Ballina Shire Council

Ballina Island and West Ballina Overland Flow Flood Study Final Overland Flood Study Report and Mapping (Exhibition Version)

November 2020

Executive summary

GHD was commissioned by Ballina Shire Council (BSC) to undertake the Ballina Island and West Ballina Flood Overland Flood Study and Flood Protection Feasibility Study and Plan.

The general scope of work for this project includes the following stages:

- Stage 1: Data collection and survey of existing stormwater network system in Ballina Island and West Ballina.
- Stage 2: Development of an overland flow path model of the Ballina Island and West Ballina catchments to identify flooding hotspots and issues associated with overland flow flood inundation.
- Stage 3: Assessment of suitable structural and non-structural flood mitigation options aimed at mitigating flooding issues resulting from overland, creek and riverine flooding in Ballina Island and West Ballina.
- Stage 4: Development of a Strategic Plan of Flood Protection.

The purpose of this report is to provide a detailed description of the activities completed as part of Stage 2 of the project (the Overland Flood Study) which included:

- Collection and review of the available data.
- Development of a direct rainfall (rain-on-grid) overland flow path model of Ballina Island and West Ballina inclusive of the existing stormwater network system.
- Simulation of the 0.2%, 1%, 2%, 5%, 10%, 20% and 50% AEP design flood events in accordance with ARR 2019 guidelines. This has included simulation of ten (10) temporal patterns for each storm duration.
- Simulation of year 2100 RCP 8.5 climate change scenario.
- Post-processing of overland flow path model results for each design storm event in accordance with the procedure outlined in ARR 2019 guidelines.
- Sensitivity testing of the overland flow path model against the following items:
  - Tide level conditions, including HAT, MHWS and MLWS tide levels;
  - 100% blockage of the stormwater network system;
  - 20% increase in Manning's n coefficients throughout the catchment;
  - Initial and continuing rainfall loss values of 0 mm and 0.0 mm/hr, respectively;
  - Coincidental occurrence of 1% AEP local rainfall event and 1% AEP storm tide.
- Identification of overland flow flooding hotspots and problem drainage areas.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.4 and the assumptions and qualifications contained throughout the Report.

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Abbreviations

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
AHD	Australian Height Datum
ARF	Areal Reduction Factor
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
BSC	Ballina Shire Council
CL	Continuing rainfall loss
DEM	Digital Elevation Model
FMRS	Ballina's Flood Risk Management Study
GIS	Geographic Information System
HAT	Highest Astronomical Tide
HPC	High-Performance Computing
IFD	Intensity-Frequency-Duration data
IL	Initial rainfall loss
LAT	Low Astronomical Tide
LGA	Local Government Area
LiDAR	Light Detection And Ranging survey technique
MHWN	Mean High Water Neap tide level
MHWS	Mean High Water Spring tide level
MLWN	Mean Low Water Neap tide level
MLWS	Mean Low Water Spring tide level
PMF	Probable Maximum Flood
RCP	Representative Concentration Pathway (gas emission scenario)
SGS	Sub-Grid Sampling method
SLR	Sea Level Rise
SWE	Shallow Water Equations
TUFLOW	Hydrodynamic modelling software
XP-RAFTS	Rainfall-runoff modelling software
WBNM	Rainfall-runoff modelling software
2D	Two-dimensional
1D	One-dimensional

1. Introduction

1.1 Background

GHD was commissioned by Ballina Shire Council (BSC) to undertake the Ballina Island and West Ballina Flood Overland Flood Study and Flood Protection Feasibility Study and Plan.

The general scope of work for this project includes the following stages:

- Stage 1: Data collection and survey of existing stormwater network system in Ballina Island and West Ballina.
- Stage 2: Development of an overland flow path model of the Ballina Island and West Ballina catchments to identify flooding hotspots and issues associated with overland flow flood inundation.
- Stage 3: Assessment of suitable structural and non-structural flood mitigation options aimed at mitigating flooding issues resulting from overland, creek and riverine flooding in Ballina Island and West Ballina.
- Stage 4: Development of a Strategic Plan of Flood Protection.

Stage 1 of Ballina Island and West Ballina Flood Study of the project has already been completed. This report focuses on Stage 2 of the project.

1.2 Scope of work – Stage 2

The Ballina Island and West Ballina Overland Flood Study includes the following activities:

- Collection and review of available data.
- Development of an overland flow path model of Ballina Island and West Ballina local catchments using a “direct rainfall” (rain-on-grid) flood modelling approach.
- Simulation of design flood events using the overland flow path model, and
- Flood inundation mapping of overland flow paths in Ballina Island and West Ballina.
- Sensitivity testing of the model against different tide level conditions, model parameters (Manning’s n roughness coefficients and rainfall losses), 100% blockage of stormwater network system, and coincidental occurrence of 1% AEP local rainfall event and 1% AEP storm tide.
- Identify a series of flooding hotspots caused by overland flow flood inundation resulting from local rainfall events.
- Preliminary identification of potential mitigation measures aimed at reducing the adverse impacts of overland flow path flood inundation in Ballina Island and West Ballina.

1.3 Purpose of this report

The purpose of this report is to provide a detailed description of the activities completed in Stage 2 of the Ballina Island and West Ballina Flood Study project.

This report provides a summary of following items:

- Data collection and review;
- Setup of the Ballina Island and West Ballina overland flow path model;
- Setup and results of design event simulations;

- Setup and results of year 2100 RCP 8.5 climate change scenario;
- Results of the sensitivity tests carried out on the overland flow path model;
- Identification of flooding hotspots within Ballina Island and West Ballina;
- Preliminary identification of overland flow flood inundation mitigation measures.

1.4 Assumptions and limitations

The project activities completed to inform this report been carried out according to the following assumptions:

- The integrated regional (riverine and creek) flood model provided by BSC was used to establish the storm tide level conditions applied in the overland flow path modelling sensitivity analysis. The integrated regional model was considered suitable for use in this regard. No independent verification and review of the integrated regional model was carried out by GHD at this stage.
- The stormwater network included in the overland flow path hydraulic model is based on Council's GIS stormwater network database and Abbott & MACRO survey. Assumptions have been made on pipe invert levels and pipe diameters where those data were not available in either Council's GIS database or Abbott & MACRO survey.

1.5 Disclaimer

This report has been prepared by GHD for Ballina Shire Council and may only be used and relied on by Ballina Shire Council for the purpose agreed between GHD and the Ballina Shire Council as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Ballina Shire Council arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

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2. Methodology & Data

2.1 Methodology overview

The methodology adopted in the Ballina Island and West Ballina Overland Flow Flood Study can be summarised as follows:

- All the available data has been collated and reviewed in order to assess the integrity, quality and reliability of the data. The data made available to GHD by BSC included:
  - Previous regional flood studies and models commissioned by BSC, such as the regional flood model developed as part of Ballina's Flood Risk Management Study (FMRS) and the integrated regional model;
  - Council's GIS stormwater network database;
  - Survey of Council's stormwater network by Abbott & MACRO surveyors.
- A meeting with Abbott & MACRO surveyors was held to facilitate the inclusion of the updated survey data into GHD's local flood model.
- An overland flow path model of Ballina Island and West Ballina including the stormwater network system have been developed using a "direct rainfall" flood modelling approach.
- Design event simulations have been run for the 0.2%, 1%, 2%, 5%, 10%, 20% and 50% AEP design flood events by adopting rainfall durations from 15 minutes to 12 hours and ten (10) temporal patterns for each rainfall duration, in accordance with ARR 2019 guidelines. A comprehensive approach featuring the setup, run, post-processing and analysis of over 750 TUFLOW simulations has been adopted in order to assess the existing baseline overland flow flooding conditions in Ballina Island and West Ballina.
- The flood grids resulting from the design event simulations have been post-processed according to the procedure outlined in ARR 2019 guidelines.
- Simulations of year 2100 RCP 8.5 climate change scenario have been performed for the 0.2%, 1% and 5% AEP design flood events.
- A series of sensitivity tests have also been carried out as follows:
  - Sensitivity tests on tide level conditions featuring the application of HAT, MHWS and MLWS tide levels along the model's ocean boundary have been carried out to identify the areas of West Ballina and Ballina Island more sensitive to the variations in tide levels.
  - Sensitivity tests on the blockage of the stormwater network have been carried out to assess the role played by the stormwater network efficiency on the flood levels in West Ballina and Ballina Island.
  - Sensitivity tests on model parameters, including Manning's n coefficients and rainfall losses, have been carried out to assess the changes in flood levels associated to different model parameters.
  - Coincidental occurrence of 1% AEP local rainfall event and 1% AEP storm tide.
- The overland flow path model results have been used to identify a series of flooding hotspots generated by local storm events.
- A preliminary identification of potential flood mitigation options aimed at mitigating local overland flow flooding issues has been undertaken to inform the next phase of the project.

2.2 Data collection and review

2.2.1 Previous flood studies & models

A number of previous flood studies have been completed to assess riverine and creek flooding in the Richmond River catchment. A summary of these is provided below. Aside from some localised one-dimensional modelling of stormwater networks, a comprehensive assessment of overland flow within Ballina Island and West Ballina has not been previously undertaken.

Ballina Flood Study (2008)

The regional model including the Richmond River, North Creek and tributaries catchments was originally developed in 2008 as part of the Ballina Flood Study (BSC, 2008).

The regional model was developed using a hydrologic-hydraulic modelling approach, featuring the development of the following models:

- An XP-RAFTS hydrologic model of the Richmond River, North Creek and tributaries catchments;
- A 1D/2D TUFLOW model of the lower Richmond River, North Creek and tributaries catchments, including Ballina Island and West Ballina.

The regional model was calibrated against three historical flood events, namely the March 1974, February 1976 and June 2005 flood events. Design flood event simulations were performed for the 5, 20, 50, 100, and 500-year ARI events and the probable maximum flood (PMF) according to the ARR 1987 guidelines.

As part of the 2008 Ballina Flood Study, the regional model was also used to investigate a series of mitigation options aimed at mitigating the flood issues resulting from the inundation of Ballina Island and West Ballina due to regional flood events from Richmond River and creeks, and inundation from storm tide.

Please refer to BSC (2008) for a detailed description of the 2008 regional model setup, results and outcomes from 2008 Ballina Flood Study.

Ballina's Flood Risk Management Study - FRMS (2012)

The regional model developed as part of the 2008 Ballina Flood Study (BSC, 2008) was used as a base to develop Ballina's Flood Risk Management Study (FRMS 2012a,b).

The FRMS was developed in 2012, and includes an assessment of the regional flood issues affecting BSC's LGA. Regional modelling of the lower Richmond River, Maguire Creek, Emigrant Creek, and North Creek was carried out using a traditional hydrology-hydraulic approach, featuring the development of a WBNM hydrologic model and a TUFLOW 2D hydraulic model.

Ballina's FRMS regional model was calibrated against the 2009, 2008 and 1974 historical flood events. The design flood event simulations in Ballina's FRMS were setup according to the ARR 1987 guidelines.

The FMRS regional model was used by BSC to set the minimum floor levels throughout Ballina.

The model files, post-processed results and associated reports produced as part of Ballina's FRMS have been made available to GHD from BSC.

