SNUG RIVER FLOOD STUDY

KINGBOROUGH COUNCIL

December 2019

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EXECUTIVE SUMMARY

The Snug River Flood study has been prepared by Kingborough Council. The key objective of the study was to define the flood behaviour under existing and future potential climate conditions in the Snug River catchment for a range of coincident design catchment floods and coastal floods. Outcomes from this study will be used by Council to inform future land use planning, emergency management and capital expenditure planning. Assessment of flood risk has been undertaken for Snug River flooding only and does not explicitly consider flooding from stormwater within the Snug Township.

Methodology

The analysis for this study has relied on the development of numerical computer models to simulate the hydrological and hydraulic processes in the Snug River catchment, with the adopted methodology following the guidelines in ARR2016. This has been achieved by developing hydrological and hydraulic models using the XPSWMM® software, comprising the following activities:

- Collection and compilation of available data considered relevant for understanding and describing the Snug River catchment and flooding characteristics;
- Engagement with the local community via distribution of a questionnaire, aimed at raising general awareness of the study and to garner flood intelligence;
- Development of a hydrological model of the Snug River catchment using XPSWMM®, deriving inflows for the hydraulic extent of the Snug River (only riverine flooding was considered, flooding from local stormwater catchments were excluded);
- Development of a hydraulic flood model of the lower Snug River using XPSWMM®;
- Calibration of the hydrological model using historic rainfall and gauged flow data, with additional determination of model parameters using a flood frequency analysis for the Snug River streamflow gauging station;
- Analysis of a range of design flood events, with preparation of flood mapping;
- Sensitivity tests of the hydrological and hydraulic model for a range of model parameters; and
- Climate change analysis, applying predicted increases in rainfall intensities and sea levels for the years 2050 and 2100.

Results

The results of the hydraulic modelling of design flood events indicate the flooding behaviour summarised in the following table:

Table 1 General flooding behaviour from hydraulic modelling of design flood events

Floodplain location	Changes in flooding behaviour
Upstream of the Channel Highway	Flooding is generally contained within the defined river channel and floodplain. This results from a combination of: • High ground on both sides of the river channel; • Relatively few obstructions to flow along the river and floodplain corridor; • A predicted hydraulic grade of less than 1 in 50 (2%)
Downstream of the Channel Highway	Where the river widens out to the estuary in the lower reaches, flooding is affected by the combination of tide level and constriction at the river mouth, in addition to the magnitude of fluvial event in the river

The sensitivity tests undertaken for this study indicate that the various model parameters adopted for design event modelling are appropriate for use in this study. Regarding debris blockage at the Channel Highway bridges, both historic data and sensitivity modelling indicate that flooding may be exacerbated by the accumulation of debris (typically large woody debris) at the Channel Highway bridges. This indicates the need to maintain the bridges as blockage-free to minimise impacts of flooding due to debris blockage.

Modelling of the climate change scenarios indicates that the increase in rainfall intensity and sea level rise associated with each scenario results in both increased peak flood levels and extents of flooding. The increases in peak water levels upstream of and in the general vicinity of the Channel Highway bridges are generally caused by the increased rainfall intensities (fluvial events), while the peak water level increases in the wider part of the estuary are the result of both increased rainfall intensities and sea level rise. It is likely that sea level rise is the major factor affecting the peak water level increases in the lower reach of the estuary.

Recommendations

The following recommendations have been prepared to address both future uses of the tools developed in preparing the study and the study outcomes.

Table 2 Recommendations for further works

Recommendations	
1	That Council further enhance the modelling tools developed for this study, primarily to include local catchments inflows and associated stormwater drainage infrastructure in Snug.
2	That Council collects flood data during and immediately following future flood events to assist with recalibration and/or on-going validation of the modelling tools.
3	That Council develop a long-term strategy for the management of flood risk in the low-lying areas of Snug.
4	That Council investigates an entrance management plan for the mouth of the Snug River with the aim of minimising the constriction that currently exists at the river mouth.
5	That the flood mapping for the 1% AEP, year 2100, developed for this study be endorsed by Council and incorporated into the Kingborough Interim Planning Scheme as a flood overlay for the area (noting that stormwater flooding has not been addressed in this study).
6	That Council establishes and promotes a community education program in conjunction with the SES to provide information on what to do before, during and after a flood event, and to facilitate the communication of existing flood risks at flood-prone properties.

1 INTRODUCTION

1.1 THE STUDY AREA LOCATION

Snug is a small coastal township located approximately 15km south of Kingston via the Channel Highway, as shown in Figure 1 and Figure 2. The majority of the catchment is forested with the main area of development centred around the township of Snug at the downstream extent of the catchment. The vicinity of the residential area, Snug beach and Caravan Park are low and flat, with elevations of approximately 1m to 3m above the Australian Height Datum (AHD). Thus, it is highly vulnerable to flooding from heavy rainfall and storm surge.

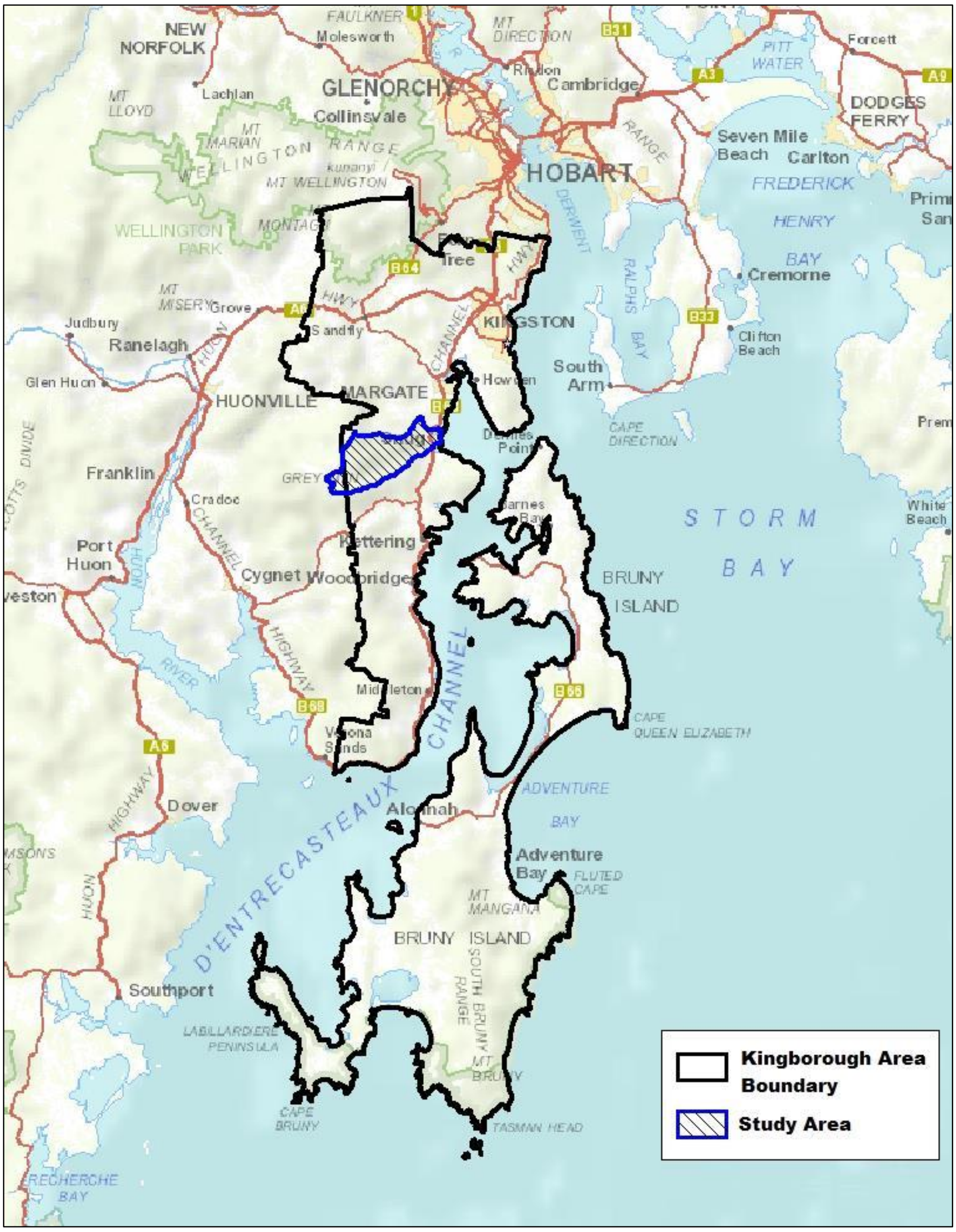


Figure 1: Snug River catchment location within the context of the Kingborough Municipality

Figure 2: Aerial photograph of the Snug River Catchment.

1.2 CONTEXT AND SCOPE

This project is funded and undertaken by Kingborough Council. This report summarises the flood risk study undertaken for the Snug River, providing a comprehensive assessment of the existing flood risk from both coastal and fluvial sources, including predicted climate change impacts.

Assessment of flood risk has been undertaken for Snug River flooding only and does not explicitly consider flooding from stormwater within the Snug Township.

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 Snug River catchment for a range of coincident design catchment floods and coastal floods. This study provides information on flood levels, flood depths, flood velocities, and provisional flood hazard categories.

The objectives of the Snug River Flood Study are as follows:

i. To assess the existing and future flood risk of Snug River;
ii. To investigate the level of severity of the flood events and its impact on the community;
iii. To provide information to facilitate better management of the potential flood impacts for existing and future conditions, including identification of potential future mitigation strategies and priorities for emergency management, land use planning and flood management;
iv. To update and extend the flood knowledge in the Snug area for planning, development assessment and emergency management purposes; and
v. To produce robust hydrology and hydraulic modelling tools according to current best practice procedures which are able to estimate the flood characteristics and behaviour of the Snug River catchment.

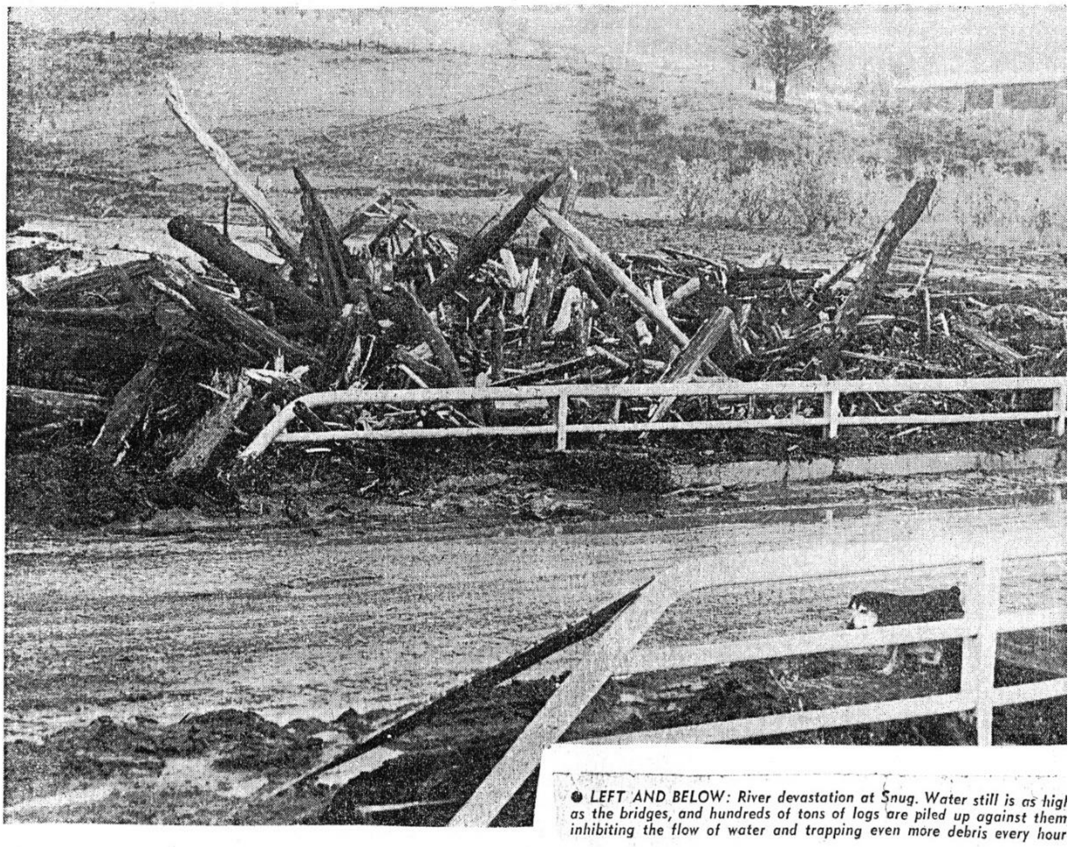
1.4 SNUG RIVER FLOOD HISTORY

There have been a number of previous flood events affecting the Snug River, albeit with limited details relating to flood levels, extents of flooding or flood affected properties. Examples of key flood risk factors derived from the details of known past flood events for the Snug River include:

- June 1872: Intense rainfall event, resulting in the loss of two bridges (‘KINGBOROUGH.’ 1872)
- November 1881: Landslip, deposition of material and subsequent pseudo-dam failure following heavy rainfall (‘THE MERCURY’ 1881);
- June 1954: Flooding resulting in road damage ('KINGBOROUGH "WORST SUFFERER" IN FLOODS' 1954); and
- May 1973: Flooding resulting in debris accumulation at the highway (refer to images in Figure 3 to Figure 7).

These records indicate that significant flooding of the Snug River has previously occurred, where the degree of flooding can be exacerbated by other associated factors, specifically, debris flow and blockage due to landslip. Further discussion on data relating to historical events is provided in Section 3.3.

