KINGSTON BEACH FLOOD STUDY

KINGBOROUGH COUNCIL

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TABLE OF CONTENTS

List of Tables

List of Figures

Glossary

1D	One- dimensional
2D	Two-dimensional
AEP	Average Exceedance Probability
AHD	Australian Height Datum
ARI	Average Recurrence Interval
ARR	Australian Rainfall and Runoff
BOM	Bureau of Meteorology
DEM	Digital Elevation Model
FFA	Flood Frequency Analysis
GIS	Geographic Information System
IFD	Intensity-Frequency-Duration
LiDAR	Light Detection and Ranging
MHWS	Mean High Water Spring
QUDM	Queensland Urban Drainage Manual
SLR	Sea Level Rise
SWMM	Stormwater & Wastewater Management Modelling
TCAP	Tasmanian Coastal Adaptation Decision Pathways Project
v.d	Velocity Depth Product

afflux

The change in water level from existing conditions resulting from a change in the watercourse or floodplain – eg construction of a new bridge.

Annual Exceedance Probability (AEP)

The chance of a flood of a given size (or larger) 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 (ie a 1 in 20 chance) of a peak discharge of 500 m^3/s (or larger) occurring in any one year (see also average recurrence interval).

Australian Height Datum (AHD)

National survey datum corresponding approximately to mean sea level.

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 20yr ARI design flood will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event (see also annual exceedance probability).

Australian Rainfall and Runoff (AR&R)

Engineers Australia publication pertaining to rainfall and flooding investigations in Australia

Bathymetric survey

Survey of the bed levels of a waterway.

calibration

The adjustment of model configuration and key parameters to best fit an observed data set

catchment

The catchment at a particular point is the area of land that drains to that point.

critical duration

The critical duration is the design storm duration which provides the highest peak water levels for a given design flood (e.g. 1% AEP) at a given location. For example, if the following design durations were modelled - 2-hour, 6-hour, 9-hour and 12-hour – and the 9-hour duration resulted in the highest peak water level at a given location then the critical duration for that location would be 9-hours.

design flood event

A hypothetical flood representing a specific likelihood of occurrence (for example the 100yr ARI or 1% AEP flood).

development

Existing or proposed works that may or may not impact upon flooding. Typical works are filling of land, and the construction of roads, floodway and buildings.

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).

flood

Relatively high river or creek flows, which overtop the natural or artificial banks, and inundate floodplains and/or coastal inundation resulting from super elevated sea levels and/or waves overtopping coastline defences.

flood behaviour

The pattern / characteristics / nature of a flood.

flood hazard

The potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies with circumstances across the full range of floods.

flood level

The height or elevation of floodwaters relative to a datum (typically the Australian Height Datum). Also referred to as “stage”.

floodplain

Land adjacent to a river or creek that is periodically inundated due to floods. The floodplain includes all land that is susceptible to inundation by the probable maximum flood (PMF) event.

floodplain management

The co-ordinated management of activities that occur on the floodplain.

flood prone land

Land susceptible to inundation by the probable maximum flood (PMF) event. Under the merit policy, the flood prone definition should not be seen as necessarily precluding development. Floodplain Risk Management Plans should encompass all flood prone land (i.e. the entire floodplain).

flood storage

Floodplain area that is important for the temporary storage of floodwaters during a flood.

freeboard

A factor of safety usually expressed as a height above the adopted flood level thus determining the flood planning level. Freeboard tends to compensate for factors such as wave action, localised hydraulic effects and uncertainties in the design flood levels.

geomorphology

The study of the origin, characteristics and development of land forms.

gauging (tidal and flood)

Measurement of flows and water levels during tides or flood events.

historical flood

A flood that has actually occurred.

hydraulic

The term given to the study of water flow in rivers, estuaries and coastal systems.

hydrodynamic

Pertaining to the movement of water hydrograph A graph showing how a river or creek’s discharge changes with time.

hydrology

The term given to the study of the rainfall-runoff process in catchments.

hyetograph

A graph showing the depth of rainfall over time.

Intensity Frequency Duration (IFD) Curve

A statistical representation of rainfall showing the relationship between rainfall intensity, storm duration and frequency (probability) of occurrence.

LiDAR

Light Detection and Ranging –a remote sensing method used to generate ground surface elevation. Typically acquired through airborne surveys from which an aeroplane can cover large areas.

overland flow

Overland flow is surface run off before it enters a waterway. It is caused by rainfall which flows downhill along low points concentrating in gullies, channels, surface depressions and stormwater systems.

peak flood level, flow or velocity

The maximum flood level, flow or velocity that occurs during a flood event.

probability

A statistical measure of the likely frequency or occurrence of flooding.

runoff

The amount of rainfall from a catchment that actually ends up as flowing water in the river or creek.

topography

The shape of the surface features of land

velocity

The speed at which the floodwaters are moving. A flood velocity predicted by a 2D computer flood model is quoted as the depth averaged velocity, i.e. the average velocity throughout the depth of the water column. A flood velocity predicted by a 1D or quasi- 2D computer flood model is quoted as the depth and width averaged velocity, i.e. the average velocity across the whole river or creek section.

validation

A test of the appropriateness of the adopted model configuration and parameters (through the calibration process) for other observed events.

water level

See flood level.

EXECUTIVE SUMMARY

Purpose

The purpose of the this Flood Study has been to undertake a detailed flood assessment of the Kingston Beach catchment through the establishment of appropriate hydrological and hydraulic models for accurate flood level prediction.

The outcomes of this study provided a flood risk profile for Kingston Beach that informed the *Kingston Beach Integrated Climate Change and Natural Hazards Project* (Climate Planning, 2016). For this study, both catchment and ocean derived flood events and the impact of future climate change on flooding in Kingston Beach were considered.

Method

In completing the flood study, the following activities were undertaken:

- Collection and compilation of available historical and recent climate change data and flood data related to the study area;
- Development of flood models through a comprehensive 2D computer model using available data;
- Simple validation of the models using current best available data and sensitivity tests;
- Production of a range of design flood maps (peak flood level, depth, velocity and hazard) including 1%, 5% and 20% AEP events for catchment (fluvial) derived flooding with future climate change; 1%, 5% and 20% AEP events for derived storm surges level with future sea level rise and coincident floods in 9-hour peak storm events; and
- Preliminary investigation of potential flood mitigation measures.

Catchment flooding and oceanic inundation can occur due to the same storm cell and therefore design flood levels in a lower coastal waterway will be influenced by a combination of these sources. If oceanic inundation or catchment flooding is examined in isolation the resultant estimated flood risk is unlikely to be fit for purpose.

This study followed Queensland and NSW State Government guidelines that provide guidance on simplified methods to allow for coincident flooding. Current practice typically includes an analysis of two boundary cases to obtain the 1% AEP flood level, which might typically combine:

- 1% AEP river discharge with a downstream (tidal) level at mean high sea level; and
- 5% AEP freshwater inflow with a 1% AEP downstream (tidal) level.

Results

The results indicate that most of the Kingston Beach residential and commercial areas are subject to between 2.6m AHD to 3.3m AHD water levels during the peak 1% AEP coincident flood in the Year 2100. The resultant flood risk varies across the study area with lower lying areas backing onto Browns River being exposed to relatively high velocities and flood depths compared to the higher ground adjacent to Osborne Esplanade i.e. the flood risk decreases across Kingston Beach from Browns River to the beach.

The results further indicate that for the design coincident flood event catchment (fluvial) flood is the dominant factor affecting flood risk in Kingston Beach, compared with storm surge. The influence of catchment flooding on coincident flood risk in Kingston Beach increases in scenarios that incorporate a lower than design storm tide. Conversely, the dominance of the catchment flood is expected to reduce as sea level rise increases throughout the 21st century.

Due the size of the undeveloped portion of the catchment compared to the projected future urban growth area the comparison of the current and future development shows that there is only a moderate increase in inflow rate from Browns River and Whitewater Creek to Kingston Beach due to development. Projected climate change impacts to both rainfall intensity and sea level are the principle factor causing an increased flood risk in Kingston Beach throughout the 21st century.

Potential Mitigation

A Preferred Mitigation Scheme is proposed combining channel straightening with entrance opening. Both options are complimentary. Combined they have a significant impact of the flood behaviour, reducing the risk of flood inundation within the lower Browns River floodplain.

Further detailed assessment of the Preferred Mitigation Scheme is recommended due to the positive hydraulic benefits associated with the design. Recommended assessments include:

- Erosion Assessment: to identify the erosion potential associated with the design geometry for the Preferred Mitigation Scheme. This will inform the erosion protection required to safeguard the scour. This is particularly relevant for the bypass channel where it connects to the Browns River.
- Joint Probability Analysis: to examine the likelihood of coincident freshwater flooding, surge and high tide conditions. This assessment would help to understand the average recurrence interval for combined flood and tail water events.
- Data Collection: obtain a tidal water level and flow dataset to support tide model calibration which would allow a detailed assessment of tidal prism and surge propagation impacts associated with changes to the river entrance.
- Coastal Processes Assessment: to quantify the logistics and ongoing costs associated with maintaining an open entrance condition. The assessment should include liaison with local contractors to determine what sand bypassing services using land-based excavation and/or dredging machinery are available.

Conclusion

This report has provided a summary of an extensive flood risk study of Kingston Beach resulting in a number of recommendations as outlined below.

Recommendations

1. That Council develop a Flood Emergency Plan for Kingston Beach.
2. That Council investigate the costs of installing a flood gauge on Browns River and develop options for use of the data for use by the BoM in their flood warning system.
3. That Council endorse the 1% Annual Exceedence Probability co-incident flood maps developed in this study and incorporate into the Kingborough Interim Planning Scheme as a flood overlay for the area.
4. That Council undertake further detailed assessment of the potential mitigation/protection schemes that provide a significant reduction in flood risk for Kingston Beach.

1 INTRODUCTION

1.1 STUDY LOCATION

Kingston Beach is one of the older residential areas within Kingborough with many of the existing residences beginning as beach-side shacks during the late nineteenth century. The most striking feature is the beach itself which is sited along the sandy coastal landform of the Derwent River. The beach and the vicinity of the Kingston Beach Golf Course are low and flat, and are approximately 1 m to 3 m above the Australian Height Datum (AHD). Thus, it is highly vulnerable to heavy rainfall and storm surge events (Figure 1).

Figure 1: Kingston Beach, Kingborough

1.2 CONTEXT AND SCOPE

The Tasmanian Coastal Adaptation Decision Pathways Project (TCAP) is a federally funded project that, through a series of case studies, develops guidelines for how particular local areas could adapt to sea level rise and storm surge impacts. The coastal case study sites are at Kingston Beach, Lauderdale, Port Sorell and St Helens.

A key recommendation from the report *Tasmanian Coastal Adaptation Decision Pathways Project: Inundation Control Works for the Kingston Beach Area (Pitt & Sherry, Oct 2012)* was the requirement for the development of a model that could assess the potential co-incident flood risk from fluvial and coastal sources, including climate change impacts. The overarching aim of the Coastal Adaptation Pathways Project is to inform affected residents and the wider community about changing coastal risks associated with climate change.

This report summarises the subsequent flood risk study undertaken for Kingston Beach as recommended. It provides a comprehensive assessment of the flood risk from both coastal and fluvial sources including predicted climate change impacts.

1.3 STUDY OBJECTIVES

The key objective of this Flood Study is to define the flood behaviour under existing and future potential climate conditions in the Browns River catchment for a full range of design catchment flood, coastal flood and coincident flood events. This study will provide information on flood levels and depths, velocities, hydraulic categories and provisional hazard categories.

The objectives of the Kingston Beach Flood Study are as follows:

i) To assess the existing and future flood risk of Kingston Beach.
ii) To investigate the level of severity of the flood events and its impact to the community.
iii) To provide a better management of the flood impacts for existing and future conditions.
iv) To identify the mitigation strategies and priorities for emergency management, land use planning and flood management.
v) To update and extend any relevant previous flood studies' reports.
vi) To produce robust hydrology and hydraulic modelling tools according to the current best practice procedures which are able to estimate the flood characteristics and behaviour of the Browns River catchment.

1.4 KINGSTON BEACH FLOOD HISTORY

There have been many minor to moderate flood events at Kingston Beach which have been recorded over the last century in *Kingston Beach/Browns River: a flood and storm history* (Evans, K; 2015). The following are several examples of key flood risk factors that have caused damages to the properties in the past:

1) Heavy sea/storm surge (Aug 1908/Jun 1910)
2) Heavy storm event (Feb 1917)
3) Coincident flood (Jun 1909)
4) Sand bar across the mouth of Browns River backed up waters of the river flooded downstream (Sep/Oct 1951)
5) Flooded due to drainage blockage at low lying area during high tide (May/Jul 1935)

Those recorded moderate flood events resulted in damages to property and loss which included the drowning of a child in Browns River under flood (March 1911), bridges damaged (Feb 1917), jetty and platform damaged (June 1937/July 1939/March 1946), retaining wall washed away/collapsed (Aug 1917/May 1973), houses flooded (Aug 1908/Oct 1926/Feb 1933/ May/July 1935/March 1938), significant beach erosion (Feb 1933), golf course inundated (March 1938), boats washed ashore (Sept/Oct 1951), picnic shed damaged (Oct 1952), Beach Road inundated (Aug 1908), landslide occurred (June 1954) and shopping centre inundated (March 1997). Flooding has occurred several times since with the most recent event occurring on 14 January 2015 when Beach Road houses adjacent to Browns River experienced minor flooding of back yards and several low lying fairways of the Kingston Beach Club were partially inundated.

A more comprehensive history of flood and other natural hazard events in Kingston Beach can be found in the *Kingston Beach Integrated Climate Change and Natural Hazards Project Report,* (Climate Planning, 2016).

2 STUDY APPROACH

2.1 CATCHMENT DESCRIPTION

The Browns River catchment is located close to the CBD of Kingston in north-eastern corner of the Kingborough municipal area in the South East of Tasmania as shown in Figure 1. The catchment occupies a total area of approximately 6000 ha and drains to the Derwent Estuary through a mobile coastal dune system at the northern end of Kingston Beach.

The Browns River catchment can be separated into three major sub-catchments namely Browns River, Vincent's Rivulet and Whitewater Creek. Figure 2 highlights some of the minor creeks and rivulets that comprise the Browns River catchment including Fork Creek, Long Creek, Fern Tree Creek, Fawcett Rivulet, Fisher Creek, Dunns Creek, Boddy's Creek and Colonels Creek. Area and stream length details of the major and minor sub-catchments within Browns River catchment are presented in Table 1.

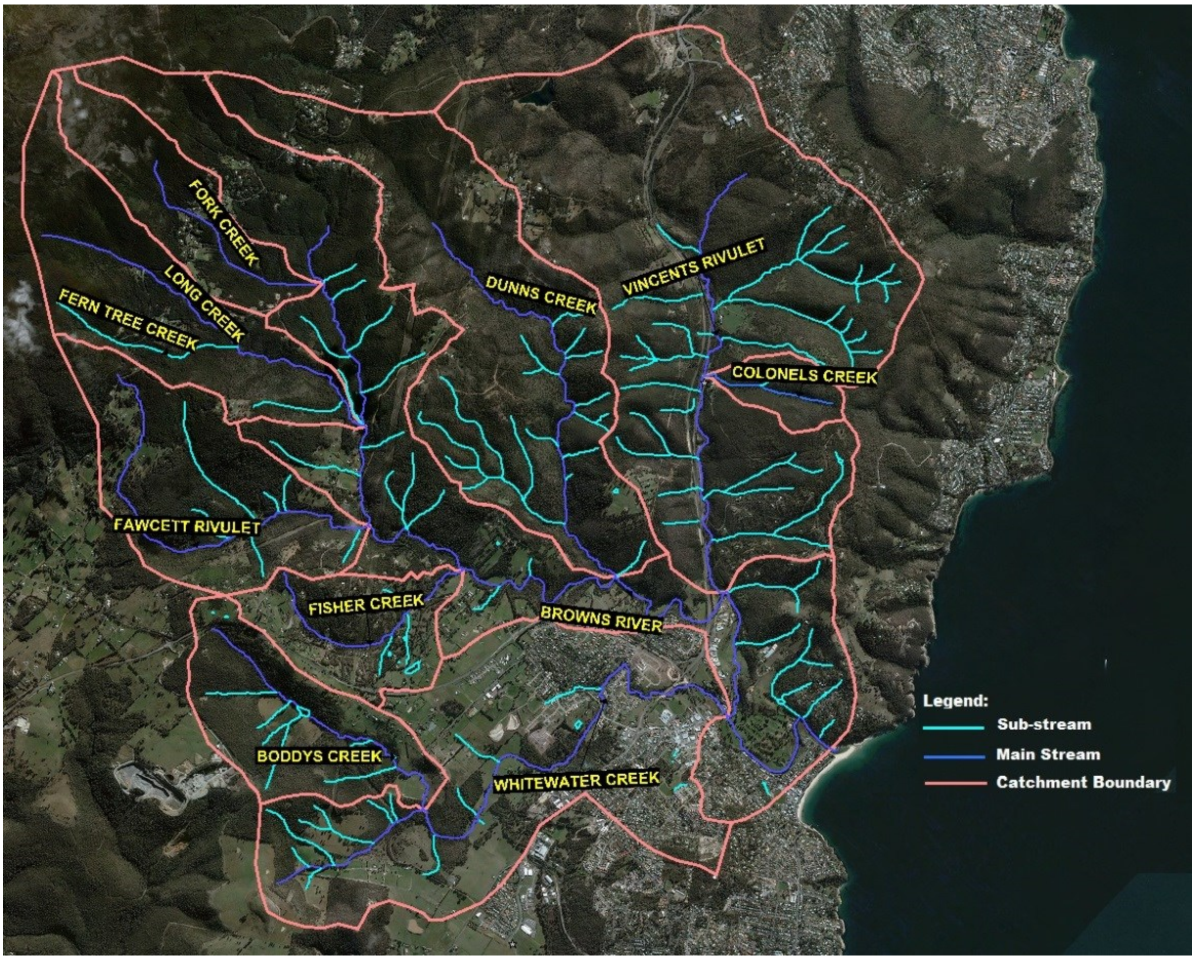


Figure 2: Waterways in Browns River Catchment

Table 1: Catchment Areas

River Catchment	Main Stream Length (km)	Area (Ha)
Colonels Creek	1.75	68
Vincent's Rivulet	4.98	1421
Dunns Creek	4.98	816
Fork Creek	2.51	231
Long Creek & Fern Tree Creek	4.21	428
Fawcett Rivulet	4.63	421
Fisher Creek	2.68	213
Boddys Creek	3.47	302
Whitewater Creek	6.83	880
Browns River	12.8	1179

The topography of the catchment is depicted in Figure 3, which illustrates the significantly varying topography across the catchment from the steep upper slopes of Mt Wellington and Ridgeway in the North-west to the moderately steep rolling hills of Leslie Vale and the upper reaches of Whitewater Creek in the middle third of the catchment and lastly to the flat low coastal floodplain around Kingston Beach close to Browns River's confluence with the River Derwent.

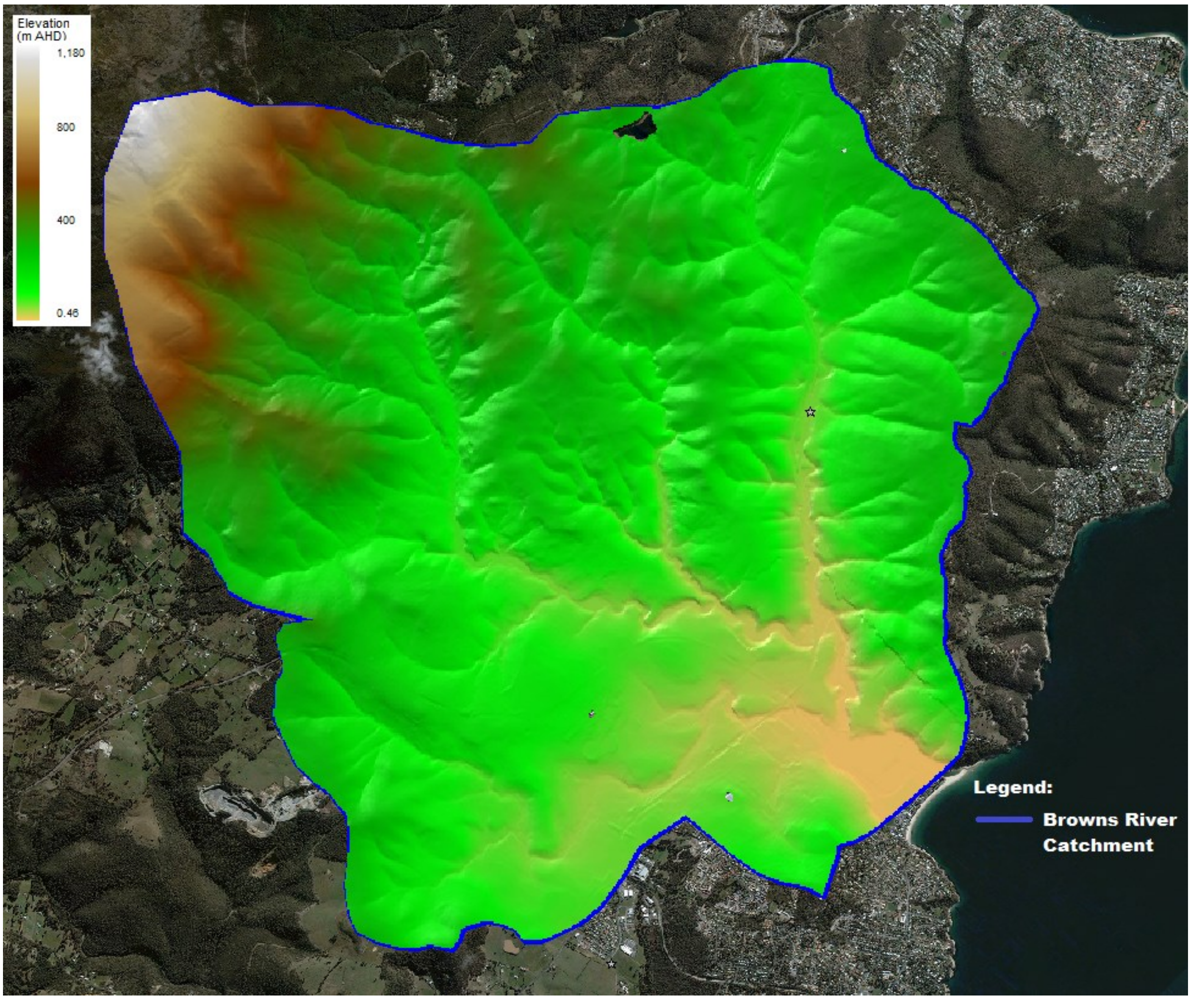


Figure 3: Topography of Browns River Catchment

2.2 REVIEW OF AVAILABLE DATA

2.2.1 PREVIOUS FLOOD STUDIES

2.2.1.1 TASMANIAN COASTAL ADAPTATION PATHWAYS PROJECT: KINGSTON BEACH – FINAL REPORT (SGS, 2012)

This was the first report undertaken as part of the TCAP project to examine the impact of climate change on coastal risks in the vicinity of Kingston Beach. There were several coastal storm surge hazard maps produced including scenarios under the present sea level and predicted sea level rise of 0.3 m, 0.9 m and 1.8 m with 1% AEP extreme event.

Additionally, the report tabled the present day storm surge levels with different probabilities of occurrence, reproduced here in Table 2.

Table 2: Present Day Storm Surge Level (SGS, 2012)

Average Return Interval (ARI)	1	5	10	50	100	200
Annual Exceedance Probability (AEP)	**63%**	**18%**	**9.5%**	**2%**	**1%**	**0.5%**
Storm Sea Level (m AHD)	0.97	1.12	1.18	1.28	1.32	1.35

The study estimated the damages of an extreme storm surge event (1% AEP) by year 2100 to be up to $7 million on today's values was reported in the study. This is a base scenario excluding subsequent depreciation and/or capital value increases. Table 3 summarised the key finding about storm surge inundation risks at Kingston Beach.

Table 3: Number of Kingston Beach Properties Inundated by 1% AEP Storm Surge

Height of SLR (m)	Estimated Year	Estimated no. of inundated properties	Average over-floor depth (m)
0.0	2010	4	0.15
0.25	2050	11	0.20
1.0	2100	84	0.32

A significant limitation of this study was that it did not consider the coincident risk of fluvial or river sourced flood with storm surge. Consequently, a key recommendation was for the development of a comprehensive flood risk model able to analyse the coincident flood risk.

2.2.1.2 TASMANIAN COASTAL ADAPTATION DECISION PATHWAYS PROJECT: INUNDATION CONTROL WORKS FOR THE KINGSTON BEACH AREA (PITT & SHERRY, 2012)

The objectives of this report were to further investigate climate change impacts on Kingston Beach flood risk and to identify potential mitigation options. The mitigation options considered a 0.5 m and 0.9 m sea level rise with the 100 year ARI storm surge event.

A hydrological analysis of the Browns river catchment was undertaken using RORBwin and flood levels were estimated using the 1D hydraulic modelling software HEC-RAS for Browns River from the Channel Highway to the mouth of the river at Kingston Beach.

The results of estimated flow rates in Browns River upstream of Kingston Beach are shown in Table 4.

Table 4 : Estimated Flow Rates in Browns River (Pitt & Sherry, 2012)

Average Recurrence Interval (years)	Peak Flow at the mouth of Browns River (m^3/sec)
10	126
20	167
50	218
100	266

The study provided un-calibrated 100 year ARI flood levels for Browns River adjacent to Kingston Beach for the Year 2100 including tailwater incorporating climate change predictions.