Please refer to FRMS (2012a,b) for a detailed description of Ballina's FRMS regional model setup and outcomes.

The integrated regional model

BSC's integrated regional model consists of an update of the FRMS regional model, featuring the integration between FMRS regional model and the North Creek hydraulic model.

The integrated regional model is a work-in-progress model, which is continuously updated and changing at the time of writing.

The integrated regional model will be used to run the regional (riverine and creek) model simulations in the future stages of the Ballina Island and West Ballina Flood Overland Flood Study and Flood Protection Feasibility Study and Plan.

2.2.2 Data overview

The data collected and used in the present study are summarised in Table 2-1.

Table 2-1 Summary of the data adopted in this study

Data	Source	Access date
0.6 m grid DEM of West Ballina and Ballina Island produced from 2017 LiDAR data • Reference system: GDA94/MGA zone 56 • Surveyed by from Atlass	Provided by BSC	27/11/2019
1 m grid DEM of the coast including Ballina produced from 2010 LiDAR Data: • Date of acquisition: June 2010 • Reference system: GDA94/MGA zone 56 • Horizontal spatial accuracy: 0.8 m • Vertical spatial accuracy: 0.3 m • Surveyed by Land & Property Information	Provided by BSC	27/11/2019
2.5 m grid DEM of the bathymetry of the Richmond River, Emigrant Creek, Fishery Creek and North Creek	Sourced from the integrated regional model provided by BSC	27/11/2019
Council's GIS stormwater network database: • Used to setup the baseline geometry of the 1D stormwater network in the model • Used as a reference for pipe diameters, invert levels and pit locations where no data were surveyed by Abbott & MACRO	Provided by BSC	From 14/06/2019 to 4/08/2020
Survey of pipe diameters, invert levels and pit location • Used to setup the 1D stormwater network in the model	Provided by Abbott & MACRO Land and Engineering Surveyors	1/07/2020
Rainfall depths from 2016 Intensity-Frequency-Duration (IFD) data • Coordinates: -28.864 lat, 153.55 long	Bureau of Meteorology (BoM) website: http://www.bom.gov.au/water/designRainfalls/revised-ifd/	26/06/2020
Rainfall temporal patterns	ARR 2019 Data Hub: https://data.arr-software.org/	26/06/2020
Climate change factors	ARR 2019 Data Hub: https://data.arr-software.org/	26/06/2020
Rainfall losses	Sourced from 2008 Ballina Flood Study (BSC, 2008)	-

Data	Source	Access date
Tidal planes at Richmond River inlet: • HAT: 1.11 mAHD • MWHS: 0.61 mAHD • MHWN: 0.31 mAHD • MLWN: -0.29 mAHD • MLWS: -0.59 mAHD • LAT: -0.79 mAHD	Sourced from 2008 Ballina Flood Study (BSC, 2008)	-
Sea level rise projections for Year 2100	NSW Sea Level Rise Policy Statement (DCCW, 2009) BSC Climate Action Strategy 2012-2020 (BSC, 2011)	-
Floor level survey of Ballina, including: • 2,844 residential buildings: – 1,073 from 1979 survey – 1,743 from 2009 survey – 8 assumed from 1979 survey – 20 assumed from 2009 survey • 376 commercial buildings: – 164 from 1979 survey – 211 from 2009 survey – 1 assumed	Provided by BSC	10/09/2019

3. Overland Flow Path Model Setup

3.1 General approach & methodology

A hydraulic model of the Ballina Island and West Ballina local catchment has been developed using a rain-on-grid approach (also known as "direct rainfall" approach).

In rain-on-grid models, rainfall hyetographs are applied directly on the computational grid of the hydrodynamic model and the flow paths are automatically computed by the numerical solver on the basis of the specific catchment characteristics, such as the catchment shape, flow path slopes, land-use and establishing flow conditions, among others.

The general model setup is shown in Figure A1, Appendix A.

3.2 Software

The Ballina Island and West Ballina overland flow model has been developed using the TUFLOW HPC software package. TUFLOW solves the Shallow Water Equations (SWE) using a finite volume numerical technique on the central nodes of a fixed grid, which is used to schematise the area of interest.

The numerical simulations have been carried out using the TUFLOW HPC solver, 2020-01-AB release.

3.3 Model extent and boundaries

The model includes West Ballina and Ballina Island, as well as a portion of the Richmond River, Emigrant Creek, Fishery Creek and North Creek. The hydraulic model boundary is shown in Figure A1, Appendix A.

3.4 Grid cell size

The Ballina Island and West Ballina local catchment has been schematised by adopting a 3 m grid cell size. The adopted grid cell size is considered suitable to properly represent all the key morphological features and land use of the study area, with no significant adverse effects on the model simulation runtime.

3.5 Topography

3.5.1 Digital Elevation Model (DEM)

The Digital Elevation Model (DEM) has been provided by Council through the provision of the FMRS and integrated regional models. The DEM has been built starting from the following data:

- 2017 LiDAR survey of Ballina Island and West Ballina supplied as original LiDAR data survey and as post-processed 0.6 m grid DEM. This LiDAR data survey was undertaken in 2017 by Atlass.
- 2010 LiDAR survey of Ballina covering the lower Richmond River, Emigrant Creek, Fishery Creek and North Creek valleys supplied as original LiDAR data survey and as post-processed 1 m grid DEM. This LiDAR survey was undertaken by Land and Property Information in June 2010. The 2010 LiDAR survey has been adopted to represent the ground elevations in the land areas not covered by the 2017 LiDAR survey.
- The bathymetry of the Richmond River, Emigrant Creek, Fishery Creek and North Creek have been sourced from the integrated regional model, and provided as a 2.5 m grid DEM.

The DEM used in the present study is the same included in the integrated regional model for the representation of Ballina Island, West Ballina and adjacent watercourses. The adopted DEM is shown in Figure A2, Appendix A.

3.5.2 Sub-Grid Sampling (SGS) method and topography modifications

The TUFLOW SGS method has been applied to run all the rain-on-grid simulations for the West Ballina and Ballina Island local catchment.

The use of the SGS method is an alternative to the enhancements of road and gullies using z-shapes, and produces better flood definition in comparison with the adoption of z-shape polylines.

3.6 Manning's roughness coefficients

The Manning's n roughness coefficients adopted in this study have been initially sourced from the regional integrated model, which was calibrated against a series of historical flood events (please refer to Section 3.1 for additional information on the regional model calibration).

The Manning's n coefficients of the urban and industrial/commercial areas within Ballina Island and West Ballina have been adjusted to suit the overland flow model using a rain-on-grid approach by adopting depth-varying Manning's n roughness coefficients. The adopted Manning's n representation is as follows:

- Constant Manning's n values have been adopted to represent the surfaces and land-use classes that do not exhibit a significant variability of roughness with increasing flood depths. A list of the surface classes together with the adopted constant Manning's n values is shown in Table 3-1. The Manning's n coefficients shown in Table 3-1 are consistent with the industry standard values.

Table 3-1 **Adopted Manning's n values (constant values)**

Description	Manning's n
Pasture	0.060
Roads	0.025
Sealed storage areas/open concretes and roads/urban open space	0.050
Building	0.050
Cane	0.150
Dams, open water, bare soil	0.030
River Bed - Richmond River, Goat Island	0.020
Creek Bed (middle of creek) - North Creek - Missingham to North Ck Rd	0.020
Creek Bed (middle of creek) - Emigrant Ck - Richmond to Twin Bridges	0.020
Grass (maintained)	0.035
Medium density vegetation	0.100
Dense Vegetation	0.120

- Depth-varying Manning's n values have been adopted to represent the gardens/backyards of the residential and industrial areas to provide a more realistic simulation of the hydraulic behaviour in urban areas. In these areas, the roughness coefficients varies as follows:
  – For flood depths between 0 and 20 mm, the Manning's n is a constant high value (i.e., rough surface). These high values take into consideration the obstacles, such as grass, fences, landscaping, etc., encountered by very shallow water depths when propagating through gardens and backyards.

– For flood depths above 50 mm, the Manning's n is a constant typical value adopted to represent gardens and backyard.
– For flood depths between 20 and 50 mm, the Manning's n value is linearly interpolated between the first (i.e. high value) and second (i.e., typical value) values described above. This approach is adopted to avoid any abrupt changes in roughness coefficients along the water depth.

The depth-varying Manning's n adopted to represent the residential and industrial areas are summarised in Table 3-2.

Table 3-2 **Adopted Manning's n values (depth**-varying values)

Description	Manning's n (Flood depths < 0.02 m)	Manning's n (Flood depths > 0.05 m)
Low density urban block	0.20	0.10
Medium density urban block	0.50	0.20
Commercial/Industrial	0.50	0.20

A map showing the Manning's n coefficient values assigned to each land-use class is contained in Figure A3, Appendix A. The Manning's n roughness coefficients map shown in Figure A3, Appendix A, represents the current land-use conditions within the Ballina Island and West Ballina local catchment, and has been adopted to run the design event simulations.

3.7 Stormwater network representation

3.7.1 General approach

The stormwater network has been represented in the West Ballina and Ballina Island catchments using a mixed approach as follows:

- The stormwater main trunks and cross-drainage structures have been represented as 1D network elements. A detailed description of the methodology adopted to model the main stormwater trunks is provided in Section 3.7.2.
- The remaining "minor" stormwater network has been represented as Virtual Pipes. A detailed description of the methodology adopted to model the minor stormwater system is provided in Section 3.7.3.

The stormwater network included in the model is shown in Figure A4, Appendix A.

3.7.2 Trunk stormwater system

The trunk stormwater network has been sourced from Council's GIS database and updated including the Abbott & MACRO stormwater network survey of pipe diameters and invert levels. The trunk stormwater network has been extracted from Council's database on the basis of the following general rules:

- Pipes characterised by a diameter greater than 400 mm have been retained as part of the trunk stormwater system.
- All the pipes discharging directly into the river and creeks have been retained as part of the trunk stormwater system in order to model and assess the flooding issues associated to the backwater effects induced by higher tide levels.

The trunk stormwater system has been represented as a series of 1D pit & pipe features dynamically linked to the 2D hydrodynamic model domain. In the trunk stormwater system, the 1D pits are dynamically linked to the 1D pipes, and the flows captured by the pits are conveyed into the river and creeks through the pipes.

The 1D pits of the trunk stormwater system have been included in the overland flow path model according to the following approach:

- A rectangular type “R” attribute has been assigned to the pits classified as “grated pits” according to Abbott & MACRO’s survey of the stormwater network. In this case, the flows captured by the pit are automatically calculated by TUFLOW on the basis of the pit size, geometry and adjacent terrain topography, with no rating curve assigned a priori by the modeller.
- A weir type “W” attribute has been assigned to the pits classified as “side entry pits” according to Abbott & MACRO’s survey of the stormwater network. In this case, the flows captured by the pit are automatically calculated by TUFLOW on the basis of the pit size, geometry and adjacent terrain topography, with no rating curve assigned a priori by the modeller.
- A blockage factor of 100% has been applied to the pits flagged as “pit blocked” in the Abbott & MACRO’s stormwater network survey.

