes Water Drainage Study and Figure 4 shows the hydraulic model extents.

Table 18: Hydraulic Modelling Approach

Item	Description
Model engine and version	TUFLOW HPC (2023-03-AE) in single precision mode.
Model extent and grid size	A variation in cell sizes will be used for Agnes Water and other populated areas. This variation will be managed by Quadtree within TUFLOW, as per the following: • Level 1 – 16 m grid size - this extent will cover less populated areas of the catchment. • Level 3 – 4 m grid size – this extent will cover the more rural areas of the catchment. • Level 4 – 2 m grid size – the extent will cover the main township of Agnes Water, and more densely populated area of the catchment. Sub-Grid-Sampling will be utilised to better represent the storages within coarser grid areas.
Inflows	Areas within Agnes Water will be modelled using a combination of traditional point inflow and inflows distributed to pits, where relevant. Areas outside of the main town centre of Agnes Water will utilise a direct rainfall approach, noting the lack of clearly defined flow paths as well as sparse stormwater assets. Direct rainfall will be used as the use of lumped inflows may not fully represent the flow paths through the region. Traditional point inflow, directed to the pits as relevant, will be utilised within the township. The extents of the modelling methodologies are presented in Figure 4.
Boundaries	The downstream 2D boundary parameters were informed by the CHAS, developed by Gladstone Regional Council.
DEM	The DEM is a combination of the six topographic datasets, as detailed in Section 4.5. These were developed into a DEM and form the basis of the hydraulic model.
Roughness	The roughness layer for the model was derived using supplied land use, cadastral data and aerial photography. Adopted Manning's 'n' values were based on industry standard values consistent with ARR 2019.
Structures	Culverts were modelled as 1D elements linked to the 2D domain.
Stormwater	The stormwater network features were modelled as 1D elements linked to the 2D domain.

7.2. Hydraulic Model Development

7.2.1. Digital Elevation Model (DEM)

Topography data was used in the development of the hydraulic model to provide an accurate representation of the topography of the study area. Due to the diversity of topographical features within the study area, a variety of datasets was used to create the DEM. The extents of each of the datasets are shown in Figure 3. Table 19 lists the datasets in the order they were used in the hydraulic model (i.e. subsequent datasets override any previous datasets).

Table 19. Topography Data Used in Hydraulic Model

Dataset	Resolution (m)	Source
2009 LiDAR	1	Queensland Government (Elvis (fsdf.org.au))
2023 LiDAR – Agnes Water	1	
Intertidal LiDAR	10	Gladstone Regional Council
Bathymetry – Round Hill	1	Aquamap Pty Ltd
Bathymetry – Agnes Creek	3	

It was noted that there were minor differences in vertical elevation at the interface of the different datasets. The interface of each dataset was checked to ensure that there were no impacts in the hydraulic model such as 'ponding of water' or a 'waterfall effect' due to the edge of the dataset acting as a wall.

7.2.2. Model Resolution

A variable cell size was adopted for Agnes Water and other populated areas, using Quadtree layering within the TUFLOW model, as per the following:

- Level 1 – 16 m grid size – this extent covers more rural and conservation areas.
- Level 3 – 4 m grid size – this extent covers primarily rural residential areas.
- Level 4 – 2 m grid size – the extent covers the main township of Agnes Water and more densely populated area of the catchment.

Additionally, SGS was utilised to better represent the storages within coarser grid areas while still incorporating features that block flow (hydraulic controls) such as roads.

7.2.3. Model Boundaries

To inform the model validation, a 2D HQ (water level – flow relationship) boundary setup was used at the downstream end of the model. An HQ boundary is a boundary that uses the slope to calculate the flow at the outlet of the model. Since there is no data available for calibration or validation events, this approach was used to mitigate any backwater effects on levels and flows in the creek caused by high tides.

For the design runs, the downstream boundary was simulated as a static level to represent tidal conditions for the scenario modelled (i.e. MHWS, HAT or storm surge).

7.2.4. Model Inflows

Areas within Agnes Water are modelled using a combination of traditional point inflow and inflows distributed to pits, where relevant. Areas outside of the main town centre of Agnes Water utilised a direct rainfall approach, noting the lack of clearly defined flow paths as well as sparse stormwater assets. Direct rainfall was used, as the use of lumped inflows may not fully represent the flow paths through the region.

Traditional point inflow, directed to the pits using 2D SA Pits where relevant, was utilised within the township. The extents of the modelling methodologies are presented in Figure 4.

The flows for point inflow locations are simulated by the hydrologic model, accounting for factors such as initial and continuing loss, while in the direct rainfall areas of the hydraulic model, rainfall losses were applied based on land use. Losses applied were consistent with the hydrology model (refer section 6.4).

7.2.5. Roughness

The roughness layer for the model was derived using supplied land use, cadastral data and aerial photography. Adopted Manning's 'n' values were based on industry standard values consistent with ARR 2019. Table 20 lists the Manning's 'n' values that were used in the model.

Table 20: Manning's 'n' for Lumped Land Use

ID	Land Use	Manning's n
1	Centre (level 1 Zone)	0.100
2	Character Residential	0.060
3	Community Facilities	0.060
4	Conservation	0.100
5	Emerging Communities	0.040
6	Industry Investigation Area	0.100
7	Low Density Residential	0.060
8	Low Impact Industry	0.100
9	Low-medium Density Residential	0.080
10	Medium Density Residential	0.100
11	Minor Tourism	0.100
12	Mixed Use	0.100
13	Neighbourhood Centre	0.100
14	Open Space	0.040
15	Rural	0.070
16	Rural Residential	0.060
17	Special Purpose	0.060
18	Sport And Recreation	0.040
19	Tidal Waterway	0.022

ID	Land Use	Manning's n
20	Waterway	0.030
21	Waterbodies	0.025
22	Road and berm	0.035
71	Wetland	0.120
72	Character Residential	0.060
73	Community Facilities	0.060
74	Conservation	0.100
75	Emerging Communities	0.040
76	Industry Investigation Area	0.100
77	Low Density Residential	0.040
78	Low Impact Industry	0.100
79	Low-medium Density Residential	0.080
80	Medium Density Residential	0.100
81	Minor Tourism	0.100
83	Neighbourhood Centre	0.100
84	Open Space	0.040
85	Rural	0.070
86	Rural Residential	0.060
88	Sport And Recreation	0.040