The report identified potential mitigation options to minimise the flood risk in Kingston Beach including raising dwelling floor levels, roads and streets, extending the existing sea wall and building a barricade. Further, it provided an order of magnitude cost estimate for the sea wall/barricade option of approximately $17 M, with this figure excluding several significant costs such as relocation/replacement of telecommunication and sewerage infrastructure.

The report recognised that the flood risk analysis, due to limited data and budget, was limited and did not include an analysis of the coincident fluvial and coastal flood risk. Therefore it recommended a comprehensive flood study be undertaken to further develop a meaningful understanding of the flood risk in Kingston Beach.

2.2.2 SITE INSPECTION

Several inspections of key areas within Browns River were undertaken by Council officers over the period of the study. The purpose of the site inspections was to:

i) Identify the vegetation in each region are the same as GIS aerial photographs.
ii) Identify the manning roughness and characteristics of the river banks.
iii) Gather photographic and anecdotal evidence of previous flood heights.
iv) The dimension of the Whitewater Creek Bridge, Browns River Bridge and Pedestrian Bridge.

2.2.3 GIS INFORMATION

All GIS data used in this study has been derived from Kingborough Council's MapInfo GIS database, including the location and details of waterways, roads, drainage network system, cadastre, up-to-date planning land use zones, background images and the Digital Elevation Model (DEM). The overall catchment and 78 sub-catchments were delineated according to the LIDAR generated 5m contours.

2.2.4 TOPOGRAPHIC DATA

The LiDAR data was collected on 20 to 28 January 2011 by Photomapping Services. The LiDAR data was derived with a stated vertical accuracy +/- 0.15m @ 68% confidence and horizontal accuracy +/- 0.30m @ 68% confidence.

Raw LiDAR data in the form of ground surface points were used to create a high accuracy DTM in the vicinity of Kingston Beach. The ground surface elevation for the 2D model grid points were sampled directly from the DEM.

The stated vertical and horizontal accuracy of the LiDAR data is only applicable to land surface areas with detailed survey and bathymetry used to improve accuracy around structures and define channel shape.

2.2.5 SURVEY & BATHYMETRIC DATA

Council's asset team undertook survey of several bridges within the study area on 17 April 2015 utilising a Nikon Pulse laser Total Station (Model NPL 352).

A bathymetric survey of Browns River was undertaken using a Trimble R8 DGPS related back to a Topcon Base Station located at Council's Civic Centre (Kingborough Council, 2015). The bathymetric survey was incorporated into the DTM to improve channel definition within the study area.

2.2.6 AERIAL PHOTOGRAPHY

The high resolution aerial photography utilised in this project were derived from (Land Information Service Tasmania LIST – 2011). The photographs taken from the elevated position to the ground provide the information on existing development extent and vegetation patterns.

The aerial photos are used to determine the existing surface condition such as pervious and impervious areas and manning's 'n' roughness values. The photographs also aided in cross checking catchment delineation based on the LiDAR.

2.2.7 LAND USE DATA

Existing and future land use was modelled in the flood study to reflect current and future levels of urbanisation across the Browns River catchment. Existing land use and extent of development was estimated from interrogation of aerial photography taken in year 2011. The Kingborough Interim Planning Scheme 2015 adopted by Council in July 2015 was used as the guide to determine the predicted future landuse and extent of development as shown in Figure 4.

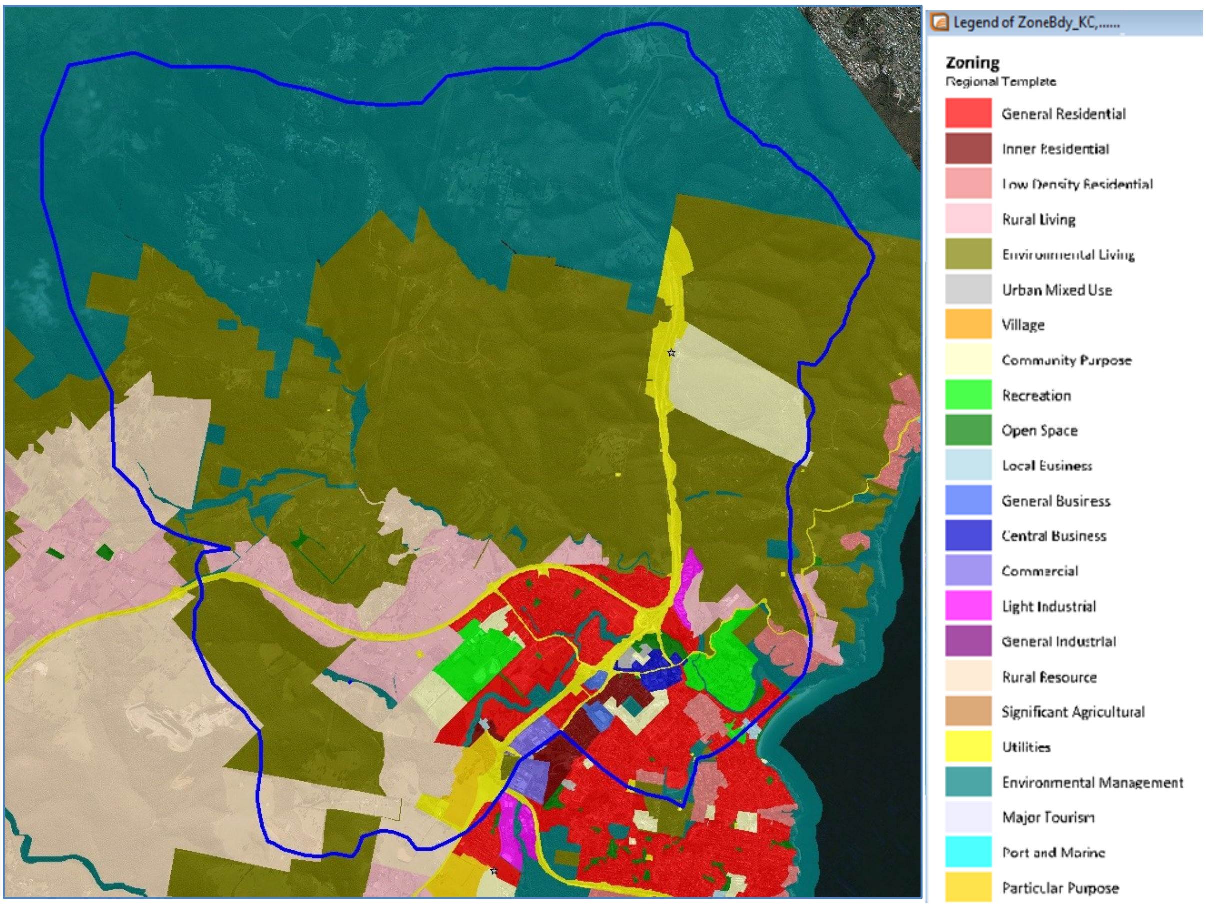


Figure 4: Browns River Catchment Ultimate Land Use (KIPS, 2014)

The Kingborough Interim Planning Scheme 2015 allows for significant increases in urbanisation in the lower and middle reaches of the catchment which has been reflected in the future scenario models. In addition to urbanisation of the middle reaches the KIPS 2015 allows for infill development of the lower reaches of the catchment including Kingston Central and some areas of Kingston Beach. The ultimate land use designations are shown in Figure 4.

2.2.8 DESIGN RAINFALL

The rainfall data used in the study was derived from Intensity–Frequency–Duration (IFD) obtained from BOM and defined by Australia Rainfall and Runoff (AR&R 87).

Browns River catchment is divided into 3 rainfall IFD regions which have been delineated roughly according to their height datum. The derivation of location specific design rainfall parameter (eg rainfall depth and temporal pattern) of Fern Tree, Summerleas Road and Kingston Beach are presented in Figure 5 and the IFD for each station is recorded in Table 5, Table 6 and Table 7

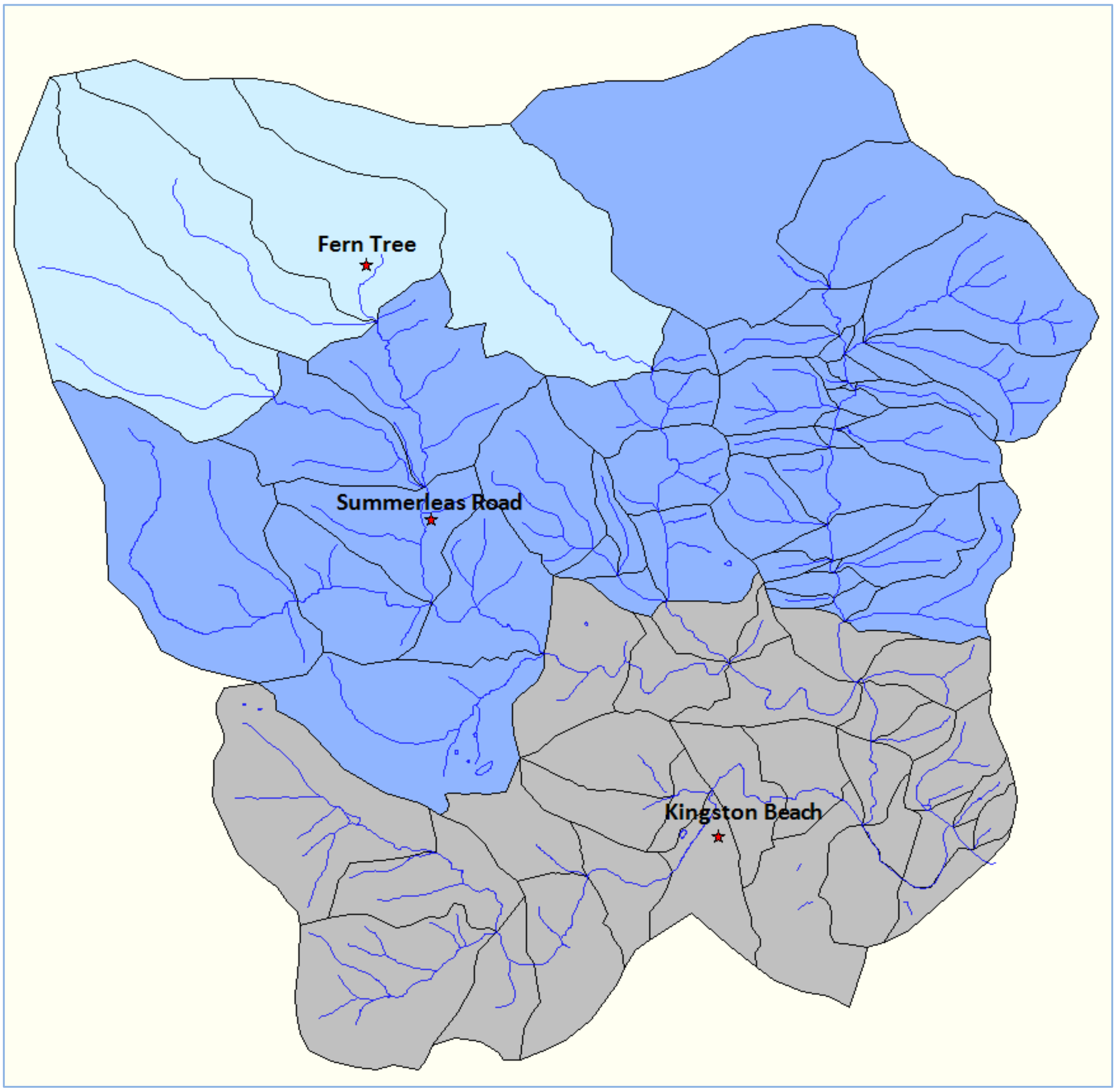


Figure 5: Rainfall Catchments IFD Location Obtained for Browns River Flood Study

Table 5: Design Rainfall Data for Kingston Beach (Location: 42.975S; 147.300E)

Duration	Design IFD for Annual Exceedance Probability (AEP)						
	63%	40%	20%	10%	5%	2%	1%
	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
5 Mins	31.3	43.1	64.2	79.7	100.3	131.2	157.9
6 Mins	29.5	40.5	59.8	74.0	92.6	120.6	144.6
10 Mins	24.5	33.3	48.0	58.5	72.3	92.7	110.1
20 Mins	18.3	24.5	33.9	40.3	48.9	61.2	71.5
30 Mins	15.2	20.1	27.0	31.6	37.8	46.7	54.0
1 Hr	10.7	13.8	17.7	20.2	23.5	28.2	32.0
2 Hrs	7.3	9.5	12.3	14.1	16.5	19.9	22.7
3 Hrs	5.9	7.6	9.9	11.4	13.4	16.2	18.4
6 Hrs	4.0	5.2	6.8	7.9	9.3	11.3	12.9
9 Hrs	3.2	4.2	5.5	6.4	7.5	9.2	10.5
12 Hrs	2.7	3.6	4.7	5.5	6.5	7.9	9.1
18 Hrs	2.1	2.8	3.7	4.3	5.1	6.2	7.1
24 Hrs	1.8	2.3	3.1	3.6	4.2	5.2	5.9

Table 6: Design Rainfall Data for Summerleas Road (Location: 42.950S; 147.275E)

Duration	Design IFD for Annual Exceedance Probability (AEP)						
	63%	40%	20%	10%	5%	2%	1%
	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
5 Mins	34.6	47.2	69.0	84.7	105.5	136.6	163.2
6 Mins	32.6	44.4	64.3	78.7	97.6	125.8	149.8
10 Mins	27.2	36.6	51.8	62.4	76.6	97.3	114.8
20 Mins	20.3	27.0	36.7	43.3	52.2	64.8	75.3
30 Mins	16.8	22.1	29.3	34.1	40.6	49.7	57.2
1 Hr	11.8	15.3	19.3	21.9	25.5	30.4	34.3
2 Hrs	8.2	10.6	13.6	15.6	18.2	21.9	24.9
3 Hrs	6.6	8.5	11.1	12.7	14.9	18.1	20.6
6 Hrs	4.5	5.9	7.7	8.9	10.6	12.9	14.8
9 Hrs	3.6	4.7	6.3	7.3	8.7	10.6	12.2
12 Hrs	3.1	4.0	5.4	6.3	7.5	9.3	10.7
18 Hrs	2.4	3.1	4.2	4.9	5.9	7.2	8.3
24 Hrs	2.0	2.6	3.5	4.1	4.9	6.0	7.0

Table 7: Design Rainfall Data for Fern Tree (Location: 42.925S; 147.250E)

Duration	Design IFD for Annual Exceedance Probability (AEP)						
	63% (mm/hr)	40% (mm/hr)	20% (mm/hr)	10% (mm/hr)	5% (mm/hr)	2% (mm/hr)	1% (mm/hr)
5 Mins	38.6	53.0	78.5	97.2	122.0	159.5	192.0
6 Mins	36.4	49.9	73.4	90.6	113.5	147.9	177.5
10 Mins	30.3	41.2	59.6	72.9	90.4	116.7	139.1
20 Mins	22.6	30.5	42.9	51.6	63.2	80.2	94.6
30 Mins	18.7	25.0	34.6	41.2	50.0	62.8	73.5
1 Hr	13.2	17.4	23.2	27.1	32.4	39.9	46.1
2 Hrs	9.4	12.4	16.6	19.4	23.1	28.5	33.0
3 Hrs	7.7	10.1	13.5	15.8	18.9	23.3	27.0
6 Hrs	5.4	7.2	9.6	11.2	13.4	16.5	19.1
9 Hrs	4.4	5.8	7.8	9.2	11.0	13.5	15.7
12 Hrs	3.8	5.1	6.8	8.0	9.5	11.7	13.6
18 Hrs	2.9	3.9	5.3	6.2	7.4	9.2	10.7
24 Hrs	2.4	3.2	4.4	5.2	6.2	7.7	9.0

2.2.9 CLIMATE CHANGE

The potential impacts of predicted climate change were considered for all future events. *Climate Future for Tasmania* modelling (White et al, 2012) indicates that the 24 hr 1% AEP rainfall event intensities may increase by 10% to 30% in the South Eastern Tasmanian area. Potential changes in rainfall intensity in different duration events may be different.

The NSW Government's Practical Consideration of Climate Change, Floodplain Risk Management Manual (DECC, 2007) allows for an increase in design rainfall intensities of up to 30%. The local climate profile for Kingborough Municipality shows increases of rainfall intensities approximately 15-30%.

In this study, 10% and 30% increase in rainfall intensities were adopted for all design events of Year 2050 and 2100 respectively.

2.2.10 ENTRANCE BOUNDARY CONDITION

The Browns River entrance is influenced by a large mobile dune system extending across the northern end of Kingston Beach through to Tyndall Beach. The entrance is regularly closed by the action of waves, tides, wind and sand deposit, combined with periods of low flow in the river. However, it can be opened by flood flows and/or minor dredging, which results the entrance intermittently closed and open.

Council has a policy to keep the mouth of Browns River open by excavation if necessary when the river reaches a level that increases the risk of flooding to upstream infrastructure and property.

A sensitivity analysis was undertaken on different berm conditions and it is presented in Section 8 for the purposes of the design flood condition. A 2m scour at the front of the river mouth was adopted in the design runs.

2.2.11 SEA LEVEL RISE

Sea level rise allowances as a result of climate change have been adopted from a report letter from John Hunter (April, 2015) *Sea-Level Rise Planning Allowances for Kingston Beach, Tasmania*.

Table 8: Allowances of Sea Level Rise in Year 2050 and Year 2100

Source of storm tide data	Year 2010 - 2050	Year 2010 - 2100
Storm-tide model	0.24m	0.99m
Hobart tide gauge	0.23m	0.94m

A conservative allowance of 0.3m sea level rise in Year 2050 and 1 m sea level rise in Year 2100 was adopted in this flood study.

2.2.12 OCEAN TIDE DATA

Water Research Laboratory (WRL, Feb 2016) has developed a set of design ocean water level time series for Kingston Beach for use as boundaries in a numerical flood model. A typical 1% AEP tidal signal is shown in Figure 6. The tidal signal constructed includes Year 2100, 2050 and present day of 63%, 10%, 5%, 2% and 1% AEP storm surge events.

Table 9 provides a summary of these tidal signals that shows values for their major components. Full details of the derivation of the tidal signals are provided in **Appendix A**.

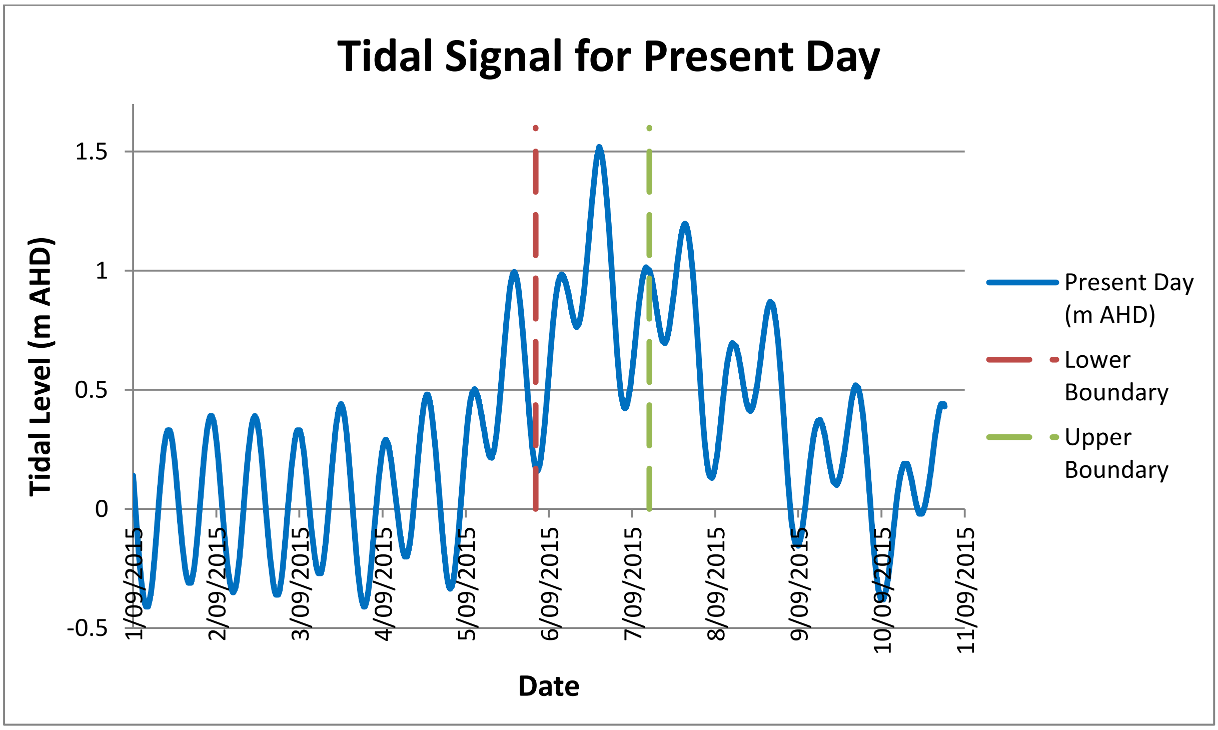


Figure 6: Typical 1% AEP Tidal Signal (Tide + Anomaly + Wave Setup)

Table 9: Summary of Tail Water Levels

Scenario	AEP	ARI	Tide + Storm Surge	Sea Level Rise	Peak Wave Setup d = 0m	Peak Design Nearshore Water Level
(year)	(%)	(year)	(m)	(m)	(m)	(m AHD)
Present Day	63	1	0.97	0	0.25	1.22
	9.5	10	1.21		0.30	1.51
	5	20	1.26		0.34	1.60
	2	50	1.37		0.35	1.72
	1	100	1.44		0.38	1.82
2050	63	1	0.97	0.4	0.25	1.62
	9.5	10	1.21		0.30	1.91
	5	20	1.26		0.34	2.00
	2	50	1.37		0.35	2.12
	1	100	1.44		0.38	2.22
2100	63	1	0.97	0.9	0.25	2.12
	9.5	10	1.21		0.30	2.41
	5	20	1.26		0.34	2.50
	2	50	1.37		0.35	2.62
	1	100	1.44		0.38	2.72

3 COMMUNITY ENGAGEMENT

This flood study has been undertaken under the umbrella of the Tasmanian Climate Change Adaptation Study and as such community engagement to date has been facilitated through that project's Community Engagement Strategy. The details of the community engagement approach and outcomes can be found in *Kingston Beach Integrated Climate Change and Natural Hazards Project Report* (Climate Planning, 2016).

It is critical that the flood-prone communities of Kingborough be made aware – and remain aware – of their role in the overall floodplain management strategy for the municipality, including defence of their communities and the evacuation of themselves. Sustaining an appropriate level of flood awareness involves continuous effort by Council and the emergency services but can significantly increase the community's resilience to future flood events.

There can be widespread variation in flood awareness in a community which may result in a degree of variation in flood damage assessment and risk management. Feedback from long term Kingston Beach residents at a recent Natural Hazard and Climate Change information session held at Kingston Beach Hall on 31 March 2016 highlighted the variability of knowledge and perception of historical flooding in the area, with some residents having markedly different accounts of the same historical events depending on their specific experiences. As time passes between significant events awareness of previous events reduces and may be absent in residents new to the area. Council can enhance flood awareness through, for example, regular public education programs via newspaper, videos, pamphlets, meetings and other media outlets. Community awareness brochures have been widely adopted in more flood prone areas of the State. Launceston City Council provides a good example of actively promoting flood risk awareness for their communities in Invermay via the use of the communication measures listed above. For Kingston Beach provision of flood awareness brochures could include material specific to the local region and provide the following information:

- What floods are and the history on flooding in Kingston Beach

- Flood behaviour in Kingston Beach

- Flood warnings

- What to do before, during and after a flood

- Preparation of a household emergency plan

4 MODEL DEVELOPMENT

4.1 MODELLING APPROACH

A hydrology model was developed that covers all of the Browns River catchment from Kingston Beach to the slopes of Mount Wellington. The catchment is approximately 6,000 ha and has been delineated into 78 sub-catchments. The extent of the Browns River catchment and its location in relation to Kingborough is shown in Figure 7.

A 2D hydraulic model was developed to encompass the lower Browns River Flood Plain as shown in Figure 7. The hydraulic model extends from immediately upstream of the Channel Highway to the outlet of Browns River on Kingston Beach with the side boundaries defined by steeply rising hills in the north and south.