Where data was lacking or not included in the Abbott & MACRO’s stormwater network survey, the following assumptions have been adopted to represent the trunk stormwater network in the model:

- Where pipe diameters data was lacking in the Abbott & MACRO’s survey, assumptions have been made according to the following approach:
  - Pipe diameters have been sourced from Council’s GIS database;
  - Where no pipe diameters data was available in Council’s GIS database, engineering judgement has been applied to estimate the pipe diameters by comparison with nearby pipes.
- The pits characterised by no classification in the Abbott & MACRO’s survey have been assumed to be “side entry pits” and, therefore, assigned type “W” attribute. This assumption was supported by a series of spot checks performed on several pit locations using Google Street View.
- Where the pit size was lacking, an average size of 600x600mm have been assigned to the grated pits characterised by “R” attribute.
- Where the pit size was lacking, an average lintel length of 1 m has been assigned to the side entry pits characterised by “W” attribute.

3.7.3 Minor stormwater system

The remaining stormwater network has been represented as Virtual Pipes. In the Virtual Pipes method, each inlet pit is represented by a “sink” that extracts a pre-specified flow from the 2D grid surface through the application of a predefined rating curve. These pits are characterised by a type “Q” attribute, and are statically linked to the 2D hydrodynamic model domain.

The minor stormwater system has been included in the overland flow path model according to the following procedure:

- The minor stormwater network system was not included in the Abbott & MACRO’s survey, therefore, Council’s GIS stormwater network database was adopted as a reference for the location and classification of the pits.
- Following Council’s GIS database classification, the inlet pits have been divided into three categories: kerb inlet (K), drop inlet (D) and surface inlet (S).

Different rating curves have been estimated and assigned to each inlet category as shown in Figure 3-1. The rating curves have been estimated by assuming the following average pit sizes:

- A lintel length of 1 m for kerb inlets;
- A size of 900x900mm for drop inlets;
- A size of 900x600mm for surface inlets.

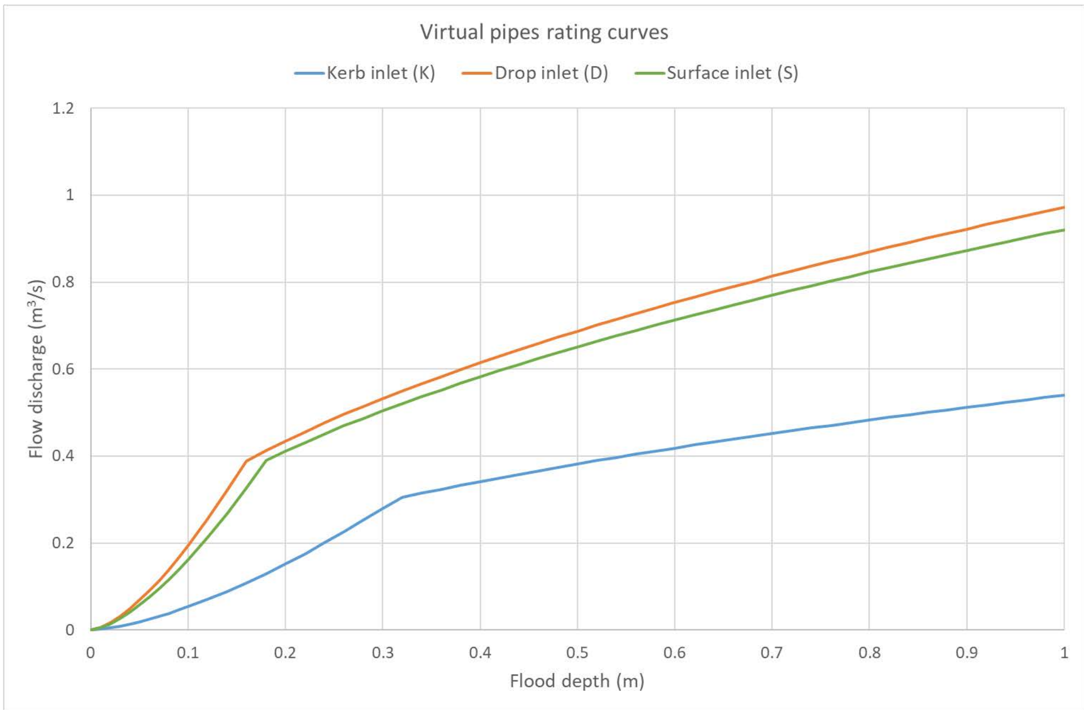


Figure 3-1 Rating curves assigned to the virtual pipes

4. Design Event Simulations

4.1 Simulation setup

4.1.1 AEP events and rainfall durations

The design event simulations have been performed for the 50%, 20%, 10%, 5%, 2% 1%, 0.2% AEP events.

In the present study, a series of rainfall durations spanning from 15 minutes to 12 hours have been simulated in order to identify the critical storm durations.

A set of ten (10) different temporal patterns have been run for each rainfall duration, according to the procedure outlined in the ARR 2019 guidelines.

4.1.2 Rainfall spatial distribution

A homogeneous spatial distribution of rainfall above Ballina Island and West Ballina featuring the application of the design rainfall depths and temporal patterns extracted at the local catchment centroid has been adopted in the present study.

A detailed description of the derivation of the design rainfall hyetographs applied above Ballina Island and West Ballina is provided in Section 4.2.

4.1.3 Upstream boundary conditions

A series of steady state inflows mimicking nominal river and creek baseflow conditions have been applied at the upstream boundaries of the model along the Richmond River and creeks. An overview of the applied upstream boundary conditions is provided in Table 4-1.

Table 4-1 Baseflows applied as upstream boundary conditions

Watercourse	Baseflow (m^3/s)
Richmond River	50
Emigrant Creek	10
Fishery Creek	1.5
North Creek	50

4.1.4 Downstream boundary conditions

The downstream boundary conditions of the model consist of tide levels applied along the ocean boundary of the model.

In the baseline design event simulations, a mean high water spring (MHWS) tide level value of 0.61 mAHD have been applied as constant tide level along the downstream boundary of the hydraulic model.

In addition, GHD performed a series of sensitivity tests featuring the application of mean low water spring (MLWS) tide, high astronomical tide (HAT) and 1% AEP storm tide levels as downstream boundary conditions. Please refer to Section 6 for a detailed description of the sensitivity tests on the tide level conditions, and the coincidental occurrence of local rainfall and storm tide events.

4.2 Estimation of design rainfall hyetographs

4.2.1 Design rainfall depths

Design rainfall depths have been downloaded from the BoM website for all the analysed storm durations and AEP events. The rainfall depths have been estimated using the 2016 IFD curves produced by BoM according to the procedure outlined in the ARR 2019 guidelines.

The rainfall depths downloaded from the BoM website and adopted in the present study are provided in Table 4-2. The rainfall depths shown in Table 4-2 have been extracted at the centroid of the Ballina Island and West Ballina local catchment.

Table 4-2 Design rainfall depths (mm) – 2016 IFDs - BoM website

Rainfall duration	AEP event						
	50%	20%	10%	5%	2%	1%	0.2%
15 min	20.7	27.3	31.7	35.9	41.3	45.2	54.1
30 min	28.9	38.2	44.4	50.4	58.1	64.0	76.7
45 min	34.2	45.3	52.9	60.2	70.0	77.4	93.0
1 hr	38.2	50.9	59.6	68.1	79.6	88.5	106.0
1.5 hr	44.4	59.7	70.4	80.9	95.5	107.0	129.0
2 hr	49.4	67.0	79.3	91.7	109.0	123.0	147.0
3 hr	57.6	79.0	94.3	110.0	132.0	149.0	179.0
4.5 hr	67.5	93.8	113.0	133.0	160.0	182.0	217.0
6 hr	75.9	106.0	129.0	152.0	184.0	209.0	249.0
9 hr	90.2	128.0	155.0	184.0	223.0	254.0	302.0
12 hr	102.0	146.0	177.0	211.0	254.0	290.0	344.0

4.2.2 Temporal patterns

Ten temporal patterns per each rainfall duration have been run in the overland flow path model to identify the critical storms within the Ballina Island and West Ballina local catchment in accordance with ARR 2019 guidelines.

The temporal patterns have been extracted at the Ballina Island and West Ballina local catchment centroid and downloaded from the ARR 2019 data hub. The temporal patterns downloaded from the ARR 2019 data hub are classified in three categories: frequent, intermediate, rare. The temporal pattern classification has been applied to each AEP event as summarised in Table 4-3.

Table 4-3 Temporal patterns assigned to all AEP events up to 1% AEP

AEP event	ARI event	Temporal pattern classification
50%	2 years	Frequent
20%	5 years	Frequent
10%	10 years	Frequent
5%	20 years	Intermediate
2%	50 years	Intermediate
1%	100 years	Rare
0.2%	500 years	Rare

4.2.3 Areal reduction factors (ARFs)

ARR 2019 guidelines recommend the adoption of Areal Reduction Factors (ARFs) for catchments larger than 1 km^2. The areal reduction factors aim at adjusting the rainfall distribution on the basis of the catchment size.

ARFs have been calculated for each AEP and rainfall duration according to the procedure outlined in ARR 2019 Data Hub for short durations (i.e., durations shorter than 12 hours).

The adopted ARFs values in the West Ballina and Ballina Island catchment are provided in Table 4-4 below.

Table 4-4 Adopted ARFs

Rainfall duration	0.2% AEP	1% AEP	2% AEP	5% AEP	10% AEP	20% AEP	50% AEP
15 min	0.8682	0.8776	0.8817	0.8871	0.8912	0.8952	0.9006
30 min	0.9065	0.9173	0.9219	0.9281	0.9327	0.9374	0.9435
45 min	0.9232	0.9353	0.9405	0.9474	0.9526	0.9578	0.9647
1 hr	0.9330	0.9463	0.9521	0.9597	0.9654	0.9712	0.9788
1.5 hr	0.9441	0.9598	0.9666	0.9756	0.9823	0.9891	0.9981
2 hr	0.9504	0.9681	0.9758	0.9859	0.9935	1.0000	1.0000
3 hr	0.9580	0.9777	0.9862	0.9974	1.0000	1.0000	1.0000
4.5 hr	0.9671	0.9834	0.9905	0.9998	1.0000	1.0000	1.0000
6 hr	0.9748	0.9850	0.9894	0.9952	0.9996	1.0000	1.0000

4.2.4 Initial and continuing rainfall losses

ARR 2019 guidelines and NSW Flood Risk Management Guide recommend adopting site-specific calibrated initial (IL) and continuing (CL) in lieu of the values suggested by ARR 2019 Data Hub when available.

The IL and CL values adopted in the present study were sourced from the 2008 Ballina Flood Study report (BSC, 2008). The 2008 Ballina Flood Study models were calibrated against the following three historical events:

- March 1974 flood event;
- February 1976 flood event;
- June 2005 flood event.

The calibrated storm burst IL and CL values adopted in the 2008 Ballina Flood Study models are provided in Table 4-5.