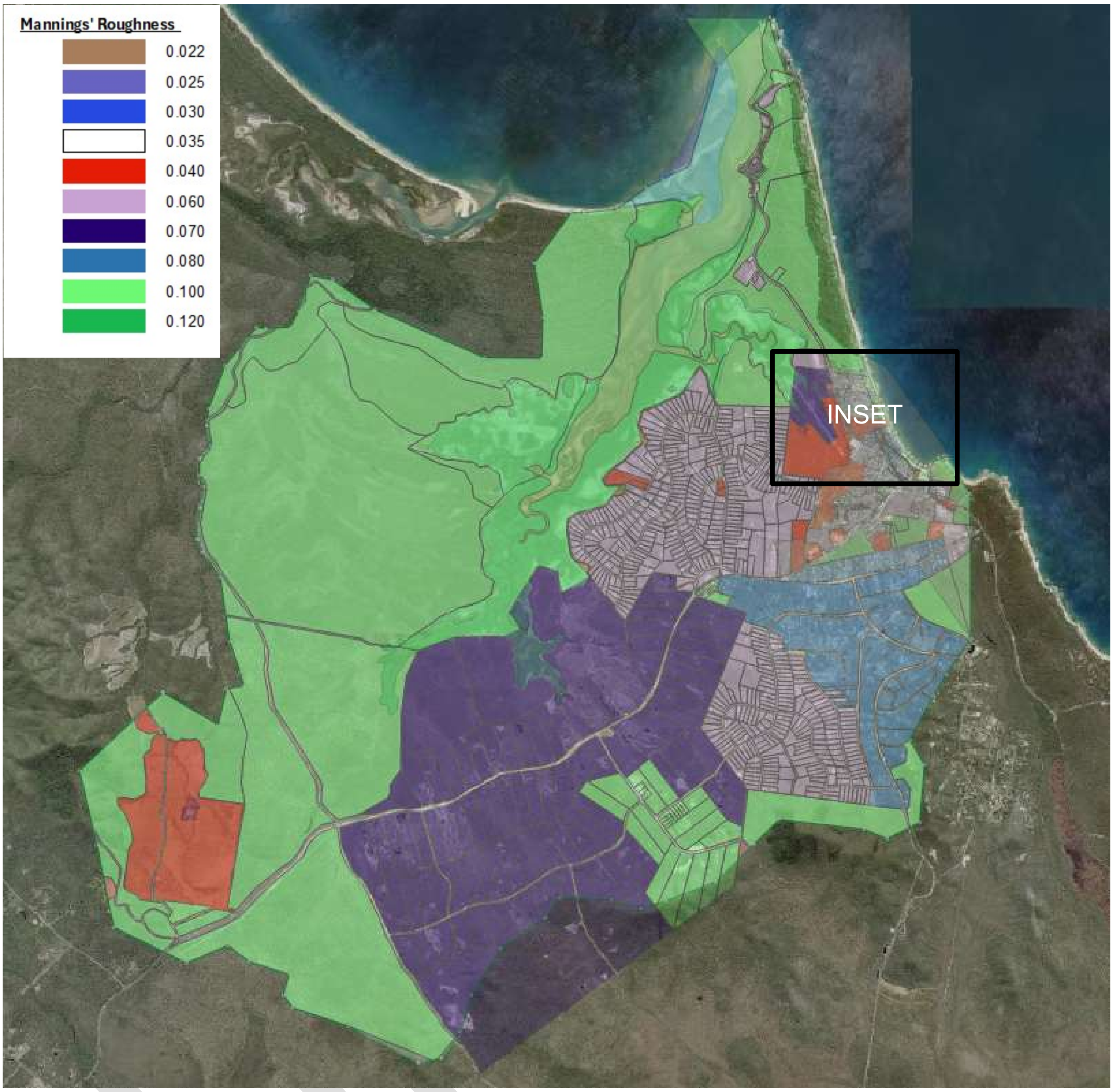


Diagram 3: Material Roughness based on landuse

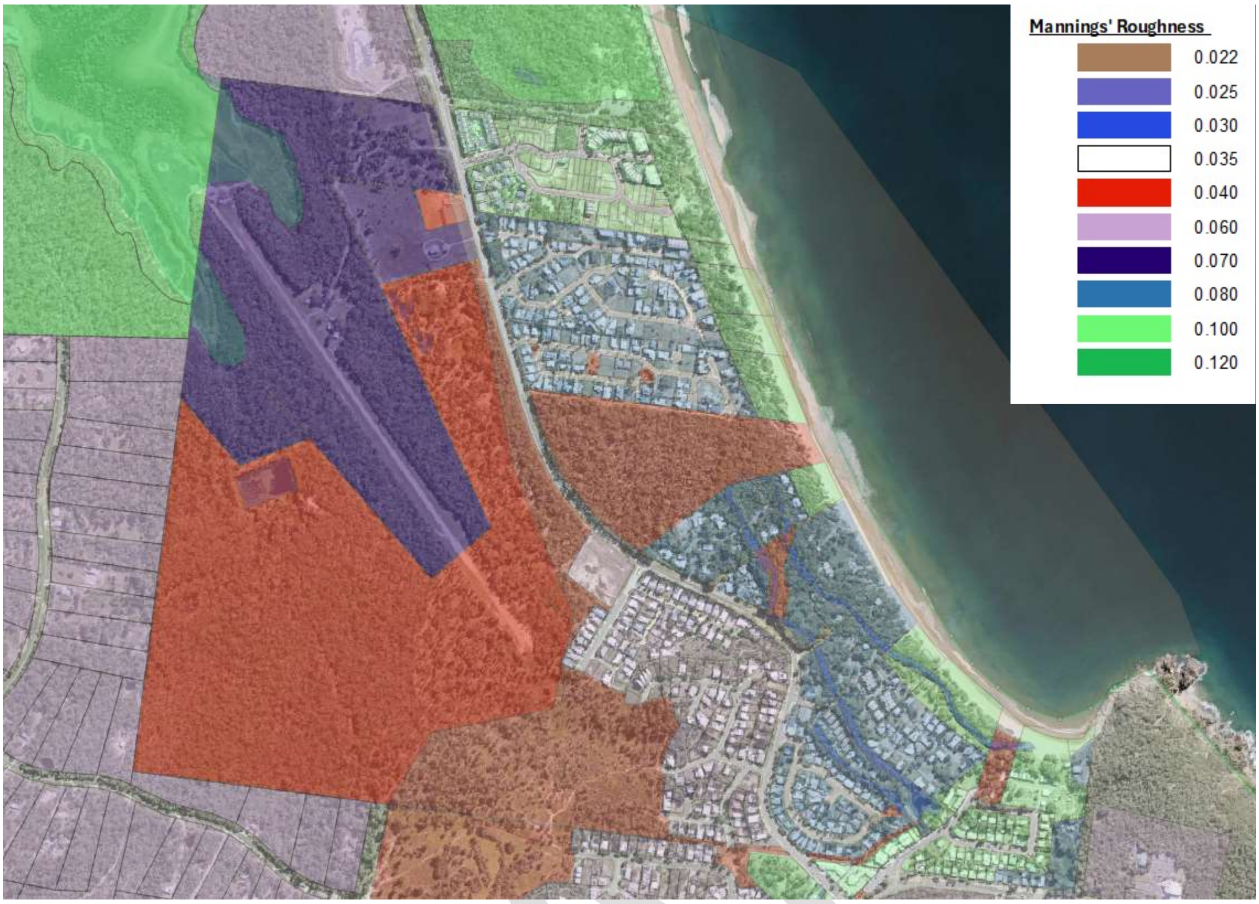


Diagram 4: Material Roughness based on landuse (inset)

7.2.6. Stormwater and Culverts

GRC provided a structure and culvert database containing the stormwater and drainage network within the study area, including Agnes Water, Round Hill and Seventeen Seventy. The datasets were included in the hydraulic model.

Where there was missing data (pipe sizes and/or invert levels), data was inferred from the surrounding network or the DEM (e.g. match downstream pipe size or invert at a pit). Additionally the dataset that was used in the previous study (Engeny, 2015) was utilised in case of missing data or features. Figure 5 shows the stormwater network features within the study area that were included in the hydraulic model.

All pits are 1D SX type R pits, allowing for flow between the 1D and 2D model domains.

7.2.7. Reporting Points and Lines

Reporting points and lines were included in the hydraulic model to record the flow and water levels at critical locations and to compare them to expected flows (based on the Rational Method, RFFE and results from previous studies). The same reporting points and lines as were used by Engeny (2015) were included in the model, as well as additional points across the rural areas.

7.3. Model Stability

The hydraulic model was checked for stability and mass error. The cumulative mass error for each run across both 1D and 2D components for model runs was generally ≤0.01%.

8. VALIDATION

Due to the absence of available historic flood information for the Agnes Creek and Round Hill catchments, validation of the models was undertaken through developing flow estimates through Regional Flood Frequency Estimation (RFFE) and the Rational Method. These flow estimates were then checked against the flows in the hydrologic and hydraulic models for selected sub-catchments for the 10% AEP and 1% AEP events.

8.1. Critical Durations

Critical durations were identified by running a range of durations and temporal pattern ensembles through the hydrologic model. For each duration the resulting peak flows at a particular location were averaged across the ensemble and the duration that caused the highest mean peak was selected as the critical duration. The temporal pattern above and closest to the mean was selected as the representative temporal pattern for that event. This was undertaken at the outlet of Round Hill Creek for 45 – 120 minute duration events. The 30 minute duration event was taken from a smaller sub-catchment with local flows only. The critical durations and temporal patterns that were selected are detailed in Table 21.

Table 21: Adopted Critical Durations and Temporal Patterns

AEP	Duration (mins)	Temporal Pattern
1%	30	TP5137
	45	TP5194
	60	TP5263
	90	TP5321
	120	TP5177
10%	30	TP5243
	45	TP5270
	60	TP5308
	90	TP5333
	120	TP5368

8.2. Comparison of various methods of peak flow estimation

Peak flows were estimated using a variety of methods including:

- Rational Method
- Regional Flood Frequency Estimation (RFFE)
- WBNM (refer Section 6 above)
- Rain on Grid (TUFLOW) with inflows from WBNM within Agnes Water township (refer Section 7 above).

A comparison to the peak flows for the various methods was undertaken to validate the flows of the more detailed combined hydrologic and hydraulic model.

The Rational Method is an empirical method to estimate runoff from catchments (Reference 3). It is a simplistic method using catchment characteristics such as stream length, size, slope and fraction impervious (via runoff coefficient). The Rational Method works best when the catchment has clearly defined flow paths that do not limit flow.

The assessment was undertaken for four catchments, west of Agnes Water, that have different sizes and shapes and are still relatively undisturbed. The catchments are identified in Diagram 5 and the results of the assessment are shown in Table 22.

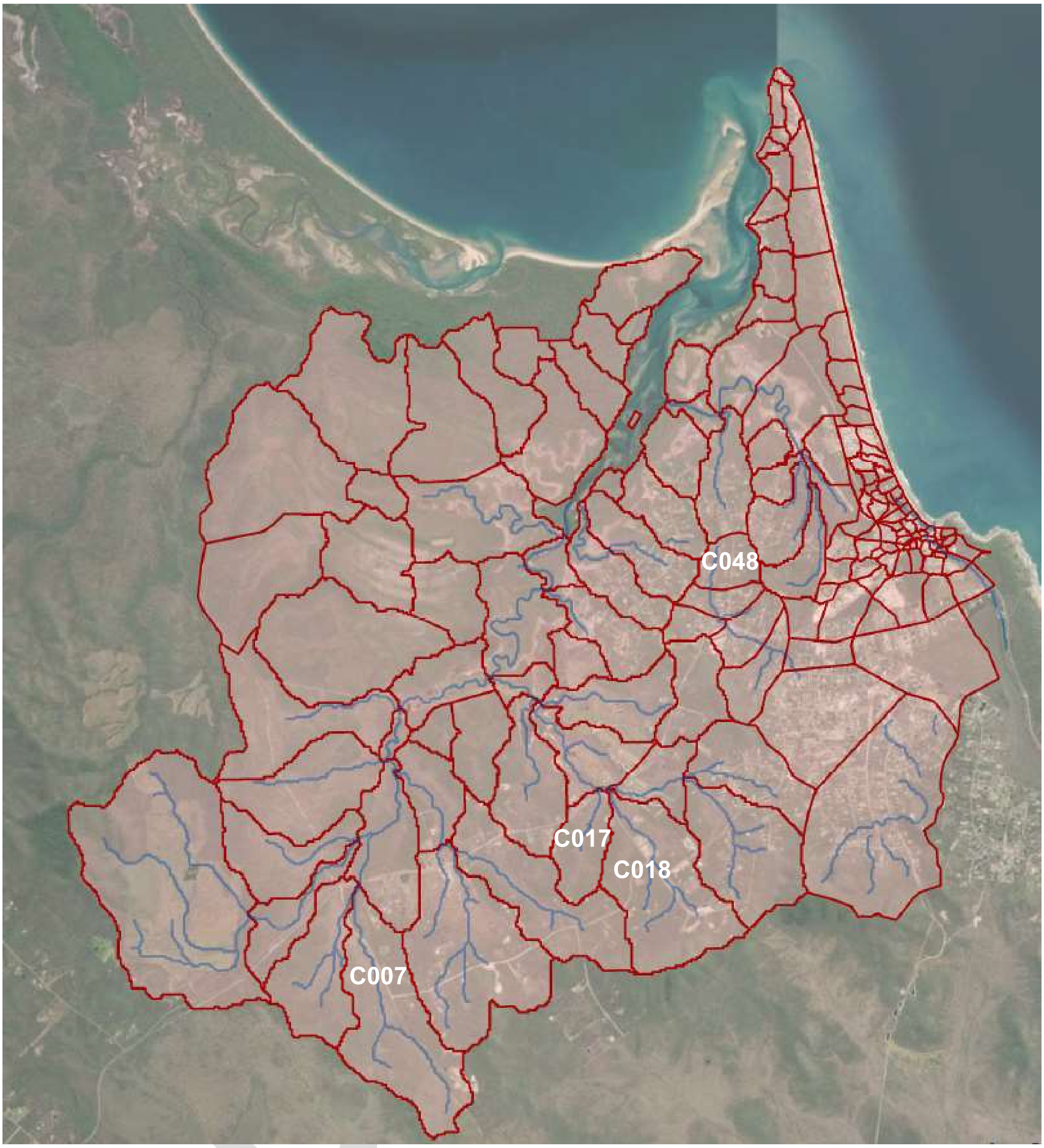


Diagram 5: Validation Catchment Locations

Table 22: Peak Flow Method Comparisons

Catchment	AEP	Rational Method (m^3/s)	WBNM (m^3/s)	TUFLOW (m^3/s)
C018	1%	50.9	53.8 (+6%)	65.7 (+29%)
	10%	28.7	28.1 (-2%)	30.0 (+4%)
C007	1%	62.1	53.8 (-13%)	60.7 (-2%)
	10%	34.5	29.8 (-14%)	42.5 (+23%)
C017	1%	21.5	20.6 (-4%)	25.2 (+18%)
	10%	12.2	11.3 (-8%)	12.6 (+3%)
C048	1%	11.8	13.8 (+17%)	17.7 (+50%)
	10%	6.8	7.1 (+3%)	9.0 (+31%)

Each of the three methods above rely on different key assumptions. Overall, for these four sub-catchments, a good agreement with expected peak flows is achieved. The difference between the expected flows and the modelled flows is generally less than 10%.

8.3. Comparison to Previous Studies

8.3.1. Flows

The previous flood study (Engeny, 2015) compared modelled flows to the Rational Method and the results from the Cox Andrews study (2003). The results from this study are also compared to the previous results and the comparison is presented below in Table 23. Figure 6 shows the reporting locations.