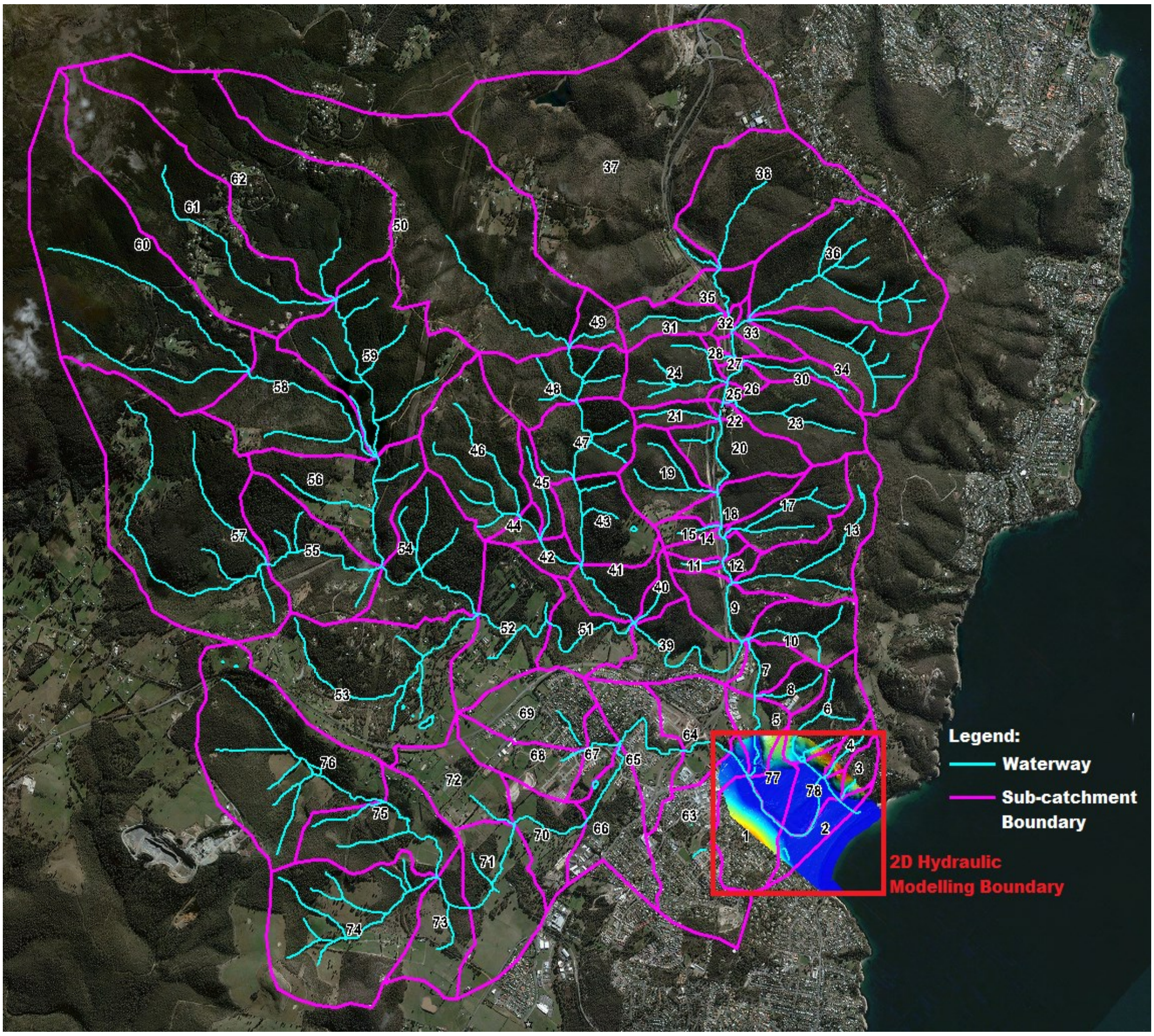


Figure 7: Browns River Catchment, Kingborough

4.2 SOFTWARE OVERVIEW

All GIS data used in this study has been derived from Council's MapInfo Pro GIS database, including the location and details of rivers, cadastre, planning zones, background images and the Digital Elevation Model (DEM).

MapInfo is a mapping and geographic analysis application. It can turn data into information; creating and sharing the visualised data in relationships between data and geography. Engage3D and Engage3D Surface are also frequently used in this study. Engage3D can produce stream-lined maps to powerful 2D and 3D analytical tools. The model uses spatial information such as terrain or demographic data against interpolated surfaces with Engage3D, allowing powerful trend identification, analysis and refinement. The visualised model is extremely helpful in presentations.

XP Solution's Stormwater & Wastewater Management Model (SWMM) has been used to assess the hydrology and hydraulics for existing and ultimate development and determine the flood risk in the catchment. It is a dynamic modelling tool that is the combination of one-dimensional (1D) calculations for the channel flow and two-dimensional (2D) calculations for the surface runoff modelling. It is software that easily examines the flow condition in the channel and also the surfaces. Thus, using software modelling could increase the accuracy, time and cost to assess a catchment's flood behaviour.

4.3 HYDROLOGICAL MODEL

4.3.1 CATCHMENT DELINEATION

The overall catchment and its constituent sub-catchments were delineated according to the LIDAR generated contours in GIS. The sub-catchment delineation provides for generation of flow hydrographs at key confluences or inflow points to the hydraulic model. The delineated catchments are exported in MapInfo Interchange (.mif) file type in order to import in SWMM.

The catchment occupied 6000 ha and drains to the Derwent River. There are 78 sub-catchments delineated. Table 10 presents a summary of key catchment parameters adopted in the XP-RAFTS model, including the catchment size, impervious area, catchment roughness and slope.

Table 10: Details for Each Sub-catchment

Catchment	Node Name	Area (ha)	Impervious (%)		Slope (%)	Infiltration
			Existing	Ultimate		
1	Node 5	52.6	70	70	10	Pervious Urban
2	Node 55	21.8	70	70	1	Pervious Urban
3	Node 2	12.1	26.9	26.9	17.2	Pervious Urban
4	Node 3	10.8	29.1	29.1	20.9	Pervious Urban
5	Node 47	30.0	20.0	28.0	9.7	Rural (pasture)
6	Node 4	46.9	11.8	11.8	10.3	Pervious Urban
7	Node 7	23.2	10	23.9	11.1	Pervious Urban
8	Node 7	19.0	6.4	6.4	14.1	Rural (pasture)
9	Node 8	39.6	2.8	10.1	8.4	Rural (pasture)
10	Node 8	48.4	0	4.0	14.6	Light Forest
11	Node 10	6.4	0	8.7	27.0	Light Forest
12	Node 9	8.6	5	15.8	14.3	Light Forest
13	Node 9	82.2	2.3	11.7	13.6	Light Forest
14	Node 10	13.5	5	20.3	14.7	Light Forest
15	Node 12	11.3	2	7.5	21.0	Light Forest
16	Node 11	1.7	39.8	39.8	17.8	Light Forest
17	Node 11	54.1	17.3	17.3	17.3	Light Forest
18	Node12	30.9	5	18.9	15.1	Light Forest
19	Node 13	51.8	0	5.4	12.6	Light Forest
20	Node 13	61.3	5	36.4	10.0	Light Forest
21	Node 14	16.8	0	17.4	19.5	Light Forest
22	Node 14	4.3	10.0	47.7	8.6	Light Forest
23	Node 15	68.2	0	5.1	11.6	Light Forest
24	Node 16	55.6	0	9.6	16.1	Light Forest
25	Node 15	4.8	10	62.5	10.7	Light Forest
26	Node 16	8.2	5	34.3	12.1	Light Forest
27	Node 17	0.6	5.1	60.1	10.3	Light Forest
28	Node 18	4.0	5	41.4	16.0	Light Forest
29	Node 18	6.3	10.0	48.5	15.8	Light Forest
30	Node 17	22.0	0	5.0	16.8	Light Forest
31	Node 21	32.3	2	9.0	18.3	Light Forest
32	Node 19	4.8	10.0	84.2	19.9	Light Forest
33	Node 19	14.8	0	12.0	13.3	Light Forest
34	Node 20	83.5	0	5.0	8.4	Heavy Forest
35	Node 21	22.2	10.0	35.9	19.3	Light Forest
36	Node 20	163	0	3.8	8.4	Heavy Forest
37	Node 22	497.3	0	0	5.8	Heavy Forest
38	Node 22	145.1	0	1..0	8.7	Heavy Forest

39	Node 8	67.8	10.0	29.8	2.6	Rural (pasture)
40	Node 23	13.7	0	5.0	7.3	Light Forest
41	Node 23	36.0	2.2	2.2	14.3	Light Forest
42	Node 24	16.1	0	5.0	10.4	Light Forest
43	Node 24	64.1	0	5.0	8.5	Light Forest
44	Node 25	10.9	0	5.0	15.9	Light Forest
45	Node 25	20.3	0	5.0	14.4	Light Forest
46	Node 26	113.9	0	5.0	13.5	Light Forest
47	Node 27	65.9	0	5.0	9.2	Light Forest
48	Node 28	72.5	0	5.0	19.3	Light Forest
49	Node 29	20.4	0	5.0	32.9	Heavy Forest
50	Node 29	381.1	0	1.2	6.9	Heavy Forest
51	Node 23	50.1	14.3	14.3	21.5	Rural (pasture)
52	Node 30	98.6	5.0	7.2	8.7	Rural (pasture)
53	Node 31	212.9	5.0	10.2	6.2	Light Forest
54	Node 31	113.3	2.0	4.9	6.4	Light Forest
55	Node 32	104	2.0	4.5	8.6	Light Forest
56	Node 32	104.8	2.0	4.6	11.3	Light Forest
57	Node 33	317.3	2.0	4.2	9.8	Light Forest
58	Node 34	109.8	0	4.0	9.7	Light Forest
59	Node 34	173.5	0	4.6	7.3	Light Forest
60	Node 35	318	0	2.0	20.5	Heavy Forest
61	Node 36	231.4	0	0	18.8	Heavy Forest
62	Node 36	255.4	0	0	15.4	Heavy Forest
63	Node 6	106.3	61.0	61.0	5.2	Rural (pasture)
64	Node 37	57.9	71.9	71.9	4.1	Pervious Urban
65	Node 38	61.8	70.4	70.4	4.5	Pervious Urban
66	Node 39	69.9	76.7	76.7	3.6	Pervious Urban
67	Node 39	20.9	72.4	72.4	6.0	Pervious Urban
68	Node 40	47.5	27.1	27.1	7.4	Rural (pasture)
69	Node 40	68.5	55.8	55.8	6.8	Pervious Urban
70	Node 41	50.8	20	55.3	2.2	Rural (pasture)
71	Node 42	96.8	0	37.2	2.6	Rural (pasture)
72	Node 42	60.4	0	15.8	1.0	Rural (pasture)
73	Node 43	60.5	0	12.1	6.2	Rural (pasture)
74	Node 44	178	0	5.0	6.4	Rural (pasture)
75	Node 44	93.6	0	6.2	6.5	Rural (pasture)
76	Node 45	208.3	2	7.8	6.7	Light Forest
77	Node 55	20.0	0	0	0.1	Rural (pasture)
78	Node 56	31.4	0.1	0.1	1.0	Rural (pasture)
Total		6000	11.5	21.3	-	-

4.3.2 DESIGN RAINFALL

The rainfall intensity, frequency and duration data were obtained from the BOM. In this project, 3 different IFD zones were applied across a catchment according to their range of height from the sea level.

The 20% AEP, 5% AEP and 1% AEP design flood extents within the Browns River catchment were determined by using the XP-SWMM dynamic modelling software for both hydrology and hydraulics.

Each of the nominated design flood events was simulated in the hydrology runoff mode in order to identify the critical storm. The design storm durations that have been tested include 30, 60, 90, 120, 180, 270 minutes, also, 6, 9, 12, 18 and 24 hours. After the comprehensive analysis of these results through the software, the critical storm duration for 1% AEP design rainfall was determined to be the 9-hour storm event as shown in Table 11 and Figure 8.

Table 11: Peak flow at the Confluence of Browns River and Whitewater Creek in Year 2100 with Mean High Water Spring (MHWS) Tail Water Level

Duration (mins)	30	60	90	120	180	270	360	540	720	1080	1440
Peak Flow (m^3/s)	150	201	269	320	367	383	469	513	512	378	427

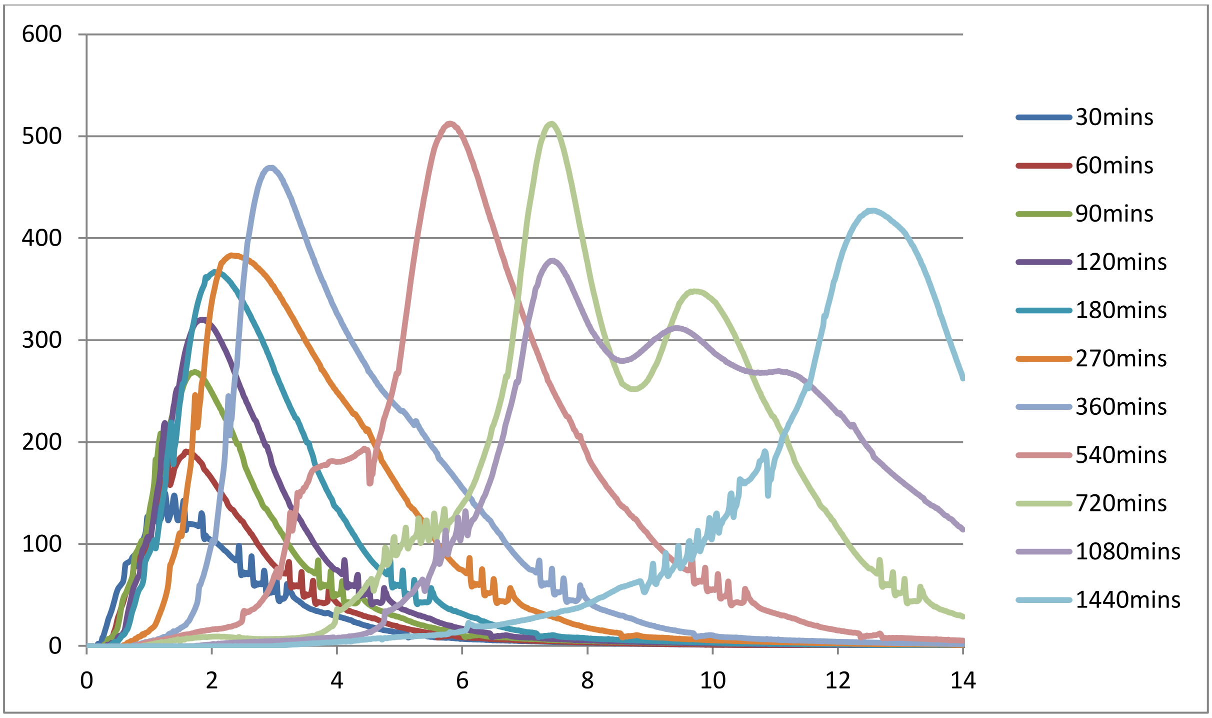


Figure 8: Browns River Catchment Flow Rate in Year 2100 with MHWS Tail Water Level at Different Storm Durations

4.3.3 RAINFALL LOSSES

In this model, the initial loss - constant continuing loss model has been adopted for the hydrology modelling process. Initial-continuing loss models have been adopted for many Australian catchments, yet no single model has been demonstrated to be uniformly superior across all catchments (ARR Urban Loss Project 6). The physical processes contributing to loss are typically modelled by separating into initial losses which represent as depression, infiltration prior to saturation and interception storage and continuing losses are mainly infiltration.

Initial losses tend to vary across the catchments. It occurs early in the storm prior to the soil becoming saturated and before surface runoff occurring. The constant continuing loss is the average loss into the ground throughout the rest of the storm event after the surface runoff occurred in the catchment.

Rainfall losses depend on the soil type, rainfall intensity, vegetation and catchment size. A range of adopted design initial and continuing rainfall losses were derived from the Soil Health for Farming in Tasmania (DPIPWE, 2009) in Table 12. The soil types in the Kingborough area are attached in **Appendix B**.

Table 12: Suggested Infiltration Rate at Different Soil Texture

Soil Texture	Suggested application rate (mm/hr)		Infiltration rate range (mm/hr)
	Average soil structure	Well-structured Soil	
Sandy Loam	20	45	10-80
Loam	20	45	1-20
Clay Loam	20	40	2-15

Table 13 shows adopted initial loss and continuous loss in all design events in this study. An initial loss of 20 mm was adopted in this study based on Coffey's Hydrology Report. This is consistent with regional estimates of initial losses provided in IE Aust (1998) and SMEC (2008).

Table 13: Adopted Initial Loss and Continuous Loss for Pervious and Impervious Area

	Pervious Area	Impervious Area
Initial Losses (mm)	20	5
Continuous Losses (mm/hr)	2	1

4.3.4 FRACTION IMPERVIOUS

In this project, the percentage of impervious area and land use/land cover surface roughness were classified using a combination of aerial photography and cadastral information. The existing development conditions were estimated based on aerial photography based on Figure 2 and the planning of future development conditions were estimated based on Kingborough Council's *Future Strategic Growth Strategy* (KIPS,2014), shown in Figure 4. The fraction impervious applied to each of the designated land uses were based on guidance provided in various drainage manuals including QUDM (2013).

Table 14 below shows the fraction impervious, total area and area of impervious of different landuse categories used to classify future development.

Table 14: Area of Each Zoning/Landuse in Planning of Future Development Conditions

Zoning/Land Use	Fraction Impervious	Total Area (Ha)	Impervious Area (Ha)
Low Density Residential	0.3	49	22
General Residential	0.75	311	233
Inner Residential	0.9	30	27
Utilities (eg Highway etc)	0.85	177	150
Central Business	1.0	18	18
Local Business	0.9	2	1.8
General Business	0.9	10	9
Light Industrial	0.9	11	9.9
Commercial	0.9	30	27
Urban Mixed Use	0.9	5	4.5
Rural Living	0.1	267	26.7
Environmental Living	0.05	2636	131.8
Rural Resource	0.05	371	18.6
Particular Purpose	0.1	30	3
Community Purpose	0.30	179	53.7
Recreation	0.0	97	0
Open Space	0.0	18	0
Environmental Management	0.0	1765	0

4.4 HYDRAULIC MODEL

4.4.1 EXTENTS AND LAYOUT

The common elements to be considered when constructing a model are:

- Topographical data coverage and resolution (eg LiDAR data etc).
- The information on the availability of catchment details (eg slopes, manning 'n' roughness etc).
- Location of controlling features (eg bridges, sand berm etc).
- Catchment specific factors (eg sand berm at the river outlet etc).
- Computational limitations.

In this project, the 1D/2D model was developed from the Kingston Beach shoreline extending to immediately upstream of the Channel Highway bridges across Whitewater Creek and Browns River. The majority of the catchment waterways were modelled in 1D for the purposes of hydrological routing while the low lying and relatively flat flood plain in the area of interest Kingston Beach, and Kingston Golf Course was modelled in full 2D as shown in Figure 9 below.

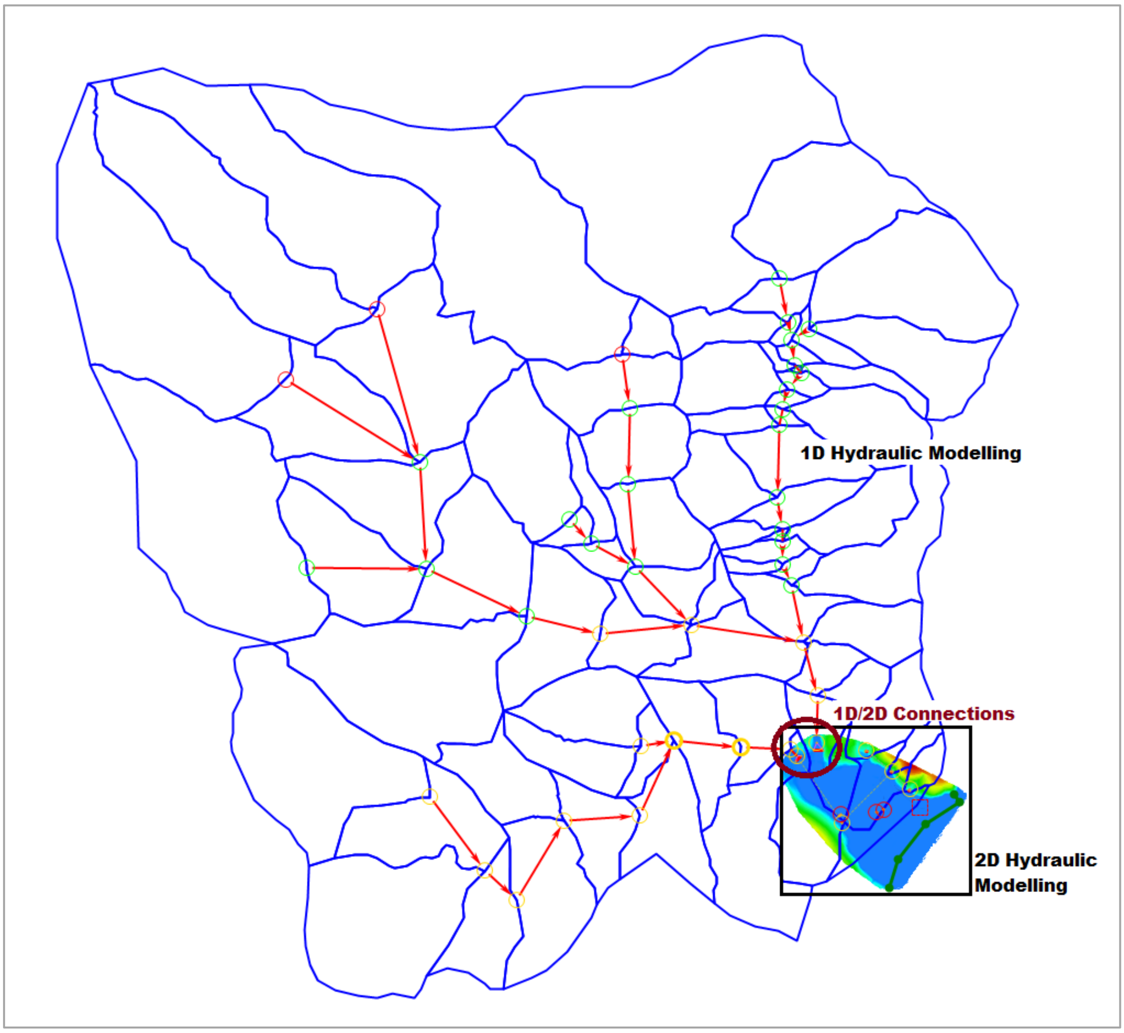


Figure 9: 1D & 2D Hydraulics Modelling Extent of Kingston Beach Catchment

The floodplain area modelled within the 2D domain comprises a total area of approximately 108 ha which includes the entire golf course, and the residential and business area in front of the beach.

4.4.2 COMPUTATIONAL GRID

A robust TUFLOW 2D model engine with a 9-point calculation which can produce higher accuracy to the result is adopted in SWMM. In a grid, 9 sample points including cell centres, mid-sides and corners were obtained for calculation. The grid size of 2 m was used for the Browns River catchment. Thus, the results of a 2 m size of grid adopted in the model are being sampled in every 1 m. The time step adopted in the model is 0.5 s.

The grid resolution was selected according to detail required for accuracy of presentation of floodplain, channel and river entrance, topography, key floodplain obstructions such as buildings and road/structure embankments and to keep simulation times within acceptable limits considering the size of model domain.

4.4.3 HYDRAULIC ROUGHNESS

The amount of frictional resistance of water flowing when passing over land and channel features has different measure according to the land uses. Therefore, different hydraulic roughness zones were assigned. These zones are delineated from aerial photography and cadastral data identifying different land-uses for modelling the variation in flow resistance. Table 15 shows the runoff manning ‘n’ roughness of different land uses applied in the model.

Table 15: Manning’s 'n' Values Used in Hydrologic Model

Land Use	Manning's Roughness Value
River Channel	0.045
River Overbank	0.100
Pervious Urban	0.035
Rural (pasture)	0.050
Light Forest	0.080
Heavy Forest	0.100

The Surface Manning ‘n’ Roughness Values Presented in Table 16 were applied to the 2D model area as shown in Figure 10.

Table 16: Manning’s 'n' Values for Different Major Hydraulic Features Within 2D Model Area

2D Model	Manning’s Roughness Coefficient
Building	0.800
Road	0.015
Shrubs – Golf Coarse	0.060
Trees – Golf Coarse	0.055
Forest – Golf Course	0.090
Water Bodies	0.020

Figure 10: 2D Roughness at Kingston Beach

4.4.4 STRUCTURES

There are three bridges included as structures within the hydraulic model extent. The location of the bridges is shown in Figure 11. There is an additional small pedestrian bridge within the golf course that was not modelled in this study as it was considered that under the design flood event it would not have a significant effect on flood levels within flood affected residential areas. However, it is noted that it is likely to increase flood levels within the golf course itself, particularly in more frequent flood events.

The stormwater reticulation system within the Browns River catchment was not specifically modelled in this study. However, the impact of the reticulation system is implicitly catered for in the hydrologic analysis of the urban catchments contributing flows to Browns River. The stormwater reticulation system within Kingston Beach itself has also not been modelled as it primarily consists of small capacity pipes which are not considered to have a significant influence on flood hazard in the rare events which are the focus of this study.

Figure 11: The Location of the 3 Bridges

Bridges can affect the hydraulic behaviour of the river flow through their structure as evidenced by changes to velocity and head profiles. The hydraulic losses associated with bridges tend to induce an afflux upstream and increased velocity downstream of the structure which may affect the peak water level and flood extent within the catchment.

Survey of the bridge piers, abutments and decks were carried out in order to accurately represent the structures in the model. Table 17 summarises the energy loss coefficient, blockage and levels of the three bridges.

Due to the distance upstream from Kingston Beach itself the hydraulic effect of the two bridges crossing Browns River at the Channel Highway do not influence the flood hazard in Kingston Beach.

The pedestrian bridge spanning Browns River immediately upstream of the outlet has only minor influence on flood behaviour due to the close alignment of the abutments to the river bank and relatively high deck level compared to the resultant flood levels.