10—THE MERCURY, FRIDAY, 4-5-1973



● *LEFT AND BELOW: River devastation at Snug. Water still is as higl as the bridges, and hundreds of tons of logs are piled up against them inhibiting the flow of water and trapping even more debris every hour*

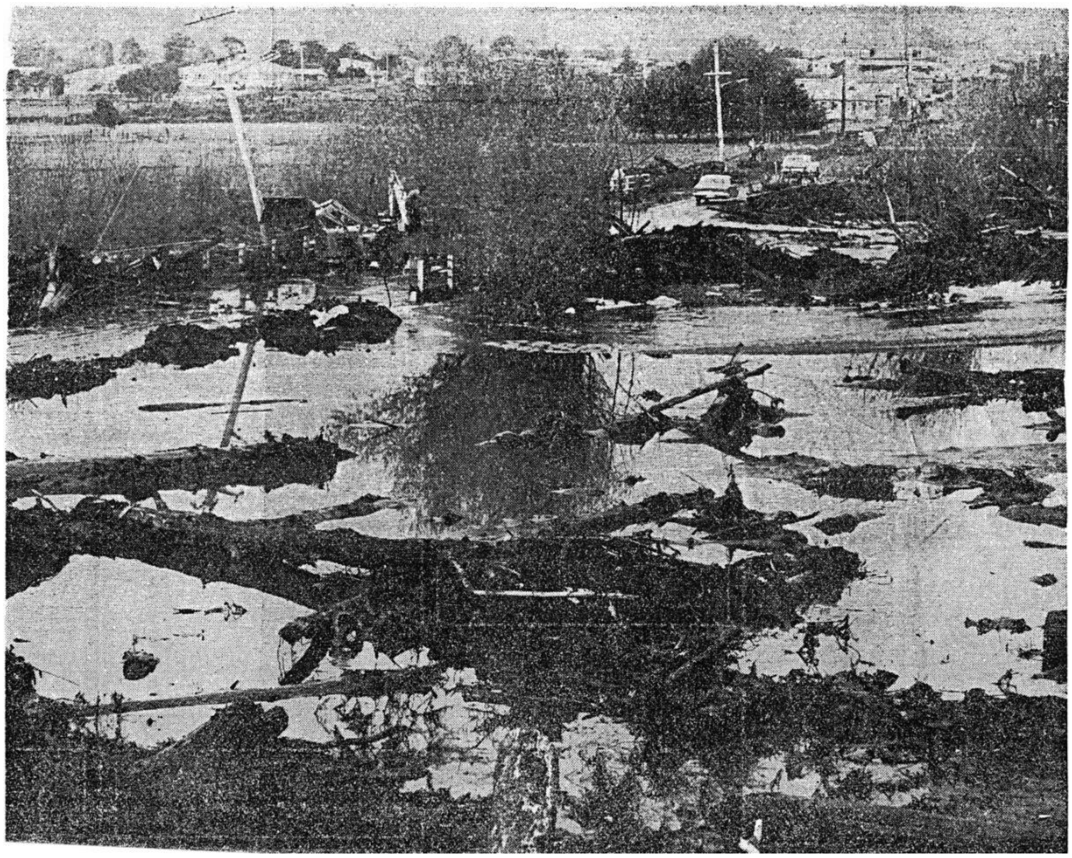


Figure 3: May 1973 flood event

Figure 4: Debris accumulation at the highway, May 1973

Figure 5: Debris accumulation adjacent to the school (unspecified date but likely to be May 1973)

Figure 6: Debris accumulation along the Snug River channel (unspecified date but likely to be May 1973)

Figure 7: Workmen clearing debris (unspecified date but likely to be May 1973)

2 THE STUDY CATCHMENT

2.1 CATCHMENT DESCRIPTION

The Snug River catchment study area has a total area of approximately 2,192 hectares consisting of predominantly undeveloped natural area at the upper catchment and residential development, light industrial, school, commercial area and caravan park at the bottom of the catchment near the river outlet. The study area discharges to the North West Bay via Snug River and into the D'Entrecasteaux Channel.

The topography within the study area varies along the catchment from nearly flat surface at the river outlet to steeper surface slopes with average of 20% at the middle catchment and less than 10% at the top of the catchment. The topography of the Snug River catchment is shown in Figure 8.

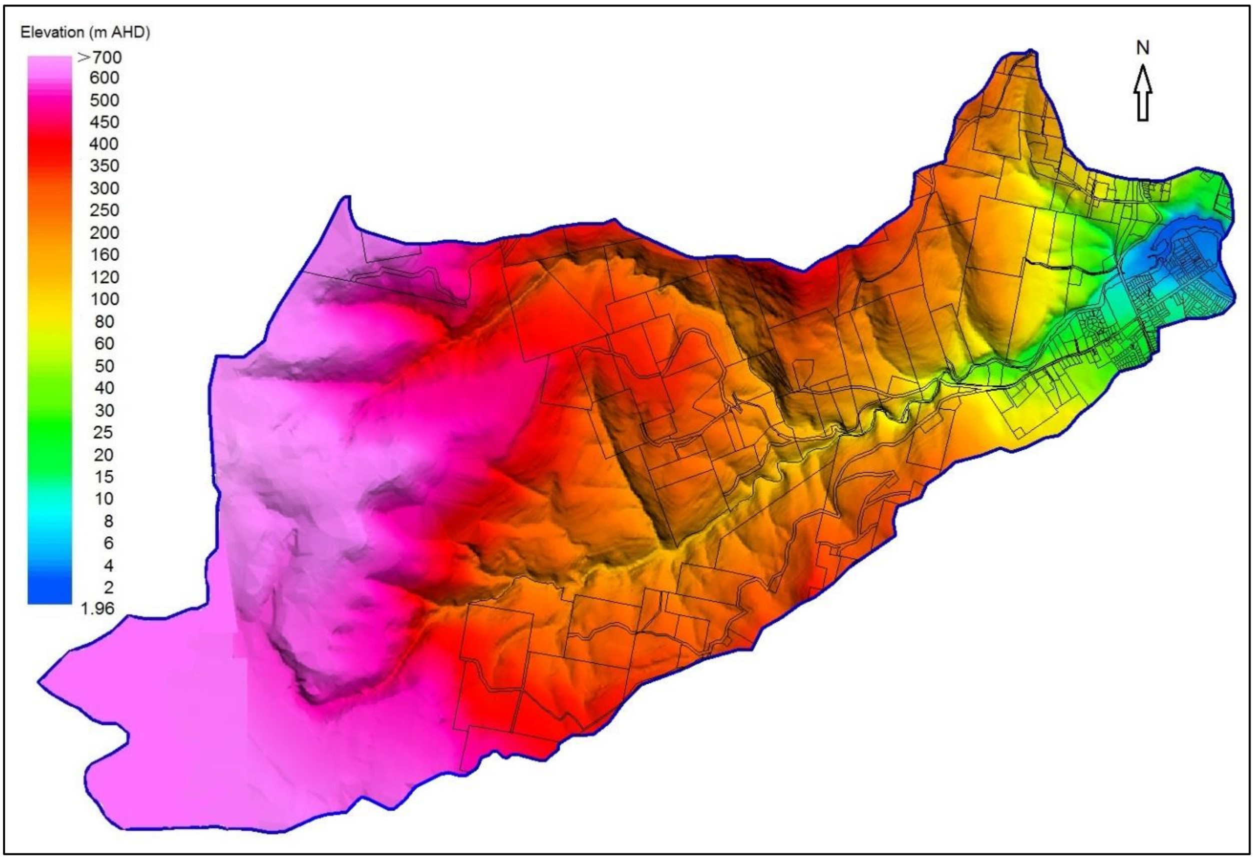


Figure 8: The elevation of Snug Catchment.

The upper catchment is characterised by the vegetated slopes on Snug Tiers Nature Recreation Area, with the reserve rising to an elevation of approximately 700m AHD. The reserve occupies approximately 46% of the total catchment, approximately 12% of the total catchment is developed and the rest is classified as Environmental Living Zoning (Figure 9). The portion of the catchment comprising the Snug Tiers Nature Recreation Area has restrictions on development and is therefore likely to remain in an undeveloped state in the future, noting that certain changes in landuse may be permitted (e.g. mining). Rural residential development extends along Snug Falls Road and Snug Tiers Road. There are some areas of open space at the top of the catchment where logging has occurred historically.

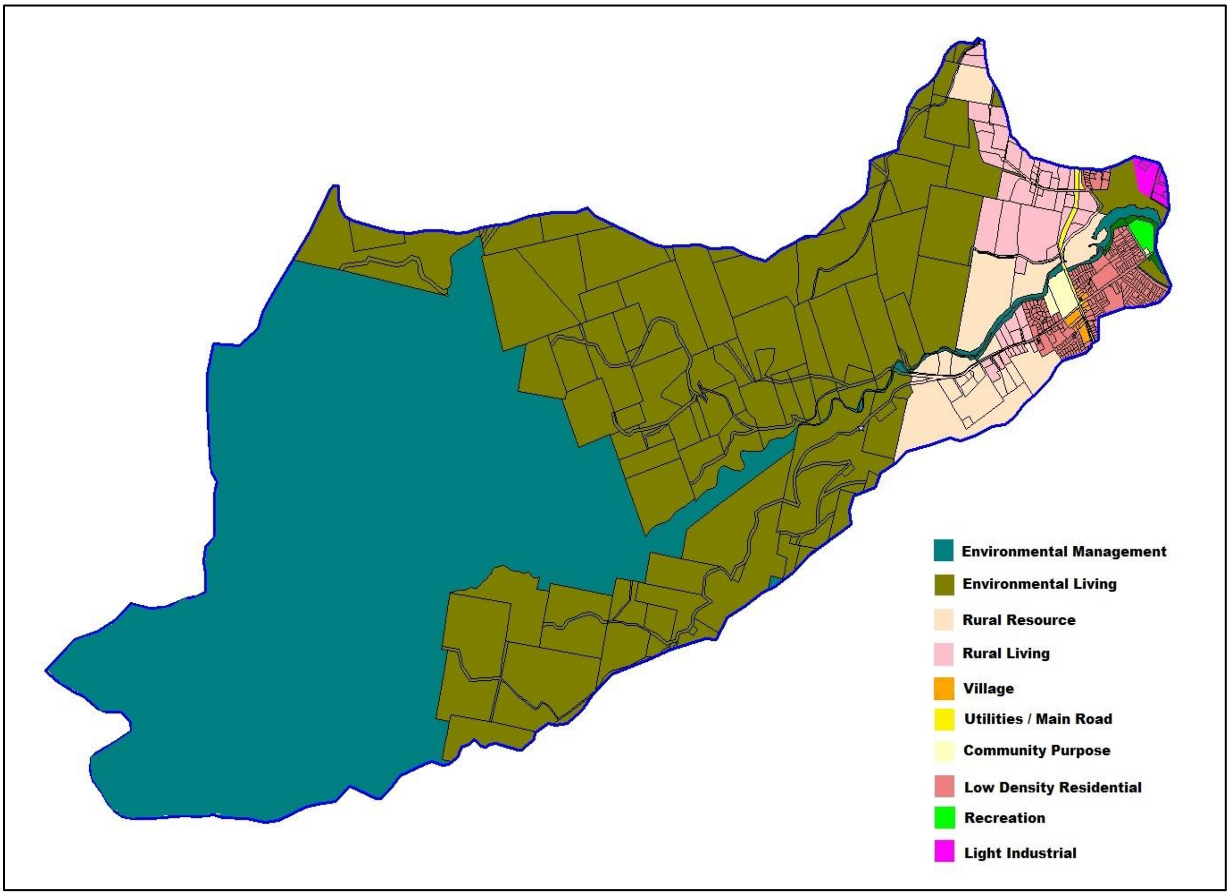


Figure 9: Snug River Catchment Ultimate Landuse (KIPS, 2014)

2.2 TIDAL CONDITION

The tide level can affect the degree of inundation in the study area, especially at the low-lying area such as the residential area behind the sandy beach. In the event of concurrent heavy rainfall and high tide, the capacity of the stormwater drainage network discharging to the estuary is reduced, generally resulting in broader flood inundation extents and longer times of inundation. During extreme tidal conditions (which includes storm surge), water levels in the lower reaches of the river will be higher due to the elevated tide level.

2.3 DEVELOPMENT TRENDS

The Snug River catchment study area comprises predominantly undeveloped natural areas to the west and urban land-uses to the east. Current zoning indicates that the undeveloped natural areas within the study area will remain in their current state. It is therefore likely that future development mainly will occur to the east as there are potential of existing land parcels for subdivision and/or more intensive infill development within the Snug area.

2.4 CLIMATE AND IMPACTS OF CLIMATE CHANGE

Future climate change, characterised by increased rainfall intensities and sea level rise, is likely to affect flooding in the Snug River catchment. A climate change analysis has been undertaken as part of this study to assess flooding impacts as a result of predicted climate change.

2.5 SOILS AND UNDERLYING GEOLOGY

Characteristics of the riverine and geology across the study area have been derived and reported in the Snug Rivercare Action Plan (Telfer, 2001).

According to the study, although some dolerite outcrops occur in the headwaters, the majority of the Snug plateau is formed of Quaternary alluvium, sourced from erosion of the plateau surface over a very long period (<2 million years before present). The alluvial surface is shallow and overlies very old sandstones (Triassic 220-180 million years ago) which occurs at this elevation due to faulting and uplift that occurred back in the Tertiary era (60-40 million years ago). The sandstones are relatively flat and uniform and underlies most of the flat plateau like surfaces that occur in the middle to upper areas of the catchment. Heath typically grows on the shallow soils on top of the sandstones.

3 REVIEW OF AVAILABLE DATA

3.1 INTRODUCTION

The information and data used in the preparation of this study have been obtained from various qualified experts and organisations. The available data have been reviewed and numerous site inspections have been undertaken to gain a better understanding of the catchment and drainage features across the study area.

3.2 PREVIOUS STUDIES

No comprehensive catchment-wide hydrological and hydraulic assessment has previously been completed for the Snug River study area. Related studies and reports include:

- The *Snug River Hydraulic Analysis* was completed by Pitt & Sherry for Kingborough Council in 2008, where the study was prepared to assess whether the 100-year ARI flood level will encroach over the property boundary of 9 residential lots located adjacent to the river on the downstream side of the Channel Highway. Unfortunately, neither Council nor Pitt & Sherry were able to retrieve a copy of this report for use in this current study.
- *Snug Rivercare Action Plan* study about the future management needs of the Snug River. The characteristics of the catchment and the stream are contained in the report.

3.3 HISTORICAL ARTICLES AND PHOTOGRAPHS

Historical newspaper articles and photographs of flooding of the Snug River have been obtained from available data sources. Including the photographs provided in Section 1.4, the historical data sources include:

- Archives and records of the Channel Highway Museum;
- Digitised newspaper articles, as provided by the National Library of Australia[1]; and
- Register of flooding complaints as maintained by Council, noting that the majority of these records generally relate to stormwater flooding which is not explicitly addressed by this study.

3.4 HYDROMETRIC DATA

3.4.1 RAINFALL DATA

There are no continuous (pluviograph) rainfall stations located within the Snug River catchment. However, there is a daily rainfall station near the top of the catchment. There is also an extensive network of rainfall gauges across Kingborough, Huon Valley and greater Hobart area, with many of these gauges operated by the Bureau of Meteorology. The selected pluviograph rainfall stations close to the study area are:

- Hobart (Ellerslie Road) which has a long period of record, commencing in 1893;
- Grove (Research Station); and
- Leslie Vale.

The rainfall stations located in close proximity to the study area and considered suitable for defining historic rainfall for specific rainfall and flood events within the study area are summarised in Table 3. The locations of these rainfall stations are shown in Figure 10. The combination of daily rainfall stations and pluviometer

[1] https://trove.nla.gov.au/

stations to define the temporal pattern of rainfall for historic events presents a reasonable rainfall data set for use in this study.