Table 23: Flow Comparisons

Location	AEP (%)	WMA (2025)		Engeny (2015)			Cox Andrews (2003) (m^3/s)	RFFE (m^3/s)
		TUFLOW (m^3/s)	WBNM (m^3/s)	TUFLOW (m^3/s)	XPRAFTS (m^3/s)	Rational Method (m^3/s)		
1	1	10.0	9.5	11.0	12.9	10.0	-	-
	10	5.7	5.7	6.9	7.2	5.4	-	-
2	1	13.0	12.4	12.1	12.4	13.1	-	-
	10	6.1	7.5	-	7.9	7.1	-	-
Agnes Mouth	1	28.9	48.4	23.1	52.9	31.0	54.5	50.5
	10	14.9	26.2	-	29.5	16.4	-	-

The hydraulic model (TUFLOW) peak flows are significantly lower than the flows calculated using hydrologic methods (WBNM, XPRAFTS, Rational Method, and RFFE). This is likely due to local water ponding near the mouth being reflected in the hydraulic model reducing the peak outflow.

In general, it can be concluded that there is a good agreement between the results obtained in the previous studies and this study. The flows are very similar to the expected flows, based on the Rational Method, and similar to what was modelled by Engeny (2015).

However, the flows at some locations are slightly lower compared to the previous study. The difference is attributed to the different sub-catchments, modelling methodology and slightly higher continuing loss, as mentioned in Section 6.4.

Compared to the previous study, the most northern sub-catchment is split (AW8, see Diagram 5) since approximately half of the runoff from that sub-catchment goes north, and therefore dividing the runoff from that sub-catchment towards Agnes Creek. Additionally, the sub-catchment AW3 (see Diagram 6 more likely drains directly into the ocean. Those two areas would have contributed approximately 4.5 m^3/s to the discharge of Agnes Creek in a 1% AEP event and would have increased the total peak discharge in a 1% AEP to 52 m^3/s, which is almost identical to the modelled flow in the previous study.

The previous study used the ARR 1987 IFDs which, generally, are approximately 10-15% higher than the 2016 BoM IFD files. However, for this study these BoM IFD files were updated for climate change, typically resulting in IFDs approximately 10-15% higher.

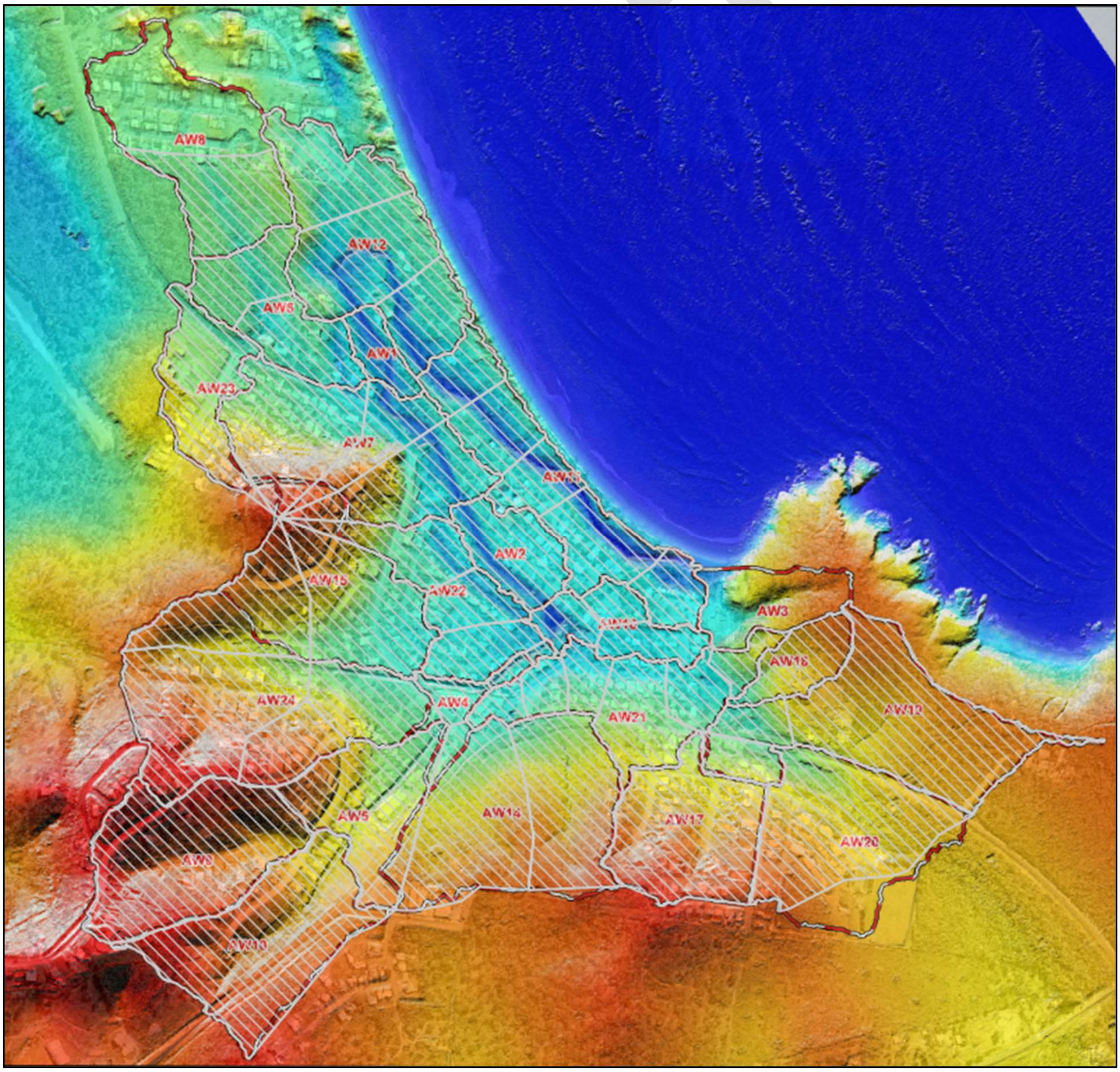


Diagram 6: Comparison of the sub-catchments contributing to Agnes Creek, as used in the previous study (red and white lines) and this study (white hash) (source: Engeny (2015))

8.3.2. Water Level

In addition to the comparison in flows, a water level comparison was undertaken between the results from the previous flood study and this study. The results of this comparison are presented in Table 24. Generally, the water levels that are modelled in this study are slightly lower.

Table 24: Water Level Comparison

Location[1]	10%			1%		
	Engeny (2015)	WMA (2025)	Difference (m)	Engeny (2015)	WMA (2025)	Difference (m)
1	14.29	14.09	-0.20	14.46	14.20	-0.26
2	12.84	12.96	0.12	13.09	13.19	0.10
3	7.53	7.37	-0.16	7.70	7.44	-0.26
4	7.30	7.33	0.03	7.43	7.41	-0.02
5	6.91	6.69	-0.22	7.04	6.84	-0.20
6	6.14	5.91	-0.23	6.40	6.08	-0.32
7	5.79	5.41	-0.38	5.95	5.58	-0.37
8	5.78	5.78	0.00	5.92	5.92	0.00
9	4.41	4.32	-0.09	4.79	4.77	-0.02
10	4.97	4.55	-0.42	5.03	4.79	-0.24
11	4.39	4.30	-0.09	4.78	4.76	-0.02
12	4.33	4.33	0.00	4.65	4.75	0.10
13	4.23	3.95	-0.28	4.60	4.46	-0.14
14	3.78	3.20	-0.58	4.02	3.60	-0.42
15	3.40	3.08	-0.32	3.62	3.39	-0.23
16	1.88	3.02	1.14	2.64	3.20	0.56

1. Shown in Figure 6

The difference between the two studies can predominantly be explained by the difference in DEMs. The DEM used in this study is on average 0.11 m lower compared to the DEM used in the previous study. In Agnes Creek, the difference in ground levels are larger, with elevations that are generally lower in the current DEM, ranging from 0.3 m to more than 1 m at the outlet. This is relevant for the reporting locations 9 to 16. Reporting points 5 and 6 are upstream and downstream of the Captain Cook Drive.

There is a large difference between studies at Location 16. This is at the downstream end of Anges Water Creek and is likely due to differences in the DEM, initial water level, and/or tailwater conditions.

Differences in the Manning's 'n' roughness coefficient can also result in lower or higher water levels. For example, the reporting locations 5 to 7 have a lower Manning's 'n' roughness value of 0.04 (open drain) compared to a value of 0.07 and 0.08 (medium to dense vegetation) in the previous study. Reporting locations are shown in Figure 6.

Additionally for the 1% AEP, the results from the previous study are an envelope of the 1% AEP model runs, where one of the runs has a 1% AEP tide as a downstream boundary condition.

Given the absence of data to further calibrate the model, it is concluded that a reasonable validation result is achieved.

8.4. Photographic Verification

Discussions with GRC indicated that the community may be requested to supply information to support a more thorough verification of the model. Several photos were provided by GRC showing overland flow and flooding in Agnes Water for two events, the January 2013 event and the October 2017 event. Daily rainfall data indicates that the 2013 event was similar to approximately a 5% AEP event (not adjusted for climate change), while the 2017 event was closer to between a 50% and 20% AEP event (not adjusted for climate change).

8.4.1. 2013 Event

8.4.1.1. Southern Cross Backpackers

One of the areas that flooded in 2013 was the area around the entrance to the Southern Cross Backpackers (2694 Round Hill Rd, Agnes Water). Photo 10 and Photo 11 show that significant inundation was observed with depths likely ranging between a few centimetres to a couple hundred millimetres.

Diagram 7 shows that there is a relatively good agreement between the 10% AEP flood depth and the observed flooding at the entrance of the Southern Cross Backpackers. The drain along the main road is flooded, with a few metres after that which seem to have less flood impact. More significant flooding seems to have occurred further towards the berm.

Photo 10. Entrance to Southern Cross Backpackers during the 2013 Flood Event.

Photo 11. Area just right of the entrance to the Southern Cross Backpackers, showing relatively significant flooding in the 2013 event.