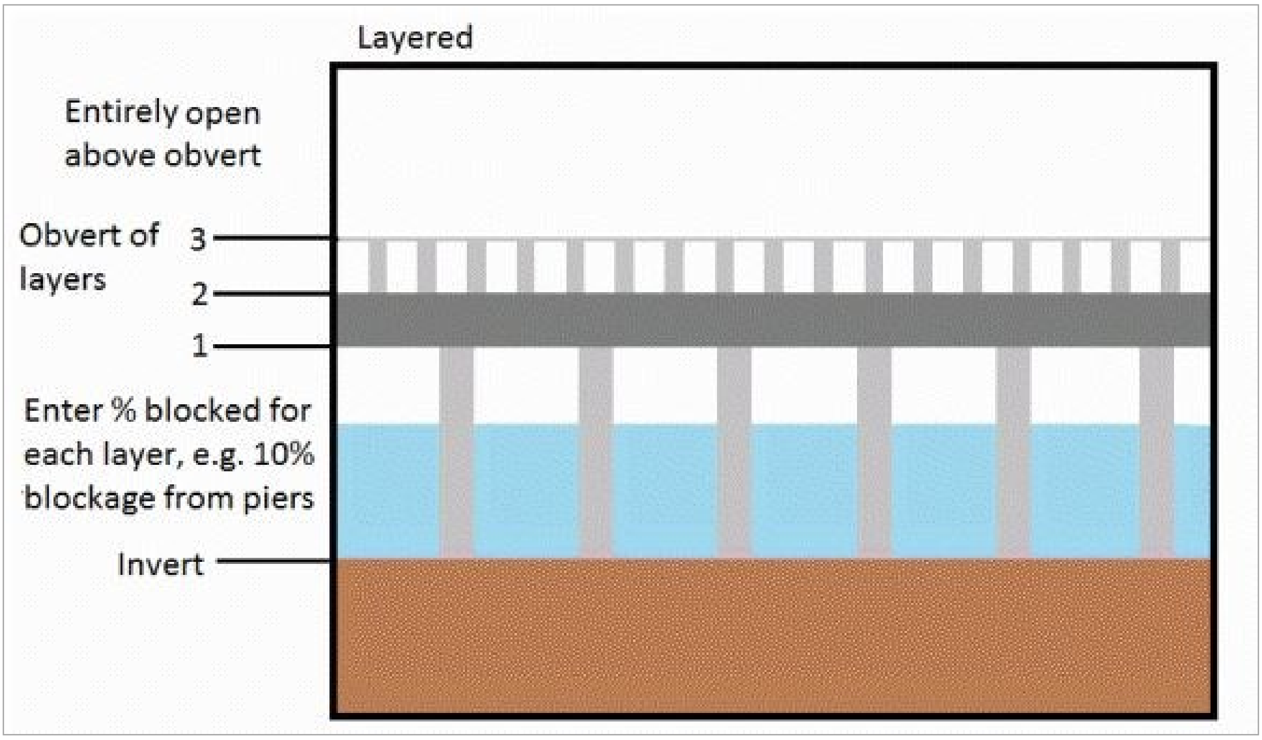


Figure 12: 2D Bridge Set-up in SWMM

Table 17: Structure Details

	Layer 1		**Layer 2**	**Layer 3**
Energy Loss Coefficient	0.05		0.2	0.1
Blockage (%)	5		100	25
	Constant Invert (m AHD)	**Constant Obvert (m AHD)**	**Constant Obvert (m AHD)**	**Constant Obvert (m AHD)**
Whitewater Creek Bridge	0.058	2.168	2.358	3.358
Browns River Bridge	0.000	2.750	3.730	4.730
Pedestrian Bridge	-1.500	2.270	2.720	3.720

4.4.5 OCEAN BOUNDARY DATA

Ocean tide data for the River Derwent was used as the downstream water level boundary in the hydraulic model of Browns River. Water Research Laboratory (WRL, Feb 2016) developed a set of design ocean water level time series for Kingston Beach. Full details of the derivation of the time series are provided as Table 18.

Table 18 shows the summary adopted ocean boundary with sea level rise to all design models in this study.

Table 18: Summary of Adopted Ocean Boundary with Sea Level Rise

Scenario	AEP	ARI	Tide+ Storm Surge	Sea Level Rise	Peak Wave Setup d=2m	Peak Design Nearshore Water Level
(year)	(%)	(year)	(m)	(m)	(m)	(m AHD)
Present Day	63	1	0.97	0	-0.05	0.92
	20	5	1.12		-0.05	1.07
	9.5	10	1.21		-0.05	1.16
	5	20	1.26		-0.05	1.21
	2	50	1.37		0.05	1.42
	1	100	1.44		0.08	1.52
2050	63	1	0.97	0.3	-0.05	1.22
	20	5	1.12		-0.05	1.37
	9.5	10	1.21		-0.05	1.46
	5	20	1.26		-0.05	1.51
	2	50	1.37		0.05	1.72
	1	100	1.44		0.08	1.82
2100	63	1	0.97	1	-0.05	1.92
	20	5	1.12		-0.05	2.07
	9.5	10	1.21		-0.05	2.16
	5	20	1.26		-0.05	2.21
	2	50	1.37		0.05	2.42
	1	100	1.44		0.08	2.52

4.5 MODEL CALIBRATION

4.5.1 SELECTION OF CALIBRATION EVENTS

GHD Pty Ltd (Oct 2015) was engaged to undertake a review of the available data for calibration. This section presents a summary of their review of the calibrated models and the flood frequency analysis.

The selection of suitable historical events for calibration of flood models is largely dependent on the availability of relevant historical rainfall and stream flow data. Ideally the calibration process should cover a range of flood magnitudes to demonstrate the suitability of a model for the range of design events to be considered.

A 15-mins measurement steam-gauge flow near Summerleas Road Bridge (Station Number 5200, DPIPWE) was available from year 1963 to year 1992. Unfortunately, there was very limited high flow events recorded in this period for flow calibration uses. A few higher flow events have been selected for the model calibration which includes June 1981, March 1983, December 1985 and May 1986. May 1973 event has the highest recorded stream flow records since the installation of the stream flow gauges, however insufficient data to support the calibration process has caused this to be redundant.

4.5.2 CALIBRATION DATA

4.5.2.1 RAINFALL DATA

There is no rainfall gauge available at Browns River in the history records. Thus, Hobart (Station No. 094029 – Ellerslie Road) rainfall data has been adopted for this study as it is the only available pluviograph station from year 1911 to present where located approximately 10 km to the north of the Browns River stream gauge. The 6-minute rainfall pluviograph temporal pattern was scaled for each historic storm event to match the daily rainfall depth recorded at Kingston, Fern Tree and Mount Wellington daily rainfall stations. Table 19 shows the rainfall gauge stations that were adopted for calibration.

Table 19: Detail of Rainfall Stations

Gauge No.	Station Location	Start Year	End Year	Type
#094029	Hobart (Ellerslie Road)	Jun 1893	Current	6-mins rainfall
#094164	Kingston (75 Channel Hwy)	Jan 1983	Apr 2002	Daily rainfall
#094139	Fern Tree (Grays Road)	Mar 1967	Jan 2016	Daily rainfall
#094066	Mt Wellington (The Spring)	Jun 1891	Nov 2015	Daily rainfall

The rainfall pluviograph at Ellerslie Road in Hobart has been used to calibrate the high flow at Summerleas Road Browns River Gauge. A few daily rainfall totals from rainfall gauge stations in close proximity, as listed in Table 19, to the Summerleas Road Browns River Gauge have been applied to calibrate the model.

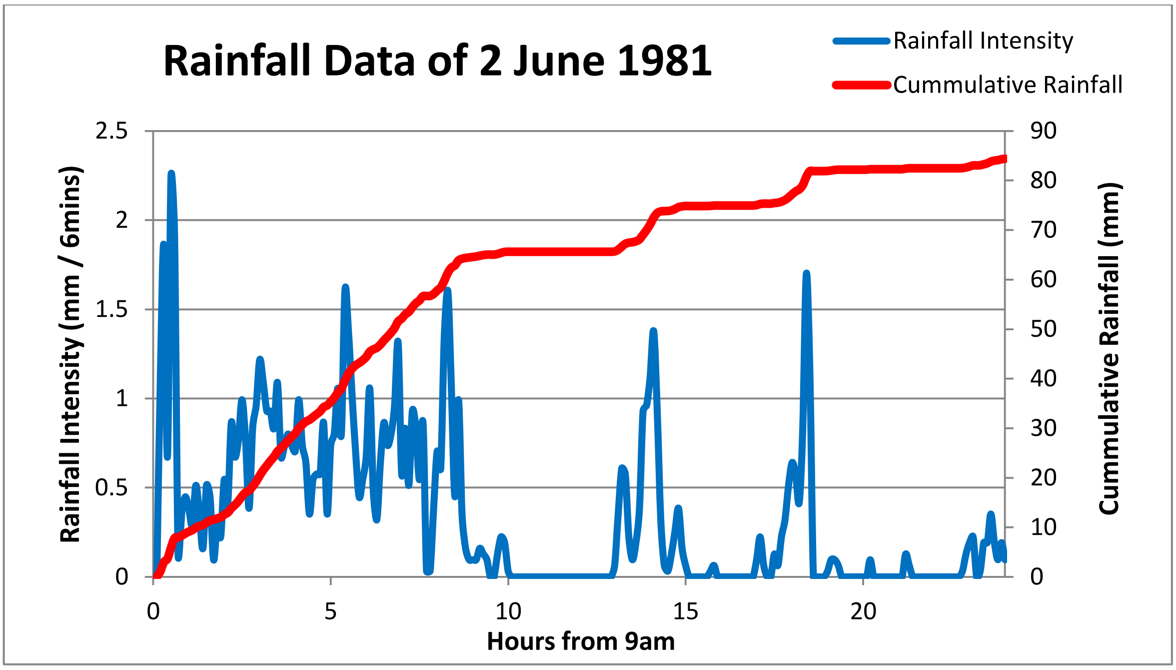


Figure 13: 2 June 1981 Rainfall (from 9am) – Based on Fern Tree Daily Rainfall Depth

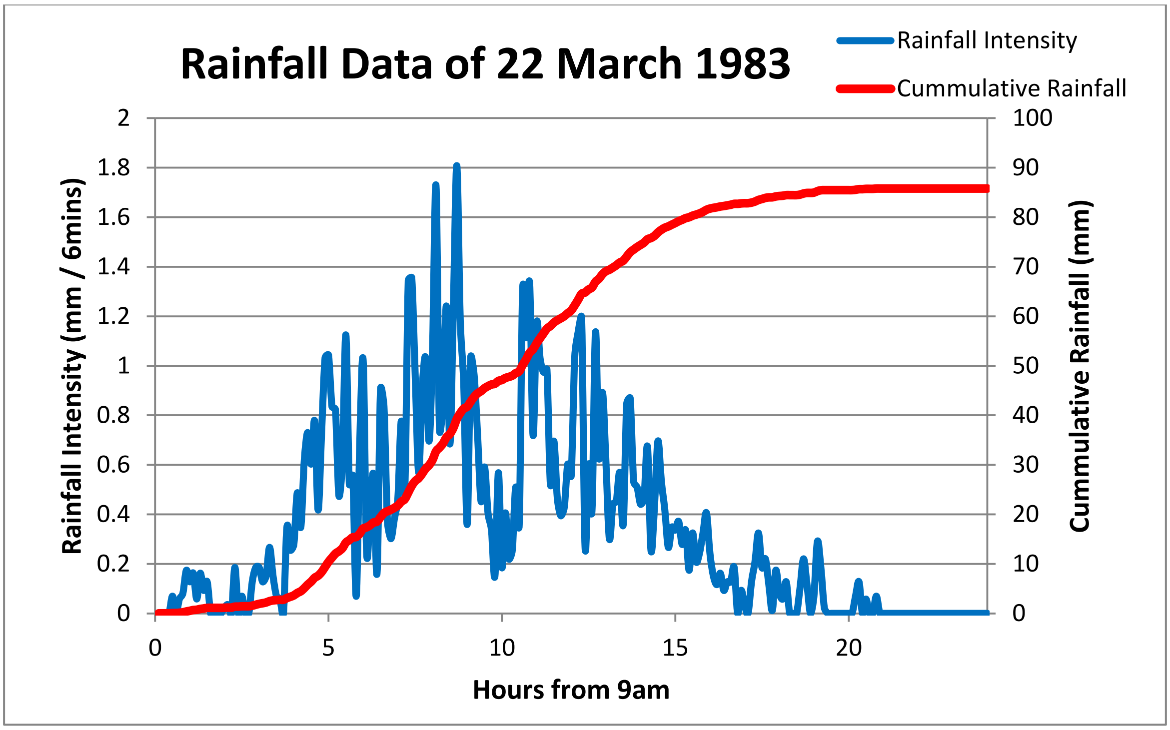


Figure 14: 22 March 1983 (from 9am) - Based on Fern Tree Daily Rainfall Depth

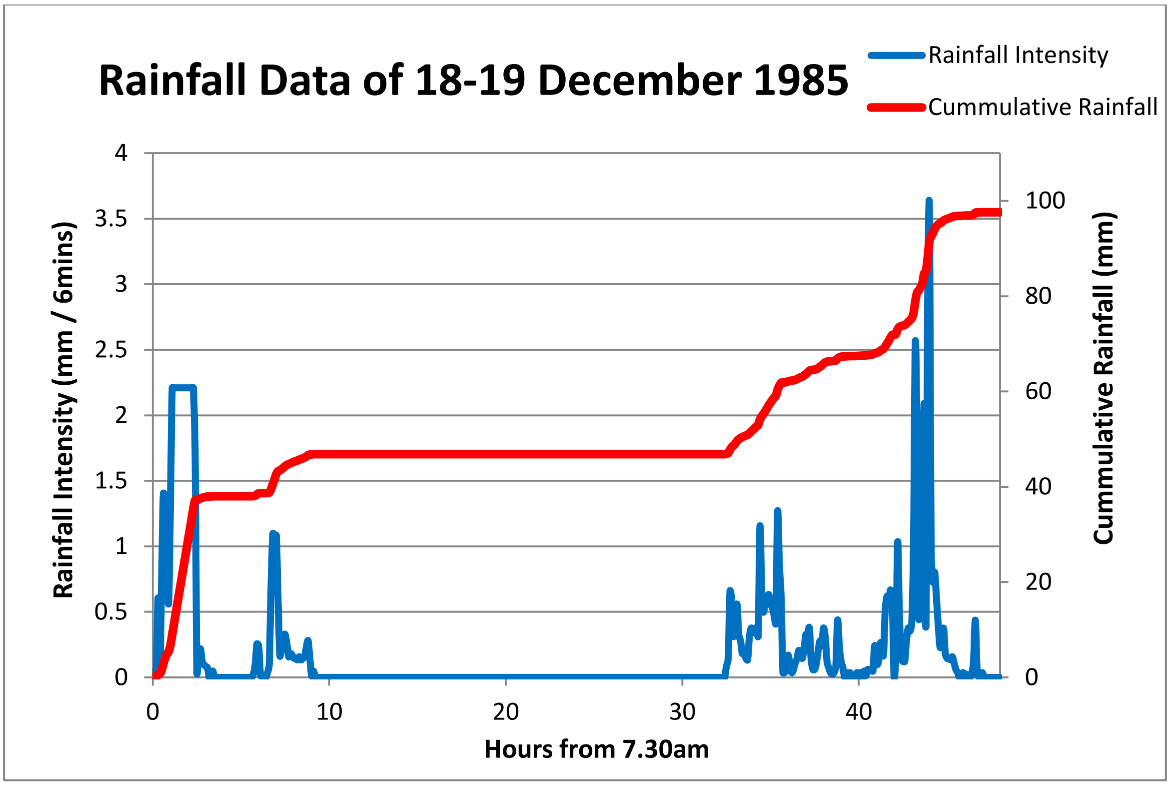


Figure 15: 18-19 December 1985 (from 7.30am) - Based on Kingston (75 Channel Highway) Daily Rainfall Depth

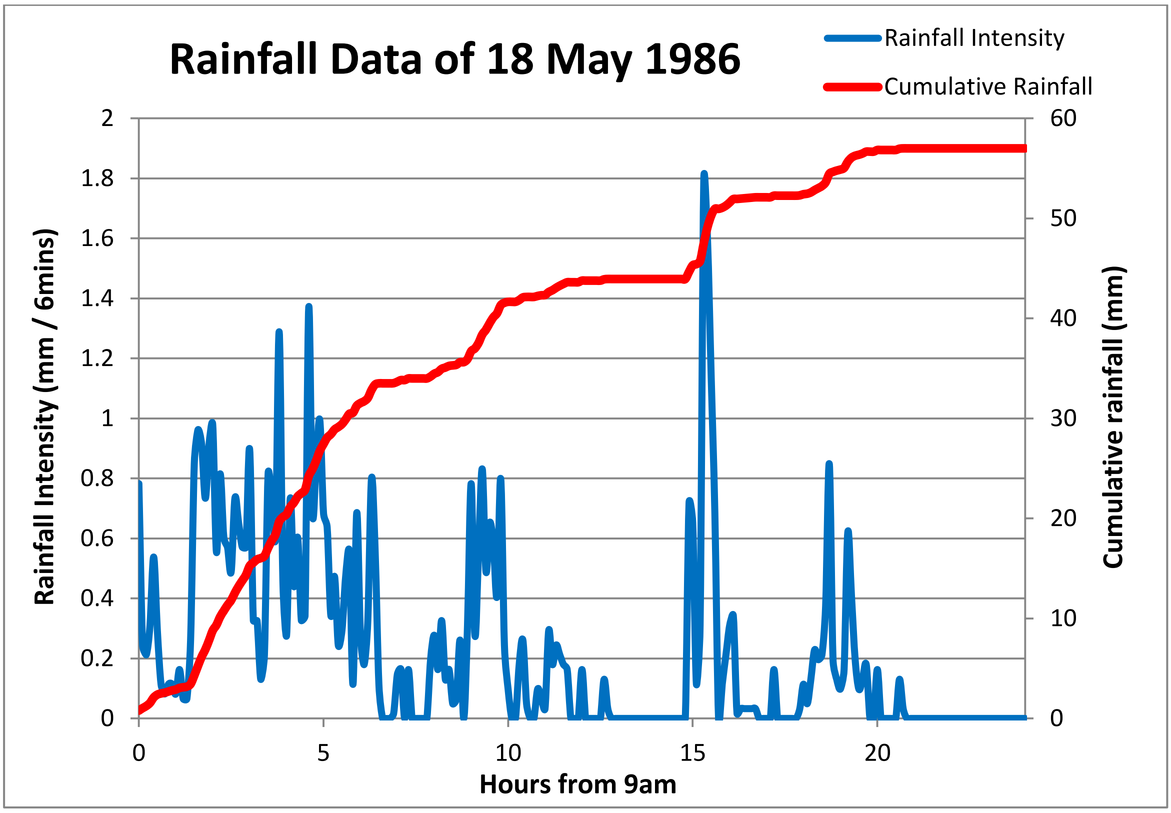


Figure 16: 18 May 1986 (from 9am) - Based on Kingston (75 Channel Highway) Daily Rainfall Depth

For the 1983 rainfall event, both the Kingston (75 Channel Highway) and the Fern Tree (Grays Road) daily rainfall depths (112.4 mm and 85.8 mm respectively) were adopted in the calibration. Based on a review of the calibration, adoption of the lower rainfall depth record at Fern Tree was recommended. This lower rainfall value gives a result that is more consistent with results from the other historic events when using a consistent set of hydrologic model parameters.

4.5.3 STREAMFLOW DATA

Table 20 shows high flow events which have been selected for the model calibration. As mentioned above, due to lack of rainfall information for year 1973 event, it was not able to be used to calibrate the model despite it having the highest stream flow in the record.

Table 20: Selected High Flow Events for Calibration.

Date	Peak Time	Flow Range (m^3/s)
2 June 1981	17:00	24.24
22 March 1983	22:15	27.82
18 December 1985	03:45	22.89
18 May 1986	17:15	24.51

4.5.4 ADOPTED MODEL PARAMETERS

According to the Reconnaissance Soil Map Series of Tasmania (Hobart), most of the Browns River catchment was occupied with Podzoilic soils on Deletire (Chromosol - fine sandy loams) and Podzol soils on sandstone. Thus, based on the *Soil Health for Farming in Tasmania* (DPIPWE, 2009), the initial infiltration losses of 20 mm and the continuous losses of 2 mm/hr for impervious areas was adopted. The initial loss for impervious area is 5 mm and continuing loss is 1 mm/hr. The manning's 'n' was ranging from 0.014 for impervious areas to 0.1 for heavy forest.

It is deemed that the adopted values are within normal reasonable bounds, and that the parameters result in a reasonable level of calibration given the limitations in available data. The adopted calibration values are therefore considered appropriate for the purposes of design flood estimation.

4.6 OBSERVED AND SIMULATED FLOOD CONDITIONS

The level of calibration achieved is satisfactory given the limitations on available data. A summary of modelled vs recorded peak flow rates for each event is included in Table 21. A good match has been achieved for the 1981, 1983 and 1985 events. While the peak flows are slightly lower in the XP-SWMM model when compared to the streamflow record, the differences are within acceptable limits and can potentially be explained by other factors (as discussed below). A poorer match is achieved for the 1986 event. If using the Kingston rainfall station, the peak flows are approximately 42% too low, and if using the Fern Tree rainfall station, the peak flows are 31% too high.

The modelled vs recorded streamflow hydrographs for each of the calibration events are included below. For each event (with the exception of 1986), a reasonable match to the timing and shape of the recorded hydrograph has been achieved. Accordingly, the best explanation for observed differences between the timing and shape of the modelled and recorded hydrographs is the rainfall temporal pattern which was based on the closest pluviograph station at Hobart, 10 km away. For the 1986 event, there is considerable variability in the local rainfalls recorded at Kingston and Fern Tree, and this limits the level of calibration that can be reliably achieved. It is considered that the hydrologic model is well calibrated given the limitations in the available rainfall data.

Table 21: Summary of Modelled vs Recorded Peak Flows

Event	Recorded (m^3/s)	Modelled (m^3/s)	Difference (m^3/s)	Difference (%)
1981	24.2	21.0	-3.28	-13
1983	27.8	26.1	-1.98	-6
1985	22.9	20.8	-2.20	-9
1986 (Kingston rainfall)	24.5	14.3	-10.2	-42
1986 (Fern Tree rainfall)	24.5	32.0	7.5	31

The modelled vs recorded stream flow hydrographs for each of the calibration events are included in Figure 17 to Figure 21 below.