Table 4-5 Calibrated IL and CL values adopted in 2008 Ballina Flood Study models

Loss	Pervious surfaces (rural areas)	Impervious surfaces
Initial loss (storm burst)	25 mm	0 mm
Continuing loss	2.5 mm/hr	0.0 mm/hr

The Ballina Island and West Ballina local catchments are strongly urbanised, with urban blocks mostly characterised by medium and low density residential land-uses. For this reason, the IL and CL values shown in Table 4-5 have been adjusted to derive more suitable values representing the low, medium and high density residential land-uses by interpolating between the values for rural areas and impervious areas.

The derived IL and CL values which have been adopted in the present study are provided in Table 4-6 below.

Table 4-6 IL and CL values adopted in the present study

Loss	Pervious surfaces	Low density urban block	Medium density urban block	High density urban block	Impervious surfaces
Initial loss (storm burst)	25 mm	19 mm	13 mm	7 mm	0.0 mm
Continuing loss	2.5 mm/hr	1.9 mm/hr	1.3 mm/hr	0.7 mm/hr	0.0 mm/hr

An IL value of 0.0 mm and a CL value of 0.0 mm/hr have been adopted for the 0.2% AEP design event because of the “very rare” nature of such event.

Sensitivity tests featuring the application of IL = 0.0 mm and CL = 0.0 mm/hr have also been carried out to test the changes in flood level resulting from the application of different IL and CL model parameters. Please refer to Section 6 for a detailed description of the sensitivity test methodology and results.

5. Modelling Results

5.1 Post-processing of the results and mapping

5.1.1 Maximum of median peak grids

Overland flow flood inundation maps have been produced by selecting the maximum of the median peak values for flood depth, level, flow velocity and flood hazard grids, in accordance with the procedure outlined by the ARR 2019 guidelines. For each AEP event, this includes statistical analysis of the model results in each grid cell for the full range of storm durations assessed.

5.1.2 Filtering of the rain-on-grid results

Due to the nature of direct rainfall (rain-on-grid) model results, a filtering process has been applied to the raw rain-on-grid modelling results to discern the more significant flood depths from very shallow sheet flows.

The model results have been filtered in three steps according to the following procedure:

- Step #1: The results are retained in cells where at least one of the following conditions is satisfied:
  - Depth ≥ 0.05 m, or
  - Depth-velocity product ≥ 0.01 m^2/s
- Step #2: In the grids obtained from Step #1, the results are retained in cells where the following condition is satisfied:
  - Pond areas > 500 m^2

5.1.3 Flood depth, level and flow velocity maps

The filtered maps of flood depths, levels, and flow velocities for the analysed AEP events are provided in Appendix B.

5.2 Flood hazard

The filtered maps of flood hazards for the analysed AEP events are provided in Appendix C.

Flood hazard maps have been prepared in accordance with the flood hazard vulnerability thresholds provided in *Australian Disaster Resilience Handbook 7 Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia* (AIDR 2017).

Figure 5-1 illustrates the AIDR flood hazard vulnerability thresholds.

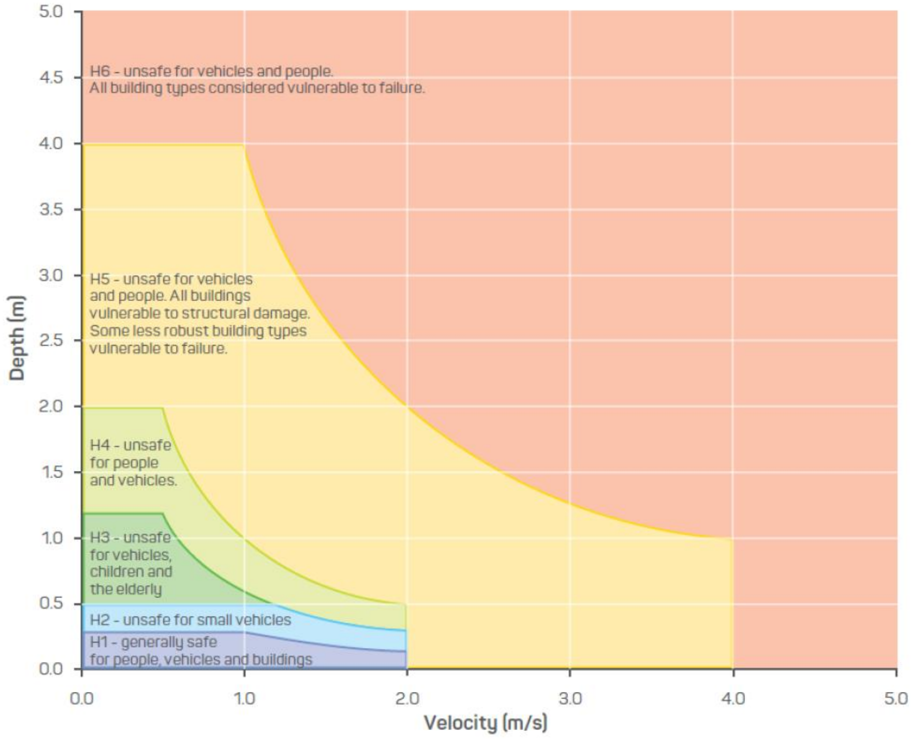


Figure 5-1 Flood hazard classification according to AIDR (2017)

5.3 Flood function

According to AIDR (2017) guidelines, a floodplain can be classified in areas such as flood conveyance, flood storage and flood fringe. The flood function classification is particularly meaningful when considering flooding issues induced by creek and riverine systems.

The flood function classification is deemed by GHD to be not applicable to the overland flow flooding in Ballina Island and West Ballina, given the relatively small flood depths, extent and general nature of overland flow flooding.

It is recommended to perform the flood function classification when considering regional flooding events from the Richmond River and creeks in the future stages of this project.

5.4 Climate change

The potential impacts of a future climate change scenario on existing flood conditions has been assessed by adopting the climate change projections for year 2100 gas emission scenario RCP 8.5.

The climate change simulations have been setup in order to assess the flood extent and levels resulting from the following scenarios:

- Increase in rainfall intensity of local rainfall events on Ballina Island and West Ballina, associated to Mean High Water Spring (MHWS) tide levels increased by Sea Level Rise (SLR).
- MHWS tide and Highest Astronomical Tide (HAT) levels increased by SLR, with no local rainfall events on Ballina Island and West Ballina.

A summary of the analysed climate change scenarios is provided in Table 5-1.

Table 5-1 Summary of climate change simulation setup

Description	Climate change scenario	Analysed storm events	Increase in rainfall intensity	Tide level applied as downstream boundary condition
Increase in rainfall intensity and SLR on MHWS Tide Level	Year 2100 RCP 8.5	0.2% AEP 2h TP02 1% AEP 2h TP02 5% AEP 6h TP05	+19.7%	1.51 mAHD (MHWS tide level + SLR)
SLR on MHWS Tide Level and No Rainfall	Year 2100 RCP 8.5	No rainfall	No rainfall	1.51 mAHD (MHWS tide level + SLR)
SLR on HAT Level and No Rainfall	Year 2100 RCP 8.5	No rainfall	No rainfall	2.01 mAHD (HAT level + SLR)

The increase in rainfall intensity and SLR values have been sourced as follows:

- An increase in rainfall intensity of +19.7% has been applied to the local rainfall inflows. The adopted value has been sourced from ARR 2019 Data Hub.
- A 2100 Sea Level Rise (SLR) value of 0.9 m has been used to increase the tide levels. The SLR value has been sourced from the NSW Sea Level Rise Policy Statement (DECCW, 2009), which suggest adopting SLR values of 0.4 m and 0.9 m for 2050 and 2100 climate change projections, respectively. The DECCW (2009) recommendations are no longer prescribed by the NSW state government, however, a SLR value of 0.9 m has been adopted in the present study as this benchmark has been adopted by Council (BSC, 2011).

The flood depth, level, flow velocity, flood hazard, and changes in flood level maps resulting from the simulations of the climate change scenario are provided in Appendix D.

Please refer to Figures D5, D10 and D15, Appendix D, for the changes in flood level obtained by comparing the flood levels resulting from the climate change scenario and the baseline existing condition scenario for the 0.2%, 1% and 5% AEP local rainfall events.

6. Sensitivity Tests on Overland Model Results

6.1 Overview of the sensitivity tests

A range of sensitivity tests was undertaken to assess the sensitivity of the overland model to key model parameters and boundary conditions.

An overview of the sensitivity tests performed on the overland flow path model and key boundary conditions applied to the model is provided in Table 6-1.

A discussion on the impacts of the analysed scenarios on the existing flood conditions is provided in the following sub-sections for each sensitivity test scenario.

Table 6-1 Overview of the sensitivity tests

Test #	Sensitivity test description	Analysed local rainfall events	Tide level applied as downstream boundary condition
1	Tide levels – MLWS	0.2% AEP 2h TP02 1% AEP 2h TP02 5% AEP 6h TP05 10% AEP 6h TP05 20% AEP 4.5h TP05	-0.59 mAHD (MLWS tide level)
2	Tide levels – HAT		1.11 mAHD (HAT level)
3	Tide levels – HAT	No rainfall	1.11 mAHD (HAT level)
4	Tide levels – King Tide	No rainfall	1.29 mAHD (January 2018 King Tide level)
5	Tide levels – 1% AEP storm tide	No rainfall	2.0 mAHD (1% AEP storm tide level)
6	100% blockage of stormwater network	1% AEP 2h TP02 20% AEP 4.5h TP05 5% AEP 6h TP05 0.2% AEP 2h TP02	0.61 mAHD (MHWS tide level)
7	+20% in Manning's n roughness coefficients	1% AEP 2h TP02 20% AEP 4.5h TP05 5% AEP 6h TP05 0.2% AEP 2h TP02	0.61 mAHD (MHWS tide level)
8	IL = 0 and CL = 0 values	1% AEP 2h TP02 20% AEP 4.5h TP05 5% AEP 6h TP05	0.61 mAHD (MHWS tide level)
9	Coincidental occurrence of 1% AEP local rainfall event and 1% AEP storm tide	1% AEP 2h TP02 (local rainfall event) 1% AEP storm tide	2.0 mAHD (1% AEP storm tide level)

6.2 Tide level conditions with local rainfall events

The effects of different tide levels applied as downstream boundary conditions to the overland flow path model with coincident local rainfall events in West Ballina and Ballina Island have been investigated. These sensitivity tests aimed at assessing the changes in flood level induced by backwater effects along the stormwater pipe network and coastal inundation due to a range of different tide levels. The sensitivity tests carried out on the overland flow path model include the Mean Low Water Spring (MLWS) tide and the High Astronomical Tide (HAT) levels.

The key characteristics of the model setup for the tide level sensitivity scenarios are summarised in Table 6-1.

6.2.1 MLWS tide level and local rainfall event

The flood depth and changes in flood level maps resulting from the application of the MLWS tide level as downstream boundary condition are provided in Figures E1 to E10, Appendix E.