Table 3: Rainfall Stations in the vicinity of the study area (as at January 2018)

Station No.	Station	Data Type	Record Period
94029	HOBART (ELLERSLIE ROAD)	Continuous	1893 - 2018*
94030	HOBART BOTANICAL GARDENS	Daily	1885 - 2018*
94031	HOBART (WATERWORKS RESERVE)	Daily	1897 - 2018*
94040	LYMINGTON (FATTYS LANE)	Daily	1920 - 2018*
94043	MIDDLETON POST OFFICE	Daily	1910 - 2018*
94068	WOODBRIDGE	Daily	1927 - 2018*
94085	SNUG PLAINS (CATARACT FALLS)	Daily	1961 - 2018*
94089	HUONVILLE (TUTTON AVENUE)	Daily	1962 - 2018*
94098	MOUNT NELSON (RIALANNAH ROAD)	Daily	1998 - 2018*
94111	TAROONA (TAROONA CRESCENT)	Daily	1961 - 2018*
94125	MARGATE (SUNNYSIDE)	Daily	1968 - 2018*
94139	FERN TREE (GRAYS ROAD)	Daily	1967 - 2018*
94151	LONGLEY (TELOPEA)	Daily	1976 - 2018*
94163	BLACKMANS BAY TREATMENT PLANT	Daily	1982 - 2018*
94166	BULL BAY (LAURISTON)	Daily	1983 - 2018*
94175	LUCASTON (BAKERS CREEK ROAD)	Daily	1978 - 2018*
94179	JUDBURY (HUON RIVER)	Daily	1990 - 2018*
94185	NIERINNA (CUTHBERTS ROAD)	Daily	1992 - 2018*
94219	CYGNET (SYNOTTS ROAD)	Daily	2001 - 2018*
94220	GROVE (RESEARCH STATION)	Continuous	2006 - 2018*
94222	KINGSTON (GREENHILL DRIVE)	Daily	2002 - 2018*
94223	BONNET HILL	Daily	2002 - 2018*
94231	LONGLEY (RIVER BEND ROAD)	Daily	2005 - 2018*
94239	LESLIE VALE	Continuous	2006 - 2018*
94247	TINDERBOX (TINDERBOX ROAD)	Daily	2011 - 2018*
94261	FRANKLIN (SOUTH)	Daily	2013 - 2018*
94263	ABELS BAY (SANDREEF ROAD)	Daily	2013 - 2018*
94255	DENNES POINT	Daily	2012 - 2018*
94104	GLAZIERS BAY	Daily	1998 - 2016
94025	SNUG (ESPLANADE)	Daily	2002 - 2013
94200	LOWER LONGLEY (LOMATIA VALE)	Daily	1995 - 2011
94025	GLENORCHY (RESERVOIR)	Daily	1950 - 2018*
94087	KUNANYI (PINNACLE)	Daily	1961 - 2018*
94210	ROKEBY (GRANGE RD EAST)	Daily	1998 - 2016
94211	BELLERIVE (YORK STREET)	Daily	1998 - 2016

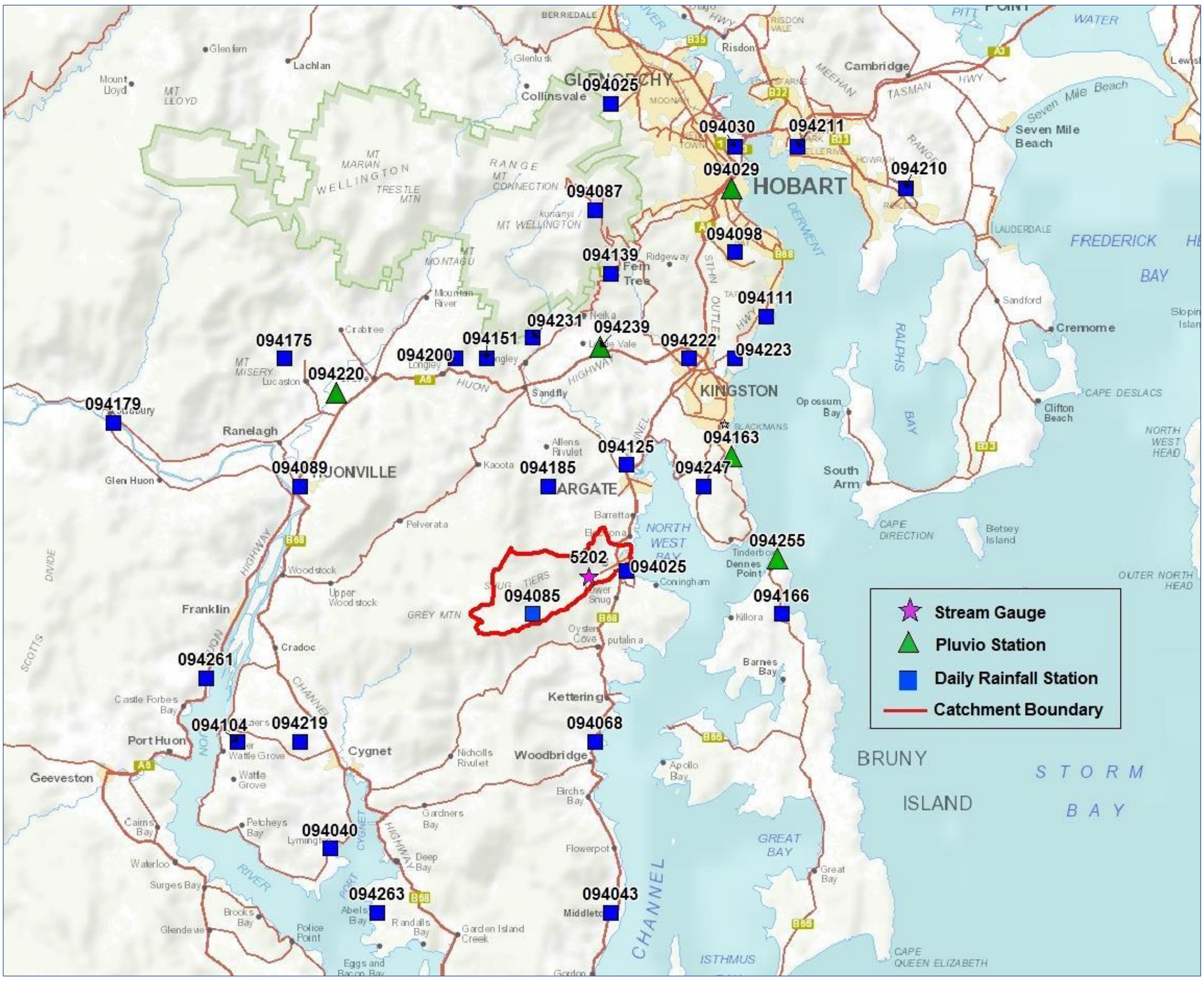


Figure 10: Rainfall Station Locations

3.4.2 STREAMFLOW GAUGING DATA

A stream gauge within the Snug River catchment is located approximately 2.8km upstream of the river mouth, with a record covering a period of approximately 40 years (1976-2018). The highest peak flow recorded at this gauging station is 30.71m^3/s in 2011.

The real-time Snug stream gauge data is available through the Water Information Tasmania Web Portal (https://portal.wrt.tas.gov.au/) which is administered by the Department of Primary Industries, Parks, Water and Environmental (DPIPWE).

3.4.3 REVIEW OF AVAILABLE HYDROMETRIC DATA

The available hydrometric data indicates that:

- There is an extensive network of daily rainfall stations and a number of continuous (pluviograph) rainfall stations in the vicinity of the Snug River catchment; and
- The streamflow gauging site on the Snug River is suitable for use in this study for the purpose of undertaking event calibration.

3.5 WATER LEVEL DATA

The tailwater level at Snug River catchment is controlled by tide levels (including anomaly tide such as storm surge). Table 4 shows the tide levels for Hobart (DPIPWE 2019).

Table 4: Tide Levels for the port of Hobart

Tide	Tidal Level (m AHD)
Highest Astronomical Tide (HAT)	0.86
Mean Sea Level (MSL)	0.05
Lowest Astronomical Tide (LAT)	-0.83

Note: 1) Australian Height Datum (AHD) is approximately present mean seal level.

3.6 COUNCIL GIS DATA

Most of the Council's information data is available on Council's Digital Geographical Information Systems (GIS). 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 (noting that the drainage network has not been modelled as part of this study), cadastre, up-to-date planning land use zones, background images, contours, property information and the Digital Elevation Model (DEM).

3.7 TOPOGRAPHIC DATA

Council's own aerial topographic survey, referred to as LiDAR (Light Detection And Ranging), covering the hydraulic study area has been used in this study. The LiDAR data sets provided have a stated vertical accuracy of +/- 0.15m with 68% confidence and horizontal accuracy of +/- 0.55m with 68% confidence.

The LiDAR data set has been filtered by Geoscience Australia, where the filtering routine applied to the raw data removes non-ground features such as buildings and vegetation. The resulting filtered data set provides a representation of the ground surface. The LiDAR data provided by Council has a horizontal resolution of 1m.

Kingborough Council has also engaged a contractor to carry out topographical and aerial survey using Unmanned Aerial Vehicle (UAV), commonly known as a drone. The survey data along the river channel, obtained via UAV, has been merged with the LiDAR data for use in the hydraulic modelling exercise.

3.8 SITE INSPECTION

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

- Inspection of known locations where flooding problems exist;
- Verification of major river channel, including levels and dimensions;
- Inspection of the general nature of the study area catchment and floodplain;
- Inspection of local hydraulic controls such as bridges;
- Inspection of the manning roughness and characteristics of the river-banks; and
- Verification that vegetation in some regions are the same as on GIS aerial photographs.

The information and understanding gained during these site inspections have been used to assist with model development.

4 COMMUNITY ENGAGEMENT

4.1 COMMUNITY FLOOD AWARENESS AND THE FLOODPLAIN MANAGEMENT PROCESS

It is critical that the flood-prone communities of the Municipality of Kingborough be identified and made aware, and to remain aware, of their role in the overall floodplain management strategy for the municipality. This includes awareness of the existing level of protection of their community as well as their personal evacuation during future flood events. Sustaining an appropriate level of flood awareness involves continuous effort by Council and the emergency services but it can in turn 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 flood risk management. 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, for example, 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 given above. For the township of Snug, provision of flood awareness brochures could include material specific to the local region and provide the following information:

- What floods are and the history of flooding in Snug;
- Known flood behaviour in Snug;
- Flood and/or storm warnings;
- What to do before, during and after a flood; and
- Preparation of a household emergency plan.

It is recommended that Council establishes and promotes a community education program in conjunction with the SES to provide information on what to do before, during and after a flood event, and to facilitate the communication of existing flood risks at flood-prone properties.

4.2 FLOODING INFORMATION QUESTIONNAIRE

To assist with calibration/validation of the hydrologic and hydraulic models and initiate the community awareness process, a community engagement campaign was undertaken via distribution of a questionnaire (a copy of the questionnaire is provided in Appendix D). This questionnaire sought to elicit any information and history from residents in Snug relating to previous flood events and was distributed to residents in the Snug area (refer to Figure 11) and was also made available on Council's website. A summary of the responses received from the community is provided in Table 5.

The responses received indicate there have been past flood events occur in the Snug River, although there is insufficient data for use in the calibration or validation of the models. However, the information received does assist with a qualitative assessment of flooding in certain areas of the Snug River and floodplain.

Figure 11: Extent of distribution of questionnaire

Table 5: Summary of responses from questionnaire

Period of residence	**Flood details / responses**	**Photos**
5 years	Approx. 2014, there was flooding in the bush track at the end of the road in front of the Sea Scouts Hall.	N/A
Unknown	Live on the banks of the Snug river and my land is prone to flooding	
2.5years 18 Pybus St	Water at the West end of the river, near the stormwater outlet, occurs regularly when heavy rain + high tide occur together	
38 years	Yes, 1996	
1 year	no	
37 years	Snug River, opposite Esp North, and upriver to the bridge – both banks have been inundated on several occasions following heavy rainfall	
2.5years	Rain and tide in 2016- couldn't walk closest to the Snug Beach reserve.	
20 years	No	
4.5 years	No	
10years	Their neighbour who passed away last year were longtime residents of Snug and lived in Torpy Avenue. They had seen flooding over the bridge which cut access to Kingston. Also where the new houses are built (snow gum etc) have been under water – don't know what year	
3 years	46 Snug Tiers Road, no	

5 HYDROLOGIC AND HYDRAULIC MODEL DEVELOPMENT

5.1 MODELLING APPROACH

A hydrological model has been developed that covers the entire Snug River catchment to its outlet at the Snug foreshore. The extent of the catchment is shown in Figure 12. The hydrological model has been used to estimate the discharge from the Snug River catchment for a range of flood events, where the discharge hydrographs are used as inputs to the hydraulic model.

A 2D hydraulic model has been developed for the lower reaches and the floodplain of the Snug River, with the extent modelled shown in shown in Figure 12 and Figure 13.