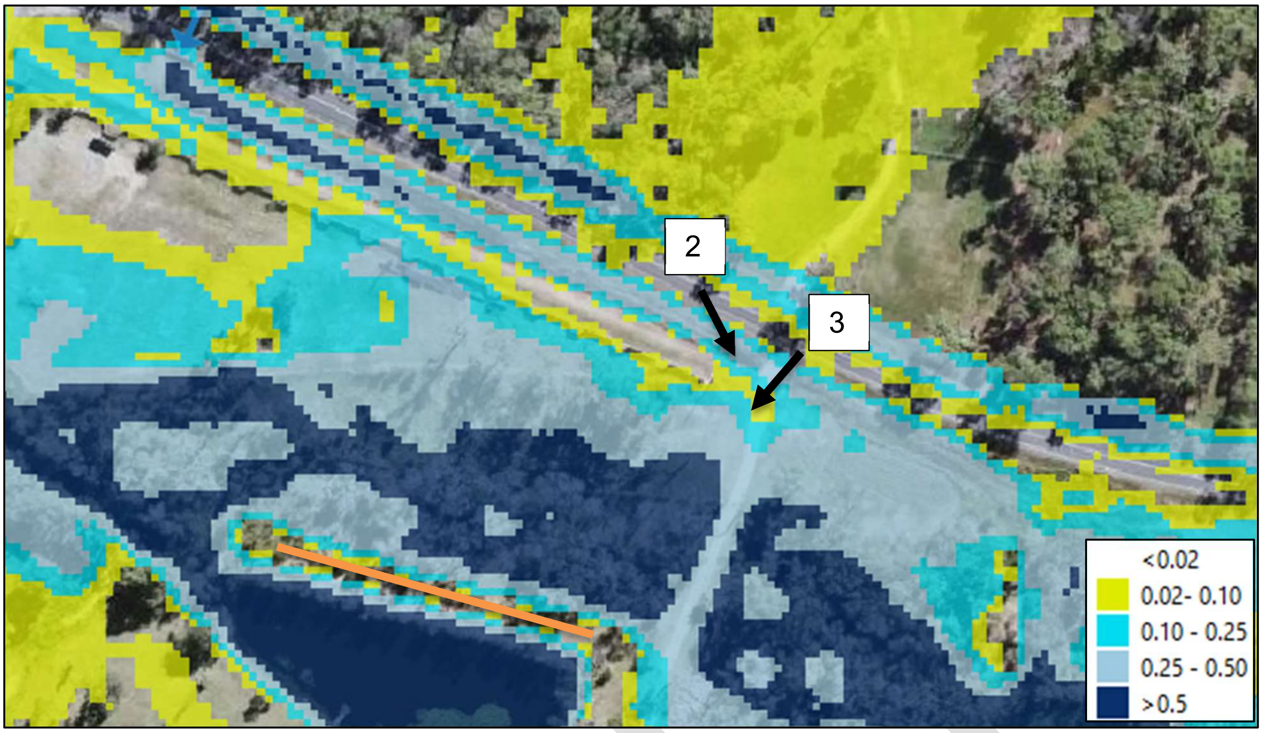


Diagram 7: 10% Flood depth, with the arrows indicting where Photo 2 and Photo 3 were taken from. The orange line indicates the berm that is visible in Photo 2.

8.4.2. 2017 Event

Evidence provided by GRC for the 2017 event shows flooding on the roads in the Beaches Village suburb north of Agnes Water (shown in Photo 12), where it appeared that the soak pits were not able to drain the water fast enough resulting in water on the roads. The photos were georeferenced as best as possible and compared to the 10% AEP flood depth. Since the 10% AEP results are adjusted for climate change, they are roughly similar to a 5% AEP that is not adjusted or climate change. It appears that photos were taken after the event since there is no rainfall visible in the photos and the extent of the flooding might therefore have been larger than shown in the photos.

There is a relatively good agreement between the photos and the modelled 10% AEP flood depth. Only Northbreak Drive (shown in Photo 14) appears to show more flooding in the 10% AEP event compared to observations during the 2017 Event. GRC provided updated information on these culverts which has been adopted in the Agnes Water drainage study design events.

Photo 12. Water on the road at the Beach Village Entrance

Diagram 8: 10% Flood depth showing similar water on the road at the Beach Village Entrance

Photo 13: Water on Sunset Drive

Diagram 9: 10% Flood depth showing water on Sunset Drive.

Photo 14: Water on Northbreak Drive

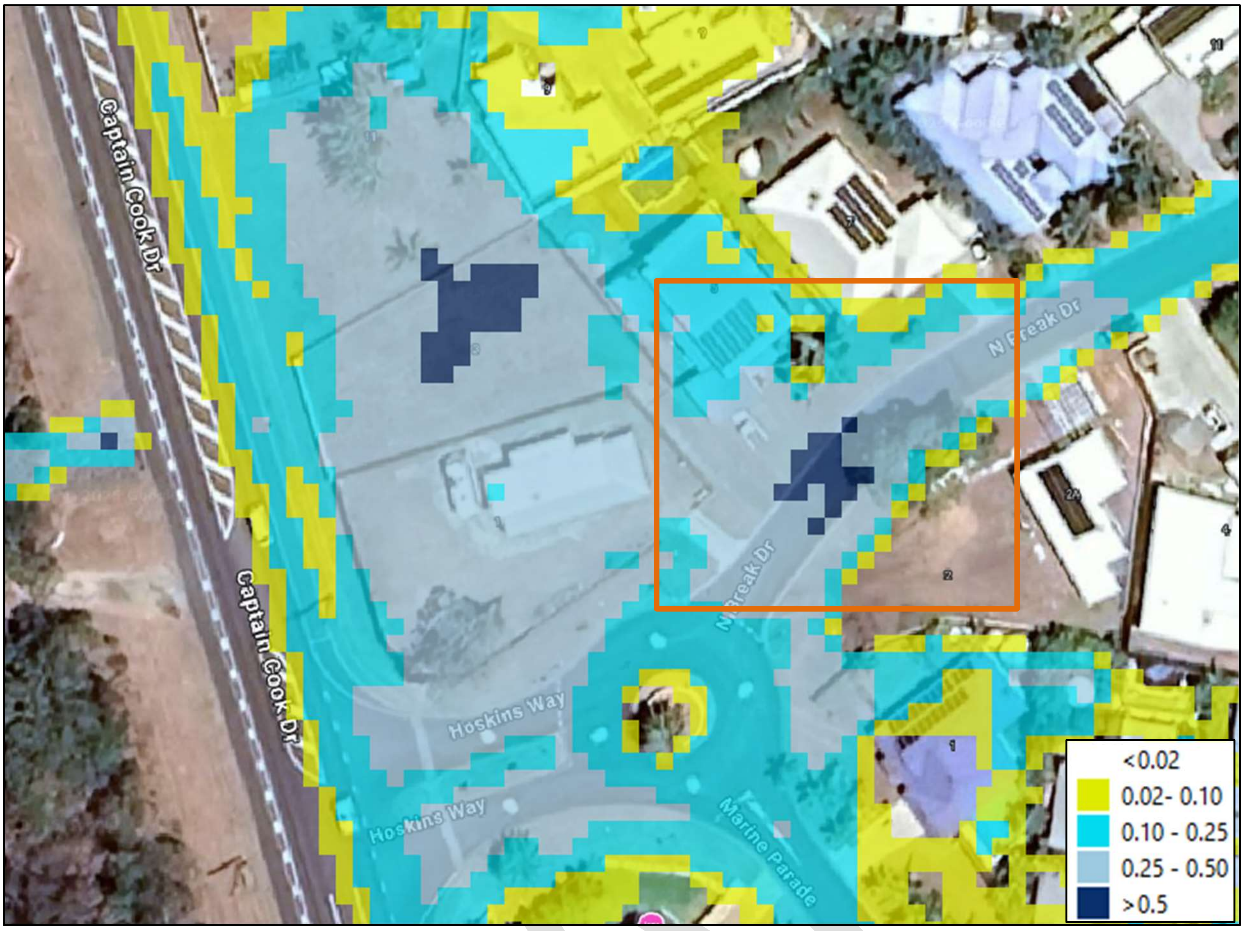


Diagram 10: 10% Flood depth on Northbreak Drive. The 10% flood extent appears to be larger than what was photographed.

8.5. Anecdotal evidence

GRC also provided some anecdotal evidence of flooding. This section provides a comparison of provided quotes with the modelled 10% AEP flood depth results, as an indication that there is a relatively good agreement between the model and observations.

Observation	Refer to
Throttled flow	***1 in*** Diagram 11
Agnes Creek flows overtop Thomson Street	***3 in*** Diagram 11
Water backed up to Murry Hilton Close with debris marks about 400mm up a corrugated fence	***2 in*** Diagram 11
Culvert near 86 Anderson Way floods after significant rainfall	Diagram 12
Flood onto the road near 76 Watkins Road	Diagram 13
Flood onto the road 2853 Round Hill Road	Diagram 14
Flood onto the road 2366 Round Hill Road	Diagram 15

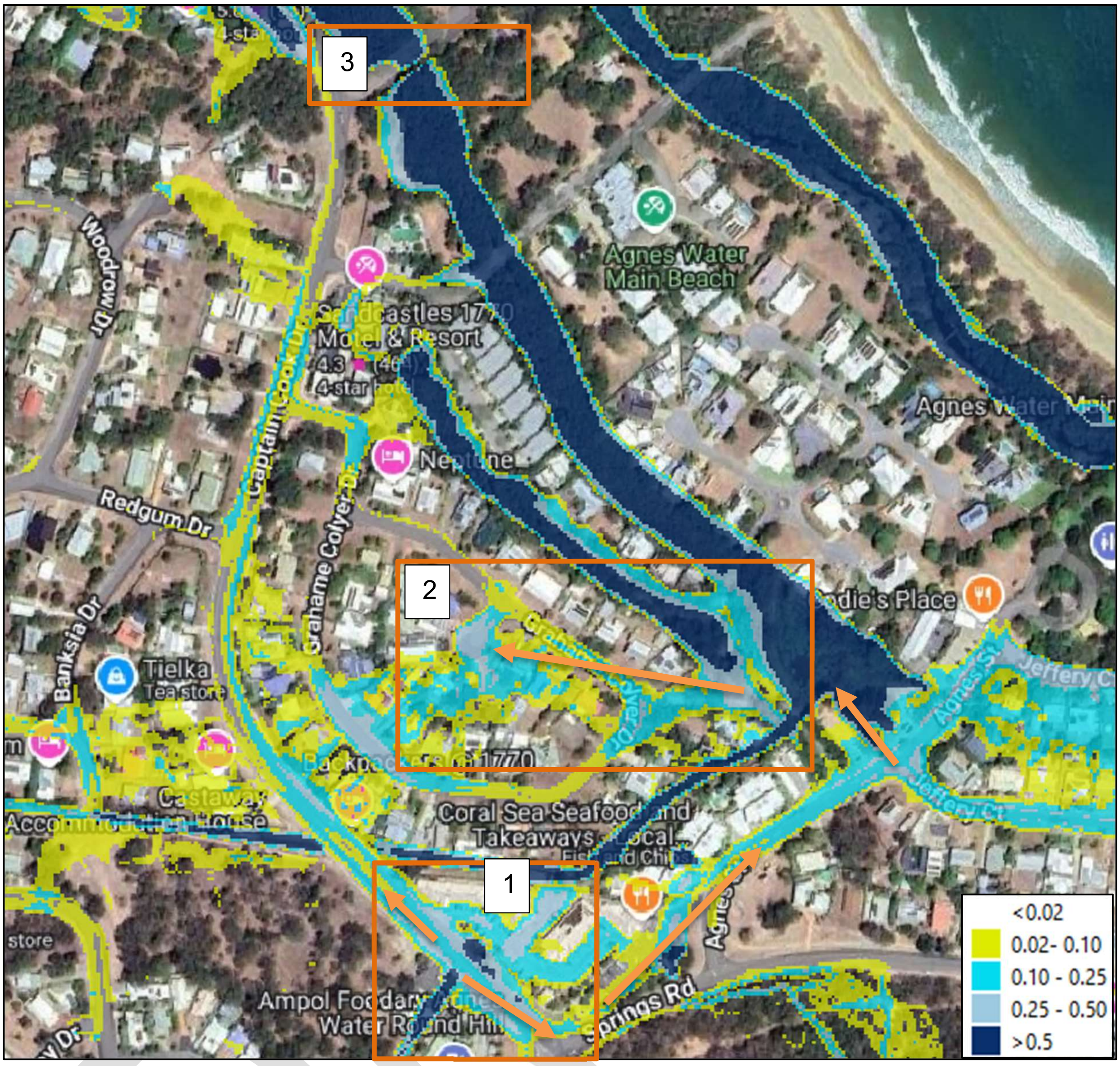


Diagram 11: 10% Flood depth, with arrows indicating the direction of flow. Flooding seems to be similar to what was described.