The key outcomes of the sensitivity test on MLWS tide level conditions can be summarised as follows:

- The application of a MLWS tide level as boundary condition produces small differences in flood levels when compared to the MHWS tide level condition for all the analysed AEP events.
- In all cases, the reductions of flood level observed when applying the MLWS tidel as boundary condition are associated to the improved conveyance of the local stormwater network.
- The most significant reductions in 1% AEP flood levels occur in the following locations:
  - Up to -99 mm along Tamar St between the intersections with Moon St and Grant St;
  - Up to -27 mm along Tamar St west of the intersection with Grant St;
  - Up to -27 mm along Crane St;
  - Up to -67 mm along Grant St between the intersections with Crane St and Tamar St;
  - Up to -29 mm along Winton Ln between the intersections with Grant St and Kerr St;
  - -14 mm along Richmond Ave;
  - Up to -22 mm at 7 Bolding St;
  - Up to -63 mm along Skinner St west of the intersection with Martin St;
  - Up to -23 mm along Martin St in proximity of the intersection with Skinner St;
  - Up to -25 mm along Riverview Ave, and at the intersection between Riverview Ave and Riverside Dr (West Ballina);
  - Up to -25 mm along Howard Cres (West Ballina);
  - Up to -23 mm along Kalinga St (West Ballina);
  - Up to -28 mm along Dolphin Dr (West Ballina);
  - Up to -50 mm at the intersection between Kalinga St and Burns Point Ferry Rd (West Ballina).
- The reductions in flood levels are minor when considering more frequent flood events. The reductions in 20% AEP flood levels can be summarised as follows:
  - Up to -84 mm along Swift St and Grant St in proximity of the intersection between these two roads (Ballina Island);
  - Up to -26 mm along Grant St between the intersections with Swift St and Burnet St (Ballina Island);

- Up to -89 mm along Crane St west of the intersection with Grant St (Ballina Island);
- Up to -111 mm along Tamar St west of the intersection with Grant St (Ballina Island);
- Up to -152 mm along Grant St in proximity of the intersection with Tamar St (Ballina Island);
- Up to -73 mm along Winton Ln between the intersections with Grant St and Kerr St (Ballina Island).

6.2.2 HAT level and local rainfall event

The flood depth and changes in flood level maps resulting from the application of the HAT level as downstream boundary condition are provided in Figures E11 to E20, Appendix E.

The key outcomes of the sensitivity test on HAT tide level conditions can be summarised as follows:

- An increase in flood levels is observed in few locations of Ballina Island and West Ballina as a result of the application of the HAT level as downstream boundary condition.
- In all cases, the increase flood levels is associated to the backflow from the Richmond River and creeks through the stormwater pipe network.
- An increase in the 1% AEP flood levels is observed at the following locations:
  - Up to +173 mm along Grant St between the intersections with River St and Crane St (Ballina Island);
  - Up to +200 mm along Tamar St between the intersections with Grant St and Moon St (Ballina Island);
  - Up to +41 mm along Crane St between the intersections with Grant St and Moon St (Ballina Island);
  - Up to +33 mm on the area located south-west of the intersection between Kerr St and Tamar St (Ballina Island);
  - Up to +47 mm along Brunswick St (Ballina Island);
  - Up to +49 mm along Richmond Ave (Ballina Island);
  - Up to +122 mm along Tweed St (Ballina Island);
  - Up to +52 mm along Camoola Ave (Ballina Island);
  - Up to +20 mm along Norlyn Ave (Ballina Island);
  - Up to +29 mm along Norton St between the intersection with River St and Tamar St (Ballina Island);
  - Up to +77 mm at the intersection between Tamar St and Owen St (Ballina Island);
  - Up to +119 mm along Holden Ln (Ballina Island);
  - Up to +51 mm along Owen St between the intersections with Crane St and Swift St (Ballina Island);
  - +44 mm in Kingsford Smith Park (Ballina Island);
  - Up to +215 mm along Skinner St west of Martin St (Ballina Island);
  - Up to +44 mm along Martin St (Ballina Island);
  - Up to +79 mm along Riverside Dr (West Ballina);
  - Up to +72 mm along Riverview Ave (West Ballina);
  - Up to +25 mm along Howard Cres (West Ballina);
  - Up to +67 mm along Quays Dr (West Ballina);
  - Up to +26 mm along Dolphin Dr (West Ballina);

- Up to +375 mm along Burns Point Ferry Rd (West Ballina);
  - Up to +16 mm along River St between the intersections with Quays Dr and Riverview Ave (West Ballina).
- An increase in the 20% AEP flood levels is observed at the following locations:
  - Along Grant St, and in proximity of the intersections with Burnet St, Swift St, Crane St, and Tamar St (Ballina Island). The highest increase of +202 mm is observed along Tamar St in proximity of the intersection with Grant St;
  - Along Brunswick St, Richmond Ave, Tweed St and Camoola Ave (Ballina Island);
  - Along Martin St and Skinner St (Ballina Island);
  - Along Riverside Dr and Riverview Ave (West Ballina);
  - Along River St in proximity of the intersection with Sunset Ave (West Ballina).

6.3 Tide level conditions with no local rainfall events

The coastal inundation induced by different tide level conditions associated to no local rainfall events in Ballina Island and West Ballina have been investigated as part of this overland flow flood study.

6.3.1 HAT level with no local rainfall event

A sensitivity test simulation has been run by assuming no local rainfall event with an HAT tide level of 1.11 mAHD applied along the ocean boundary of the overland flow flood model. The main outcomes of this sensitivity test can be summarised as follows:

- No flooding due to coastal inundation occurs when considering an HAT tide level of 1.11 mAHD.
- A series of pipes fill in because of backwater effects, thus reducing the capacity of the pipes in case a local rainfall event should occur. The pipes affected by HAT tide levels are shown in Figure E21, Appendix E.

6.3.2 King Tide with no local rainfall event

A sensitivity test simulation has been run by assuming no local rainfall event with the King Tide level of 1.29 mAHD recorded during the January 2018 storm tide event applied along the ocean boundary of the overland flow flood model. The main outcomes of this sensitivity test can be summarised as follows:

- No flooding due to coastal inundation occurs when considering a King Tide level of 1.29 mAHD.
- Some areas in West Ballina and Ballina Island are affected by flooding due to backwater effects through the stormwater pipe network. The areas affected by flooding when considering a king tide level of 1.29 mAHD are:
  - Tamar St between the intersections with Kerr St and Cherry St;
  - Grant St in proximity of the intersection with Tamar St;
  - Grant St between the intersections with Swift St and Burnet St;
  - Cherry St between the intersections with Burnet St and Tamar St;
  - Skinner St east of intersection with Cherry St;
  - Martin St between intersections with Hamilton Ln and Skinner St;
  - Riverside Dr and Monica Pl;
  - River St in proximity of intersection with Sunset Ave;

– Cedars Caravan Park along Barlows Rd.

- A series of pipes fill in because of backwater effects, thus promoting a reduction of the pipe capacity in case a local rainfall event should occur.

The flood depth maps and pipes affected by backwater effects when considering a King Tide level of 1.29 mHAD are shown in Figure E22, Appendix E.

6.3.3 1% AEP storm tide with no local rainfall event

A sensitivity test simulation has been run by assuming no local rainfall event with a 1% AEP storm tide level of 2.0 mAHD applied along the ocean boundary of the overland flow flood model. The main outcomes of this sensitivity test can be summarised as follows:

- A significant portion of West Ballina and several areas of Ballina Island experience flooding due to coastal inundation when considering a 1% AEP storm tide level of 2.0 mAHD.
- In this scenario, almost all the pipes are filled in with water as a consequence of the following issues:
  – Pipes not equipped with tidal flap devices fill in because of backwater effects from the Richmond River and creeks;
  – All the other pipes fill in through the pits because of the inundation from coastal waters.

A flood map showing the flood extent and depths resulting from this tide scenario, as well as the pipes affected by backwater effects and coastal inundation, is provided in Figure E23, Appendix E.

6.4 100% blockage of stormwater network

Sensitivity tests have been carried out to assess the impacts of the stormwater network blockage on the flood levels resulting from local catchment flooding at Ballina Island and West Ballina.

The change in flood levels resulting from a 100% blockage of the stormwater network are shown in Figures F1 to F4, Appendix D, for the 0.2%, 1%, 5% and 20% AEP design events.

The key outcomes of the sensitivity tests carried out by applying a 100% blockage of stormwater network can be summarised as follows:

- The modelling results have highlighted that the stormwater network system plays a key role in the collection and conveyance of flows during local rainfall events throughout West Ballina and Ballina Islands.
- The 100% blockage of the stormwater network produces an increase in flood levels, which generally ranges between 100 and 400 mm for all the analysed AEP events.
- The locations affected by the highest increases in the 1% AEP flood levels are summarised as follows (please refer Figure F2, Appendix F):
  – Up to +590 mm in Tamar St along both the west and east sides of the intersection with Moon St (Ballina Island);
  – Up to +566 mm in Skinner St, east of the intersection with Martin St (Ballina Island);
  – Up to +514 mm in Temple St in proximity of the intersection with Fox St (Ballina Island).
- The impacts of the 100% blockage of the stormwater network are exacerbated when considering more frequent flood events. The locations affected by the highest increases in the 20% AEP flood levels can be summarised as follows (please refer Figure F4, Appendix F):

– Up to +615 mm in Tamar St between the intersections with Grant St and Cherry St (Ballina Island);
– Up to +620 mm in Grant St north of the intersection with Tamar St (Ballina Island);
– Up to +535 mm in Tamar St west of the intersection with Kerr St (Ballina Island);
– Up to +561 mm in Crane St east of the intersection with Grant St (Ballina Island);
– Up to +644 mm in Skinner St east of the intersection with Martin St (Ballina Island);
– Up to +620 mm along Martin St in proximity of the intersection with Skinner St (Ballina Island);
– Up to +511 mm along Fox St in proximity of the intersection with Temple St (Ballina Island);
– Up to +539 mm in Claire Cct at the intersections with Horizon Dr and Westland Dr (West Ballina).

6.5 +20% increase in Manning's n coefficients

Sensitivity tests have been carried out to assess the impacts of a 20% increase in Manning's n roughness coefficients on the flood levels resulting from local catchment flooding at Ballina Island and West Ballina.

An increase in Manning's n roughness coefficients of 20% produces negligible impacts throughout Ballina Island and West Ballina for all the analysed AEP events. For this reason, the flood maps resulting from this sensitivity test scenario have been omitted in the present report.

6.6 No initial and continuing rainfall losses

Sensitivity tests have been carried out to assess the impacts of adopting initial and continuing losses values of 0 mm and 0.0 mm/hr on the flood levels resulting from local catchment flooding at Ballina Island and West Ballina.

The changes in flood level resulting from a 100% blockage of the stormwater network are shown in Figures F5 to F7, Appendix D, for the 1%, 5% and 20% AEP design events.

The changes in flood level resulting from the adoption of IL = 0 mm and CL = 0 mm/hr values highlighted minor impacts on the flood levels for all the analysed AEP events.