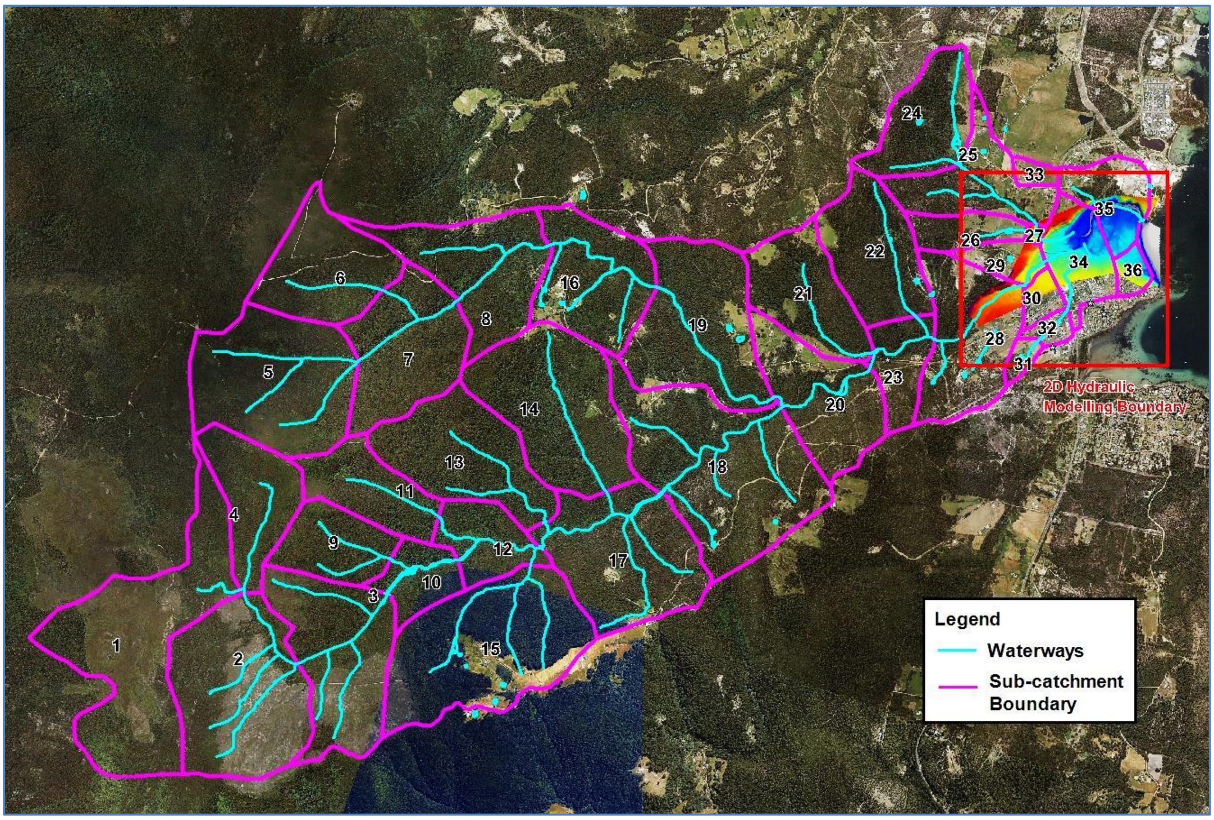


Figure 12: Hydrologic and Hydraulic Model Extents

5.2 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).

XP Solution's Stormwater & Wastewater Management Model (XPSWMM®) has been used to assess the hydrology and hydraulics for the existing catchment and floodplain condition and ultimate development condition (derived from land use zoning and applied for 2050 and 2100 climate scenarios) to 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.

5.3 HYDROLOGICAL MODEL

5.3.1 INTRODUCTION

The overall catchment and its constituent sub-catchments have been delineated based on Council's contour data set which has been derived from the LiDAR data. The sub-catchment delineation provides for generation of flow hydrographs at key confluences or inflow points to the hydraulic model.

5.3.2 CATCHMENT DELINEATION

The catchment covers approximately 2,190 ha and drains to the North-West Bay which is at the northern extent of the D'Entrecasteaux Channel. A total of 36 sub-catchments have been delineated to represent the total catchment. Each sub-catchment has been assigned appropriate parameters for use in the XPSWMM® model (i.e. catchment size, impervious area, catchment roughness and slope), based on topography and aerial imagery. Relevant hydrological parameters for each sub-catchment area summarised in Table 6.

5.3.3 RAINFALL DATA

Rainfall data applied in the hydrological model has been derived from recorded rainfall at daily and continuous recording rainfall stations (refer to Section 6.1) and design rainfall data (refer to Section 6.4).

5.3.4 RAINFALL LOSSES

In this model, the initial loss – constant continuing loss model has been adopted for the hydrological modelling. 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 (Phillips et al., 2014). Initial losses often vary across a given catchment. This type of loss occurs early in a storm prior to the soil becoming saturated and before surface runoff commences. The constant continuing loss is the average infiltration loss into the ground throughout the rest of the storm event (i.e. after surface runoff commences). Rainfall losses depend on the soil type, rainfall intensity, vegetation and catchment size. The values adopted for the losses for design event modelling are discussed in Section 6.3.4.

Table 6: Hydrological model sub-catchment properties

Sub-catchment ID	Area (ha)	Fraction impervious c2015	Fraction impervious c2100	Slope
1	148.15	0.0%	0.0%	9.7%
2	118.93	0.0%	0.0%	10.2%
3	94.36	0.0%	0.0%	16.0%
4	54.95	0.0%	0.0%	7.1%
5	112.25	0.0%	0.0%	17.3%
6	68.06	0.0%	2.1%	21.5%
7	79.63	0.0%	0.2%	19.3%
8	78.92	0.0%	3.7%	19.9%

Sub-catchment ID	Area (ha)	Fraction impervious c2015	Fraction impervious c2100	Slope
9	42.46	0.0%	0.0%	27.0%
10	28.40	0.0%	1.2%	31.8%
11	47.02	0.0%	0.0%	28.0%
12	36.28	0.0%	1.7%	20.5%
13	83.13	0.0%	0.0%	23.7%
14	106.97	0.0%	2.4%	17.5%
15	128.37	0.0%	3.9%	16.3%
16	72.86	0.0%	4.8%	14.4%
17	102.69	0.0%	3.0%	14.9%
18	146.77	0.0%	4.3%	14.1%
19	99.98	0.0%	4.8%	16.6%
20	69.59	0.0%	4.7%	19.9%
21	59.24	0.0%	4.8%	26.0%
22	65.34	0.0%	0.0%	20.7%
23	30.29	0.0%	4.5%	19.0%
24	53.30	0.0%	5.3%	19.2%
25	51.46	0.0%	8.1%	13.4%
26	20.45	0.0%	7.1%	20.8%
27	1.74	0.0%	16.0%	6.7%
28	74.44	4.7%	6.6%	10.6%
29	15.51	0.0%	0.0%	12.0%
30	9.29	16.7%	30.1%	4.5%
31	5.92	0.0%	5.8%	7.5%
32	6.77	9.1%	34.1%	3.9%
33	5.74	0.0%	11.8%	9.0%
34	35.13	16.7%	24.4%	2.6%
35	31.51	23.9%	23.9%	4.4%
36	7.82	23.1%	23.1%	3.0%

5.4 HYDRAULIC MODEL

5.4.1 INTRODUCTION

The development of the Snug River hydraulic model has considered the following elements:

- Topographical data, including coverage and resolution (e.g. LiDAR);
- Physical characteristics of the watercourse and floodplain (e.g. hydraulic roughness);
- Location of any hydraulic controls (e.g. bridges, embankments, river mouth constriction); and
- Computational limitations.

For this project, the 1D/2D hydraulic model was developed from just downstream of the mouth of the Snug River to upstream of the floodplain area (i.e. upstream of the Channel Highway). The reach of the Snug River with a relatively small channel has been modelled in 1D, while the remainder of the channel and all the floodplain has been modelled in 2D, as shown in Figure 13. The model includes representations of the existing bridges at the Channel Highway.

Figure 13: Hydraulic Model Extents

5.4.2 MODEL TOPOGRAPHY

The ground elevations applied in the hydraulic model have been derived from the following sources:

- LiDAR digital elevation model (DEM) obtained from Geoscience Australia
  - The DEM represents the true ground surface and has been filtered to remove features such as buildings and vegetation

- DEM of the channel bed derived from a UAV (drone) survey commissioned by Council.

The topography of the study area (combined LiDAR and UAV data sets) is shown in Figure 14.

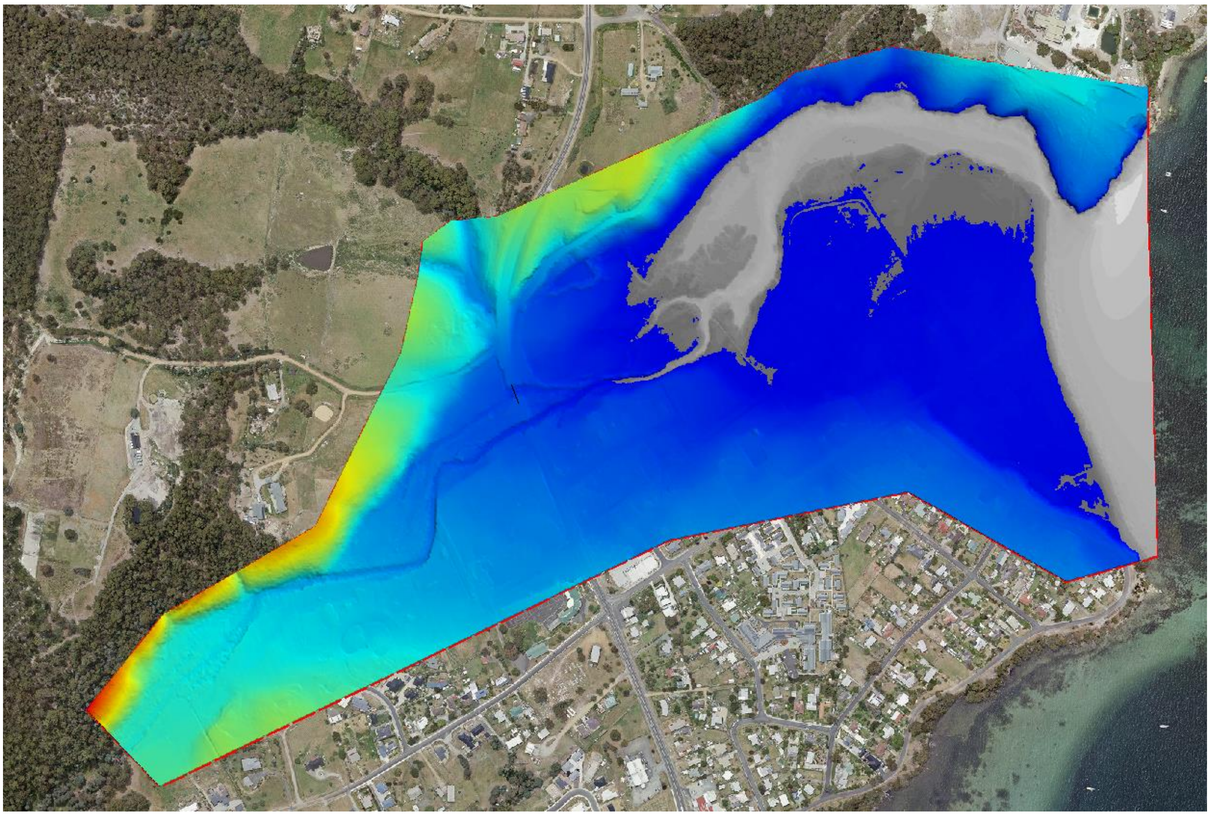


Figure 14: Hydraulic Model Topography

5.4.3 HYDRAULIC ROUGHNESS

The value for hydraulic roughness has been assigned different values according to the different land use types across the hydraulic model, resulting in spatial variation of hydraulic roughness. Land use types have been delineation from aerial photography, planning zones and cadastral data. Table 7 shows the Manning's roughness value applied for the different land use types applied in the model, with the spatial distribution of land use types shown in Figure 15.

Table 7: Manning's 'n' Roughness Values applied in the hydraulic model

Land Use	Manning's 'n' Value
1D Channel	0.035
Estuary	0.025
High-roughness channel	0.080
Paved area	0.016
Buildings	0.500
Vegetation	0.080
Maintained Open space	0.030
Open space	0.060

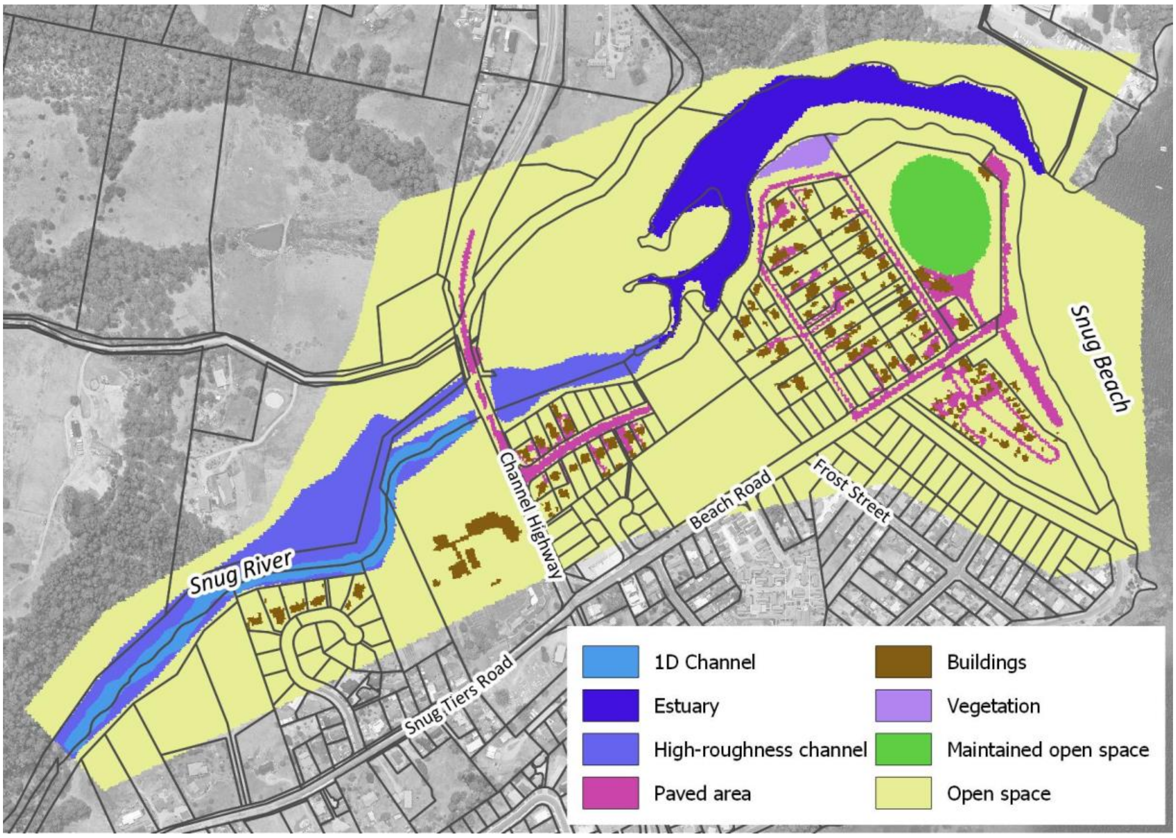


Figure 15: Hydraulic Model Land Use

5.4.4 BOUNDARY CONDITIONS

Ocean tide levels for the North-West Bay have been used as the downstream water level boundary for the hydraulic model. Council engaged Water Research Laboratory (WRL) to undertake an assessment of these water levels for the current conditions, year 2050 and year 2100, where the future water levels account for projected sea level rise. Table 8 shows a summary of the adopted water levels as applied in the design event modelling for this study. The downstream water level boundary has been included in the Snug River hydraulic model as a fixed water level, i.e. the hydraulic model does not explicitly model the tidal signal.