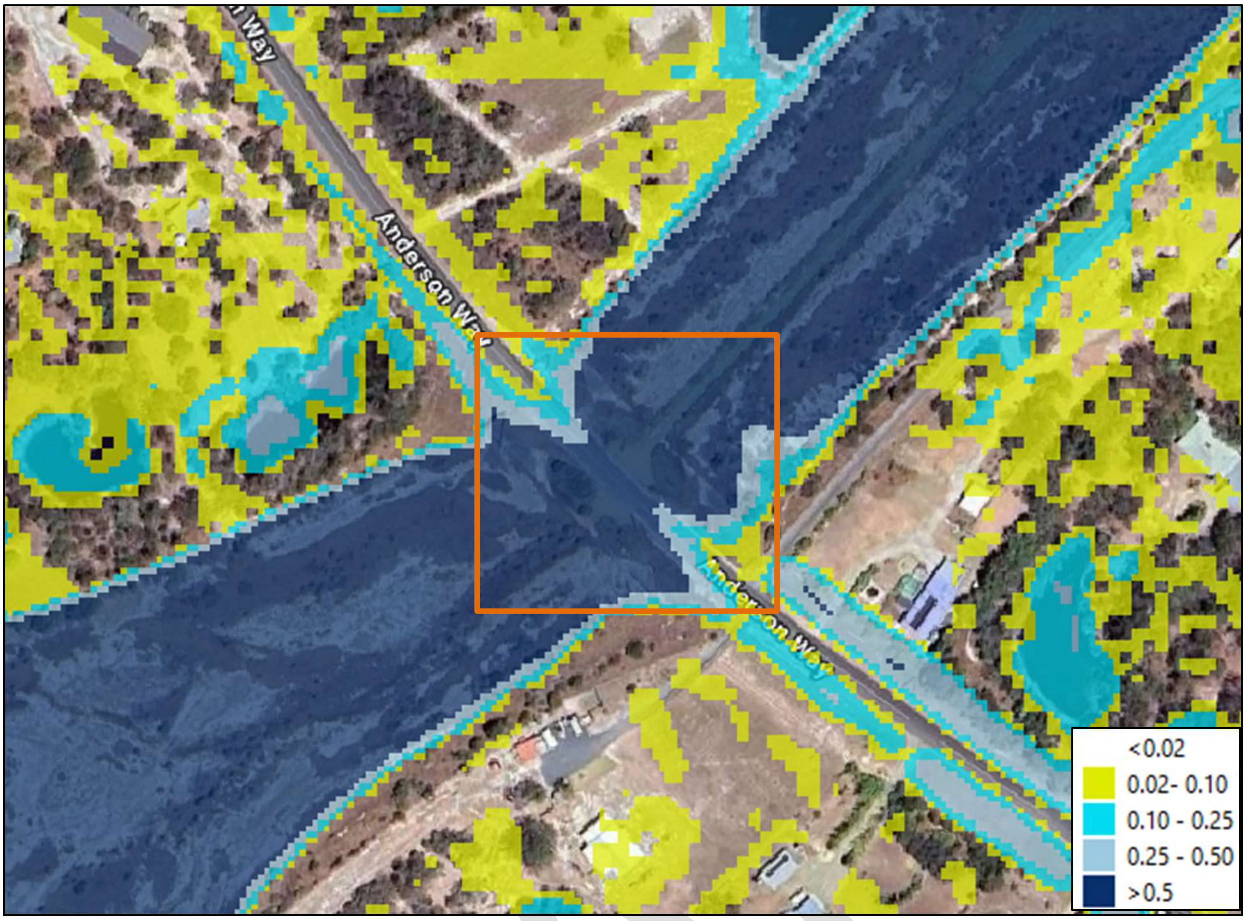


Diagram 12: 10% Flood depth with Anderson Way being overtopped

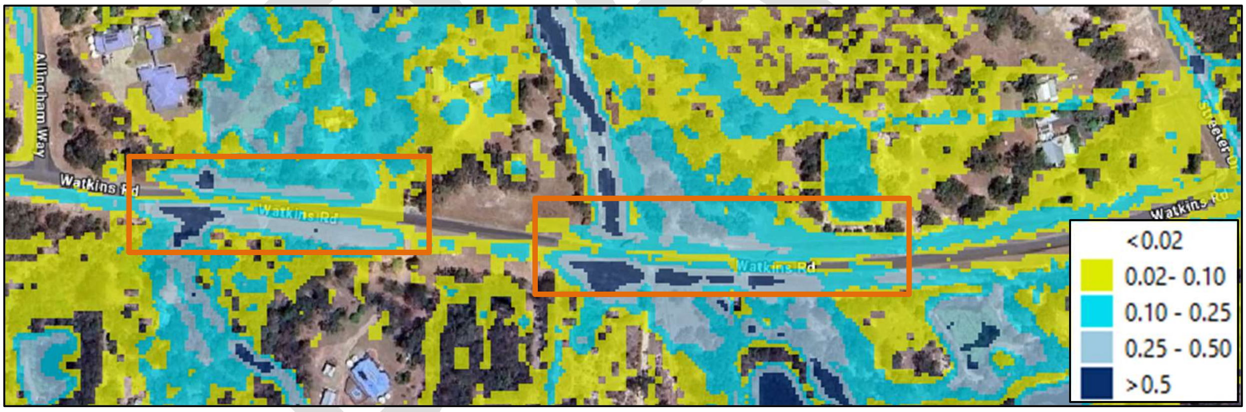


Diagram 13: 10% Flood depth, with water on Watkins Road

Diagram 14: 10% Flood depth near the the shopping centre. There appears to be no water on the road, but mainly in the drain along the road

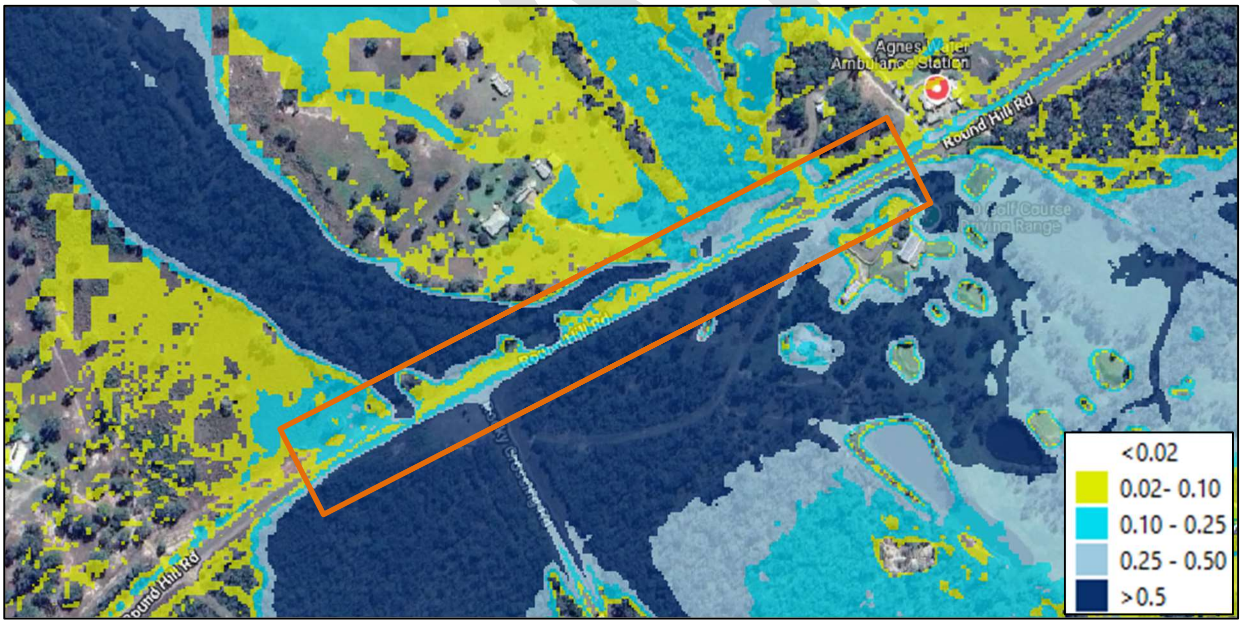


Diagram 15: 10% Flood depth with water on the road near 2366 Round Hill Road

9. DESIGN EVENT MODELLING

9.1. Overview

ARR 2019 guidelines (Reference 6) for design flood modelling were adopted for this study. The new guidelines were first published in 2016, finalised in 2019 and present a significant update on the previous version published in 1987 (Reference 3). Since 1987, there have been numerous advances in the understanding of rainfall-runoff processes, technological advances and a larger set of recorded rainfall data available. This additional 30 years of data (from approximately 1985 to 2015), particularly for continuously recorded rainfall (pluviometers), allows for Australia-specific techniques and regionalised information to be used across the country. Specifically related to design flood modelling there is updated IFD information, design temporal patterns, areal reduction factors and rainfall losses to consider.

ARR 2019 guidelines were used to estimate the 1 EY, 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 1 in 200 AEP, 1 in 500 AEP and 1 in 2,000 AEP events. The PMF flows were derived using the BoM's GSDM guideline (Reference 5) to estimate the PMP. A critical duration analysis was undertaken to determine the most representative duration and temporal patterns across the catchment. The selected storms for each AEP event were then used to simulate the design flood behaviour.

The design flood inputs were outlined in Section 6. This section outlines the critical duration analysis, coincident tailwater assumptions and the different scenarios simulated.

9.1. Temporal Patterns

Temporal patterns are a hydrologic tool that describe how rain falls over time and are used in hydrograph estimation. Previously, with ARR 1987 guidelines (Reference 3), a single temporal pattern was adopted for each rainfall event duration. However, ARR 2019 (Reference 6) discusses the potential inaccuracies with adopting a single temporal pattern and recommends an approach where an ensemble of different temporal patterns is investigated.

Temporal patterns for this study were obtained from the ARR 2019 data hub (http://data.arr-software.org/). The revised ARR 2019 temporal patterns were introduced to address the key limitations of the ARR 1987 temporal pattern approach.