The key outcomes of "no losses" scenario assessment can be summarised as follows:

- The increase in 1% AEP flood levels resulting from the application of no rainfall losses is overall lower than 50 mm in roads, residential and commercial areas, and affects only few locations in Ballina Island and West Ballina. Increases in 1% AEP flood levels higher than 50 mm occur only in very few locations.
- The increase in 1% AEP flood levels resulting from the "no losses" scenario can be summarised as follows:
  – Up to +20 mm in Tamar St east of the intersection with Grant St (Ballina Island);
  – Up to +27 mm in Grant St in proximity of the intersection with Holden Ln (Ballina Island);
  – Up to +25 mm in Winton Ln between the intersections with Kerr St and Grant St (Ballina Island);
  – Up to +15 mm in Cherry St in proximity of Ballina Coast High School (Ballina Island);
  – Up to +16 mm along Bentick St behind Ballina Coast High School's football field (Ballina Island);

- Up to +17 mm along Moon St and Acacia Pl between the intersections with Fox St and Bentick St (Ballina Island);
- Up to +15 mm on the backyards of 19 and 21 Skinner St (Ballina Island);
- Up to +12 mm on Cawarra Park and adjacent section of Cherry St (Ballina Island);
- Up to +27 mm at TAFE NSW (Ballina Island);
- Up to +104 mm on Kingsford Smith Park (Ballina Island);
- Up to +25 mm on Westland Dr, Westland Pl and Sunset Ave (West Ballina);
- Up to +20 mm on Horizon Dr and Newland St (West Ballina);
- Up to +66 mm on Emmanuel Anglican College's football field (West Ballina);
- Up to +27 mm at Riverbend Village (West Ballina).

- The number of locations affected by changes in flood levels and associated flood extent significantly reduce when considering the 20% AEP design event. However, the increase in 20% flood levels is higher than the increase in 1% AEP flood levels in some locations.
- A summary of the affected locations in the 20% AEP event with the associated increase in 20% AEP flood levels is outlined as follows:
  - Up to +14 mm on Tamar St west of the intersection with Grant St (Ballina Island);
  - Up to +17 mm on Grant St in proximity of the intersection with Tamar St (Ballina Island);
  - Up to +16 mm at the intersection between Grant St and Swift St (Ballina Island);
  - Up to +16 mm in Cherry St in proximity of Ballina Coast High School (Ballina Island);
  - Up to +20 mm along Bentick St behind Ballina Coast High School's football field (Ballina Island);
  - Up to +15 mm on the backyards of 19 and 21 Skinner St (Ballina Island);
  - Up to +32 mm at TAFE NSW (Ballina Island);
  - Up to +15 mm on Newland St (West Ballina);
  - Up to +43 mm at the intersection between Westland Dr and Westland Pl (West Ballina);
  - Up to +27 mm at Riverbend Village (West Ballina).

6.7 Coincidental occurrence of 1% AEP local rainfall event and 1% AEP storm tide

The increase in flood levels across Ballina Island and West Ballina induced by the coincidental occurrence of the 1% AEP local rainfall event and the 1% AEP storm tide event has been tested using the overland flow path model.

The key characteristics of the model setup for the coincidental occurrence scenario are summarised in Table 6-1. The flood levels applied as boundary conditions along the Richmond River, Emigrant Creek, Fishery Creek and North Creek have been sourced from the "Regional Model - Scenario C" simulated using the integrated regional model. Scenario C includes the application of 10-year ARI inflow hydrographs along the Richmond River and creek upstream boundaries, and a 100-year ARI storm tide along the ocean boundary.

The flood depth, level, and flow velocity maps resulting from the coincidental occurrence scenario are provided in Figure G1 to G3, Appendix G.

Figure G4, Appendix G, shows the changes in flood levels obtained by comparing the coincidental occurrence scenario with the baseline 1% AEP scenario featuring the application of the MHWS tide level as downstream boundary condition.

The key outcomes of the coincidental occurrence assessment can be summarised as follows:

- The increase in 1% AEP flood levels is overall ranging between 0 and 400 mm, with some locations characterised by an increase of up to 700 mm.
- The areas affected by an increase higher than 400 mm are listed as follows:
  - Up to +520 mm along Moon St between the intersections with Grant St and Cherry St (Ballina Island);
  - Up to +545 mm along River St in proximity of the intersection with Grant St (Ballina Island);
  - Ranging between +400 mm and +724 mm in the low-lying area located south-west of the intersection between River St and Kerr St (Ballina Island);
  - Up to +682 mm on Fawcett St (Ballina Island);
  - Up to +560 mm on Skinner St (Ballina Island);
  - Up to +634 mm on Riverside Dr and the low-lying area located south of Riverside Dr (West Ballina);
  - Up to +410 mm on Emmanuel Anglican College's football field (West Ballina);
  - Up to +518 mm on Cedars Caravan Park (West Ballina).

7. Consequences of Flooding to the Community

7.1 Identification of overland flow flooding hotspots

In order to identify problem flooding and drainage 'hotspots' and priority areas for potential flood mitigation works, a detailed analysis of model results was undertaken.

7.1.1 Criteria adopted for the selection of flooding hotspots

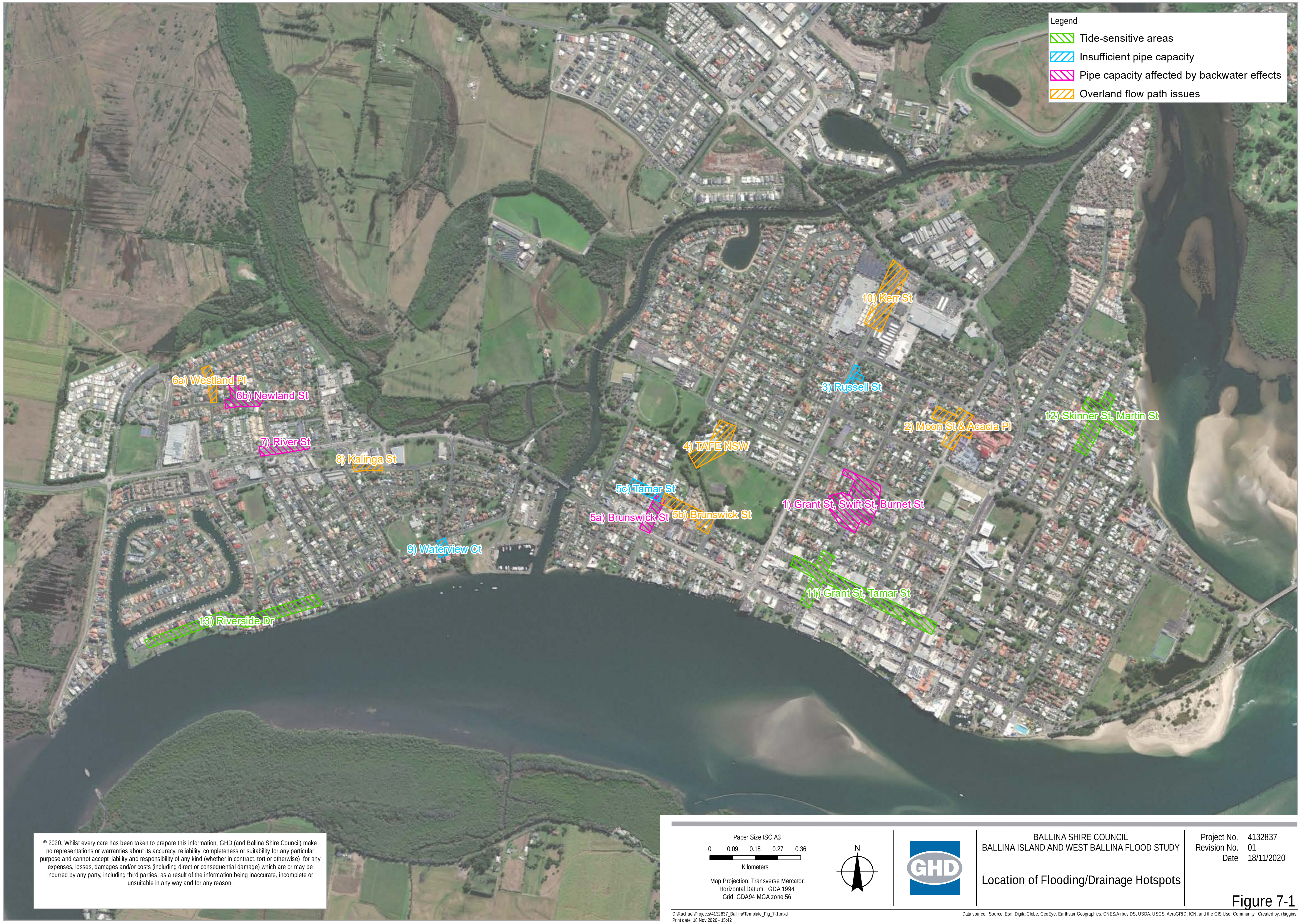
The flooding hotspots in West Ballina and Ballina Island have been identified according to the following criteria:

- According to the *Stormwater Management Standards for Development* guidelines (BSC, 2016), the Annual Return Interval (ARI) design flood event to be adopted in BSC for the design of minor stormwater network systems ranges from 1 in 5-year ARI (i.e., 20% AEP) for Rural and Urban Residential to 1 in 10-year ARI (i.e., 10% AEP) for Commercial/Industrial land-use category. Given that flooding issues generated by local rainfall events are mainly associated to inefficiencies of the existing stormwater network system, the 20% AEP design flood event has been adopted as a reference for the identification of flooding hotspots resulting from overland flows in West Ballina and Ballina Island.
- The identification of flooding hotspots has been performed through analysis of model results for design event scenarios with coincident Highest Astronomical Tide conditions.
- The flooding hotspots have been identified as inundated areas with flood depths greater than 200 mm in the 20% AEP event.
- The areas most sensitive to high tide levels have been included among the flooding hotspots. The most "tidally sensitive" areas have been identified by considering the scenario characterised by no local rainfall event while applying King Tide levels as downstream boundary conditions.

7.1.2 Flooding hotspots

A detailed review of the West Ballina and Ballina Island overland flow path model results identified ten (10) stormwater system flooding and drainage hotspots that experience relatively high degrees of flood hazard vulnerability, and three (3) flooding hotspots most sensitive to high tide levels.

The location of these flooding hotspots is provided in Figure 7-1, with 'zoomed-in' flood inundation maps provided for each flooding hotspot in Appendix H. Table 7-1 summarises the nature of the flooding issues at each of the flooding hotspot locations, the flood hazard vulnerability of each flooding hotspot and the exacerbation of the flooding issues induced by high tide levels.