Table 8: Summary of Adopted Tide Levels

Year	ARI	Sea Level Rise (m)	Tide at Peak (m AHD)	Anomaly at Peak (m)	Wave Setup at Peak (m) (Shoreline)	Peak Nearshore Water Level (m AHD)
Present Day	1	0	0.53	0.44	0.1	1.07
	10		0.53	0.68	0.16	1.37
	20		0.53	0.75	0.19	1.47
	50		0.53	0.84	0.13	1.5
	100		0.53	0.91	0.13	1.57
2050	1	0.3	0.53	0.44	0.1	1.37
	10		0.53	0.68	0.16	1.67
	20		0.43	0.75	0.19	1.77
	50		0.53	0.84	0.13	1.8
	100		0.53	0.91	0.13	1.87
2100	1	1	0.53	0.44	0.1	2.07
	10		0.53	0.68	0.16	2.37
	20		0.53	0.75	0.19	2.47
	50		0.53	0.84	0.13	2.5
	100		0.53	0.91	0.13	2.57

Inflows to the hydraulic model have been derived with the hydrological model discussed in Section 5.3.

5.4.5 CELL SIZE / MODEL RESOLUTION

The hydraulic model utilises a grid of square cells to represent the topography and hydraulic controls across the catchment. Each square grid cell contains information on ground elevation and surface resistance to flow (Manning's 'n' value). For the Snug River Flood Study, a 3-metre square grid has been adopted which is considered to provide sufficient accuracy to adequately represent the key features and variations in catchment/floodplain topography and land use.

6 HYDROLOGIC MODELLING

6.1 INTRODUCTION

The hydrological model developed for the Snug River catchment (as described in Section 5) has been used to simulate historic rainfall events to facilitate calibration of the hydrological model (refer to Section 6.2), with subsequent design event modelling (refer to Section 6.4).

6.2 HYDROLOGIC MODEL CALIBRATION

Three historic events have been selected for calibration and validation of the hydrological model, where these events occurred in April 2011, January 2015 and June 2016.

Spatial patterns of rainfall have been derived based on the recorded daily rainfall totals in and around the Snug River catchment, then comparing those totals with data at the pluviograph sites at Grove (Research Centre), Leslie Vale and Hobart (Ellerslie Road). For the purpose of undertaking hydrological modelling, the pluviograph data has been used to define a temporal pattern for each calibration event which has then been applied to the Snug River catchment based on the daily rainfall total at the Snug Plains (Cataract Falls) rainfall station. It follows that the spatial patterns developed for each calibration event may not accurately represent the spatial variation in rainfall characteristics that actually occurred during the calibration events, as there is no means to verify the that the timing or magnitude of rainfall bursts that occurred in each 24-hour period (i.e. as derived from the pluviograph data) was representative of the rainfall on the Snug River catchment. To assess the effect of the varying pluviograph-derived temporal patterns on flows in the Snug River, separate simulations have been undertaken for each temporal pattern derived from the pluviography data.

6.2.1 APRIL 2011 EVENT

Heavy rain fell in the southeast of Tasmania from the afternoon of 12 April 2011 until the morning of 13 April 2011. Several rainfall stations in the vicinity of the Snug River catchment (including Leslie Vale and Kingston) recorded in excess of 100mm in one day. Daily rainfall totals at the Snug Plains (Cataract Falls) rainfall station are provided in Figure 16 (source: Bureau of Meteorology[2])

[2] http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_display_type=dataDGraph&p_stn_num=094085&p_nccObsCode=136&p_month=04&p_startYear=2011

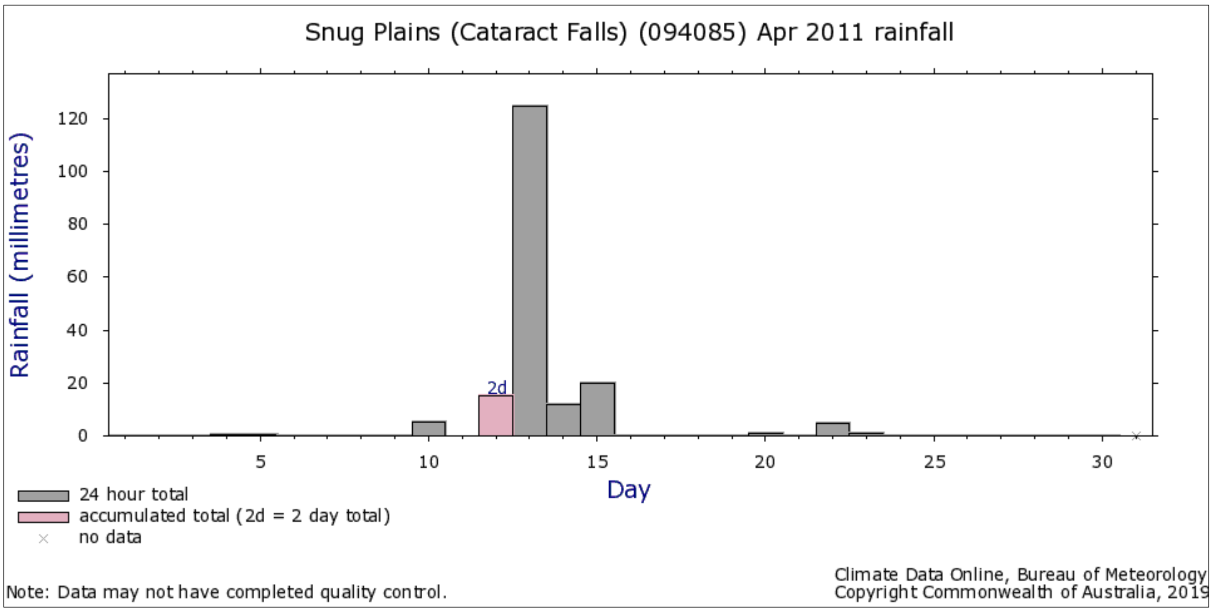


Figure 16: Daily Rainfall Totals at Snug Plains (Cataract Falls) – April 2011

Isohyets of total rainfall for the 24-hour period to 9am on 13 April 2011 are shown in Figure 17. This shows the spatial distribution of rainfall in the vicinity of the Snug River catchment, indicating that there were significant variations in total rainfall across the region, with the highest 24-hour total recorded in the Snug River catchment itself. This suggests that the temporal distribution of rainfall in the Snug River catchment may have varied from the nearby pluviograph records.

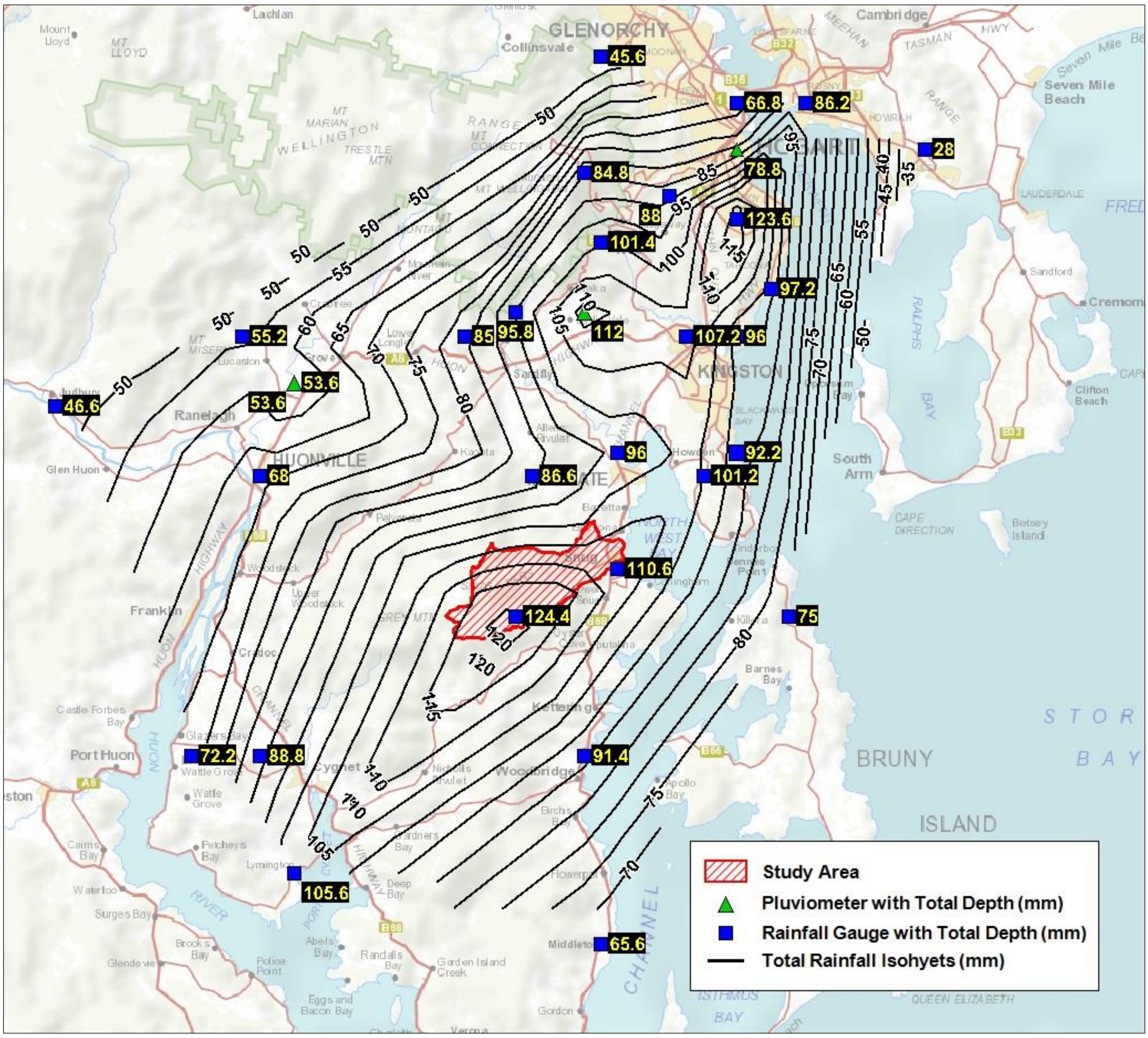


Figure 17: Rainfall Distribution for 13 April 2011

The recorded rainfall hyetographs from the Leslie Vale (LV), Hobart (Ellerslie Road) (HE) and Grove Research Station (GRS) pluviometers are shown in Figure 18. The hyetographs indicate that whilst there were different rainfall totals measured at each site, the accumulations of rainfall for the main burst associated with this event correlate well, exhibiting similar start and finish times for the main rainfall burst. The daily rainfall totals from the Snug Plains (Cataract Falls) rainfall station have also been included in Figure 18. This indicates that whilst the total rainfall for Snug Plains (Cataract Falls) is similar to the accumulated total for Leslie Vale, the total rainfall during the main burst was much higher than at the three pluviograph sites, suggesting that there may be differences between the temporal patterns at the pluviograph sites and what actually fell in the Snug River catchment.

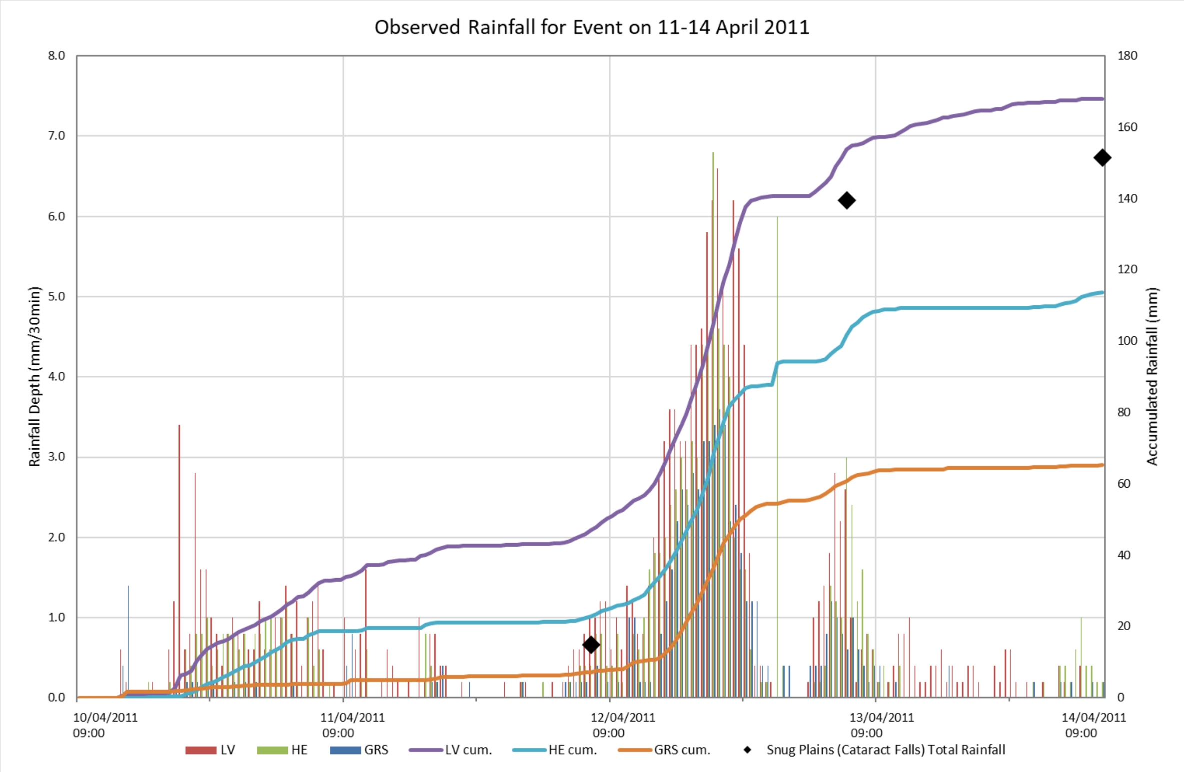


Figure 18: Recorded Rainfall – April 2011 Event

Results from the hydrological modelling of the three pluviograph-derived temporal patterns are shown in Figure 19. The predicted flow hydrographs for the three temporal patterns exhibit reasonable correlation with the gauged flow at the Snug River gauging station.