It is widely accepted that there are a large variety of temporal patterns possible for rainfall events of similar magnitude. This variation in temporal pattern can result in significant effects on the estimated peak flow. As such, the revised temporal patterns have adopted an ensemble of ten different temporal patterns for a particular design rainfall event and duration. Given the rainfall-runoff response can be quite catchment specific, using an ensemble of temporal patterns attempts to produce the median catchment response.

As hydrologic modelling has advanced, it is becoming increasingly important to use realistic temporal patterns. The ARR 1987 temporal patterns only provided a pattern of the most intense burst within a storm, whereas the ARR 2019 temporal patterns look at the entirety of the storm including pre-burst rainfall, the burst and post-burst rainfall. There can be significant variability in the burst loading distribution (i.e. depending on where 50% of the burst rainfall occurs an event can be defined as front, middle or back loaded). The ARR 2019 method divides Australia into 12 temporal pattern regions, with the Agnes Water study area falling within the East Coast North region.

ARR 2019 provides 30 temporal patterns for each duration which are sub-divided into three temporal pattern bins based on the frequency of the events. shows the three categories of bins (frequent, intermediate and rare) and corresponding AEP groups. The "very rare" bin is in the experimental stage and was not used in this flood study. There are ten temporal patterns for each AEP/duration in ARR 2019 that have been utilised in this study for the 1 EY to 1 in 2,000 AEP events.

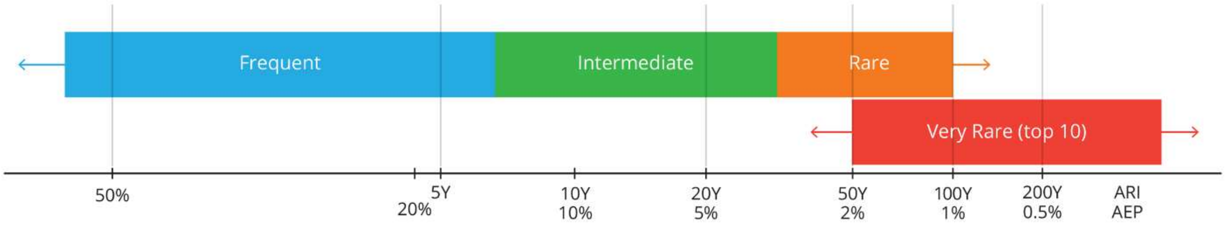


Diagram 16: Temporal Pattern Bins

The method employed to estimate the PMP utilises a single temporal pattern (Reference).

9.2. Critical Duration Assessment

ARR 2019 (Reference 6) requires an ensemble of temporal patterns to be run for each AEP and duration combination, and the 'most common' approach was adopted for the Anges Water study area, as shown in .

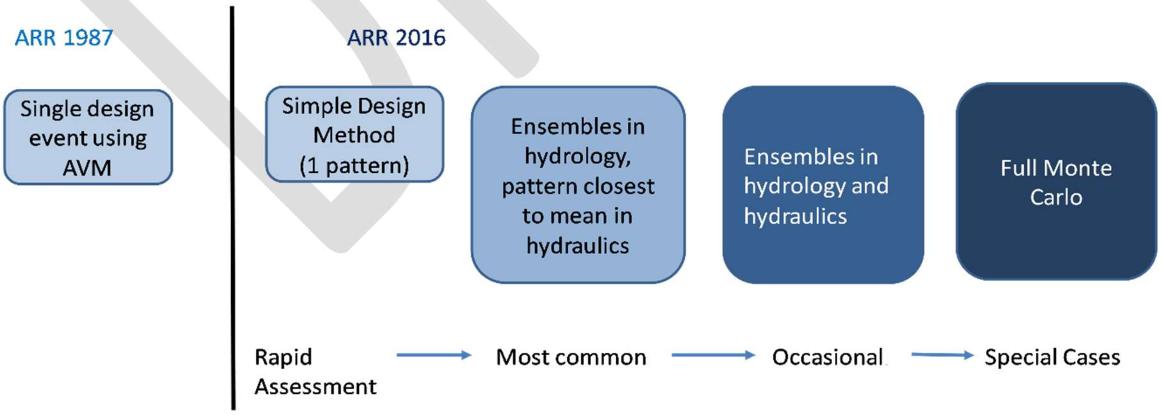


Diagram 17: Design modelling techniques for an ensemble of temporal patterns (Reference 6)

This approach requires the ensemble of temporal patterns to be run in a hydrologic model, with one pattern selected (from each duration) to be run in the hydraulic model.

9.2.1. Critical Duration

The critical duration is the storm duration that best represents the flood behaviour (e.g. flow or level) for a specific design magnitude at a particular location. It is generally related to the catchment size, as flow takes longer to concentrate at the outlet from a larger catchment, as well as other considerations such as land use, shape, stream characteristics, etc.

With ARR 2019 methodology, the mean flow (or level) is computed from the ensemble of temporal patterns for each duration. The critical storm duration for a location of interest is then the design storm duration that produces the highest mean flow (or level). Where there are multiple locations of interest with different contributing catchment sizes, there can be multiple critical durations that need to be considered.

9.2.2. Representative Temporal Pattern

Once the critical duration is established, it is usually desirable to select a representative design storm temporal pattern that reproduces this behaviour across all points of interest. This representative storm can then be used for determining design flood behaviour and for future modelling to inform floodplain management decisions. This is typically the storm that produces the next highest flow (or level) above the average (from the ensemble of temporal patterns) for the critical duration.

9.2.3. Representative Temporal Pattern Selection

The WBNM model was run for a range of durations between 15 minutes and 9 hours. Temporal patterns have been selected from the WBNM model based on total flows at representative subcatchments (i.e. small subcatchments (C063 and C064) were considered when choosing the shorter duration temporal patterns and subcatchments with large contributing area were used to choose the longer duration temporal patterns (C061)). Inflows to Agnes Water (C094) were also considered in selecting the representative temporal pattern(s) for each duration. This selection process was undertaken for each AEP and duration combination. provides the resulting temporal patterns which were selected for each probability and duration. Durations longer than the critical duration at the outlet were not considered further.

By running a range of durations, the critical duration at each point within the catchment is captured by one of the durations simulated. The critical duration for the 1% AEP event (current day, HAT) is shown in Figure 7. The critical duration ranges from 15 minutes in the upper catchment areas to 4.5 hours at the downstream outlet.

The full range of storm durations were simulated for the PMP event in both the WBNM and TUFLOW models since the GSDM adopts a single temporal pattern.

9.3. Design Flood Event Simulation

The adopted storm events () were simulated in the TUFLOW model. For each event, an envelope (maximum) was taken of storms simulated to derive design flood behaviour.

Table 25: Representative storm selection

Duration	1EY	50%	20%	10%	5%	2%	1%	1 in 200	1 in 500	1 in 2000
15	TP5158	TP5158	TP5151	TP5151	TP5153	TP5112	TP5112	TP5112	TP5112	TP5112
30	TP5254	TP5253	TP5252	TP5254	TP5254	TP5210	TP5095	TP5210	TP5210	TP5210
45	TP5281	TP5279	TP5273	TP5271 TP5269	TP5170	TP5170 TP5211	TP5170 TP5262 TP5211	TP5211 TP5144	TP5262 TP5261	TP5262 TP5264
60	TP5314	TP5313	TP5313	TP5306 TP5308	TP5292 TP5263	TP5292 TP5263	TP5292 TP5263	TP5292 TP5294	TP5292 TP5263	TP5265 TP5263
90	TP5343	TP5340 TP5343	TP5343 TP5342	TP5284	TP5322 TP5321	TP5324	TP5324 TP5171	TP5324 TP5321	TP5324 TP5321	TP5324
120	TP5387	TP5388 TP5386	TP5367 TP5372	TP5368	TP5362	TP5354	TP5356 TP5362	TP5362	TP5362	TP5362
180	TP5353	TP5421 TP5353	TP5420 TP5208	TP5410 TP5405	TP5403	TP5401	TP5401			
270	TP5452	TP5453	TP5444	TP5443	TP5436	TP5429	TP5429			
360	TP5477									
540	TP5518									

9.4. Tailwater Conditions

Three tailwater scenarios were simulated for each event – MHWS (representative of a 'high tide' condition), HAT, (representing the highest water level predicted for a location based on astronomical forces only) and a storm tide (incorporates elevated water levels due to storm conditions caused by wind action and low pressure systems). The MHWS and HAT levels for the current conditions were from the 2025 Tide Tables published by Queensland Ports for Seventeen Seventy (Reference 10). The storm tide level was adopted from Reference 7. For the future 2100 climate condition, 0.8 m was added to these values in line with Reference 11. The adopted tide levels are provided in .

Table 26: Tide Levels (mAHD)

Tide	2030*	2100
MHWS	1.20	2.0
HHWS(SS)	1.25	2.05
HAT	1.80	2.6
Storm Tide 10%	2.0	2.8
Storm Tide 5%	2.15 / 2.05	2.9
Storm Tide 1%	2.4 / 2.2	3.2
Storm Tide 0.2%	2.5	3.5

* where 2 values are provided the locations are Seventeen Seventy / Agnes Water

For storm surge conditions, the probability of a 1% AEP storm tide occurring at the same time as a 1% AEP rainfall event is less than a 1% AEP. Therefore, the storm surge conditions that are modelled to occur in conjunction with a rainfall event need to be considered. However, a complete analysis of the joint probability of these two events occurring is beyond the scope of this project. The adopted storm surge condition for each event is outlined in Table 27.

Table 27: Rainfall and tide event probability for storm surge conditions

Design AEP	Catchment Flood Scenario	Ocean Water Boundary Scenario
50% AEP	50% AEP	HHWS(SS)
20% AEP	20% AEP	HHWS(SS)
10% AEP	10% AEP	HHWS(SS)
5% AEP	5% AEP	HHWS(SS)
2% AEP	2% AEP	5% AEP
1% AEP (enveloped)	1% AEP	5% AEP
	5% AEP	1% AEP
0.5% AEP	0.5% AEP	1% AEP
0.2% AEP	0.2% AEP	1% AEP
0.05% AEP	0.05% AEP	1% AEP
PMF	PMF	1% AEP

Note: HHWS(SS) = High High Water Springs (Solstice Spring)

Storm tide levels exclude wave runup and are taken from Table 3-14 of Reference 7 (pdf page

198 of 245) such that, under the 2030 (current day) climate scenario, tailwater boundary conditions are provided in Table 29.

Table 28: Rainfall and tide event probability for storm surge levels

Design AEP	Catchment Flood Scenario	2030 Ocean Water Boundary Scenario (mAHD)*	2100 Ocean Water Boundary Scenario (mAHD)
50% AEP	50% AEP	1.25	2.05
20% AEP	20% AEP	1.25	2.05
10% AEP	10% AEP	1.25	2.05
5% AEP	5% AEP	1.25	2.05
2% AEP	2% AEP	2.1 / 2.2	2.9
1% AEP (enveloped)	1% AEP	2.1 / 2.2	2.9
	5% AEP	2.2 / 2.4	3.2
0.5% AEP	0.5% AEP	2.2 / 2.4	3.2
0.2% AEP	0.2% AEP	2.2 / 2.4	3.2
0.05%	0.05% AEP	2.2 / 2.4	3.2
PMF	PMF	2.2 / 2.4	3.2

* where 2 values are provided the locations are Agnes Water / Seventeen Seventy

9.5. Initial Conditions

An initial water level was applied to the Agnes Water Creek near the outlet to the ocean. The initial water level was set to 2.5 mAHD or equal to the height of the ocean water boundary or tide level when this is higher. The 2.5 mAHD level corresponds to the height of the berm on the beach at the outlet. This will ensure that the available storage is in the creek is at least partially filled before the peak of the flood events arrive.