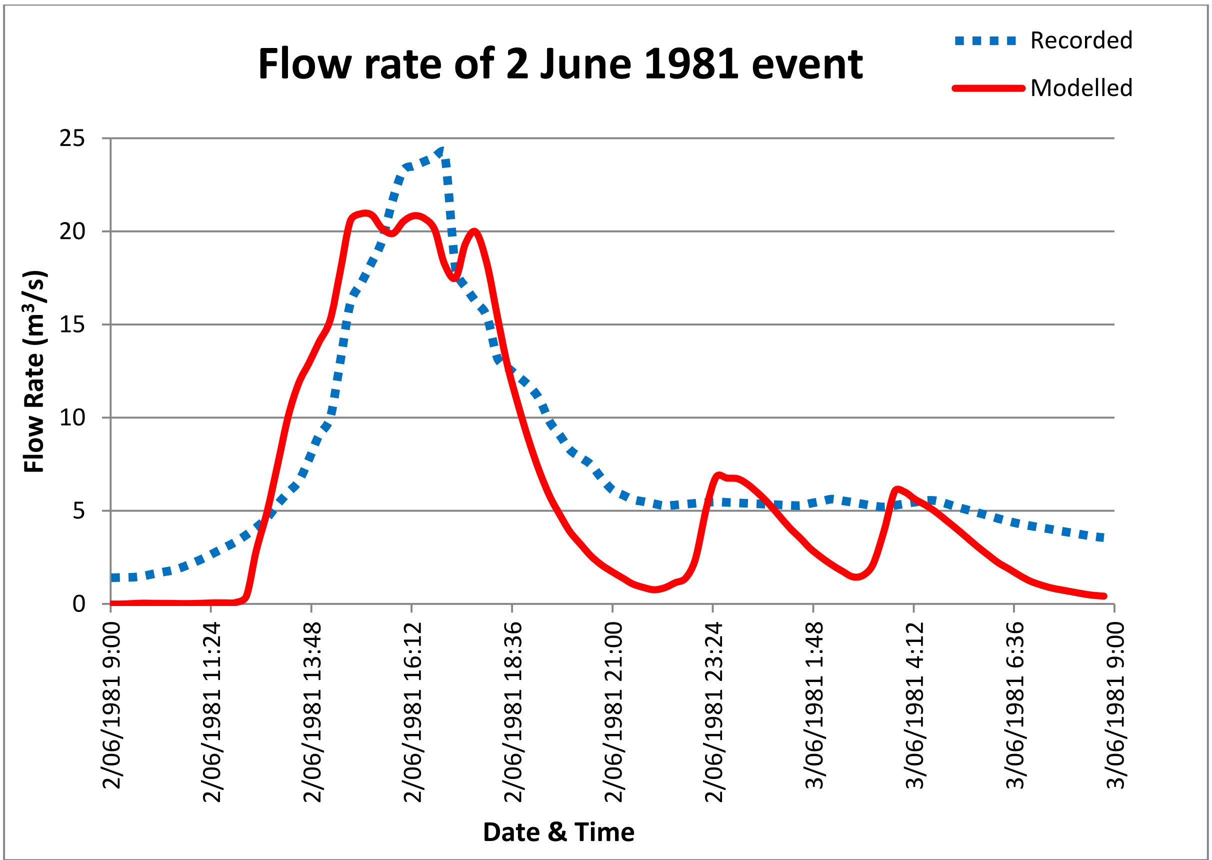


Figure 17: 2 June 1981 Calibration Event

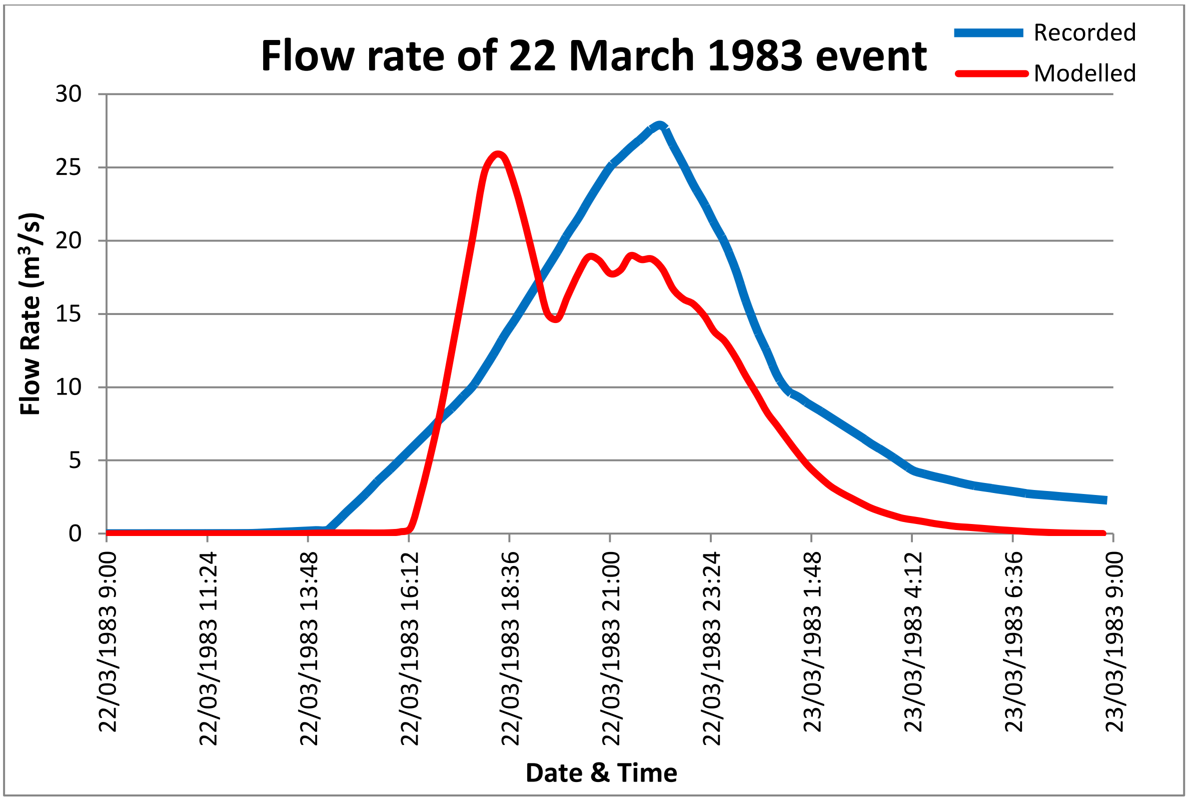


Figure 18: 22 March 1983 Calibration Event

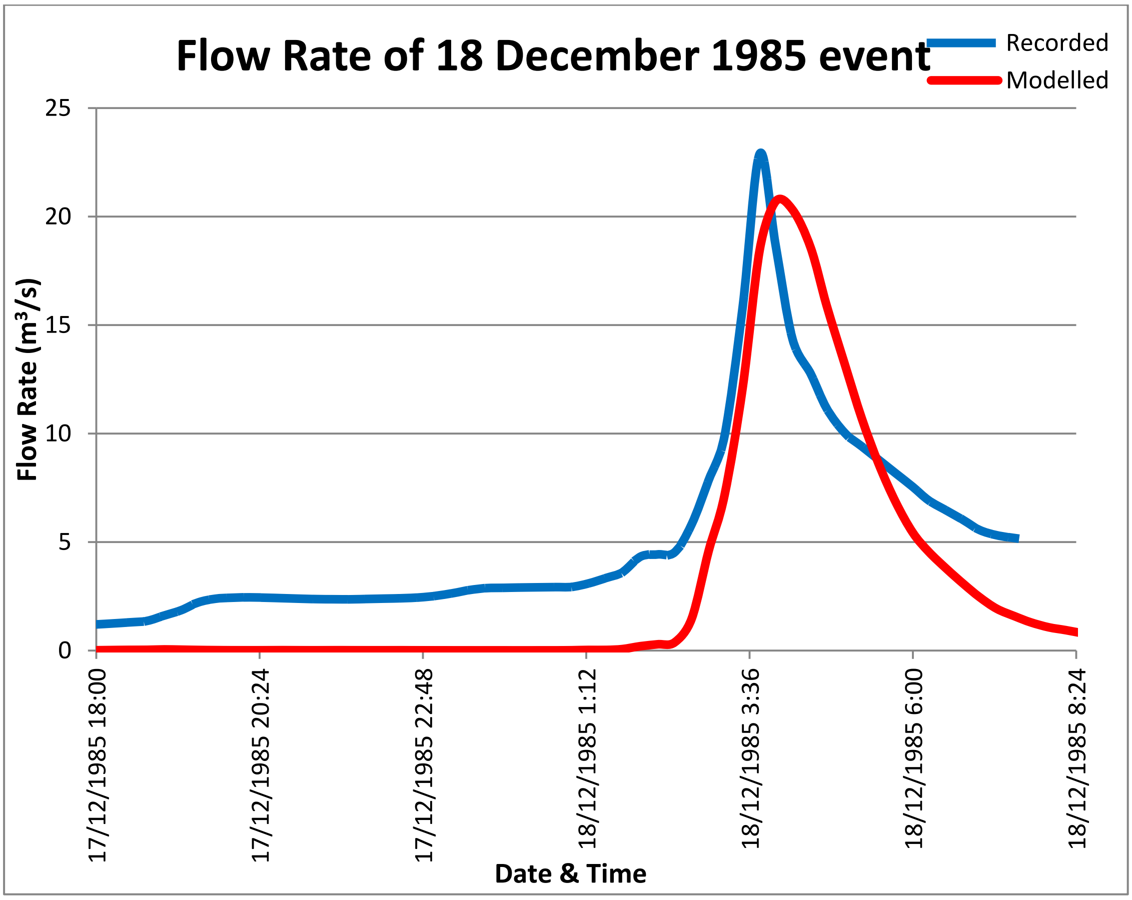


Figure 19: 18 December 1985 Calibration Event

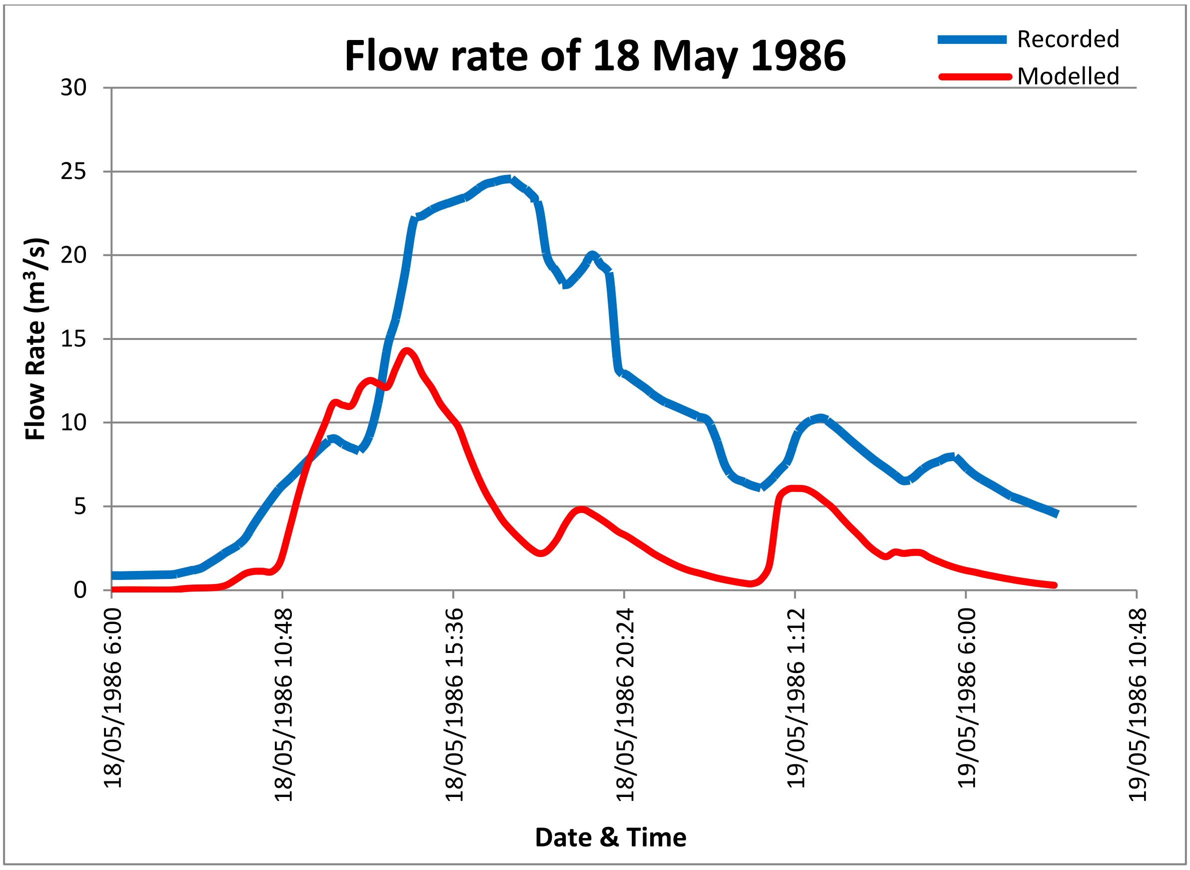


Figure 20: 18 May 1986 Calibration Event – Using Kingston Rainfall

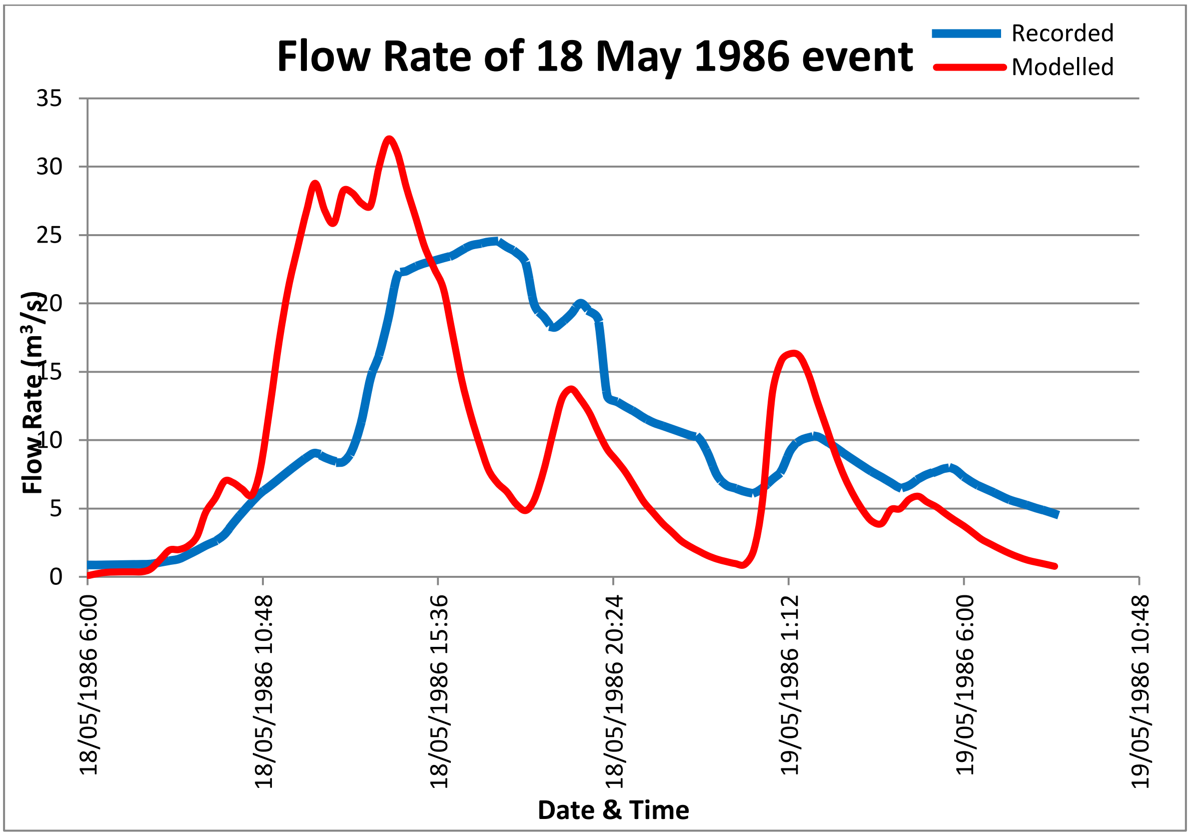


Figure 21: 18 May 1986 Calibration Event - Using Fern Tree Rainfall

4.7 FLOOD FREQUENCY ANALYSIS AND DESIGN FLOOD ESTIMATES

A flood frequency analysis (FFA) was undertaken using FLIKE (version 5.0.251.0) and was based on the 30 years of gauged data at the Brown's River gauge. The best fit was achieved using the LP3 distribution and the Bayesian inference fitting method. Visually, a good fit was achieved through all data points as shown below. The data also tested for low outliers using the Multiple Grubbs Beck test, and no outliers were found – this result confirms that it is appropriate to use the entire 30 years of data with no censoring of low flows.

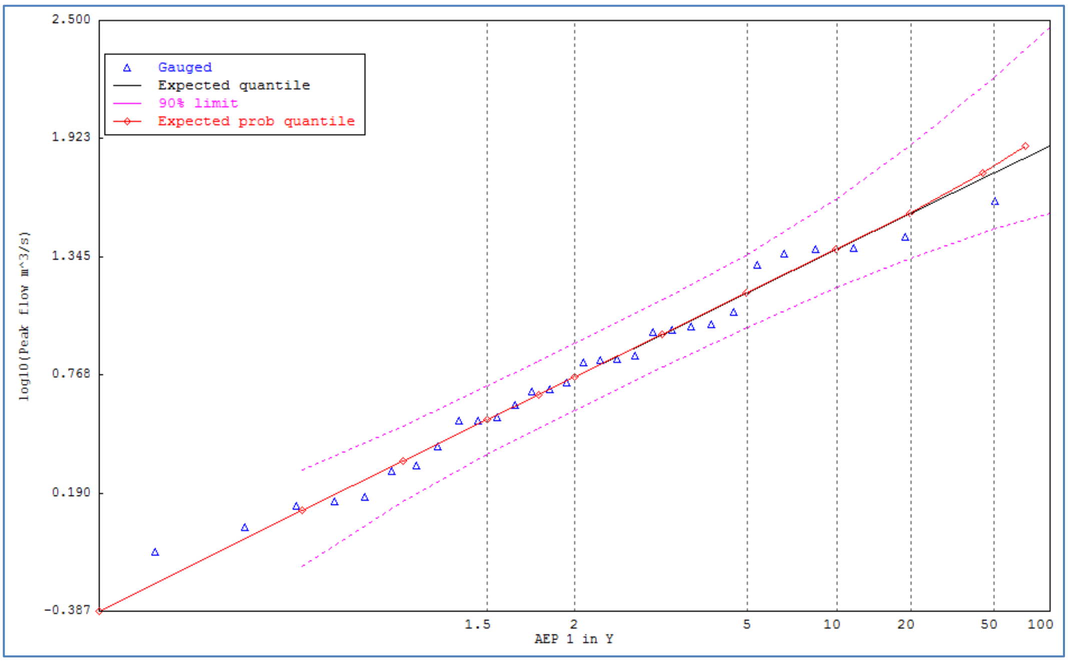


Figure 22: Best Fit Graph Using LP3 Distribution and the Bayesian Inference Fitting Method

The results of the flood frequency analysis compared to the design flood estimates from the calibrated XP-SWMM model, are included below. The XP-SWMM design flood estimates (based on the calibrated hydrologic model and design rainfalls and temporal patterns) are generally higher than the FFA expected values, but are within the predicted confidence limits (although the 5% AEP estimate is at the high end of the range). However, when considering that the recurrence intervals of the rainfall for the five highest peaks in the gauged record were in the range of 1 – 5 years (as outlined above), there is a possibility that the FFA based on the gauged record is biased towards lower flows. In other words, if by chance no large floods were captured in the relatively short 30-year period of gauged record, the FFA may under-predict the magnitude of the larger design floods. This inherent uncertainty in the FFA is reflected in the wide confidence limits (which are approximately 50% to 380% for the 1% AEP event).

Table 22: Design Flood Estimate - FFA vs XP-SWMM

Event (AEP)	FFA Expected Quantile (m^3/s)	FFA 5% Confidence Limit (m^3/s)	FFA 95% Confidence Limit (m^3/s)	XP-SWMM Design Flood Estimate (m^3/s)
5%	36.2	21.9	78.4	76.3
2%	57.2	30.3	166.8	93.5
1%	77.4	36	292.5	111

In order to improve the FFA estimates, it is possible to incorporate anecdotal historic data outside of the gauged recorded even if precise flood peaks are not known. In this instance, the "Kingston Beach / Brown's River: a flood and storm history" report is available, and provides anecdotal records of flooding dating back to 1870. In order to incorporate this anecdotal data into TUFLOW FLIKE, these historic floods must be ranked relative to the known floods. In the absence of direct information such as flood peaks, one potential approach is to rank all of the historic floods based on rainfall (implying the assumption that the magnitude of the rainfall is representative of the magnitude of the flood).

In order to demonstrate the potential influence of including the anecdotal historic data, GHD prepared a rough, preliminary ranking of historic floods based on monthly rainfall. For simplicity, the Mount Wellington (The Springs 094066) station was used, as it had the longest period of continuous operation. From this analysis, it was found that 11 of the floods reported in *Kingston Beach / Brown's River: a flood and storm history* (Evans, August 2015) occurred in months with higher rainfall than the 1973 event (which is the highest flood in the gauged record). This was incorporated into the TUFLOW FLIKE analysis as follows (41.26 m^3/s is the peak discharge for the 1973 event, and the anecdotal data is split into periods before and after the gauged record):

General | Observed values | **Censoring of observed values** | Errors in observed values

In Bayesian fit use following information about non-overlapping censored records:

Number	Threshold value	Yrs > threshold	Yrs <= threshold	Start year	End year
1	41.262	9	46	1908	1962
2	41.262	2	21	1993	2015

The FFA was then repeated with the inclusion of the anecdotal historic data. In this particular instance, the design flood estimates increased significantly, however the width of the confidence limits also increased. This suggests that the ranking of the historic storm events based on monthly rainfall is not a reliable method. In order to refine this estimate, it is suggested that a more careful ranking of the historic flood events using the best available local daily rainfall data for each flood in undertaken. It is likely that such an analysis would improve the level of agreement between the FFA results and the XP-SWMM design flood estimations.

Due to the lack of large flood data during the gauge record and the subsequent potential bias towards underestimating flows from the FFA it has been determined to use the XP-SWMM modelled flows for design flood analysis as a conservative approach.

4.8 SENSITIVITY ANALYSIS

4.8.1 CLIMATE CHANGE IMPACT ON RAINFALL INTENSITY

As discussed in Section 2.2.9, the sensitivity of 10%, 20%, 30% and 40% increase in rainfall intensity were tested. Table 23 shows the peak water level at different percentage of rainfall intensity and water level each levels of rainfall increase. The visual location of each point is shown in Figure 23.

Table 23: Peak Design Flood Level at Different Locations with Different Percentage of Climate Change

Climate Change (%)	10	20 (20%-10%)	30 (30%-20%)	40 (40%-30%)
Point	**Peak Design Flood Level (m AHD)**			
5	2.91	3.01 (+0.10)	3.09 (+0.08)	3.16 (+0.07)
6	3.02	3.11 (+0.09)	3.20 (+0.09)	3.28 (+0.08)
10	2.59	2.67 (+0.08)	2.75 (+0.08)	2.83 (+0.08)
12	3.00	3.10 (+0.10)	3.20 (+0.10)	3.29 (+0.09)
17	3.10	3.20 (+0.10)	3.30 (+0.10)	3.39 (+0.09)
21	3.05	3.16 (+0.11)	3.26 (+0.10)	3.36 (+0.10)

The average range of water level increase at each 10% increase in rainfall intensity is 0.08m to 0.1m.

4.8.2 HYDROLOGIC ROUGHNESS

Sensitivity test results on the hydraulic roughness (Manning's 'n') were carried out by applying 10% increase and decrease of the adopted design conditions are provided in Table 24. The baseline was estimated based on reference to the *Hec Ras Hydraulic Reference Manual* (Gary W. Brunner, February 2016) and the *Natural Channel Design Guidelines* (Brisbane City Council, Nov 2013).

Table 24: Parameter of Hydraulic Roughness Sensitivity Input

Land Use	Manning's 'n' Roughness Coefficient		
	Base	**10% Increase**	**10% Decrease**
Pervious Urban	0.035	0.0385	0.0315
Rural (pasture)	0.050	0.055	0.045
Light Forest	0.080	0.088	0.072
Heavy Forest	0.100	0.110	0.090

The sensitivity tests have been undertaken for Year 2100 1% AEP rainfall and 5% AEP storm surge (9-hour duration) design event. The results of the sensitivity tests on hydraulic roughness for the 1% AEP design event are summarised in Table 25. The reference point locations are shown in Figure 23.

Table 25: Design Flood Heights under Different Hydraulic Roughness Sensitivity Input

Location Point	Peak Design Flood Level (m AHD)		
	Base	10% Increase (10% Increase – Base)	10% Decrease (10% Decrease – Base)
5	3.09	3.07 (-0.02)	3.11 (+0.02)
6	3.2	3.18 (-0.02)	3.22 (+0.02)
10	2.75	2.73 (-0.02)	2.78 (+0.03)
12	3.2	3.17 (-0.03)	3.23 (+0.03)
17	3.3	3.27 (-0.03)	3.33 (+0.03)
21	3.26	3.23 (-0.03)	3.29 (+0.03)
22	3.38	3.36 (-0.02)	3.41 (+0.03)

The model simulation results show minimal influence on inundation extents in low lying flood plain area (generally ≤0.03m) by the increase and reduction of 10% hydraulic roughness at the upper catchment of Browns River catchment.

Figure 23: Location of Reference Points at Kingston Beach

4.8.3 RAINFALL LOSSES

The hydrological model parameters adopted for the design floods were similar to those used in the hydrological model calibration and validation. A range of pervious infiltration from 10 mm to 80 mm and continuous loss of 1.5 mm/hr and 2 mm/hr were tested.

The bases for adopting the above range for the sensitivity analysis of initial and continuing losses are as follows:

i) Hydrology Report *Flood Inundation & Hazard Mapping Vincent Rivulet TAS* (Coffey, March 2003) has adopted initial losses of 20 mm/hr that is based on regional estimates of initial losses provided in IEAust (1998) and the initial losses adopted in SMEC (1998). 1.5 mm/hr of continuous losses is adopted for the design events up to the 1:100AEP. The calibrated initial losses in the calibration events on this project include 70 mm/hr (year 1973), 20 mm/hr (year 1977 and year 1985) and 30 mm/hr (year 1986).

ii) According to *Tasmanian Coastal Adaptation Decision Pathways Project: Inundation Control Works for the Kingston Beach Area (Pitt & Sherry, Oct 2012)*, the adopted initial loss is 10 mm/hr and CL is 2 mm/hr. The selection is based on their previous experience with similar catchment areas.

iii) An infiltration guideline was given by *Soil Health for Farming in Tasmania by DPIPWE* as shown in Table 26 below.

Table 26: Infiltration Guideline from Soil Health for Farming in Tasmania

Soil Texture	Suggested application rate (mm/hr)		Infiltration rate range (mm/hr)
	Average soil structure	Well-structured Soil	
Sandy Loam	20	45	10-80
Loam	20	45	1-20
Clay Loam	20	40	2-15

Initial rainfall losses are to a large degree dependent on antecedent catchment conditions which vary between dry and wet conditions. In addition the Browns River catchment has many small farm dams scattered across it. During periods of prolonged low rainfall the dams may increase initial losses significantly. Conversely extended periods of rainfall can significantly reduce initial losses and the flood history of Browns River shows that most significant floods have occurred after long wet periods. To inform our determination of design rainfall losses a range of sensitivity tests on the adopted rainfall losses was undertaken for the 1% AEP catchment rainfall event (9 hour duration).

Table 27: Sensitivity of Infiltration Losses in Pervious Area in the Vicinity of Beach Road

	Initial Loss (mm)							
	10	20	30	40	50	60	70	80
Continuous Loss (mm/hr)	**Water Elevation (m AHD)**							
1.5	3.32	3.31	3.30	3.28	3.23	3.13	3.00	2.83
2	3.30	3.30	3.29	3.26	3.21	3.12	3.01	2.82

4.8.4 SEA LEVEL BOUNDARY (PHASING)

A significant flood risk factor for Kingston Beach is the coincidence or otherwise of peak catchment floods with peak storm tide levels. The sensitivity of flood levels in Kingston Beach to this coincidence was tested by phase shifting the peak of the tidal signals with the peak of the catchment flood. The tidal signal peak was shifted to occur from 4 hours before to 4 hours after the peak catchment flood including completely coincident peaks (Figure 24).