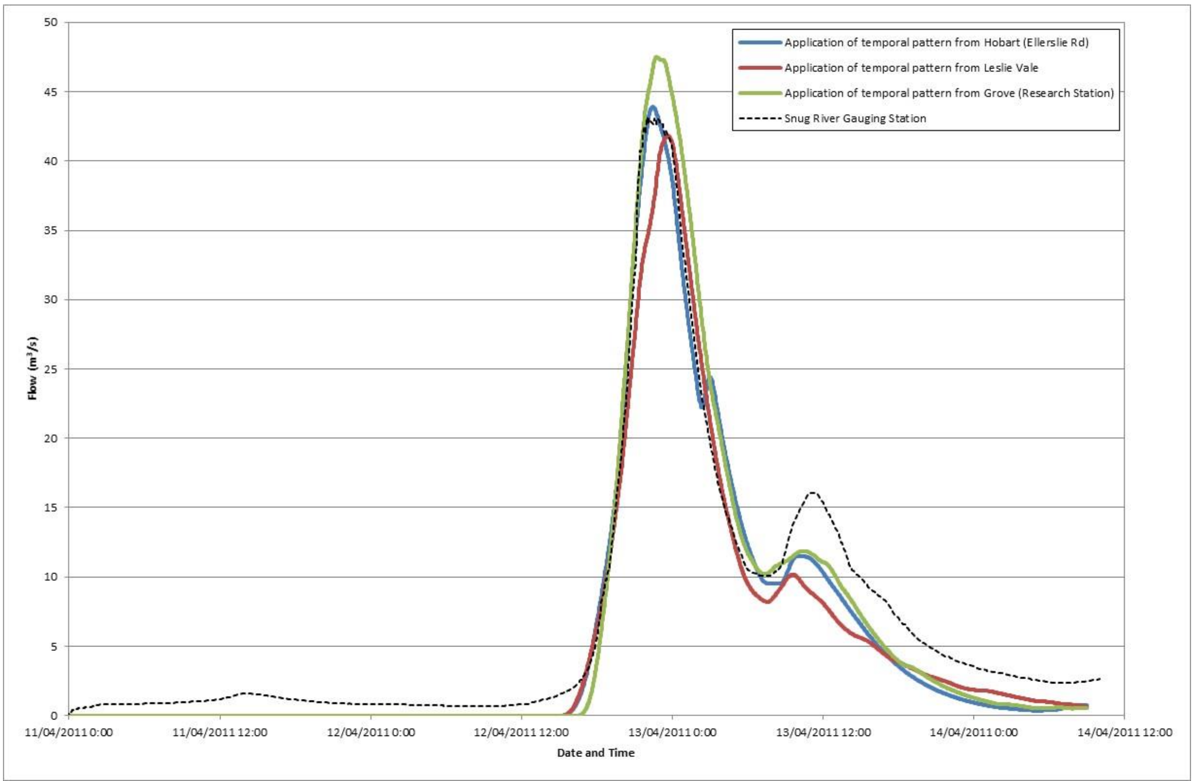


Figure 19: April 2011 Event Hydrographs at the streamflow gauging station

6.2.2 JANUARY 2015 EVENT

There was a significant rainfall event on 13 and 14 January 2015 resulting from a complex low-pressure system bringing tropical moisture to Tasmania. The highest daily rainfall was 153.4mm at Mt Wellington on 14 January. Daily rainfall totals at the Snug Plains (Cataract Falls) rainfall station are provided in Figure 20 (source: Bureau of Meteorology[3])

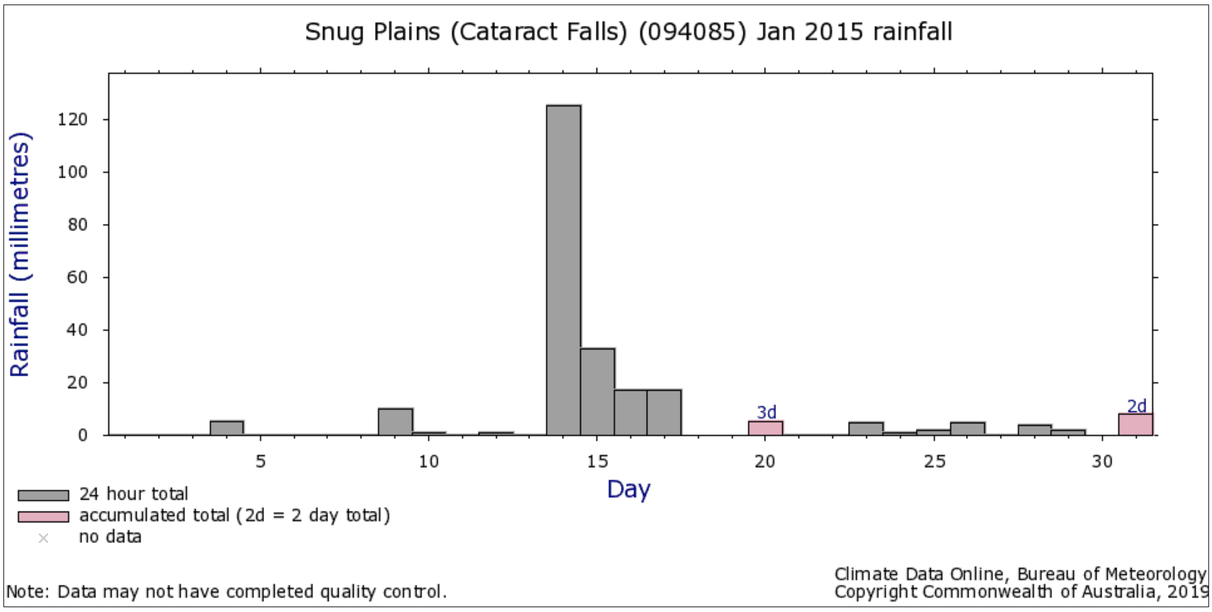


Figure 20: Daily Rainfall Totals at Snug Plains (Cataract Falls) – January 2015

Isohyets of total rainfall for the 24-hour period to 9am on 14 January 2015 are shown in Figure 21. This shows the spatial distribution of rainfall in the vicinity of the Snug River catchment, indicating that there were variations in total rainfall across the region, with the rainfall totals decreasing to the south and west of the Snug River catchment. This suggests that the temporal distribution of rainfall in the Snug River catchment may have varied from the nearby pluviograph records.

3 http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_display_type=dataDGraph&p_stn_num=094085&p_nccObsCode=136&p_month=01&p_startYear=2015

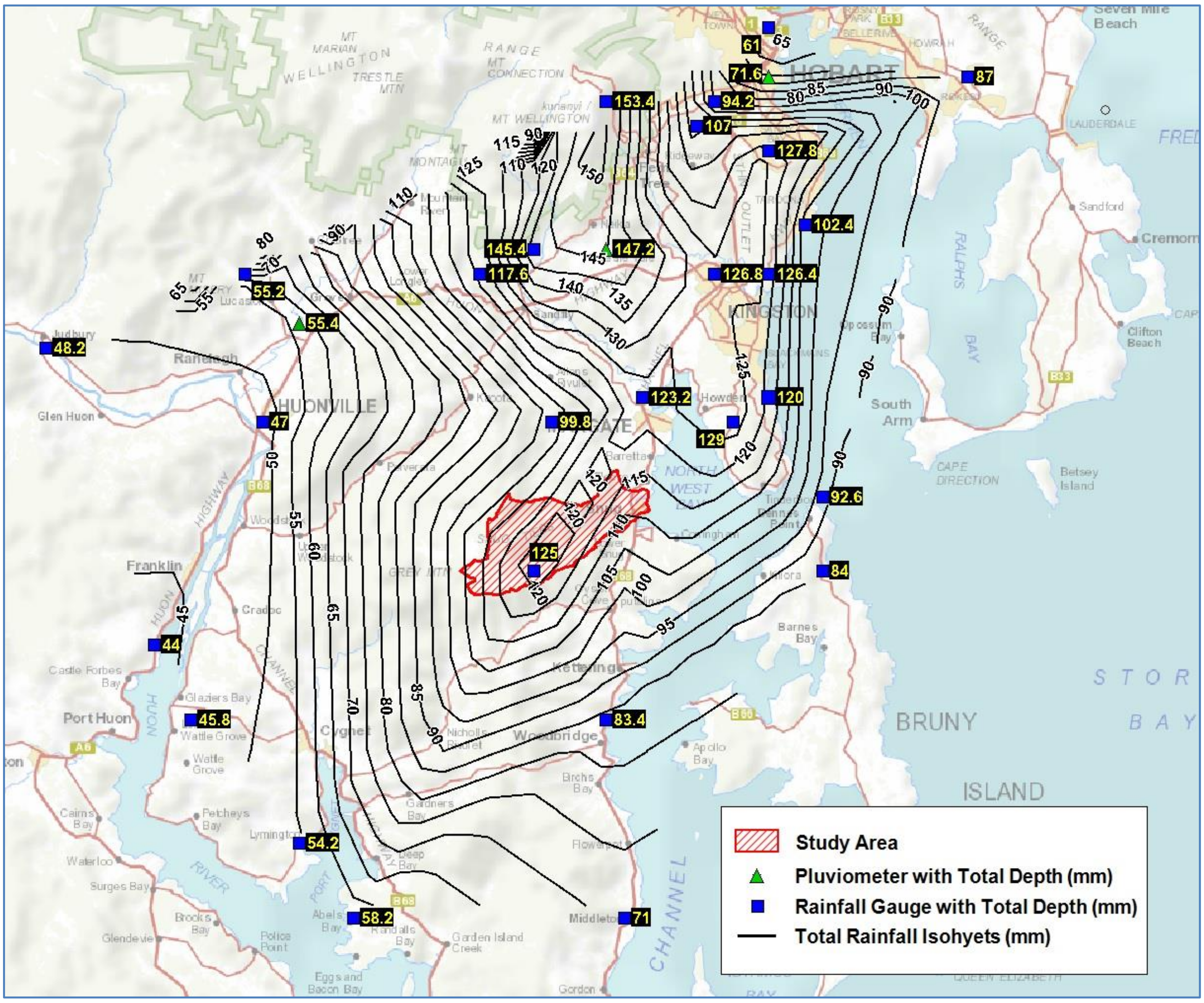


Figure 21: Rainfall Distribution for 14 January 2015

The recorded rainfall hyetographs from the Leslie Vale (LV), Hobart (Ellerslie Road) (HE) and Grove Research Station (GRS) pluviometers are shown in Figure 22. This indicates that whilst there were different rainfall totals measured at each site, the accumulations of rainfall for the main burst associated with this event correlate well, exhibiting similar start and finish times for the main rainfall burst. The daily rainfall totals from the Snug Plains (Cataract Falls) rainfall station have also been included in Figure 22. This indicates that the total rainfall for Snug Plains (Cataract Falls) is similar to the accumulated total for Leslie Vale.

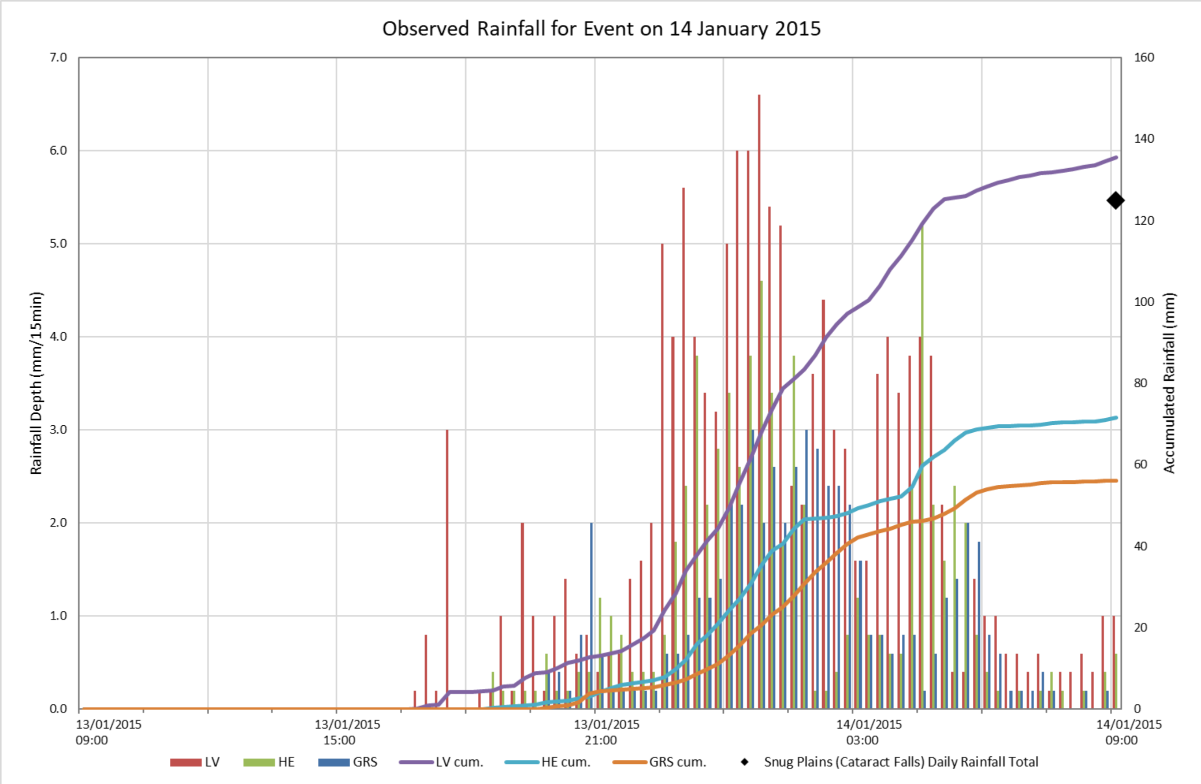


Figure 22: Recorded Rainfall – January 2015 Event

Results from the hydrological modelling of the three pluviograph-derived temporal patterns are shown in Figure 23.