Additionally, for the Round Hill Creek estuary, an initial water level was applied, equal to the ocean water boundary or tide level.

9.6. Blockage

ARR 2019 (Reference 6) recommends applying blockage to hydraulic structures and outlines a methodology to determine inlet blockage factors by considering debris availability, debris mobility, debris transportability and waterway opening of the structure. 50% blockage was applied as part of the sensitivity assessment for the 1% AEP event only (refer to Section 10.5).

9.7. Design Event Scenarios

The full range of design events, climate scenarios and tailwater conditions are summarised in Table 29 below.

Table 29: Design events, climate scenarios and tailwater conditions modelled

AEP	Climate SSP3-7.0		Tailwater		
	2030	2100	MHWS	HAT	Storm Tide
63.2% (1EY)	✓	-	✓	✓	✓
50%	✓	-	✓	✓	✓
20%	✓	-	✓	✓	✓
10%	✓	-	✓	✓	✓
5%	✓	-	✓	✓	✓
2%	✓	-	✓	✓	✓
1%	✓	✓	✓	✓	✓
1 in 200	✓	✓	✓	✓	✓
1 in 500	✓	✓	✓	✓	✓
1 in 2000	✓	-	✓	✓	✓
PMF	✓	-	✓	✓	✓

10. DESIGN FLOOD EVENT RESULTS

10.1. Overview

Flood maps were produced showing flood behaviour for the design flood events. Each event, climate scenario and tailwater condition were enveloped such that the maximum for all durations is depicted. The model results were filtered to remove shallow depths less than 50 mm. This is required due to the direct rainfall method in the upper catchment area, where shallow flows cover all areas. Filtering out shallow flow areas means that flow paths remain where flooding is of interest. The filter depth was discussed and agreed with GRC. The filtered extent for each event, climate scenario and tailwater condition was applied to all results (depth, level, velocity, hazard, etc). The maps for each event, climate scenario and tailwater condition are provided in Appendix C and summarised in Table 30. Each map set contains peak flood depth, peak flood level, peak velocity, peak velocity-depth product, peak hydraulic hazard (from Reference), and peak hydraulic risk (based on GRC's current planning scheme), in that respective order.

Table 30: Flood maps provided

Event	Climate Scenario	Tide	Maps
1% AEP	2030 SSP3	MHWS	Figure C-1 - Figure C-12
		HAT	Figure C-13 - Figure C-24
		Storm surge	Figure C-25 - Figure C-36
	2100 SSP3	MHWS	Figure C-37 - Figure C-48
		HAT	Figure C-49 - Figure C-60
		Storm surge	Figure C-61 - Figure C-72
1 EY	2030 SSP3	MHWS	Figure C-73 - Figure C-84
		HAT	Figure C-85 - Figure C-96
50% AEP	2030 SSP3	MHWS	Figure C-97 - Figure C-108
		HAT	Figure C-109 - Figure C-120
20% AEP	2030 SSP3	MHWS	Figure C-121 - Figure C-132
		HAT	Figure C-133 - Figure C-144
10% AEP	2030 SSP3	MHWS	Figure C-145 - Figure C-156
		HAT	Figure C-157 - Figure C-168
5% AEP	2030 SSP3	MHWS	Figure C-169 - Figure C-180
		HAT	Figure C-181 - Figure C-192
2% AEP	2030 SSP3	MHWS	Figure C-193 - Figure C-204
		HAT	Figure C-205 - Figure C-216
1 in 200 AEP	2030 SSP3	MHWS	Figure C-217 - Figure C-228
		HAT	Figure C-229 - Figure C-240
		Storm surge	Figure C-241 - Figure C-252
	2100 SSP3	MHWS	Figure C-253 - Figure C-264
		HAT	Figure C-265 - Figure C-276
		Storm surge	Figure C-277 - Figure C-288
1 in 500 AEP	2030 SSP3	MHWS	Figure C-289 - Figure C-300
		HAT	Figure C-301 - Figure C-312

Event	Climate Scenario	Tide	Maps
		Storm surge	Figure C-313 - Figure C-324
	2100 SSP3	MHWS	Figure C-325 - Figure C-336
		HAT	Figure C-337 - Figure C-348
		Storm surge	Figure C-349 - Figure C-360
1 in 2000 AEP	2030 SSP3	MHWS	Figure C-361 - Figure C-372
		HAT	Figure C-373 - Figure C-384
		Storm surge	Figure C-385 - Figure C-396
PMF	2030 SSP3	MHWS	Figure C-397 - Figure C-408
		HAT	Figure C-409 - Figure C-420

GRC requested overland flow be separated from riverine flooding for the 1% AEP event. WMA Water developed a single criteria to assess overland versus riverine flows. Where the maximum flood level occurs due to short duration events (categorised as 15 minutes to 45 minutes), this is classified as 'overland flow'. This represents a very short critical duration where shallow overland flow dominates. All other areas where the critical duration was greater than 45 minutes, a 'riverine' flooding condition was assigned as this provides sufficient time for flows to concentrate into flow paths that can be considered to be 'riverine' flood conditions for the purpose of the planning scheme.

This classification was reviewed considering the change in peak flood levels between the 1% AEP event and 1 in 2000 AEP event, and between the 1% AEP event and PMF event. This review indicated that for the urban areas of interest, the 'riverine' classification generally had 1 in 2000 AEP levels more than 0.4 m above the 1% AEP flood level, and PMF levels more than 1 m above the 1% AEP flood level. This scale indicates that freeboard is appropriate to account for uncertainties in the estimation of flood levels. In the 'overland' areas, the scaling between flood events was lower and the overland classification was considered appropriate.

Mapping of this classification is only provided for the 2030 SSP3 1% AEP HAT scenario (provided in Appendix E).

10.2. Summary of Results

These results are available in electronic GIS format. The digital data should be used in preference to the figures in this report as they provide more detail. The figures are intended to provide an overview of the results and should not be relied upon for detailed information at individual properties.

The design event flood maps show significant flooding bounding existing creek lines and open drains in most of the design events. The critical burst duration varies throughout the study area generally between 30 minutes and 180 minutes (3 hours). As such, there is little warning from the commencement of rainfall to the time flooding commences and reaches a peak.

Throughout the rural areas there are shallow undefined flow paths. The airstrip is inundated in most events. The town of Seventeen Seventy is largely free from flooding, being located on a ridge line.

In the town of Agnes Water, there are several flow paths that converge on the town. There is a flow path from the east that overtops Springs Road in the vicinity of Clowes Lane. This flows through some lakes and through the NRMA Agnes Water Holiday Park before inundating a substantial residential area of Jeffery Court, where 1% AEP flood depths reach 0.4 m. There is a central flow path that originates to the south of Agnes Water, flowing through two open channels that are conveyed under Captain Cook Drive (with one continuing under the Endeavour Plaza). While these channels largely contain the 1% AEP flow, floodwater does spill out of the western channel (mapped Agnes Creek waterway) upstream of Captain Cook Drive and inundating a residential area around Grahame Colyer Drive, where 1% AEP flood depths again reach 0.4 m. The confluence of the channels is located downstream of the Endeavour Plaza and it continues to an ornamental lake, where it is joined by overland flows from Jeffery Court.

From the ornamental lake, Agnes Creek continues to the west, with a second low-lying flow path forming over a private road part of the Beach Houses Estate. These areas are low-lying and subject to deep inundation in the 1% AEP event, reaching over 2 m deep. The creek then crosses Ocean Beach Drive and Thomson Street before being joined by a flow path from the west. These overland flows cause ponding upstream of the bend on Captain Cook Drive (near Thomson Street) and inundation of Lady Musgrave Circuit and a private road. Agnes Creek then continues to the north-west, crossing Lady Musgrave Circuit before turning 180 degrees and flowing back, parallel to the shoreline. Water in this section of the creek is up to 3 m deep. The outlet of the creek is over the berm formed by the sand dunes of Agnes Water Main Beach.

Flooding through the lower half of the study area is impacted by tide levels, particularly though the Round Hill Creek Estuary. This area is sensitive to the assumed ocean conditions. In Agnes Water, the tide has very little impact on peak flood levels upstream of the berm. The 2100 scenario raises 1% AEP flood levels by approximately 0.1 m in the upper catchment areas, 0.3 m in the middle reaches (including through Anges Water) and increases up to 0.8 m through the Round Hill Creek Estuary.

10.3. Hydraulic Hazard Categorisation

Hydraulic hazard is a measure of potential risk to life and property damage from flooding. Hydraulic hazard is typically determined by considering the depth and velocity of floodwaters. In recent years, there have been a number of developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity and velocity-depth product. The Australian Disaster Resilience Handbook 7: Managing the Floodplain (Reference 12) contains updated recommendations regarding the categorisation of flood hazard in guideline 7-3. A summary of this categorisation is provided in Diagram 18. This categorisation is based on an extensive literature review and laboratory testing. It considers hazard to people, vehicles and buildings to develop six categories of flood hazard based on flood depth, velocity and velocity-depth product.