BALLINA SHIRE COUNCIL
BALLINA ISLAND AND WEST BALLINA FLOOD STUDY

Location of Flooding/Drainage Hotspots

Project No. 4132837
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Figure 7-1

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Table 7-1 Preliminary assessment of flood impacts and risk

Hotspot ID	Location description	Description of flooding issues Source of flooding	Flood hazard	Impacts of high tide levels
1	Grant St, Swift St, Burnet St	Pipe capacity affected by backwater effects from the Richmond River	Up to H2 category in 20%, 5% and 1% AEP flood events	Flooding issues exacerbated by backflows due to high tide levels
2	Moon St and Acacia Pl	Overland flow path issue due to a lack of stormwater drainage system	Mostly H2 category, with small spots characterised by H3 category in 20%, 5% and 1% AEP events	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels
3	Russell St	Insufficient capacity of drainage system	Up to H2 category in 20%, 5% and 1% AEP flood events	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels
4	TAFE NSW	Overland flow path issue due to a lack of stormwater drainage system	Up to H3 category in 20%, 5% and 1% AEP flood events	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels
5	Tamar St and Brunswick St	Pipe capacity affected by backwater effects from the Richmond River along Brunswick St (Location 5a) Overland flow path issue due to a lack of stormwater drainage system along Tamar St east of intersection with Brunswick St (Location 5b) Insufficient capacity of drainage system along Tamar St west of intersection with Brunswick St (Location 5c)	Mostly H2 category, with an area characterised by H2 category along Tamar St east of Brunswick St in 20%, 5% and 1% AEP flood events	Flood levels along Brunswick St are exacerbated by high tide levels No exacerbation of flood levels due to high tide levels is observed on Tamar St east of Brunswick St
6	Newland St and Westland Pl	Pipe capacity affected by backwater effects from the Richmond River on Westland Pl (Location 6a) Overland flow path issue due to a lack of stormwater drainage system along Newland St (Location 6b)	H2 category in 20% AEP event Up to H3 category in 5% and 1% AEP events	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels
7	River St between Sunset Ave and Ronan Pl	Pipe capacity affected by backwater effects from the Richmond River	H2 category in 20%, 5% and 1% AEP events	Flood levels are strongly exacerbated by high tide levels
8	Kalinga St	Overland flow path issue due to a lack of stormwater drainage system	H2 category in 20%, 5% and 1% AEP events	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels
9	Waterview Ct	Insufficient capacity of drainage system	H2 category in 20%, 5% and 1% AEP events	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels

Hotspot ID	Location description	Description of flooding issues		
		Source of flooding	Flood hazard	Impacts of high tide levels
10	Kerr St	Overland flow path issue due to poor stormwater drainage system	H2 category in 20% and 5% AEP events Up to H3 category in 1% AEP event	No exacerbation of flood levels due to high tide levels is observed at this location when considering MHWS tide and HAT levels
11	Grant St and Tamar St	Inundation due to backflows through the stormwater pipe network during King Tide levels	H1 category	Flood levels are strongly exacerbated by higher tide levels
12	Skinner St and Martin St	Inundation due to backflows through the stormwater pipe network during King Tide levels	H1 category	Flood levels are strongly exacerbated by higher tide levels
13	Riverside Dr	Inundation due to backflows through the stormwater pipe network during King Tide levels	H1 category	Flood levels are strongly exacerbated by higher tide levels

7.2 Flood impacts

7.2.1 Properties affected by flooding above floor level

The number of buildings affected by flooding above floor level has been estimated by comparing the flood levels computed by the overland flow flood model with the floor level survey provided by Council at each survey point location. Please refer to Section 2.2.2 for a detailed description of the floor level survey provided by Council and adopted to perform this analysis.

The assessment has been performed by adopting the flood levels computed by the overland flow flood model when considering the combined effect of local rainfall events in Ballina Island and West Ballina, and MHWS tide levels as downstream boundary conditions.

A summary of the buildings affected by flooding above floor level for each analysed AEP event is provided in Table 7-2.

Table 7-2 Number of buildings affected by flooding above floor level

AEP event	Number of buildings affected by flooding above floor level		
	Residential	Commercial	Total
0.2% AEP	10	13	23
1% AEP	5	8	13
2% AEP	4	7	11
5% AEP	1	4	5
10% AEP	1	1	2
20% AEP	1	1	2
50% AEP	0	1	1

All the buildings impacted by flooding above floor level in Ballina Island and West Ballina are affected by flood depths ranging between 10 mm and 220 mm.

7.2.2 Capacity of drainage network

Table 7-3 and Table 7-4 provide a summary of the drains characterised by low performance standards during overland flow flood events in Ballina Island and West Ballina, respectively.

The drains characterised by low performance standards have been selected among those producing overland flow flooding while working 100% full.

The assessment has been carried out according to the following approach:

- The drainage capacity assessment has been performed on the baseline simulation results characterised by the application of the MHWS tide level as downstream boundary conditions.
- The drainage capacity assessment has been performed on the pipes represented as 1D elements that are dynamically linked to the 2D model domain. Please refer to Section 3.7.2 for a detailed description of the criteria adopted in the representation of the 1D stormwater network system in the overland flow flood model.

Table 7-3 Drains with low performance standards in Ballina Island

Drains with low performance standards in Ballina Island	Performance standard AEP (existing pipe capacity)
Cherry St (between intersections with Hunter St and Florence Price Pl)	< 50% AEP
Cherry St (between intersections with Cawarra St and Maine Pl)	10% AEP
Tipperary Pl	50% AEP
Martin St (north of intersection with Skinner St)	10% AEP
Skinner St (west of Martin St)	10% AEP
Skinner St (east of Martin St)	2% AEP
Martin St (south of intersection with Skinner St)	10% AEP
Camden St	10% AEP
Norton St (north of Bentinck St)	50% AEP
Bentinck St (between intersections with Martin St and Norton St)	< 50% AEP
Bentinck St (east of intersection with Carrington St)	10% AEP
Norton St (south of Bentinck St)	10% AEP
Martin St (between intersections with Burnet St and Swift St)	20% AEP
Martin St (between intersections with Swift St and Crane St)	< 50% AEP
Owen St (between intersections with Pool Ln and Swift St)	10% AEP
Holden Ln (west of Norton St)	5% AEP
Holden Ln (east of Norton St)	2% AEP
Owen St (south of the intersection with Crane St - Kingsford Smith Park side)	10% AEP
Owen St (south of the intersection with Tamar St)	2% AEP
Norton St (between intersections with Tamar St and River St)	20% AEP
River St (between intersection with Martin St and Norton St)	20% AEP
River St (between intersection with Norton St and Owen St)	10% AEP
Martin St (between intersections with Tamar St and River St)	50% AEP
Tamar St (between intersections with Cherry St and Martin St)	< 50% AEP
Cherry St (south of River St)	5% AEP
Cherry St (at the intersection with Tamar St)	< 50% AEP
Cheery St (between intersections with Burnet St and Swift St)	50% AEP
Bungalow Rd (between intersections with Cherry St and Fox Ln)	10% AEP
Bungalow Rd (at the intersection with Moon St)	2% AEP
Sheather St	< 50% AEP
Hogan St (at the intersection with Sheather St)	50% AEP
Kerr St (between the intersections with Bungalow Rd and Fox St)	< 50% AEP
Treelands Cres	50% AEP
Fox St (at the intersection with Grant St)	50% AEP
Kerr St (between the intersections with Bentinck St and Fox St)	< 50% AEP
Grant St (between the intersections with Bentinck St and Fox St)	< 50% AEP
Moon St (between the intersections with Bentinck St and Fox St)	< 50% AEP
Kerr St (south of the intersection with Bentinck St)	< 50% AEP
Grant St (between the intersections with Webster Ln and Burnet St)	< 50% AEP
Crane St (between the intersections with Grant St and Moon St)	20% AEP
Crane St (between the intersections with Kerr St and Grant St)	50% AEP
Tamar St (between the intersections with Grant St and Moon St)	5% AEP
Tamar St (between the intersections with Kerr St and Grant St)	50% AEP
Winton Ln (between the intersections with Kerr St and Grant St)	< 50% AEP

Drains with low performance standards in Ballina Island	Performance standard AEP (existing pipe capacity)
River St (between the intersections with Grant St and Moon St)	10% AEP
Camoola Ave and Tweed St (south of River St)	< 50% AEP
Brunswick St and Greenhalgh St (south of River St)	20% AEP
Henry Philip Ave and Bolding St	20% AEP
Norlyn Ave	50% AEP
Brunswick St (between the intersections with Canal Rd and Tamar St)	< 50% AEP
Tamar St (between the intersections with Bagot St and Tweed St)	< 50% AEP
Marshall St	10% AEP
Temple St-Burnet St intersection	50% AEP
Hickey St (at the intersection with Burnet St)	< 50% AEP
Hickey St (between the intersections with Leeson Ave and James St)	50% AEP
Hickey St (between the intersections with Princess Ave and Clavan St)	50% AEP
Hickey St (at the intersection with Fox St)	< 50% AEP
Vera St (at the intersection with Jamie Pl)	10% AEP
Clavan St (at the intersection with Clavan Ct)	2% AEP
Clavan St (at the intersection with Canal Rd)	20% AEP
Fox St (west of Temple St)	10% AEP
Christine Pl	20% AEP
Fox St (at the intersection with Canal Rd)	< 50% AEP
Helen Ct	20% AEP
Canal Rd (between intersections with Helen Ct and Fox St)	5% AEP
Canal Rd (at the Fripp Oval)	20% AEP

Table 7-4 Drains with low performance standards in West Ballina

Drains with low performance standards in West Ballina	Performance standard AEP (existing pipe capacity)
RMS Depot	< 50% AEP
Apsley St and Kalinga St	20% AEP
Johnson Dr	20% AEP
Brampton Ave (north of intersection with Aspley St)	2% AEP
Brampton Ave (between intersections with Aspley St and Hayman St)	10% AEP
Sunnybank Rd and Waterview Ct	< 50% AEP
Hayman St	10% AEP
Kalinga St (east of Keppel St)	20% AEP
River St (between intersections with Keppel St and Brampton Ave)	50% AEP
River St (between intersections with Riverview Ave and Ronan Pl)	50% AEP
River St (between intersections with Riverview Ave and Quays Dr)	20% AEP
River St (between intersections with Horizon Dr and Quays Dr)	< 50% AEP
River St (between intersections with Horizon Dr and Burns Point Ferry Rd)	10% AEP
Kalinga St (between intersections with Dolphin Dr and Burns Point Ferry Rd)	10% AEP
Burns Point Ferry Rd	20% AEP
Kalinga St (between intersections with Dolphin Dr and Quays Dr)	5% AEP
Kalinga St (between intersections with Riverview Ave and Quays Dr)	2% AEP

Drains with low performance standards in West Ballina	Performance standard AEP (existing pipe capacity)
Daydream Ave	10% AEP
Rainbow Ave (between intersections with Kalinga St and Linderman St)	5% AEP
Riverview Ave	10% AEP
Riverside Dr (at the intersection with Riverview Ave)	5% AEP
Howard Cres	5% AEP
Riverside Dr (between intersections with Riverview Ave and Quays Dr)	10% AEP
Quays Dr (between intersections with Kalinga St and Leach Cres)	5% AEP
Quays Dr (between intersections with Riverside Dr and Leach Cres)	2% AEP
Riverside Dr (west of the intersection with Quays Dr)	from 10% AEP to 50% AEP
Dolphin Dr	20% AEP
Spinnaker Cres	20% AEP
Sunset Ave	20% AEP
Claire Cct	20% AEP
Westland Pl	< 50% AEP
Casey Pl and Westland Dr at the intersection with Casey Pl	50% AEP
Westland Dr (between the intersections with Claire Cct and Horizon Dr)	10% AEP
Westland Dr (in proximity of intersection with Westland Pl)	< 50% AEP
Quail Pl	< 50% AEP
Amy Pl	50% AEP
Westland Dr (between the intersections with Amy Pl and Horizon Dr)	50% AEP
Newland St	< 50% AEP
Horizon Dr (west of intersection with Newland St)	< 50% AEP
Horizon Dr (at the intersection with Claire Cct)	20% AEP

7.2.3 Impacts to roads

Table 7-5 summarises flood affected roads characterised by flood hazard category equal or greater than the AIDR (2017) H3 flood hazard threshold for all the analysed AEP events.