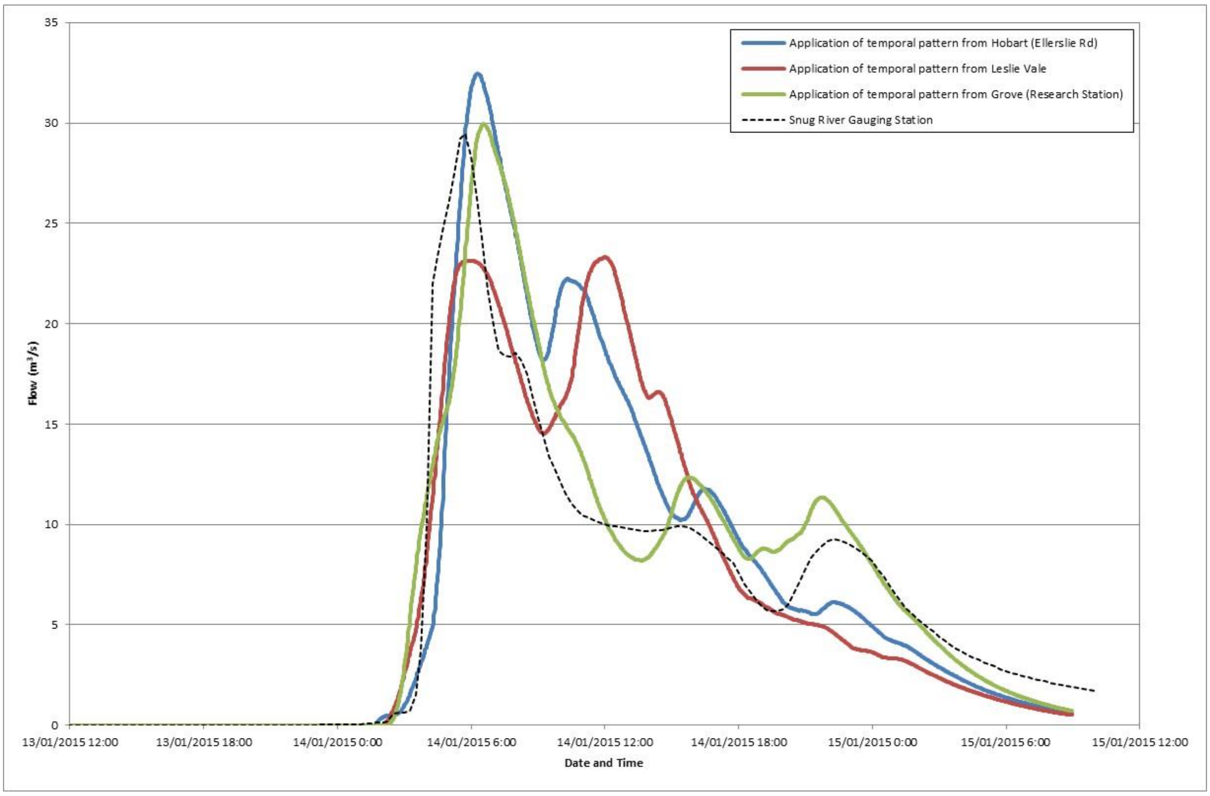


Figure 23: January 2015 Event Hydrographs at the streamflow gauging station

The predicted flow hydrographs for the three temporal patterns indicate the following:

- It is likely that there was significant spatial variation in the rainfall temporal pattern during this event, where this inference is based on the different hydrograph shapes for the three temporal patterns;
- The second peak derived from the Hobart (Ellerslie Road) and Leslie Vale pluviography-derived temporal patterns was not recorded at the Snug River gauging station, indicating that the temporal pattern for rainfall in the Snug River catchment was different from these two pluviograph sites; and
- The peak of the Snug River gauging station occurs slightly earlier than the result derived using the Grove Research Station temporal pattern. However, this particular temporal pattern reproduces the two minor peaks on the trailing limb of the hydrograph.

6.2.3 JUNE 2016 EVENT

There was a significant rainfall event from 5 June to 7 June 2016 that affected the north of Tasmania, resulting in flooding across the north of the state. The rainfall shifted to the southeast of the state, although rainfall totals were much less than in the north. Daily rainfall totals at the Snug Plains (Cataract Falls) rainfall station are provided in Figure 24 (source: Bureau of Meteorology[4])

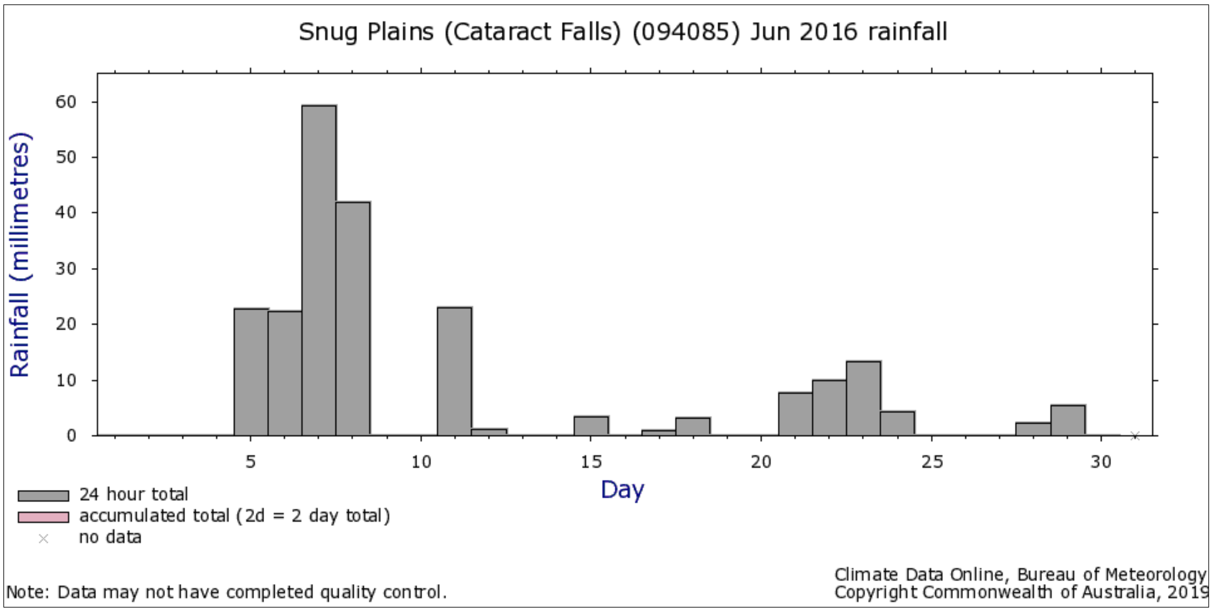


Figure 24: Daily Rainfall Totals at Snug Plains (Cataract Falls) – June 2016

Isohyets of total rainfall for the 24-hour period to 9am on 7 June 2016 are shown in Figure 25. This shows the spatial distribution of rainfall in the vicinity of the Snug River catchment, indicating the variations in total rainfall across the region.

4 http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_display_type=dataDGraph&p_stn_num=094085&p_nccObsCode=136&p_month=01&p_startYear=2015

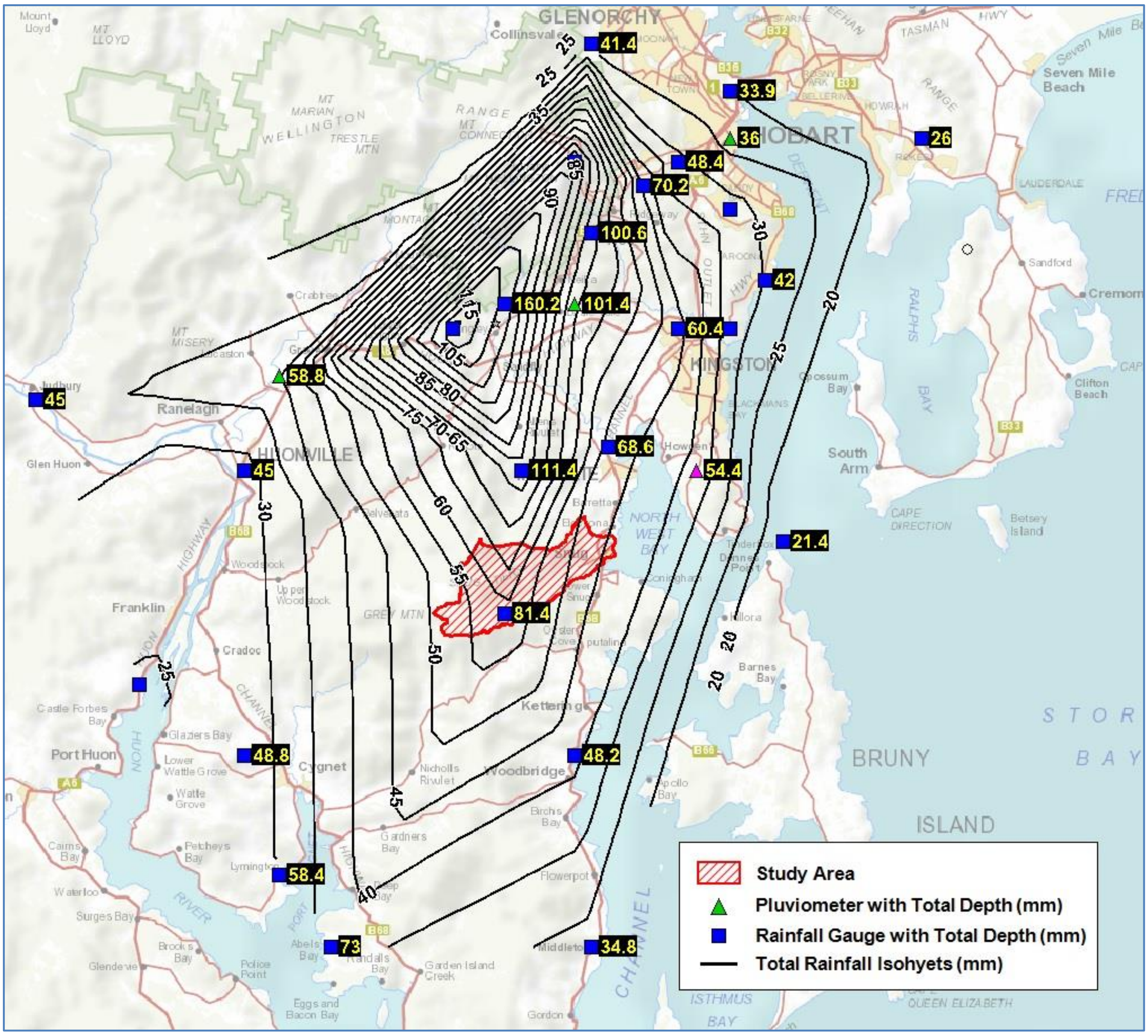


Figure 25: Rainfall Distribution for 7 June 2016

The recorded rainfall hyetographs from the Leslie Vale (LV), Hobart (Ellerslie Road) (HE) and Grove Research Station (GRS) pluviometers are shown in Figure 26. This indicates that there were multiple rainfall bursts over this 24-hour period. The daily rainfall totals from the Snug Plains (Cataract Falls) rainfall station have also been included in Figure 26. This indicates that the total rainfall for Snug Plains (Cataract Falls) is similar to the accumulated total for Leslie Vale.

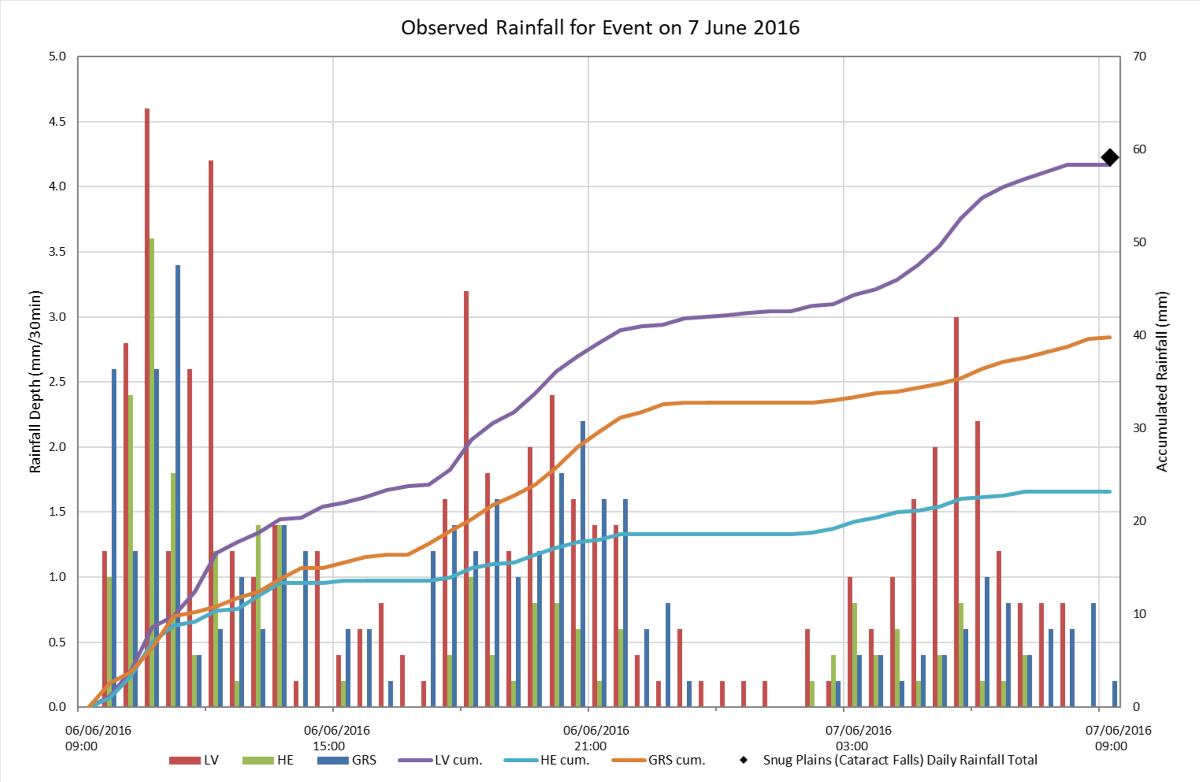


Figure 26: Recorded Rainfall – June 2016 Event

Results from the hydrological modelling of the three pluviograph-derived temporal patterns are shown in Figure 27.

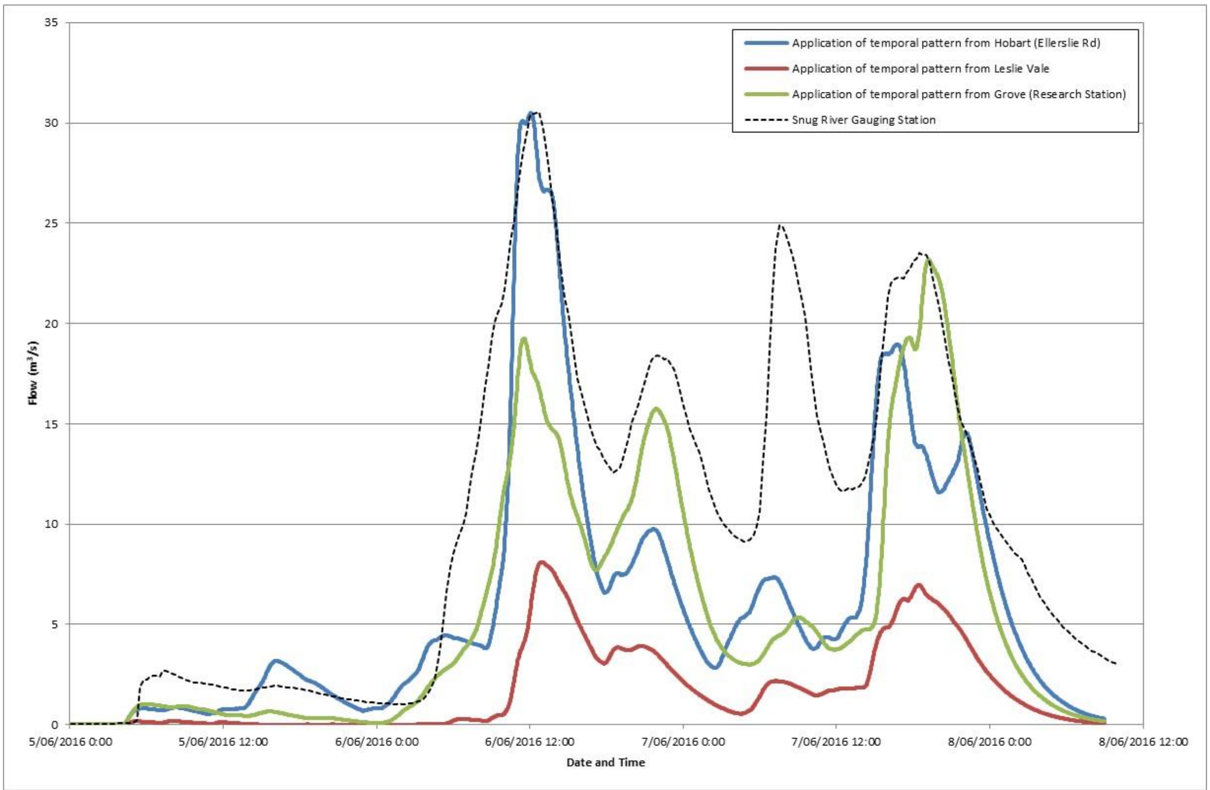


Figure 27: June 2016 Event Hydrographs at the streamflow gauging station

The predicted flow hydrographs for the three temporal patterns indicate the following:

- It is likely that there was significant spatial variation in the rainfall temporal pattern during this event, where this inference is based on the relative magnitudes of the different peaks over the modelled period. It must be noted that the third peak observed at the Snug River gauging station is the second-highest peak which is not being replicated through use of the three temporal patterns;
- The timing of the recorded peaks at the gauging station correlates well with the peaks derived from the temporal patterns; and
- It does not appear possible to utilise any single pluviograph site to represent the rainfall that occurred in the Snug River catchment during the June 2016 event.