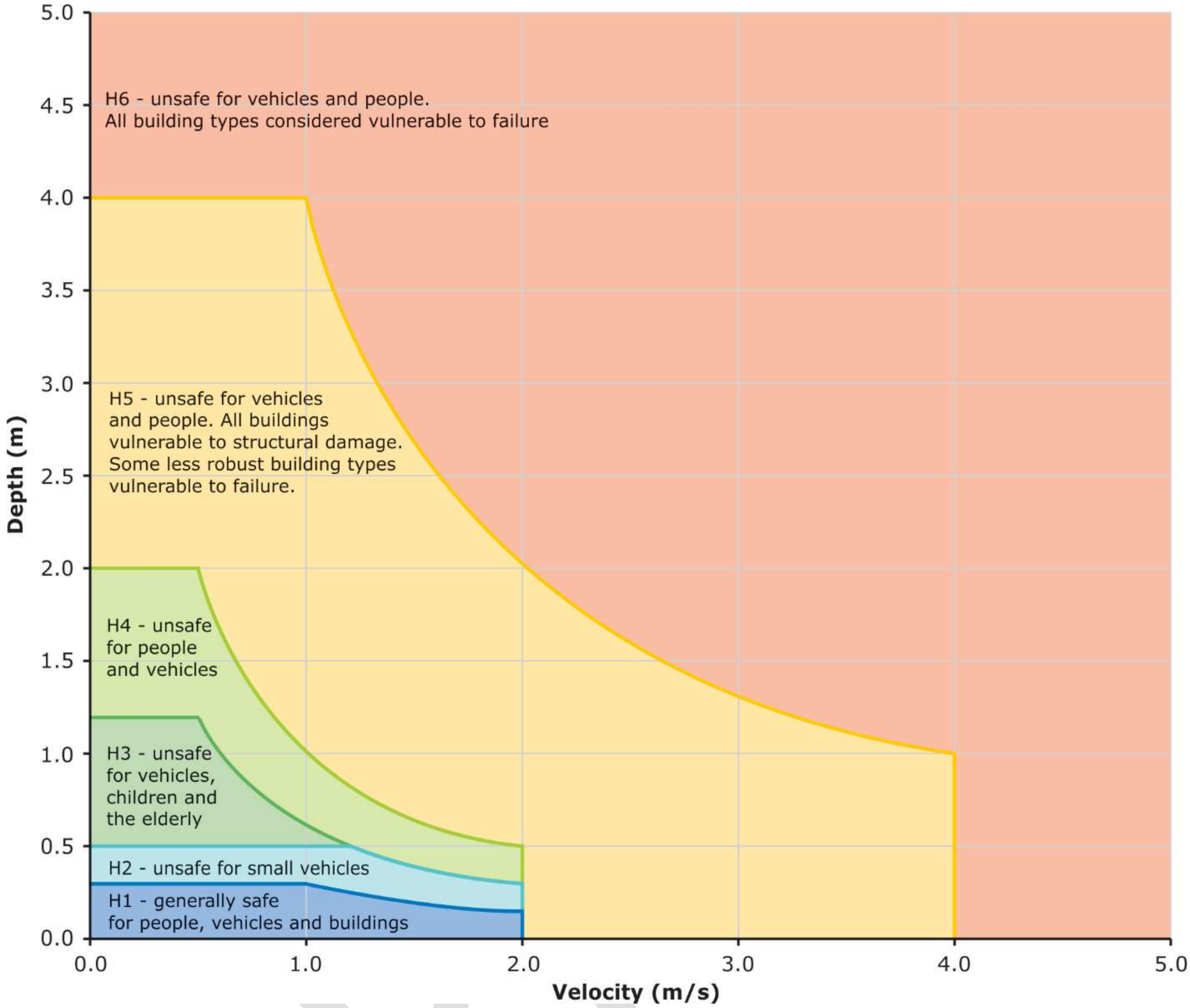


Diagram 18: General flood hazard vulnerability curves (Source: Reference)

The following 6 classes of hazard are defined:

- H1 – Generally safe for vehicles, people and buildings;
- H2 – Unsafe for small vehicles;
- H3 – Unsafe for vehicles, children and the elderly;
- H4 – Unsafe for vehicles and people;
- H5 – Unsafe for vehicles and people. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure; and
- H6 – Unsafe for vehicles and people. All building types considered vulnerable to failure.

The hazard categories using the Handbook 7 classification are provided for a range of events, climate scenarios and tailwater conditions (see Table 30). The hazard mapping depicts areas of H1 – H3 flooding in the 1% AEP events for all climate and tide scenarios around parts of Agnes Water and several of the roads throughout the study area. Higher hazard areas surround the existing creeks and waterways.

10.4. Hydraulic Risk

Hydraulic risk was defined in accordance with GRC's Planning Scheme and discussion with GRC. This criteria is outlined in Table 31 below.

Table 31: Hydraulic Risk Criteria

	Low	Medium	High	Extreme
Wading ability	V.d < 0.2 m^2/s	V.d < 0.4 m^2/s	V.d < 0.6 m^2/s	V.d ≥ 0.6 m^2/s
Vehicle navigability*	d < 0.2 m	d < 0.25 m	d < 1.2 m	d ≥ 1.2 m
Evacuation distances	Not assessed as part of this project			
Maximum flood depths	d < 0.2 m	d < 0.6 m	d < 1.2 m	d ≥ 1.2 m
Maximum flood velocity	V < 0.4 m/s	V < 0.8 m/s	V < 1.5 m/s	V ≥ 1.5 m/s
Timing	Not considered as we are not aware of any warning mechanism for the catchment			

* Applicable to roads only.
d = depth
V = velocity
V.d = velocity x depth product

The risk categories using GRC's criteria are provided for a range of events, climate scenarios and tailwater conditions (see Table 30). The risk throughout Agnes Water is typically Low and Medium risk, although there are some areas that reach High risk with extreme risk present in the creeks and waterways.

10.5. Sensitivity Analysis

A +50% blockage case and ± 20% Mannings Roughness cases have been run for the 1% AEP event in the 2030 SSP3-7.0 climate. Results are mapped in Appendix D on Figure D-1 to Figure D-42. Figure D-13 and Figure D-14 (impact maps) show that 50% blockage has little impact of the flood model. Catchment roughness has a higher influence of the extent of flooding with +20% Mannings Roughness increasing the area of inundation slightly (Figure D-27 and Figure D-28 impact maps), while decreased roughness decreases the area of inundation slightly (Figure D-41 and Figure D-42).

Overall, the severity of flooding does not change significantly with changes in blockage or roughness.

11. CONCLUSIONS

WMA Water was commissioned by GRC to undertake a drainage study for Agnes Water. The purpose of the drainage study is to develop a set of updated Flood Hazard Overlay mapping in the Planning Scheme and provide updated information on riverine flood affected properties in the urban areas of the Agnes Water township and the Agnes Creek and Round Hill Creek catchments.

WMA Water developed a hydrologic (WBNM) and hydraulic (TUFLOW) model to simulate flood behaviour in the study area. Topographic data was used to delineate catchments and land use information was used to assign impervious fractions for the hydrologic model. The hydraulic model was developed using several different topographical datasets, ranging from 1 m LiDAR data to bathymetry datasets, land use data and stormwater infrastructure. The models were validated using the limited available flood records and compared with previous flood modelling for the Agnes Water study area.

Design rainfall depths were sourced from the BoM and were used in the development of the hydrologic model to represent the likely rainfall within the Agnes Water study area, for a variety of design events. Rainfall and loss parameters represent the baseline case and were adjusted to 2030 climate change conditions using ARR version 4.2.

Validation was undertaken by comparing the model results from the hydrological and hydraulic model to expected flows, based on the Rational Method and RFFE, and results from the previous flood study (Engeny, 2015). Additional validation of the hydraulic model was undertaken by comparing the modelled water levels with results from the previous study (Engeny, 2015).

A good match was obtained to the limited observations and there is good agreement between the flows and levels estimated in this study and flows estimated by the rational method, RFFE and the previous study (Engeny, 2015). In general, the water levels in this study are slightly lower than the previous study. Given the absence of data to further calibrate the model or to validate the model results, it is concluded that a reasonable to good validation result was achieved and the models are fit for purpose. It is recommended, however, that the model is reviewed against additional data sources if and when this information becomes available.

Design events were simulated run for 2030 (near-term climate) and 2100 climate change (SSP3). The event probabilities for 2030 were modelled and mapped for the 1 EY, 50%, 20%, 10%, 5%, 1%. 1 in 200, 1 in 500, and 1 in 2000 AEPs together with PMF for MHWS, HAT and storm tide ocean conditions. In addition, the 2100 climate change scenario has been run and mapped for the 1%, 1 in 200, and 1 in 500 AEP events under MHWS, HAT and storm tide conditions. These results provide GRC with a range of flood event scenarios for consideration in planning decisions and a basis for consideration and modelling of mitigation measures.

WMA Water undertook a sensitivity assessment of the flood modelling including modelling with +/- 20% Mannings roughness and 50% blockage of hydraulic structures. The model was shown to be relatively insensitive to these parameters, with increases and decreases in catchment roughness or blockage having limited impact on the extent of flooding.

Flood results were mapped, including peak flood depth, peak flood level, peak velocity, peak velocity-depth product, peak hydraulic hazard and peak hydraulic risk. A classification of 'riverine' versus 'overland' flooding was undertaken for the 1% AEP event. These outputs inform the flood component of Gladstone Regional Council's planning scheme.

12. REFERENCES

1. Engeny Water Management
   Agnes Water Flood Mitigation Project
   Report for Gladstone Regional Council, 2015

2. Natural Resources and Water
   Queensland Urban Drainage Manual
   Queensland Government, Volume 1, Second Edition, 2007

3. Pilgrim DH (Editor in Chief)
   Australian Rainfall and Runoff – A Guide to Flood Estimation
   Institution of Engineers, Australia, 1987.

4. Bureau of Meteorology IFD website
   http://www.bom.gov.au/water/designRainfalls/revised-ifd/ (accessed 23/09/2024)

5. Bureau of Meteorology
   The Estimation of Probably Maximum Precipitation in Australia: Generalised Short Duration Method, June 2003

6. Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors)
   Australian Rainfall and Runoff: A Guide to Flood Estimation
   Version 4.2, Commonwealth of Australia, Australia, 2019

7. Gladstone Regional Council
   Coastal Hazard Adaptation Strategy Phase 3 - 8
   Phase 3 Summary Report
   Prepared by Alluvium, NCE and JBP for Gladstone Regional Council, September 2020

8. Cox Andrews Engineers Pty Ltd
   Agnes Creek Drainage Report
   Prepared for Gladstone Regional Council, 2003

9. URS Australia Pty Ltd
   Concept Flood Storage and Conveyance Improvement Assessment at Agnes Water
   Prepared for Gladstone Regional Council, 2008

10. The State of Queensland (Department of Transport and Main Roads),
    Queensland Tide Tables Standard Port Tide Times 2025, 2024

11. Gladstone Regional Council
    Our Coast. Our Future Strategic Plan FINAL

12. Commonwealth of Australia
Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia
AIDR 2017

13. The University of Adelaide
Revision Project 18: Coincidence Of Fluvial Flooding Events and Coastal Water Levels in Estuarine Areas.
Report for Engineers Australia, 2014

Figures

Appendix A

APPENDIX A. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power.

redevelopment: refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.

disaster plan (DISPLAN) A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies.

discharge The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).

ecologically sustainable development (ESD) Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.

effective warning time The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.

emergency management A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.

flash flooding Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.

flood Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.

flood awareness Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.

flood education Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.

flood fringe areas The remaining area of flood prone land after floodway and flood storage areas have been defined.

flood liable land Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).

flood mitigation standard

	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammetic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL=s are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the Astandard flood event@ in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood

storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.

floodway areas Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.

freeboard Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.

habitable room **in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.

in an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.

hazard A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.

hydraulics Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity.

hydrograph A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.

hydrology Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.

local overland flooding Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.

local drainage Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.

mainstream flooding Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.

major drainage Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:

- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or

- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or

- major overland flow paths through developed areas outside of defined drainage reserves; and/or
- the potential to affect a number of buildings along the major flow path.

mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State=s rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.
modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.

probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to Awater level@. Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

APPENDIX B. VALIDATION EVENT MAPPING

Appendix C

APPENDIX C. DESIGN EVENT MAPPING

Appendix D

APPENDIX D. SENSITIVITY ASSESSMENT MAPPING

Appendix E

APPENDIX E. RIVERINE & OVERLAND FLOW