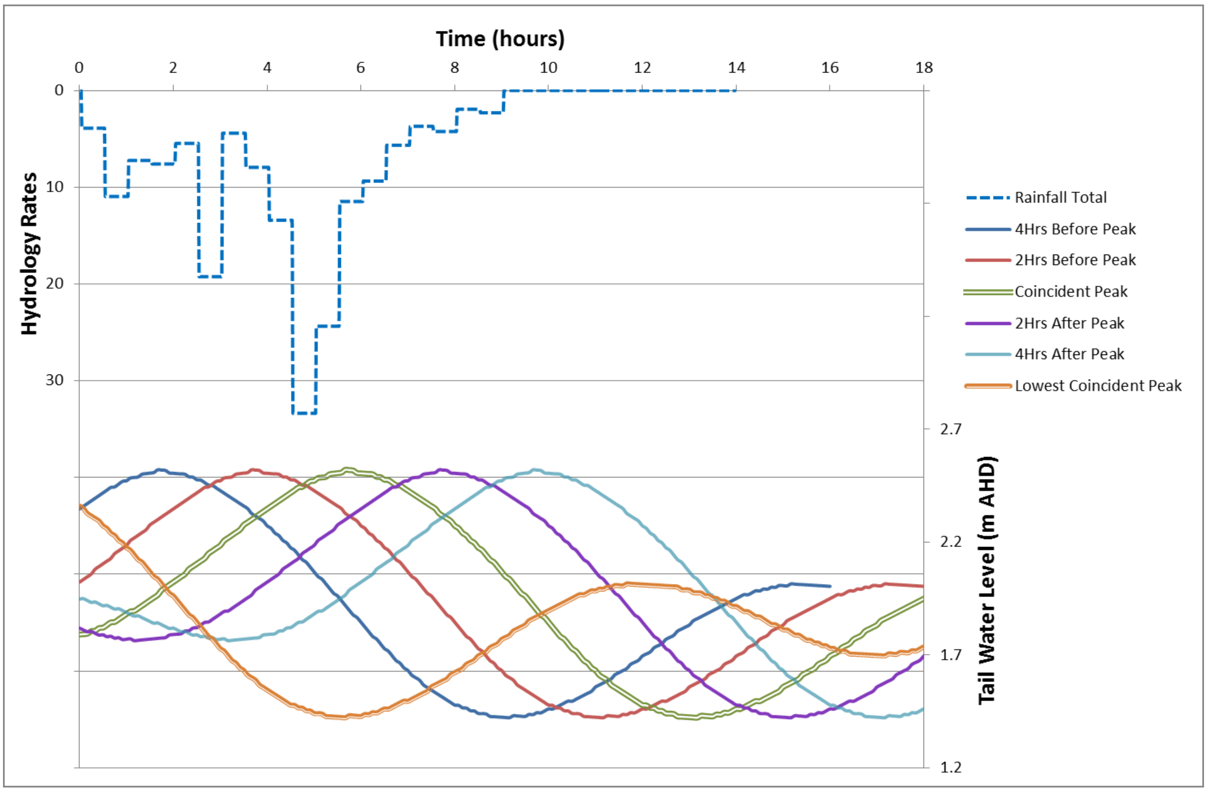


Figure 24: Design Event of Peak Rainfall and Peak Waves Coincident at Different Times

The results of the various scenarios tested including the peak rainfall coinciding with the peak tide and with lowest tide in Year 2100 1% AEP catchment flood and 5% AEP storm tide are shown in Table 28 and the Year 2100 5% AEP catchment flood and 1% AEP coastal flood provided in Table 29. The locations referred to in the subsequent tables are shown in Figure 23.

Table 28: Water Elevation for 2100 1% AEP Catchment Flood Coincident with the Highest and Lowest Tide during a 5% AEP Coastal Flood Event

Location	5	10	11	13	17	19
Time of Coincident	**Water Elevation (m AHD)**					
Peak Tide	3.09	2.75	2.90	3.25	3.30	3.45
Lowest Tide	3.07	2.72	2.87	3.23	3.28	3.43
Difference	**0.02**	**0.04**	**0.03**	**0.02**	**0.02**	**0.01**

Table 29: Water Elevation for 2100 5% AEP Catchment Flood Coincident with the Highest and Lowest Tide During 1% AEP Coastal Flood Event

Location	5	10	11	13	17	19
Time of Coincident	**Water Elevation (m AHD)**					
Peak Tide	2.88	2.70	2.77	3.02	3.05	3.20
Lowest Tide	2.76	2.35	2.46	2.79	2.85	3.08
Difference	**0.12**	**0.35**	**0.32**	**0.23**	**0.20**	**0.12**

From the results it can be seen that for 1% AEP catchment and 5% AEP coastal coincident flood scenario, the catchment flood is the dominant factor and the relative coincidence of the peak catchment and coastal floods do not influence the resultant coincident flood significantly.

Conversely, for 5% AEP catchment and 1% AEP coastal coincident flood scenario, the phasing of tidal level can affect the level of inundation by up to 0.32m depending on the location. However, the absolute flood height at most locations within Kingston Beach is higher under the 1% AEP catchment and 5% AEP coastal coincident flood scenario.

4.8.5 COASTAL BERM CONDITIONS

Several configurations of berm conditions were tested and the results were recorded on Table 30 below for Year 2100 1% AEP catchment flood. The berm rise and fall depends on the shape of the berm available on the LIDAR in the model.

Figure 25: Berm Configuration for Kingston Beach

Figure 25 shows cases were tested to represent the dune post a standard intervention and/or natural scour of approximately 30 m across the middle part of the berm and a secondly where the entire berm is removed as in a permanent opening of the mouth.

Table 30: Water Elevation under Varying Berm Conditions

	Point Locations					
	5	8	10	14	17	19
Berm Condition	Water Elevation (m AHD)					
Closed Berm*	3.07	3.01	3.12	3.27	3.30	3.44
2m Scour*	3.07	3.01	3.11	3.26	3.29	3.44
-1m AHD (Whole Berm)	2.98	2.91	3.02	3.15	3.19	3.39
1m AHD (Whole Berm)	3.08	3.02	3.12	3.28	3.30	3.45

*30m wide berm scour only.

The results show that in a design flood event, the relative condition of the river mouth is not significant where the extent of the scour is limited to that during normal flows ie approximately 30 m. This is likely due to a combination of the dominance of the catchment flood and the relatively high tailwater level.

5 DESIGN FLOOD CONDITIONS

Design floods are hypothetical floods used for planning and floodplain management investigations. They are described as having a probability of occurrence specified as Annual Exceedance Probability (AEP) expressed as a percentage and/or Average Recurrence Interval (ARI) expressed in years to measure the rarity of a rainfall event. This report uses the AEP terminology which defined as Table 31.

Table 31: Design Flood Terminology

AEP	ARI	Comments
1%	100 years	A hypothetical flood or combination of floods likely to occur on average once every 100years worst case scenario or with 1% probability of occurring in any given year.
2%	50 years	As for the 1% AEP flood but with a 2% probability.
5%	20 years	As for the 1% AEP flood but with a 5% probability.
9.5%	10 years	As for the 1% AEP flood but with a 9.5% probability.
20%	5 years	As for the 1% AEP flood but with a 20% probability.
63%	63 years	As for the 1% AEP flood but with a 63% probability.

5.1 COINCIDENT FLOODING

Catchment flooding and oceanic inundation can occur due to the same storm cell and therefore design flood levels in an estuary will be influenced by a combination of these sources. If oceanic inundation or catchment flooding is examined in isolation the resultant estimated flood risk is unlikely to be fit for purpose.

The Queensland Government guidelines *Coincident Flooding in Queensland: Joint Probability & Dependence Methodologies* (QLD Government, Oct 2012), direct that the choice of the combination of probability of catchment and coastal flood reflects an assumed level of independence between the variables: assuming independence between the variables could underestimate the likely flooding and result in higher risk to the coastal community. Similarly, an assumption of total dependence would be too conservative.

In NSW the Government allows for general and detailed approaches for joint probability analysis of flood level assessment of interaction of catchment and coastal flooding (NSW, 2010). A series of assumptions provide an envelope of peak levels and velocities that can be used to estimate the 1% AEP flood effects in a tidal system:

- estimated 1% AEP ocean flooding with 5% AEP catchment flooding with coincident peaks
- estimated 5% AEP ocean flooding with 1% AEP catchment flooding with coincident peaks
- neap tide cycle with 1% AEP catchment flooding with coincident peaks.

Teakle et al. (2005), in a joint probability analysis of water levels in estuary flood modelling in southeast Queensland, state that current practice typically includes an analysis of two boundary cases to obtain the 1% AEP flood level, which might typically combine:

- 1% AEP river discharge with a downstream (tidal) level at mean high sea level
- 5% AEP freshwater inflow with a 1% AEP downstream (tidal) level.

For this study, both catchment and ocean derived flood events and the impact of future climate change on flooding in Kingston Beach were considered. Table 32 summarised all the adopted design runs in this study.

Table 32: Summary of Adopted Design Runs at Different Scenarios

Year	Catchment Flood Scenario	Coastal Flood Scenario (Water Level Boundary)
2010	1% AEP	MHWS (0.623m AHD)
2010	1% AEP	5% AEP (1.21m AHD)
2010	5% AEP	1 % AEP (1.52m AHD)
2010	20% AEP	20% AEP (1.07m AHD)
2050	1% AEP + 10% Rainfall increase	MHWS + 0.3m SLR (0.923m AHD)
2050	1% AEP + 10% Rainfall Increase	5% AEP + 0.3m SLR (1.51m AHD)
2050	5% AEP + 10% Rainfall Increase	1% AEP + 0.3m SLR (1.82m AHD)
2050	20% AEP + 10% Rainfall Increase	20% AEP + 0.3m SLR (1.37m AHD)
2100	1% AEP + 30% Rainfall Increase	MHWS + 1.0m SLR (1.623m AHD)
2100	1% AEP + 30% Rainfall increase	5% AEP + 1.0m SLR (2.52m AHD)
2100	5% AEP + 30% Rainfall Increase	1% AEP + 1.0m SLR (2.52m AHD)
2100	20% AEP + 30% Rainfall Increase	20% AEP + 1.0m SLR (2.07m AHD)

5.1.1 OCEAN DERIVED FLOOD EVENTS

For the ocean derived flood events the elevated ocean boundaries all events are modelled with an open entrance condition (refer Section 2.2.10).

Details of the tidal signals developed for Kingston Beach are provided in Section 2.2.12. Figure 26 shows the projected tidal signal for Kingston Beach in the year 2100 under various design storm surge events.

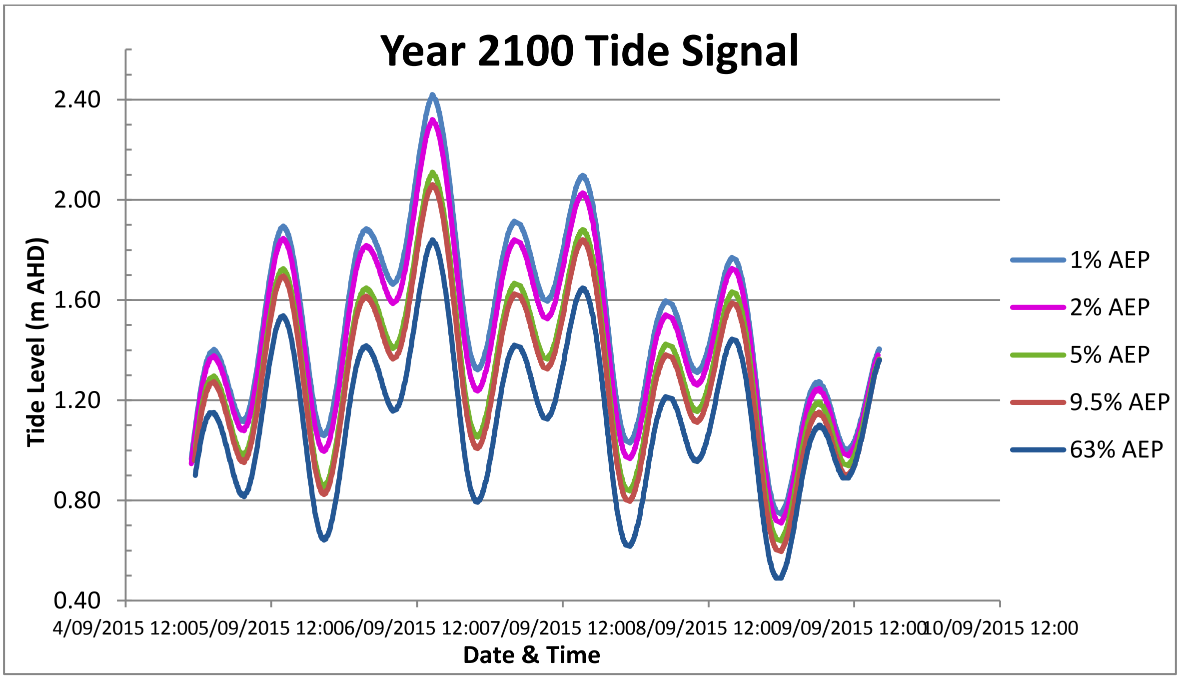


Figure 26: Tide Signal at Different Storm Surge Event

5.2 DESIGN FLOOD HYDROGRAPHS

A range of storm durations were modelled in order to identify the critical storm duration for design event flooding in the catchment. Design durations considered included the 30 mins, 60 mins, 90 mins, 120 mins, 180 mins, 270 mins, 360 mins, 540 mins (9-hour), 720 mins, 1080 mins and 1440 mins durations.

The 1% AEP flows from Whitewater Creek and Browns River in Year 2100 were simulated and recorded in Figure 27 and Figure 28. Outputs from the model simulations for Whitewater Creek show that the highest peak inflows to Kingston Beach are derived when using storm duration of 720 mins duration. For Kingston Beach, 540 mins duration provided for the highest peak flows. However, the overall storm duration of 540 mins was adopted in the model as flows from Browns River resulted in the highest levels of flooding in Kingston Beach.

Figure 29 shows the simulated peak flood at 1% AEP 9 hour duration hydrographs in Year 2100 from Whitewater Creek, Browns River and the combined flow at the confluence of Whitewater Creek and Browns River.

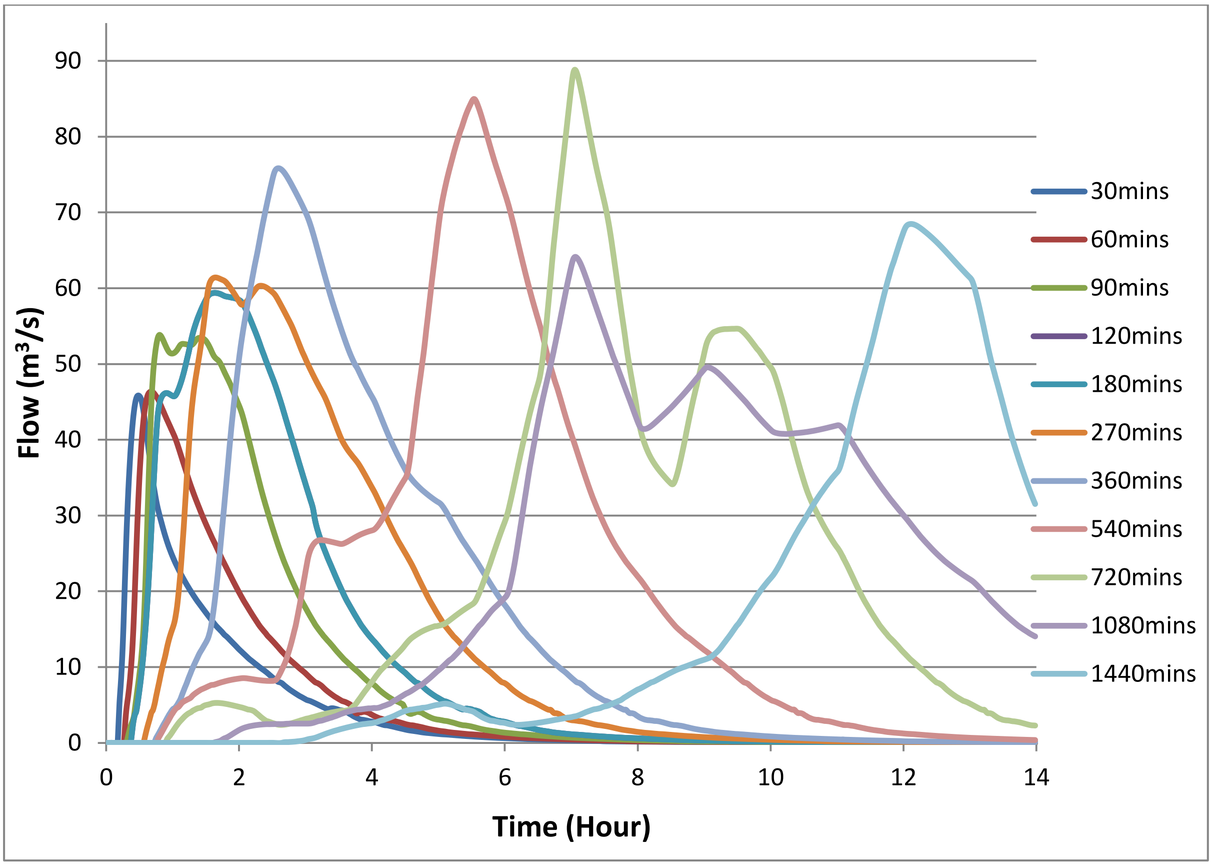


Figure 27: 1% AEP Flow Rate of Whitewater Creek for Different Storm Duration

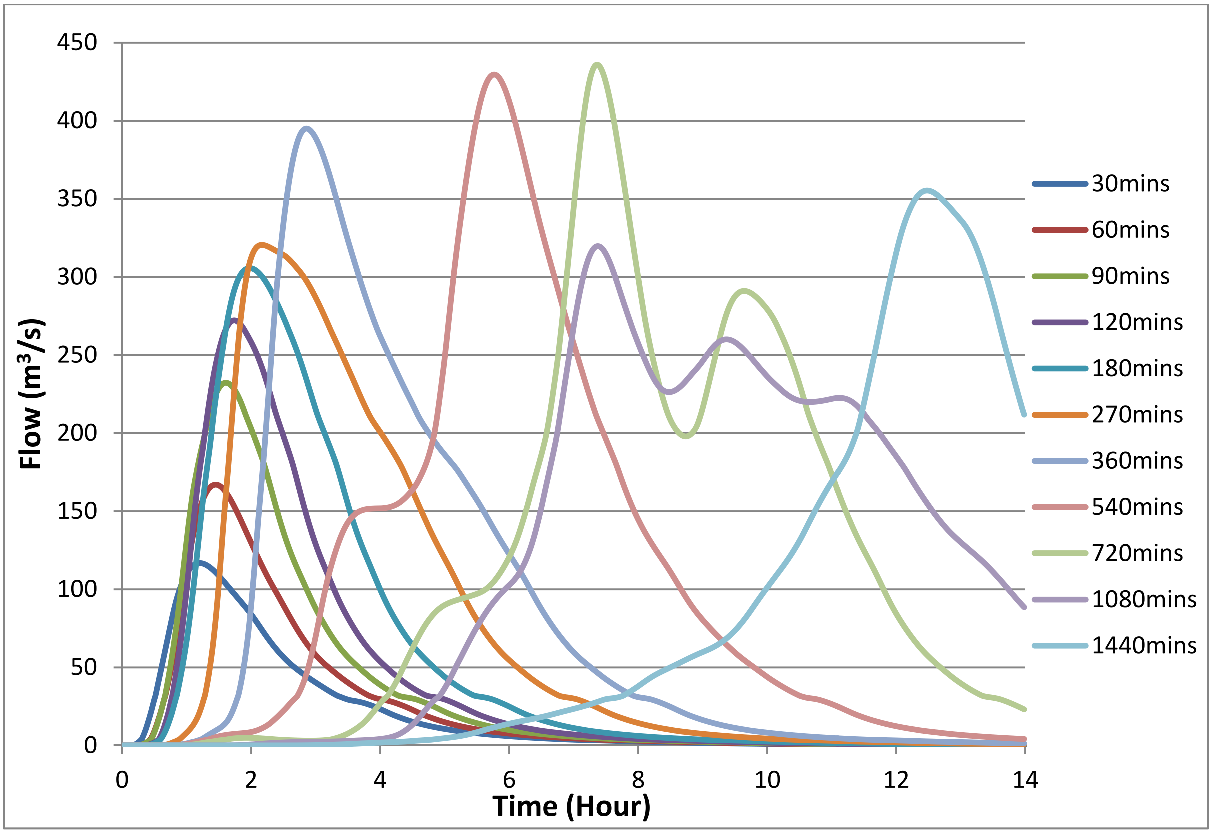


Figure 28: 1% AEP Flow Rate of Browns River for Different Storm Duration

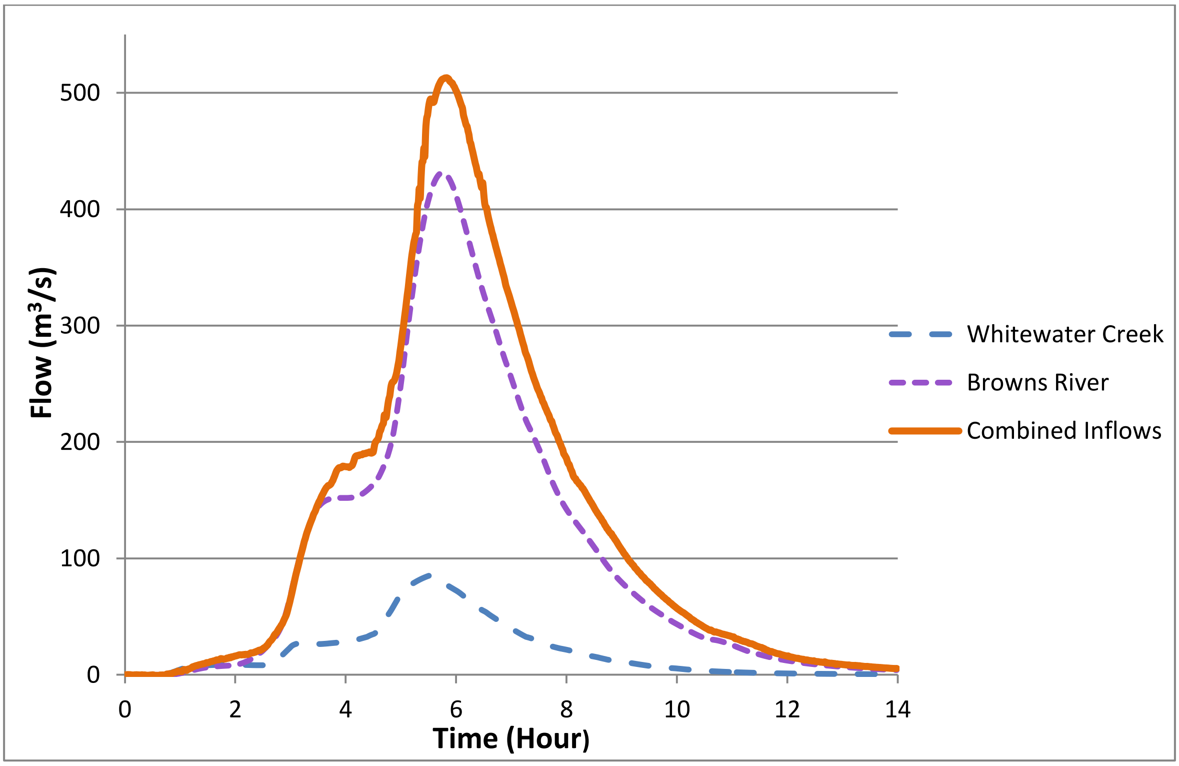


Figure 29: Flow Rate of Whitewater Creek and Browns River and Their Combined Inflows to Kingston Beach in Year 2100 (1% AEP 9-hour Event)

6 DESIGN FLOOD RESULTS

A range of design flood conditions were modelled, the results are presented and discussed below. The simulated design events included the 20% AEP, 5% AEP and 1% AEP for both catchment derived and ocean derived flooding. The design flood results are presented in a flood mapping series in https://www.kingborough.tas.gov.au/services/environmental-programs/inland-waterways/.

6.1 CATCHMENT DERIVED FLOOD EVENTS

For each of the simulated design events including the 20% AEP, 5% AEP and 1% AEP events, a map of peak flood level, depth and velocity is presented covering the modelled area.

Predicted flood levels at 22 selected locations for 1% AEP event in Year 2100 and Year 2050 are given in Table 33 for the full range of design events considered. The locations of reported flood levels are shown in Figure 23.