According to AIDR (2017) guidelines, flood hazard category H3 and above are characterised by flooding conditions that are “unsafe for vehicles, children and the elderly” on the basis of the flood depth, velocity and depth-velocity product values. For this reason, these roads have been identified as relatively higher risk inundation areas where the road is ‘cut off’ from flooding.

Table 7-5 Roads affected by flood hazard category ≥ H3

AEP event	Roads sections characterised by flood hazard category ≥ H3	
	Ballina Island	West Ballina
0.2% AEP	Marsh Ave, Acacia Pl, Kerr St in front of McDonald's, 12 Grant St	Newland St, Westland Pl, Quail Pl, few locations along internal roads of Riverbend Village
1% AEP	Marsh Ave, Kerr St in front of McDonald's, 12 Grant St	Newland St, Westland Pl, few locations along internal roads of Riverbend Village
2% AEP	Kerr St in front of McDonald's, 12 Grant St	Newland St, Westland Pl, few locations along internal roads of Riverbend Village
5% AEP	No roads cuts	Westland Pl, few locations along internal roads of Riverbend Village
10% AEP	No roads 'cut off'	No roads 'cut off'
20% AEP	No roads 'cut off'	No roads 'cut off'
50% AEP	No roads 'cut off'	No roads 'cut off'

7.3 Impacts of climate change

The potential impact of climate change was assessed by simulating flood conditions under existing and estimated future climate conditions, mapping the change in flood level induced by climate change and assessing impacts.

7.3.1 Combined effect of increase in rainfall intensity and sea level rise

A series of climate change simulations have been run by applying an increase in rainfall intensity to the 0.2%, 1% and 5% AEP local rainfall events in Ballina Island and West Ballina, associated to an increase in MHWS tide levels due to Sea Level Rise (SLR). Please refer to Section 5.4 of this report for a detailed description of the overland flood model setup for this climate change scenario.

The changes in flood level obtained by comparing the flood levels resulting from this climate change scenario and the baseline existing condition scenario are shown in Figures D5, D10 and D15, Appendix D, for the 0.2%, 1% and 5% AEP events, respectively.

The modelling results highlighted an increase in flood levels in several locations of Ballina Island and West Ballina when considering this climate change scenario. The increase in flood levels observed in the climate change simulation results is due to a combination of the following causes:

- Low-lying areas inundated by the increase in tide levels due to sea level rise. Examples of these areas are:
  - Norlyn Avenue, Brunswick St, Greenhalgh St, Richmond Ave, Tweed St, Camoola Ave, Bolding St, and Henry Philip Ave (Ballina Island);
  - Canal Rd and Helen Ct (Ballina Island);
  - Boatharbour Rd and RMS Depot (West Ballina);
  - Riverside Dr, Daydream Ave, Linderman St, Rainbow Ave, Oakland Ave, Riverview Ave, Howard Cres, Quays Dr, Kalinga St (centre), River St, Cedars Caravan Park (West Ballina);
  - West side of Kalinga St (West Ballina).

- Insufficient capacity of the existing stormwater network due to the combination of the increase in rainfall intensity and the backflow from Richmond River and creeks through the stormwater pipe network. Examples of these areas are:
  - Grant St, Tamar St, River St, and Moon St, Crane St, Swift St (Ballina Island);
  - River St, Martin St, Fawcett St, Norton St, Tamar St, Owen St (Ballina Island);
  - Martin St, Hamilton St, Skinner St, Camden St, and Marine St (Ballina Island);
  - Fox St, Temple St, Hickey St, and Catherine Cres (Ballina Island);
  - Dolphin Dr and Spinnaker Cres (West Ballina);
  - Brampton Ave, Kalinga St (east), Linderman St (West Ballina).

An increase in 1% AEP flood levels lower than 50 mm is observed in most locations. The most significant increases in the 1% AEP flood levels are observed at the following locations:

- Ranging between 100 mm and 376 mm along Tweed St, Brunswick St, Richmond Ave and Camoola Ave (Ballina Island);
- Ranging between 150 mm and 314 mm along Grant St (southern section) and Tamar St (Ballina Island);
- Ranging between 100 mm and 341 mm along Skinner St, Martin St, Camden St and Hamilton St (Ballina Island);
- Up to +412 mm along Riverside Dr (West Ballina);
- Ranging between 376 mm and 735 mm along Burns Point Ferry Rd (West Ballina).

7.3.2 Effect of sea level rise only

Climate change simulations featuring no local rainfall events in Ballina Island and West Ballina while considering an increase in tide levels due to sea level rise have been run in order to assess the flooding scenario resulting from Year 2100 sea level rise only.

The effects of sea level rise have been assessed on the MHWS and HAT tide levels. Please refer to Section 5.4 of this report for a detailed description of the overland flood model setup for these climate change scenarios. A summary of the main outcomes of this assessment is provided in the following sections.

No local rainfall event and application of SLR on MHWS tide level

Flood maps showing the flood extent, depth, flow velocity and flood hazard resulting from the MHWS tide + SLR scenario are provided in Figures D16 to D18, Appendix D.

The flooding resulting from this climate change scenario is due to the following causes:

- Low-lying areas affected by coastal inundation:
  - Norlyn Avenue, Brunswick St, Greenhalgh St, Richmond Ave, Tweed St, Camoola Ave, Bolding St, and Henry Philip Ave (Ballina Island);
  - Canal Rd and Helen Ct (Ballina Island);
  - Boatharbour Rd and RMS Depot (West Ballina);
  - Riverside Dr, Daydream Ave, Riverview Ave, Quays Dr, Kalinga St west of intersection with Dolphin Rd (West Ballina);
- Backflow from Richmond River and creeks through the stormwater pipe network:
  - Grant St, Tamar St, River St (Ballina Island);
  - Crane St, Swift St, Burnet St in proximity of the intersections with Grant St (Ballina Island);

- Moon St in proximity of intersection with Tamar St (Ballina Island);
- River St, Fawcett St, Norton St, Tamar St, Owen St east of Martin St (Ballina Island);
- Martin St, Hamilton St, Skinner St, Camden St, and Marine St (Ballina Island);
- Fox St, Temple St, Hickey St, and Catherine Cres west of Kerr St (Ballina Island);
- Rainbow Ave (West Ballina);
- Howard Cres (West Ballina);
- Kalinga St at intersection with Dolphin Dr, River St, Cedars Caravan Park (West Ballina).

No local rainfall event and application of SLR on HAT tide level

Most of West Ballina and large areas of Ballina Island experience flooding due to coastal inundation and backwater effects through the stormwater pipe network when considering a HAT tide + SLR tide level scenario.

Flood maps showing the flood extent, depth, flow velocity and flood hazard resulting from the HAT tide + SLR scenario are provided in Figures D19 to D21, Appendix D.

8. Conclusion & Recommendations

8.1 Conclusion of the overland flow flood study

An overland flow path model of the Ballina Island and West Ballina catchments has been developed using a rain-on-grid (direct rainfall) approach and the TUFLOW software package.

The main conclusions of the Ballina Island and West Ballina Overland Flood Study project are summarised as follows:

- The 0.2%, 1%, 2%, 5%, 10%, 20% and 50% AEP design flood events have been simulated using the Baliina Island and West Ballina overland flow path model according to the procedure outlined in the ARR 2019 guidelines. A set of rainfall durations ranging between 15 minutes and 12 hours, and ten (10) temporal patterns have been simulated for each AEP event.
- The raw flood grids have been filtered to discern the overland flow paths from very shallow sheet flows. The adopted set of filtering parameters have been selected as follows:
  - Flood depths > 0.05 m
  - Depth-velocity product > 0.01 m^2/s
  - Pond areas > 500 m^2
- The year 2100 RCP 8.5 climate change scenario simulation has been run for the 0.2, 1% and 5% AEP flood events to assess the change in flood levels resulting from future climate. The modelling results have highlighted an increase in the 1% AEP flood levels lower than 50 mm along most of the overland flow paths, with localised maximum increases up to 380 mm in few locations.
- Sensitivity tests on tide level conditions featuring the application of MLWS tide and HAT levels as downstream boundary conditions have been performed on the 0.2%, 1%, 2%, 5% and 20% AEP events. These sensitivity tests aimed at assessing the impacts of backflows from Richmond River and creeks through the stormwater pipe network for different tide level scenarios. The modelling results show that the following areas are most affected by high tides:
  - Grant St, and in proximity of the intersections with Burnet St, Swift St, Crane St, and Tamar St (Ballina Island);
  - Brunswick St, Richmond Ave, Tweed St and Camoola Ave (Ballina Island);
  - Martin St and Skinner St (Ballina Island);
  - Riverside Dr and Riverview Ave (West Ballina);
  - River St in proximity of the intersection with Sunset Ave (West Ballina).
- Sensitivity tests on the 100% blockage of stormwater network have been carried out on the 0.2%, 1%, 5% and 20% AEP events to assess the role played by the pit & pipe system on local levels and extent. The modelling results show that the stormwater network plays a key role in the collection and conveyance of flows during local rainfall events. When considering a 100% blockage of the stormwater network, an overall increase in flood levels ranging between 100 and 400 mm is observed along the overland flow paths throughout Ballina Island and West Ballina for all the analysed AEP events, with few locations experiencing a maximum increase in 1% AEP flood levels ranging from 510 to 590 mm. The effects of the 100% blockage of stormwater network are exacerbated for frequent flood events, with maximum increases in 20% AEP flood level ranging from 500 to 650 mm along Grant St, Tamar St, Crane St, Skinner St, Martin St and Fox St.

- Sensitivity tests on Manning's n roughness coefficients and rainfall losses have been carried out to assess the impacts of model parameters on the flood levels in Ballina Island and West Ballina. The modelling results showed negligible effects on the flood levels when considering an increase of +20% in the Manning's roughness coefficients for all the analysed AEP events. The modelling results also show minor impacts on the computed flood levels when considering initial and continuing losses values of 0 mm and 0.0 mm/hr, respectively.
- The coincidental occurrence of 1% AEP local rainfall event and 1% AEP storm tide has also been investigated. The modelling results highlighted that the increase in 1% AEP flood levels is overall ranging between 0 and 400 mm, with some locations characterised by an increase of up to 700 mm. The areas affected by the highest increase in flood levels in this scenario are: Moon St, River St, Fawcett St, and Skinner St in Ballina Island; Riverside Dr, Emmanuel Anglican College's football field, and Cedars Caravan Park in West Ballina.
- Ten (10) flooding hotspots that experience flood issues during overland flow flood events have been identified within Ballina Island and West Ballina.
- A preliminary identification of structural overland flow flood mitigation options have been performed during Stage 2 of the project. The overland flow flood mitigation options proposed in this report will inform a preliminary discussion with Council about the preferred overland flow flood mitigation options to assess during Stage 3 of the project.

8.2 Recommendations

It is recommended that the outcomes of the Overland Flood Study Report be used to inform the project activities that will inform Stage 3 – Preliminary Options Report for Mitigation Strategy.

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