6.2 JOINT CATCHMENT AND OCEAN DERIVED FLOOD EVENTS

Predicted peak flood levels at selected locations (Figure 23) for the coincident catchment and ocean flooding scenarios are provided in Table 33. The coincident flooding scenarios presented include:

- 1% AEP catchment rainfall with 5% AEP coastal flood event;
- 5% AEP catchment rainfall with 1% AEP coastal flood event; and
- 20% AEP catchment rainfall with 20% AEP coastal flood event

Table 33: Water Elevation at Different Event in Year 2100

Location Point	Modelled Peak Flood Level (m AHD)				
	1% AEP 9-hour Catchment Event	1% AEP Coastal Event	1% AEP Catchment+ 5% AEP Coastal Flood Event	5% AEP Catchment + 1% AEP Coastal Flood Event	20% AEP Catchment + 20% AEP Coastal Flood Event
1	2.58	2.52	2.63	2.64	-
2	2.97	2.52	3.00	-	-
3	2.98	-	3.00	-	-
4	2.63	2.52	2.63	2.56	-
5	3.07	-	3.09	2.88	-
6	3.18	-	3.20	2.98	-
7	3.11	-	3.12	2.86	-
8	3.01	-	3.02	-	-
9	2.79	2.53	2.82	2.71	2.21
10	2.72	2.53	2.75	2.70	2.21
11	2.87	2.53	2.90	2.77	2.26
12	3.18	2.55	3.20	2.98	-
13	3.23	-	3.25	3.02	-
14	3.27	-	3.28	3.04	-
15	3.00	-	3.23	3.00	-
16	3.26	2.53	3.28	3.04	2.50
17	3.28	2.52	3.30	3.05	2.51
18	3.33	2.52	3.34	3.10	2.58

Location Point	Modelled Peak Flood Level (m AHD)				
	1% AEP 9-hour Catchment Event	1% AEP Coastal Event	1% AEP Catchment+ 5% AEP Coastal Flood Event	5% AEP Catchment + 1% AEP Coastal Flood Event	20% AEP Catchment + 20% AEP Coastal Flood Event
19	3.44	2.53	3.45	3.19	2.75
20	3.10	2.53	3.13	2.92	2.33
21	3.24	2.53	3.26	3.02	2.45
22	3.50	2.52	3.51	3.24	2.82

6.3 FLOOD HAZARD

A number of approaches were considered when attempting to define hydraulic hazard categories for Kingston Beach low lying areas. Approaches to define hydraulic hazard categories that were considered for this assessment are as below:

- Peak water elevation/flood depth
- Peak velocity
- Peak hazard (velocity x depth)
- Duration of inundation
- Combinations of the above

The definition of hydraulic categories that was considered to best fit the application within the Browns River catchment, was based on a combination of velocity*depth and depth parameters. The adopted hydraulic categorisation is defined in Table 34.

Table 34: Flood Hazard Categories for Infants, Children and Adults

<table>
<tr><th rowspan="2">d.V (m2/s)</th><th>Infants, small children</th><th>Children</th><th>Adults</th></tr>
<tr><th>(H.M < 25 m.kg), frail and older</th><th>(H.M = 25 tp 50 m.kg)</th><th>(H.M > 50 m.kg)</th></tr>
<tr><td>0</td><td>Safe</td><td>Safe</td><td>Safe</td></tr>
<tr><td>0 to 0.4</td><td rowspan="5">Extreme Hazard; Dangerous to all</td><td>Low Hazard1</td><td rowspan="2">Low Hazard1</td></tr>
<tr><td>0.4 to 0.6</td><td rowspan="2">Significant Hazard; Dangerous to most</td></tr>
<tr><td>0.6 to 0.8</td><td>Moderate Hazard Dangerous to some2</td></tr>
<tr><td>0.8 to 1.2</td><td rowspan="2">Extreme Hazard; Dangerous to all</td><td>Significant Hazard; Dangerous to most3</td></tr>
<tr><td>> 1.2</td><td>Extreme Hazard; Dangerous to all</td></tr>
</table>

[1]Stability uncompromised for persons within laboratory testing program at these flows (to maximum flow depth of 0.5m for children and 1.2m for adults and a maximum velocity of $3.0ms^{-1}$ at shallow depths).

[2]Working limit for trained safety workers or experienced and well equipped persons ($D.V < 0.8m^2s^{-1}$)

[3]Upper limit of stability observed during most investigations ($D.V > 1.2m^2s^{-1}$)

The NSW Government's Floodplain Development Manual (2005) defines flood hazard categories as follows:

High hazard – possible danger to personal safety; evacuation by trucks is difficult; able-bodied adults would have difficulty in wading to safety; potential for significant structural damage to buildings; and

Low hazard – should it be necessary, trucks could evacuate people and their possessions; able bodied adults would have little difficulty in wading to safety.

The key factors influencing flood hazard or risk are:

- Size of the Flood
- Rate of Rise - Effective Warning Time
- Community Awareness
- Flood Depth and Velocity
- Duration of Inundation
- Obstructions to Flow
- Access and Evacuation

The provisional flood hazard is often determined on the basis of the predicted flood depth and velocity. This is conveniently done through the analysis of flood model results. A high flood depth will cause a hazardous situation while a low depth may only cause an inconvenience. High flood velocities are dangerous and may cause structural damage while low velocities have no major threat. The provisional hydraulic hazard for the 20% AEP, 5% AEP, and 1% AEP is included in the mapping series provided at **https://www.kingborough.tas.gov.au/services/environmental-programs/inland-waterways/**.

6.4 DISCUSSION

The results indicate that most of the Kingston Beach residential and commercial areas are subject to between 2.6 m AHD to 3.3 m AHD water levels during the peak 1% AEP coincident flood in the Year 2100. The resultant flood risk varies across the study area with lower lying areas backing onto Browns River being exposed to relatively high velocities and flood depths compared to the higher ground adjacent to Osborne Esplanade ie the flood risk decreases across Kingston Beach from Browns River to the beach.

The gully behind the Kingston Beach Sport Oval is also an area of elevated flood risk both from Browns River rising and overland flow from the steep hill ascending to Roslyn Avenue and Boronia Hill, which form a considerable portion of its catchment. A further area of higher flood risk is evident at the Browns River end of Windsor Street.

The results indicate that for the design coincident flood event catchment (fluvial) flood is the dominant factor affecting flood risk in Kingston Beach, compared with storm surge. The influence of catchment flooding on coincident flood risk in Kingston Beach increases in scenarios that incorporate a lower than design storm tide. Conversely, the dominance of the catchment flood is expected to reduce as sea level rise increases throughout the 21st century.

In most of the design flood events investigated the 1% AEP catchment (fluvial) flood had insignificant reduction in flood level within the range of tailwater levels tested. Further, the phasing of tide coincident with the peak flood level also appears to have minimal effect on flood levels within Kingston Beach. However, it is noted that the influence of the berm that exists across Kingston Beach negates some of the expected benefits of lower tailwater levels.

Due the size of the undeveloped portion of the catchment compared to the projected future urban growth area the comparison of the current and future development shows that there is only a moderate increase in inflow rate from Browns River and Whitewater Creek to Kingston Beach due to development. Projected climate change impacts to both rainfall intensity and sea level are the principle factor causing an increased flood risk in Kingston Beach throughout the 21st century.

7 EMERGENCY MANAGEMENT

In Kingborough the Emergency Management Group (EMG) is the agency responsible for coordinating local planning and response for flood events. A lack of available data can be a limiting factor for an agency's ability to plan for the event and to communicate the expected impacts to local residents / media. It is for this reason that it is recommended that Council officers hold workshops with key members of the EMG following the finalisation of this study to disseminate design event modelling outputs. This will enable the EMG to review the outputs and request any additional information which would be of most use during a flood emergency. The following sections provide information on several key items which should be developed to support emergency management planning.

7.1 FLOOD EMERGENCY PLAN

It is common for emergency management agencies to develop or amend their Flood Emergency Plan following the completion of a Flood Risk Study. This is a detailed document containing an agreed set of roles, responsibilities, functions, actions and management arrangements to deal with flood events of all sizes.

The primary aim of a flood emergency plan is to reduce hazard during an actual flood. Essential issues addressed in the plan are flood forecasting, flood warning, location of vulnerable people/communities and evacuation and initial recovery. A local flood emergency plan forms an essential component of a floodplain management plan and requires close liaison between emergency management staff. Typically, a flood emergency plan has several trigger points that result in the activation and implementation of the plan as the actual flood event develops. The flood emergency plan should include activities to protect and reinstate essential infrastructure services required during clean-up and in the recovery phase.

It is recommended that Kingborough Council commence the development of a Flood Emergency Plan for Kingston Beach immediately upon the completion and endorsement of this flood study.

7.2 ASSESSMENT OF CRITICAL INFRASTRUCTURE

A list of critical infrastructure within Kingston Beach at which it is likely to be inundated will be prepared. This could include infrastructure such as:

- Significant facilities for evacuation (eg child care, education, retirement, nursing care)
- Key water and sewerage infrastructure
- Roads / bridges

Previous studies as documented in this report, Section 2.2.1 have provided rough estimations of damage costs and the *Kingston Beach Integrated Climate Change and Natural Hazards Project Report* (Climate Planning, 2016), has investigated the economic costs and benefits of various levels of flood risk in Kingston Beach. This assessment included estimation of replacement costs for critical infrastructure including buildings, structures, roads and footpaths, sewerage, water main and stormwater for various design flood events.

This report concurs and reinforces the recommendations made in the *Kingston Beach Integrated Climate Change and Natural Hazards Project Report* (Climate Planning, 2016) relating to infrastructure.

7.3 FLOOD WARNINGS

The Bureau of Meteorology (BoM) provides a flood warning service for Tasmanian Rivers. The Bureau delivers this service through its Flood Warning Centre and Regional Forecasting Centre based in Hobart. The warnings they provide are used by the Police, State Emergency Service (SES) and local authorities to plan their emergency responses.

It is vital that there is a single source of information during a potential flood emergency. Mixed messages can lead to confusion, unnecessary damage to property and even lives being lost. Some councils assist BoM with its forecasting by providing rain and flood level data from their own gauges which have been strategically placed to provide the best flood warning for areas of elevated flood risk within their municipalities.

At present there is no flood gauge on Browns River that could be used in a flood warning system.

Investigate the costs of installing as flood gauge on Browns River and develop options for use of the data for use by the BoM in their flood warning system.

7.4 EVACUATION ROUTE ASSESSMENT

Using the inundation maps presented in this report, the persons likely to be affected by floods should be identified and their ability to manage their well-being during floods assessed. Evacuation routes will be assessed for susceptibility to flooding.

The assessment should include the development of evacuation messages containing the main evacuation routes, description of safe havens and a description on how to behave during an evacuation. This message should be differentiated according to the situation of the inhabitants regarding risk, evacuation routes and safe areas and shelter place. Vulnerable parts of the community should also be identified when assessing evacuation routes (ie nursing homes, kindergartens, etc.) to ensure consideration is made for evacuation timings and special requirements.

8 POTENTIAL MITIGATION MEASURES

The most visible approach for flood mitigation involves structural measures which include flood mitigation ams, retarding basins, channel levees, and channel improvements. Structural measures are expensive, highly visible and may initially appear to be the best solution, especially when the political impact is considered. However, they can only benefit specific existing developed areas (they are not appropriate in many areas) and after construction, there may be pressure for further development in the perceived flood free area which may ultimately negate the benefits obtained from construction of the measure. Furthermore, they can generate the perception that the area is flood free when in fact a flood greater than that designed for will occur at some future time; a flood the community in the protected area may not be prepared for.

The most effective approach is the use of non-structural measures which involve careful planning of development in potentially flood prone areas. This should be supported by appropriate legislation, public information and education programmes (to ensure that residents understand the flood risk), flood insurance, and flood warning systems (to reduce the impact of floods).

The most important non-structural measure is appropriate strategic and land use planning legislation which places appropriate controls upon development within floodplains. These controls should be based upon assessment of the flood risk determined through a thorough hydrological and hydraulic analysis of flooding in the catchment. The responsibility for implementation of these controls currently rests with State and Local Government Authorities.

Another non-structural measure commonly employed is flood forecasting and flood warning services. These are provided primarily by local government with the data being provided to the Bureau of Meteorology for dissemination to relevant emergency management agencies and protocols. This is an important service as the magnitude of economic and social losses associated with a flood event can be significantly reduced with warning. Flood forecasting and warning systems depend on the forecast lead time, the accuracy of the forecasts and community awareness. Long lead times where people have confidence in the forecasts will provide greater benefits.

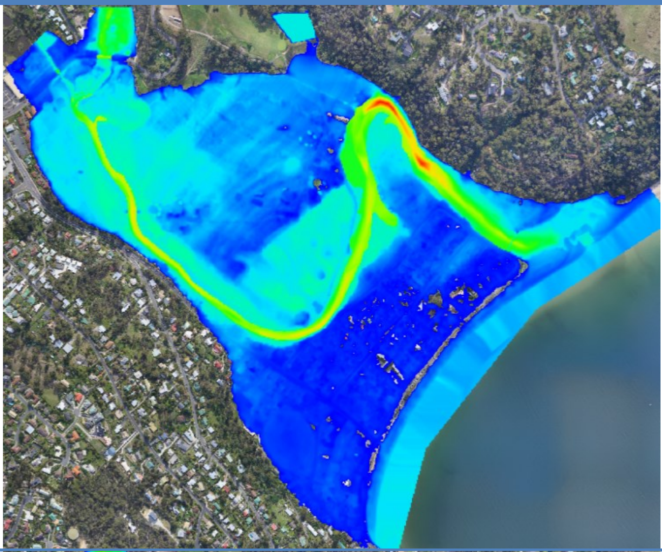
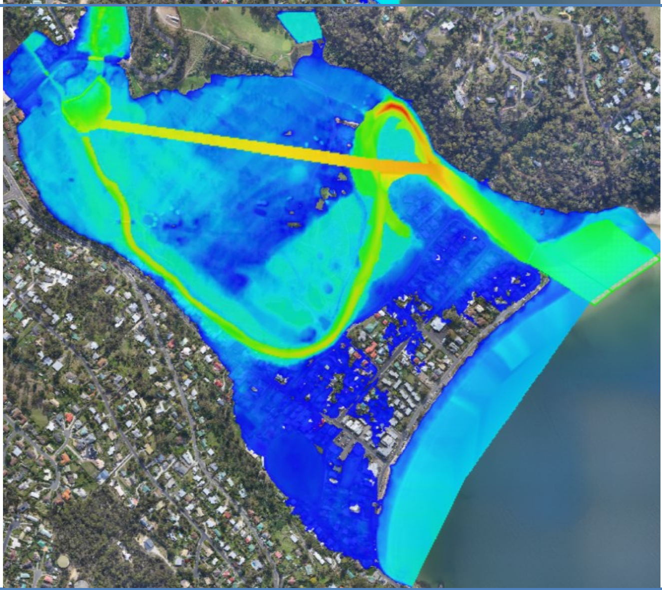
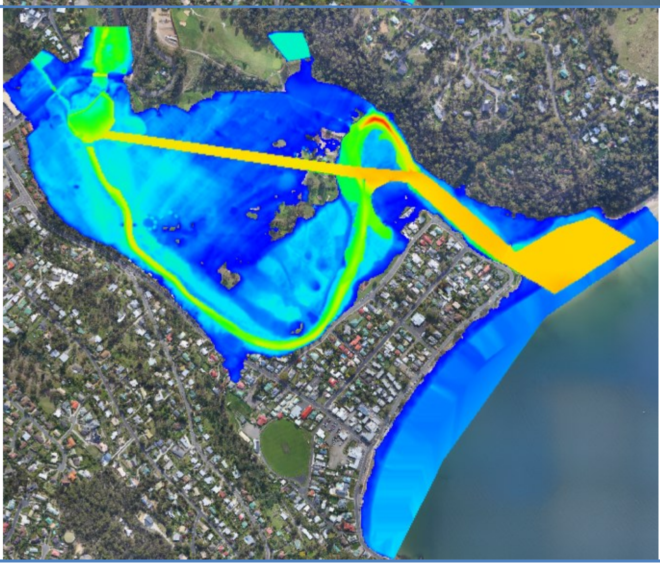
Mitigation and protection measures are generally aimed at protecting people against flood events that occur within the design level for residential buildings. Based on the Building Code of Australia and various state and national policies and strategies, the design level for residential buildings is set at the 1 % Annual Exceedence Probability (AEP) flood. Risk over this standard measure is described as 'residual risk'.

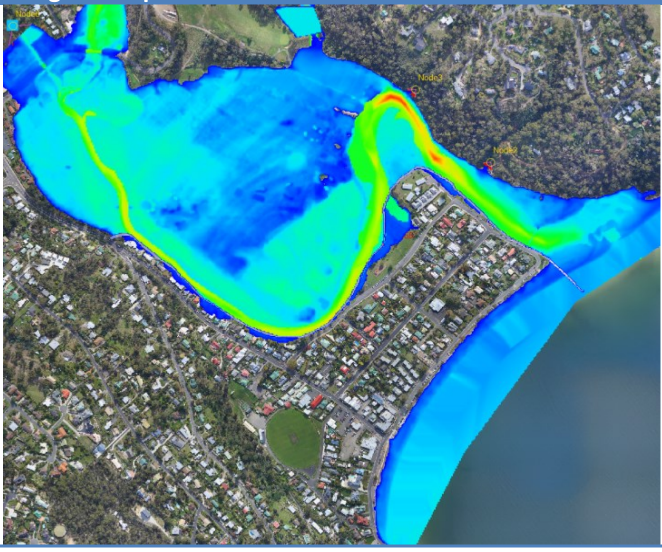
Flood mitigation options proposed, assessed and developed in this study aim to:

- Eliminate, or limit to acceptable levels, the effect of flooding on the well-being, health and safety of flood prone individuals and communities;
- Eliminate, or limit to acceptable levels, damage caused by flooding to private and public property;
- Maintain or facilitate the natural function of the floodplain (ie to convey and store floodwaters during a flood) and where necessary, enhance floodplain function along with any flood dependent ecosystems;
- Encourage planning and use of floodplains as a valuable and sustainable resource capable of multiple, but compatible uses of benefit to the community.

Several concept structural mitigation options for Kingston Beach have been assessed for effectiveness in the hydraulic model. The two most effective concepts that have been deemed worth further investigation are presented in Table 35.

Table 35: Concept Mitigation Option Assessment

Mitigation Option	Description
	**No Mitigation.**
	**Alternative channel through Kingston Beach Golf Course and channel straightening through Council reserve at 26 Balmoral Road and permanent opening of coastal berm.**
	**Combination of alternative channel straightening through Golf Course and deepen and widen the channel before the outlet and permanent opening of coastal berm.**

Mitigation Option	Description
	**Flood protection wall adjacent to Browns River**

Council engaged specialist consultants BMT WBM (Oct 2016) to review potential mitigation measures and recommend further work to progress a preferred scheme if identified. The report's conclusions are summarised below.

A Preferred Mitigation Scheme is proposed combining channel straightening with entrance opening. Both options are complimentary. Combined they have a significant impact of the flood behaviour, reducing the risk of flood inundation within the lower Browns River floodplain.

Further detailed assessment of the Preferred Mitigation Scheme is recommended due to the positive hydraulic benefits associated with the design. Recommended assessments include:

- Erosion Assessment: to identify the erosion potential associated with the design geometry for the Preferred Mitigation Scheme. This will inform the erosion protection required to safeguard the scour. This is particularly relevant for the bypass channel where it connects to the Browns River.
- Joint Probability Analysis: to examine the likelihood of coincident freshwater flooding, surge and high tide conditions. This assessment would help to understand the average recurrence interval for combined flood and tail water events.
- Data Collection: obtain a tidal water level and flow dataset to support tide model calibration which would allow a detailed assessment of tidal prism and surge propagation impacts associated with changes to the river entrance.
- Coastal Processes Assessment: to quantify the logistics and ongoing costs associated with maintaining an open entrance condition. The assessment should include liaison with local contractors to determine what sand bypassing services using land-based excavation and/or dredging machinery are available.

9 PLANNING AND DEVELOPMENT IMPLICATIONS

All levels of government have recognised that land use planning can help mitigate the threat from natural hazards. The Council of Australian Governments' National Strategy for Disaster Resilience recognised that "responsible land use planning can prevent or reduce the likelihood of hazards impacting communities", especially for new development.

It is well understood across Australia that land use planning and building controls are generally more cost effective than flood mitigation infrastructure, flood warning systems, education programs or emergency responses.

Because it is possible to predict which land is likely to be flooded, it is prudent to regulate development and building in those areas to ensure any impacts are known and managed. In so doing, the aim is to avoid or minimise the increase in future flood risks.

In order to identify the areas that need to be subject to planning and building controls, it is necessary to decide an appropriate threshold frequency of flooding. This frequency is known as the 'design flood event' (DFE).

In Australia for residential development the 1% AEP flood is the appropriate standard to regulate and protect most forms of development through the planning and building systems.

Understanding potential changes in flooding under climate change is evolving. Anticipated changes in the intensity of storms and in average stream flows may be greater under different climate scenarios, and the variability from year to year may increase. This could shift the likelihood and consequence of floods in different parts of Tasmania. Decision-making must be responsive to the latest scientific information, and this information should be consistently and transparently applied through planning schemes.

This study has developed flood maps for the 1% AEP coincident flood risk in Kingston Beach.

It is recommended that these maps be endorsed by Council and incorporated into the Kingborough Interim Planning Scheme as a flood overlay for the area.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

The purpose of the this Flood Study has been to undertake a detailed flood assessment of the Kingston Beach catchment through the establishment of appropriate hydrological and hydraulic models for accurate flood level prediction.

In completing the flood study, the following activities were undertaken:

- Collection and compilation of available historical and recent climate change data and flood data related to the study area.
- Development of flood models through a comprehensive 2D computer model (XP-SWMM) using available data.
- Simple validation of the models using current best available data and sensitivity tests.
- Production of a range of design flood maps (peak flood level, depth, velocity and hazard) including 1%, 5% and 20% AEP events for catchment (fluvial) derived flooding with future climate change; 1%, 5% and 20% AEP events for derived storm surges level with future sea level rise and coincident floods in 9-hour peak storm events.
- Preliminary investigation of potential mitigation measures.

The results indicate that most of the Kingston Beach residential and commercial areas are subject to between 2.6m AHD to 3.3m AHD water levels during the peak 1% AEP coincident flood in the Year 2100. The resultant flood risk varies across the study area with lower lying areas backing onto Browns River being exposed to relatively high velocities and flood depths compared to the higher ground adjacent to Osborne Esplanade ie the flood risk decreases across Kingston Beach from Browns River to the beach.

The results further indicate that for the design coincident flood event catchment (fluvial) flood is the dominant factor affecting flood risk in Kingston Beach, compared with storm surge. The influence of catchment flooding on coincident flood risk in Kingston Beach increases in scenarios that incorporate a lower than design storm tide. Conversely, the dominance of the catchment flood is expected to reduce as sea level rise increases throughout the 21^{st} century.

Due the size of the undeveloped portion of the catchment compared to the projected future urban growth area the comparison of the current and future development shows that there is only a moderate increase in inflow rate from Browns River and Whitewater Creek to Kingston Beach due to development. Projected climate change impacts to both rainfall intensity and sea level are the principle factor causing an increased flood risk in Kingston Beach throughout the 21^{st} century.

10.2 RECOMMENDATIONS

Recommendation 1: That Council commence the development of a Flood Emergency Plan for Kingston Beach immediately upon the completion and endorsement of this flood study

Recommendation 2: Investigate the costs of installing a flood gauge on Browns River and develop options for use of the data for use by the BoM in their flood warning system.

Recommendation 3: Council undertakes further detailed assessment of the potential mitigation schemes that provide a significant reduction in flood risk in Kingston Beach.

Recommendation 4: 1% Annual Exceedance Probability co-incident flood maps developed in this study be endorsed by Council and incorporated into the Kingborough Interim Planning Scheme as a flood overlay for the area.

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12 Appendix A

Water Research Laboratory (WRL) full details of the derivation of the tidal signals are provided as

.

Table 4: Summary of Adopted Water Levels

Scenario	ARI (years)	Tide + Storm Surge (m)	Sea Level Rise (m)	Peak Wave Setup at d = 0 m (m)	Peak Design Nearshore Water Level (m AHD)
Present Day	1	0.97	0	0.25	1.22
	10	1.21		0.30	1.51
	50	1.37		0.35	1.72
	100	1.44		0.38	1.82
2050	1	0.97	0.4	0.25	1.62
	10	1.21		0.30	1.91
	50	1.37		0.35	2.12
	100	1.44		0.38	2.22
2100	1	0.97	0.9	0.25	2.12
	10	1.21		0.30	2.41
	50	1.37		0.35	2.62
	100	1.44		0.38	2.72

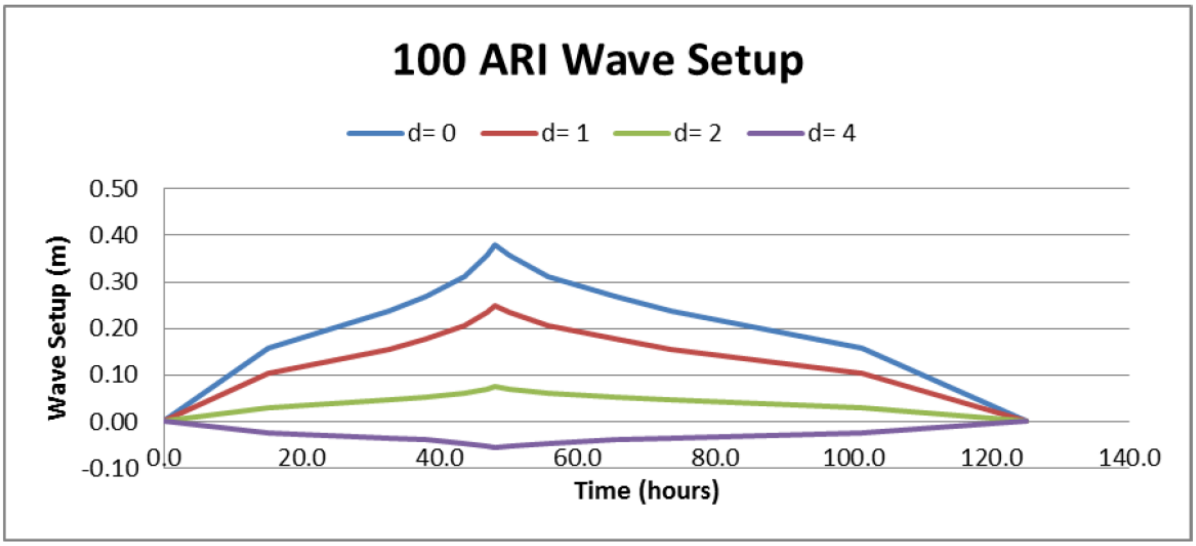


Figure 4: Wave Setup For A 100 Year ARI Wave And Water Level Conditions

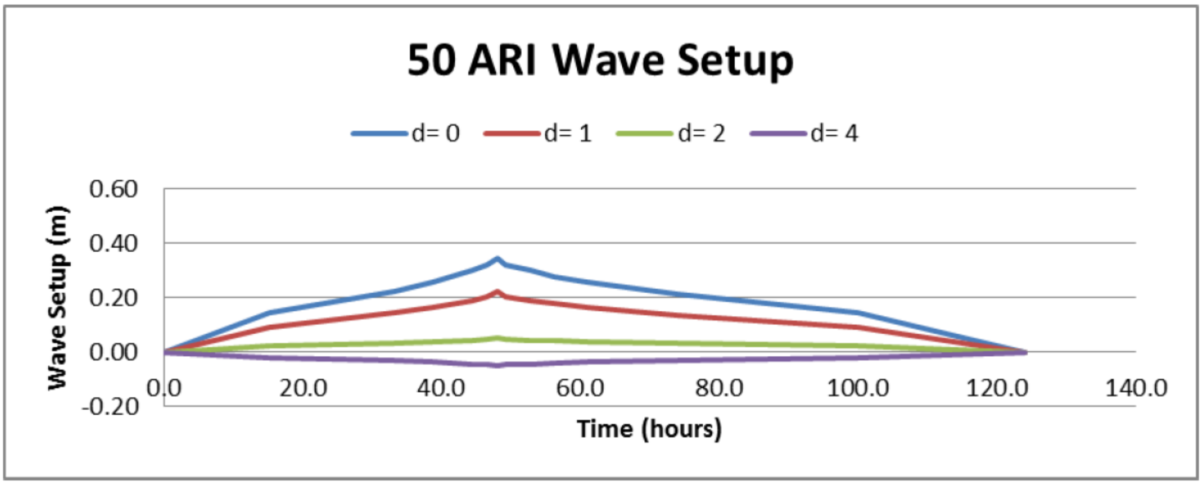


Figure 5: Wave Setup For A 50 Year ARI Wave And Water Level Conditions

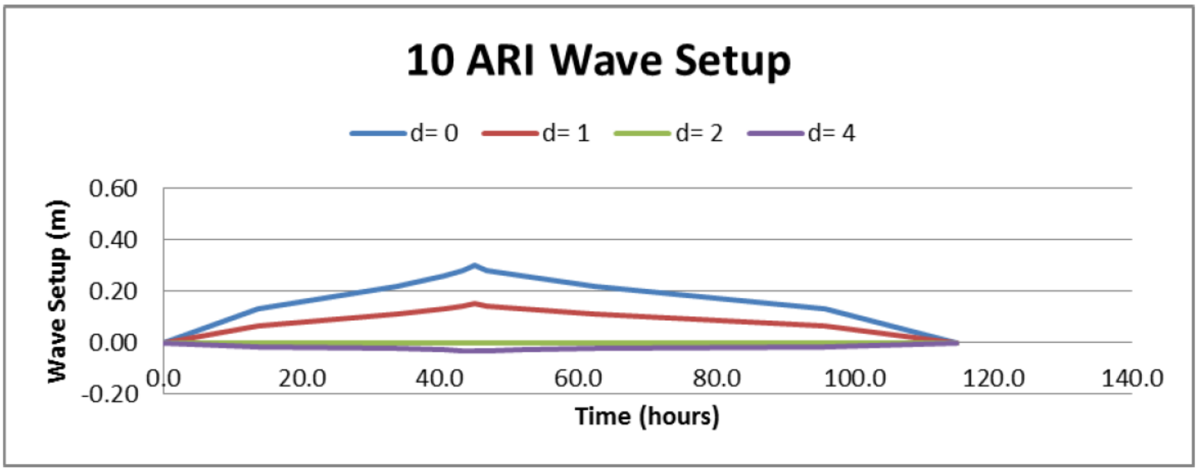


Figure 6: Wave Setup For A 10 Year ARI Wave And Water Level Conditions

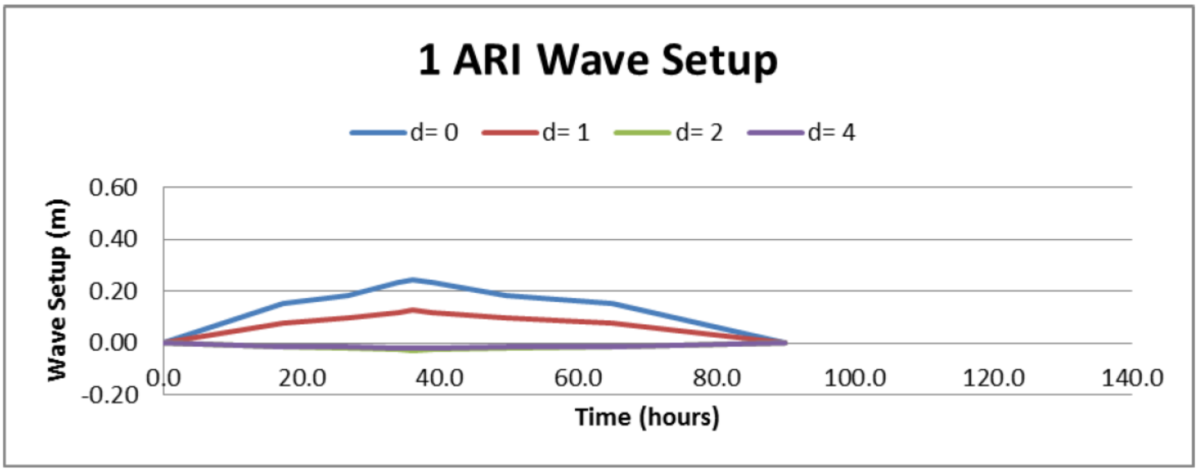


Figure 7: Wave Setup For A 1 Year ARI Wave And Water Level Conditions

The constructed tide time series for the present day 100, 50 10 and 1 ARI events are shown in Figure 9, Figure 10, Figure 11 and Figure 12 respectively.

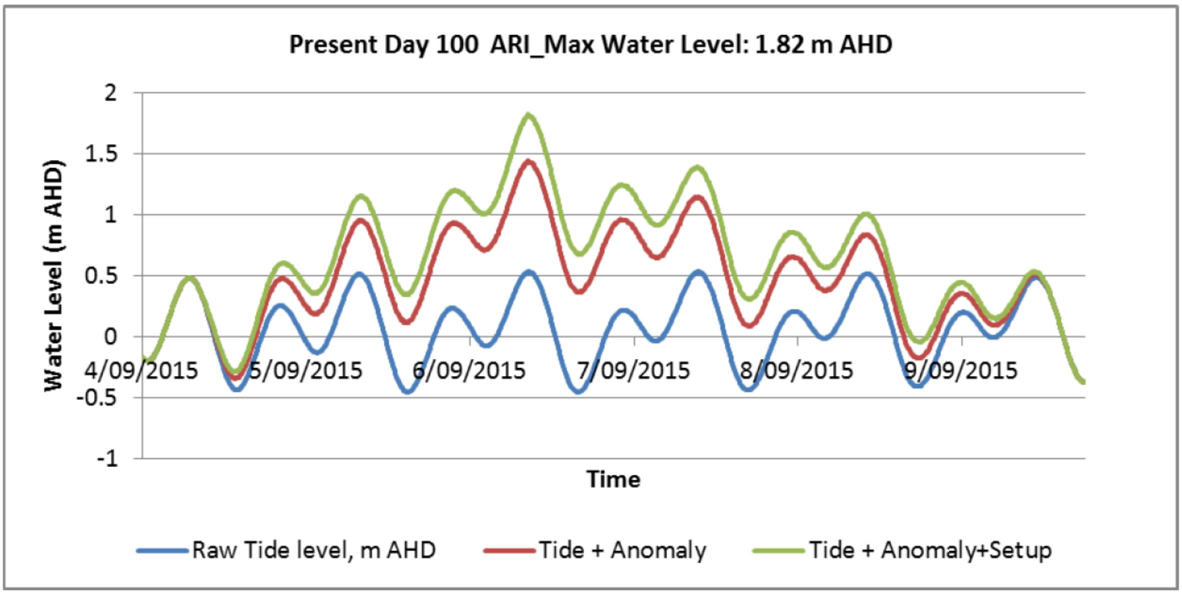


Figure 9: 100 ARI Constructed Tide Signal

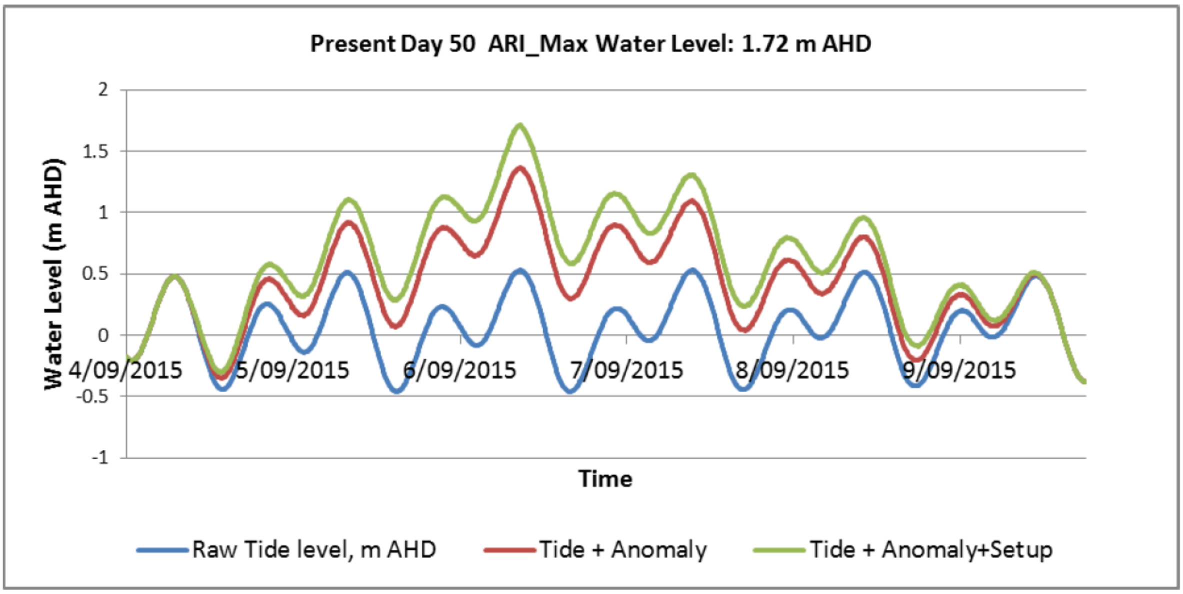


Figure 10: 50 ARI Constructed Tide Signal

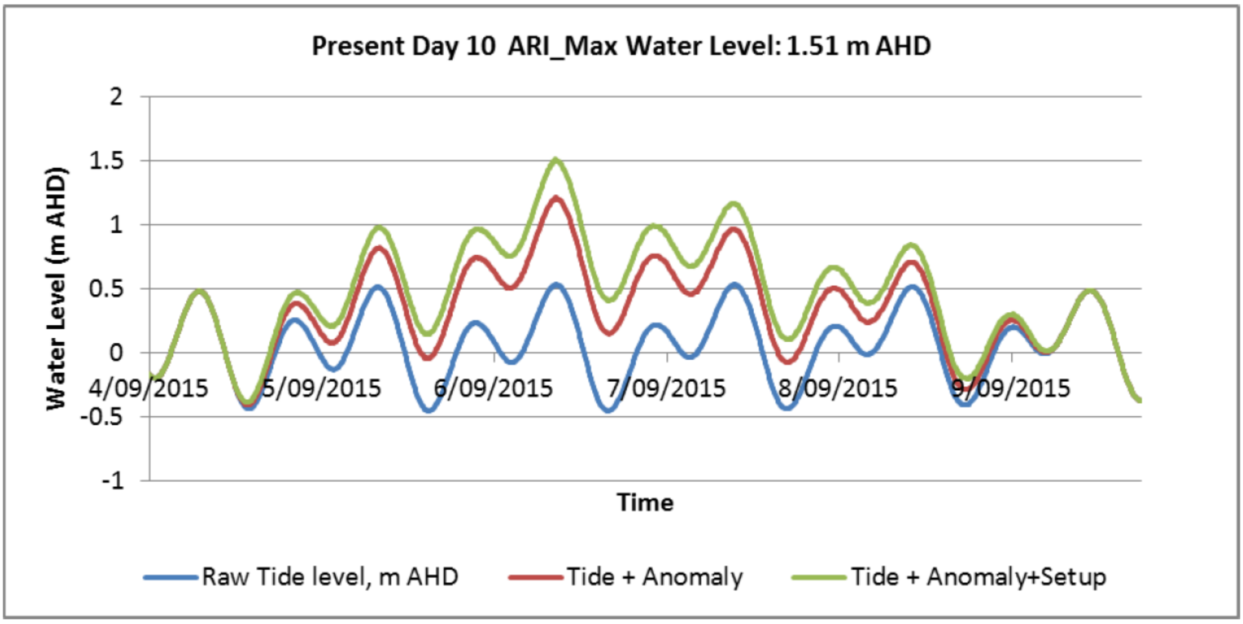


Figure 11: 10 ARI Constructed Tide Signal

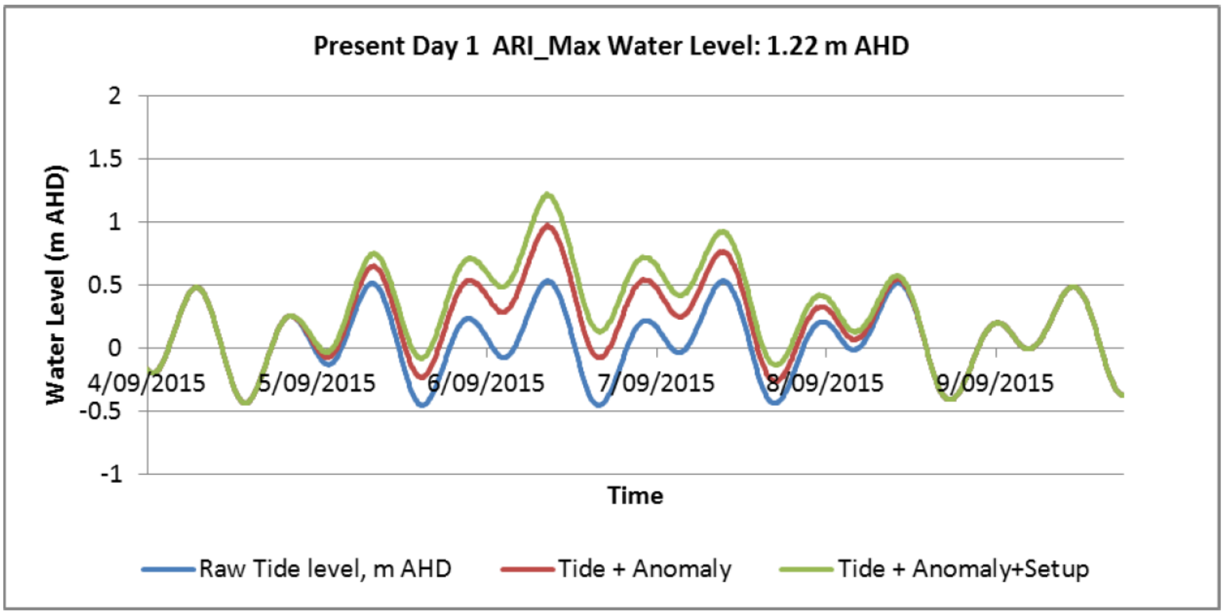
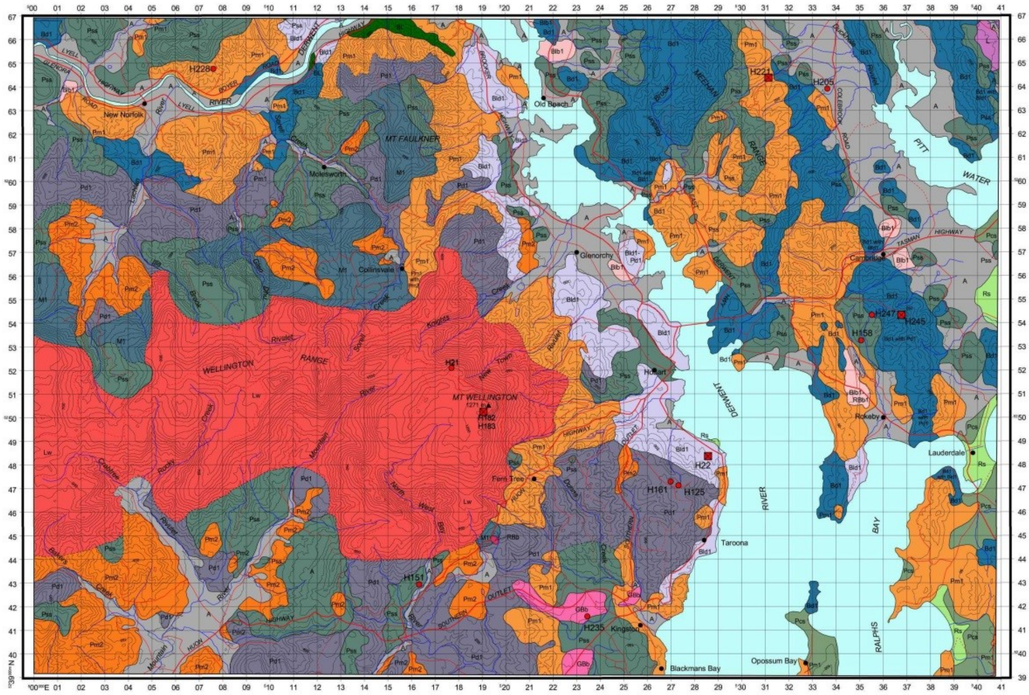


Figure 12: 1 ARI Constructed Tide Signal

13 APPENDIX B

RECONNAISSANCE SOIL MAP SERIES OF TASMANIA

HOBART



Map Reliability
The map framework depends entirely on the Second Order Triangulation, performed by the 3rd. Field Survey Company, based on data in Transverse Mercator Projection, with measurements in yards and elevation in feet. The map was subsequently converted to AMG via an undocumented procedure. Some soil boundaries and soil survey sites digitised from the original CSIRO reconnaissance soil maps contain appreciable error inherent from the source maps.

SCALE 1:100000

● Laboratory reference sites for identified dominant soils
■ Type profiles for associated minor soils

Soil Boundaries
——— Well defined
--------- Interpreted from air photos

MAP USERS NOTE

The information on this map is based on the original field work of J. Loveday, CSIRO Division of Soils, Adelaide. The map. has been updated and reprinted by the Tasmanian Department of Primary Industries, Water and Environment. Some soil boundaries or map unit codes may differ from the original map. No attempt has been made to determine the reliability or accuracy of this map. The Crown, in the right of the State of Tasmania, does not accept any responsibility for any loss or damage which may result to any person arising from reliance on all or any part of this information, whether or not that loss or damage has resulted from negligence or any other cause.

The map provides an appraisal of the soil distribution based on landforms, climate and geology. The soil boundaries have been delineated through aerial photo-interpretation and limited field work. Although the original map was surveyed at a scale of 1:63 360 (1 inch: 1mile), it has been reprinted at a scale of 1:100 000. This map should not be enlarged and should be used in conjunction with the accompanying soil report which gives additional information for the soil map units described below.

Original work by J. Loveday
Updated by S. Spanswick & D. Kidd

Refer to this map and the accompanying report as: Spanswick S. & D. Kidd, (2000) Revised Hobart Reconnaissance Soil Map of Tasmania. Department of Primary Industry Water & Environment.

Acknowledgments

Soils surveyed by J. Loveday, (1955). CSIRO Division of Soils, Adelaide.

Soil data correlated by S. Spanswick and D. Kidd (1999/2000).
Soil map digitised by J. Farrell (1993/1994).
G.I.S by A. Large and T. Davidson (1998/1999).
Map design and layout by T. Davidson (1999/2000).

Base map data supplied by Land Information Services, Department of Primary Industries Water and Environment, Tasmania.

Contour interval: 50 metres

Projection: Universal Transverse Mercator

SOIL LEGEND

MAP UNIT		OLD CSIRO CODE	MAP UNIT CONCEPT	AUSTRALIAN SOIL CLASSIFICATION FOR DOMINANT SOIL	GREAT SOIL GROUP FOR DOMINANT SOIL	SOIL PROFILE CLASS FOR DOMINANT SOIL
SOILS ON BASALT						
Blb1	Black Soils on Basalt 1	*Blb*	Moderate to imperfectly drained black cracking soils developed on Tertiary basalt bedrock and colluvium on low undulating (3-10%) land.	Vertosol	Prairie soil, black earth	Sorell SPC
Blb1-RBb1	Black Soils on Basalt 1-Red Brawn Soils on Basalt 1 Complex	*Blb - RBb*	As for Blbl with RBbl soils on the gentle slopes of ridges.	Vertosol	Prairie soil, black earth	Sorell SPC
RBb	Red Brown Soils on Basalt 1	*RBb*	Undefined soils developed on Tertiary basalt bedrock and colluvium on undulating to rolling (3-32%) land,	No data available	No data available	No data available
GBb	Grey Brown Soils on Basalt	*RBb-Blb*	Imperfect to poorly drained grey brown soils developed on Tertiary basalt bedrock and colluvium on undulating to rolling (3-32%) land.	Dermosol	Brown clay, grey clay	Insufficient data
SOILS ON DOLERITE						
Bld1	Black Soils on Dolerite l	*Bld*	Moderately well drained black soils developed on Jurassic dolerite bedrock and colluvium on low undulating (3-10%) land.	Dermosol	Black earth, prairie soil	Belmont SPC
Bld1-Pd1	Black Soils on Dolerite 1 - Podzolic Soils on Dolerite 1	B*ld-Pd*	As for Bld 1 with imperfectly drained texture contrast soils on the steeper dolerite slopes.	Dermosol	Black earth, prairie soil	Belmont SPC
Pd1	Podzolic Soils on Dolerite 1	Pd	Imperfectly drained texture contrast soils developed on Jurassic dolerite bedrock and colluvium on rolling to steep (10-56%) land.	Chromosol	Grey-brown podzolic	Eastfleld SPC
Bd1	Brown Soils on Dolerite 1	*Bd*	Undefined brown soil developed on Jurassic dolerite bedrock and colluvium on rolling to steep (10-56%) land.	Dermosol	Non Calcic Brown Soil	Tea Tree SPC
SOILS ON LIMESTONE						
BL	Brown Soils on Limestone	*Bl*	Undefined soils developed on Permian limestone bedrock on undulating to rolling (3-32%) land,	No data available	No data available	No data available
SOILS *ON MUDSTONE*						
Pm1	Podzolic Soils on Mudstone 1	*Pm*	*Poor* to imperfectly drained grey brown texture contrast soils developed on Permian siltstone bedrock and colluvium on undulating to rolling (3-32%) land. Rainfall <750mm.	Kurosol	Grey-brown podzolic, soloth	Forcette SPC
Pm2	Podzolic Soils on Mudstone 2	*Pm*	Undefined soils developed on siltstone interbedded with mudstone, sandstone and shale in areas of >750mm rainfall.	Insufficient data	Insufficient data	Insufficient data
SOILS ON SOLIFLUCTION DEPOSITS						
M1	Miscellaneous Soils 1	*YBs*	Stony well drained yellow-brown soils developed on Jurassic dolerite bedrock and colluvium on rolling to very steep (10-100%) land. Rock outcrop is frequent.	Ferrosol	Krasnozem, red podzolic	Yellow Brown Soils on Solifluction Deposits SPC, High Moor Peat SPC
SOILS *ON SOLIFLUCTION DEPOSITS & ORGANIC DEPOSITS*						
Lw	Liawenne Association	*YBs-HMP*	Stony well drained yellow brown soils developed on Jurassic dolerite bedrock and colluvium on rolling to very steep (10-100%) land. Rock outcrop is frequent and humus rich deposits occur in depressions/drainage lines.	Ferrosol with co-dominant Organosols	Red podzolic, krasnozem with co-dominant acid peat	Yellow Brown Soils on Solifluction Deposits SPC, High Moor Peat SPC
SOILS *ON SANDSTONE*						
Pss	Podzol and Podzolic Soils on Sandstone	*Pss*	Undefined soil developed on Triassic sandstone bedrock and colluvium on undulating to rolling (3-32%) land	Nodata available	No data available	No data available
SOILS ON COVER SANDS						
Pcs	Podzols on Cover Sands	PCS	Undefined soils developed on Quaternary wind blown sand on gently undulating to rolling (3-32%) dolerite, sandstone and mudstone hillslopes.	**Podosol	**Podzol	Insufficient data
SOILS *ON RECENT SAND*						
Rs	Soils of Recent Sands and Shell Beds	*Rs*	Undefined, soils developed on Quaternary sands of coastal beaches.	**Rudosols, tenosols	Insufficient data	Insufficient data
SOILS *ON RECENT ALLUVIUM*						
A	Undifferentiated Alluvial Soils	*A*	Undifferentiated soils developed on Quaternary alluvium.	No data available	No data available	No data available
LATERITIC SOILS						
L	Lateritic Soils	*L*	Undefined soils developed on deeply weathered sediments.	No data available	No data available	No data available

*** Classification based an available literature*