6.2.4 EVENT CALIBRATION SUMMARY

Hydrologic modelling of the selected calibration events has shown that the XPSWMM® model adequately replicates the Snug River catchment response.

However, the available data indicates that for any given rainfall event, there is often significant variation in rainfall across the region, with no single pluviograph station considered to be wholly representative of rainfall in the Snug River catchment. The calibration process has therefore relied on assessment of multiple temporal patterns for all three calibration events. The values for model parameters applied in the event calibration process are summarised in Table 9. The adopted values for the XPSWMM® Storage Coefficient Multiplication Factor (BX) and catchment roughness are also provided in Table 6. The Storage Coefficient Multiplication Factor uniformly modifies all subcatchment Storage Delay Time Coefficient values in the Storage Discharge relationship applied in the hydrological model (refer to the xpswwm/xpstorm Resource Center; Innovyze n.d.) The final values for initial and continuing losses applied in the design event modelling have been determined through further model calibration against the flood frequency distribution for the Snug River gauging station, as discussed in Section 6.3. The adopted parameters are described in Section 6.4.4.

Table 9: Summary of Adopted Model Parameters from Event Calibration

Event	**XPSWMM® parameter BX**	**Catchment Roughness**	**Initial Loss (mm)**	**Continuing Loss (mm/hr)**	**Peak Flow (cms)**	
					Observed	**Modelled#**
April 2011	2	0.2	32	3.2	43.1	43.9 (HE)
Jan 2015	2.9	0.1	80	3.2	29.5	29.9 (GRS)
June 2016	2.3	0.1	20	3.2	30.5	30.5 (HE)
Adopted	*2.9*	*0.1*				

Peak flow has been derived from the hydrograph giving what is considered to be the best fit vs observed data, where HE= Hobart (Ellerslie Rd), LV= Leslie Vale, GRS = Grove (Research Station)

6.3 FLOOD FREQUENCY ANALYSIS

Flood frequency analysis methods have been used to estimate peak flows at the Snug River streamflow gauging station for a range of design event magnitudes (i.e. annual exceedance probabilities, or AEP). The annual maxima series (AMS) extracted from the gauging record was fitted with a Log-Pearson-III (LP3) and a Generalised Extreme Value (GEV) distribution.

The flood frequency curves resulting from this analysis are shown in Figure 28, which also includes the flood frequency curve provided by the Bureau of Meteorology[5]. These results indicate there is good correlation between the different data sets, with some deviation in the values for the upper bounds of the 90% confidence limits.

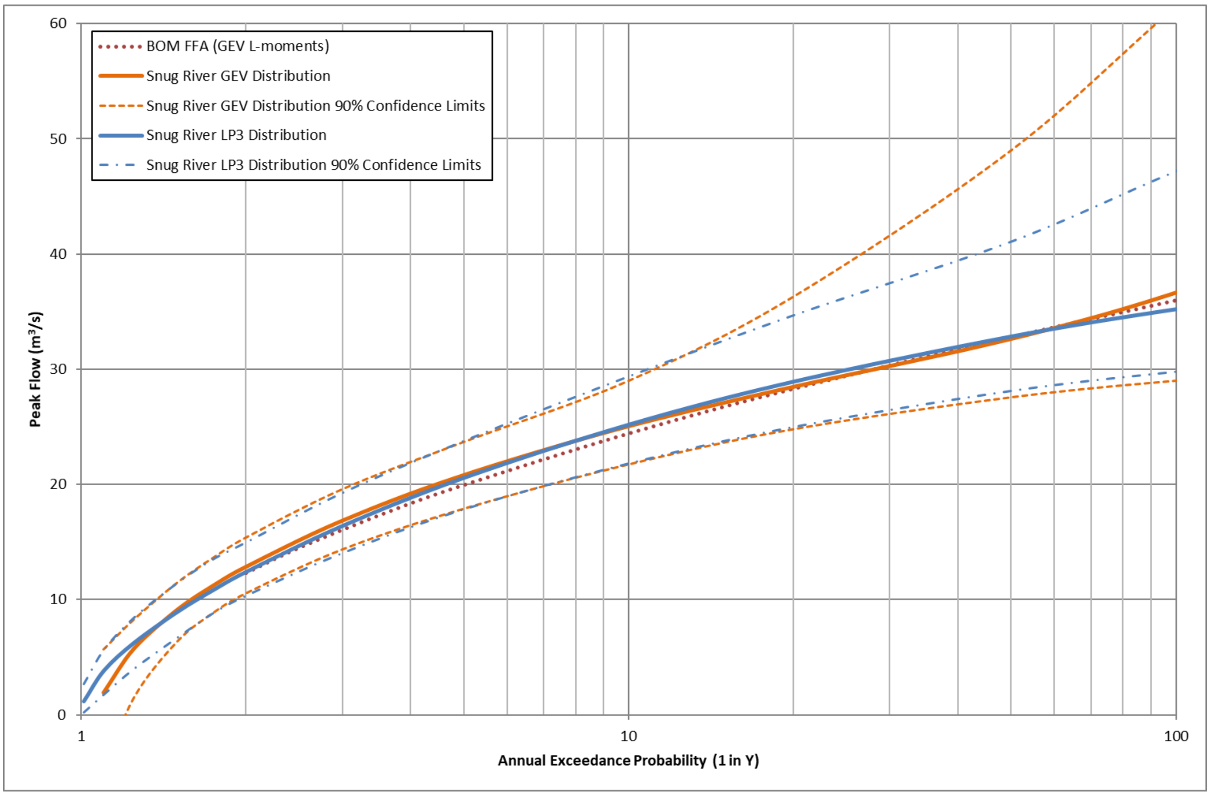


Figure 28: Snug River Flood Frequency Curves

6.4 DESIGN FLOOD EVENTS

6.4.1 INTRODUCTION

Design floods are hypothetical floods used for planning and floodplain management investigations. They are described as having a probability of occurrence, typically specified as Annual Exceedance Probability (AEP), where this is a measure of the rarity of a rainfall/flood event. This report expresses the design event magnitudes as a percentage AEP, which is described further in Table 10.

Table 10: Design Flood Terminology

Annual Exceedance Probability (AEP)	Description
1% AEP	A hypothetical flood or combination of floods likely to occur with a 1% probability of occurring in any given year
5% AEP	A hypothetical flood or combination of floods likely to occur with a 5% probability of occurring in any given year
20% AEP	A hypothetical flood or combination of floods likely to occur with a 20% probability of occurring in any given year

[5] http://www.bom.gov.au/waterdata/

6.4.2 DESIGN RAINFALL

The design rainfall events have bene modelled by applying representative design rainfall depths for a range of storm durations and design storm frequencies. The Bureau of Meteorology provides design intensity-frequency-duration (IFD) data which have been used to derive the rainfall depths applied in this study. The adopted design rainfall depths are summarised in Table 11.

Table 11: Design Rainfall Depths in mm (AR&R 2016, Lat: -43.07, Long: 147.24)

		Annual Exceedance Probability (AEP)						
Duration	**Duration (min)**	**63.20%**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 hour	60	11.1	12.7	17.6	21.2	24.8	29.7	33.7
1.5 hours	90	13.6	15.5	21.6	25.8	29.9	35.5	39.9
2 hours	120	15.8	18.1	25.1	29.9	34.6	40.9	45.7
3 hours	180	19.7	22.5	31.4	37.4	43.2	50.8	56.5
4.5 hours	270	24.6	28.3	39.7	47.4	54.7	64.3	71.5
6 hours	360	28.7	33.2	47	56.1	64.9	76.5	85.3
9 hours	540	35.6	41.3	59.2	71.1	82.6	98	110
12 hours	720	41.1	47.8	69	83.3	97.2	116	131
18 hours	1080	49.4	57.6	83.9	102	120	144	163
24 hours	1440	55.4	64.7	94.4	115	136	165	187
30 hours	1800	60	69.9	102	125	148	180	205

6.4.3 DESIGN TEMPORAL PATTERNS

AR&R 2016 guidelines provide an ensemble of 10 temporal patterns for each design storm to provide a set of temporal patterns to represent the variability of different storms and the respective catchment response. The methodology provided in the AR&R 2016 guidelines indicate that the representative design storm at a given location is to be derived from the temporal pattern of the ensemble which corresponds to the median peak flow, noting that different temporal pattern ensembles are applied for each design storm duration.

A summary of the critical storm duration (i.e. duration that produces the median peak flow) and corresponding temporal pattern from the ensemble is provided in Table 12.

Table 12: Summary of Critical Durations and Selected Ensemble Temporal Patterns

Event	Peak Duration (hour)	Temporal Pattern
1% AEP	9	6
5% AEP	9	4
20% AEP	9	5

6.4.4 DESIGN PEAK FLOWS AND FINAL ADOPTED MODEL PARAMETERS

Design flood events have been modelled using the rainfall data described in the preceding report sections. The hydrological modelling parameters listed in Table 9 in Section 6.2.4 have been utilised, with values for initial loss and continuing loss determined via an iterative process to achieve a correlation of modelled design flows versus results of the flood frequency analysis.

This analysis has yielded an initial loss value of 10mm and continuing loss value of 3.2mm. The resulting comparison against the flood frequency analysis is provided in Figure 29 (noting that the GEV distribution has been adopted). This indicates that the results from the hydrological model generally falls within the confidence limits of the flood frequency analysis, albeit with higher estimates of peak flows for design events with magnitude greater than 10% AEP (1 in 10 AEP). On the basis of these results, the derived design flood events are considered to be appropriate for use in modelling design floods in the Snug River.

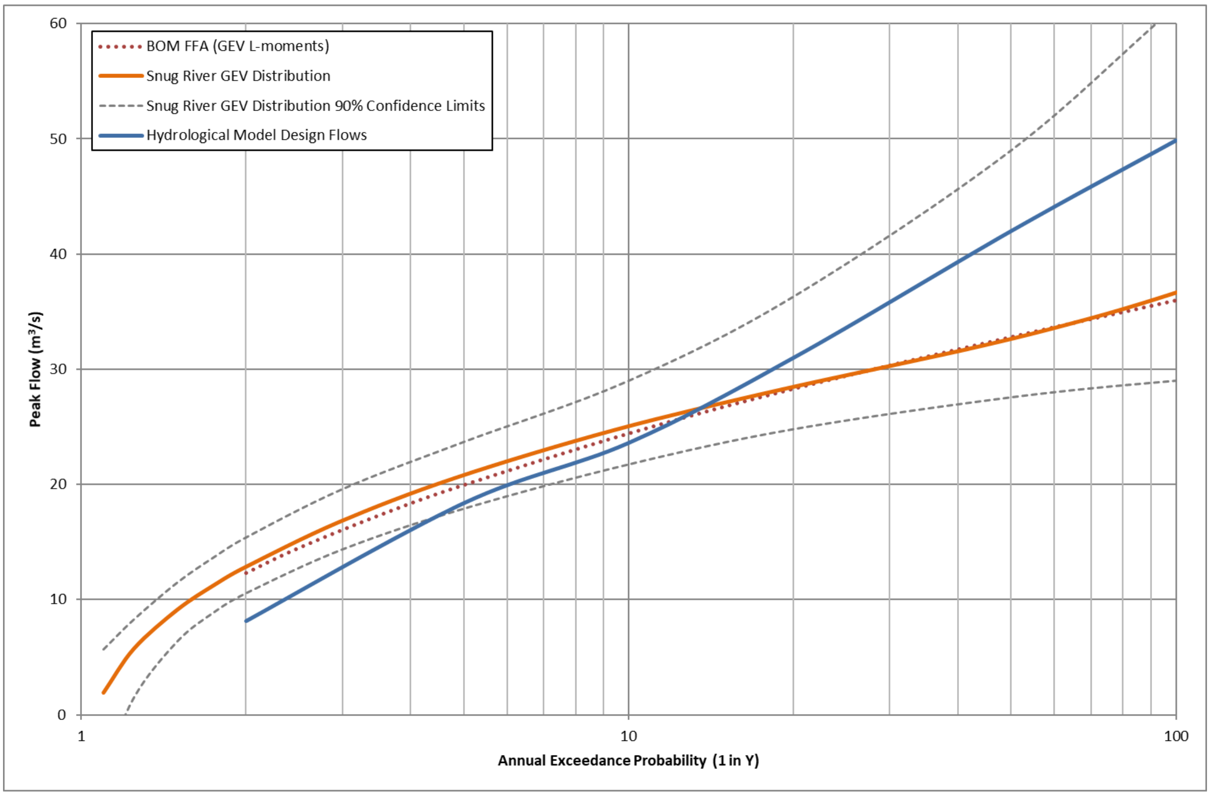


Figure 29: Adopted Flood Frequency compared with Modelled Peak Flows

6.4.5 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 Snug were considered. Table 13 summarised all the adopted design runs in this study.

Table 13: Summary of Adopted Design Runs at Different Scenarios

Year	Catchment Flood Scenario	Coastal Flood Scenario (Water Level Boundary)
Existing	1% AEP	MHWS (0.6 m AHD)
Existing	1% AEP	5% AEP (1.47 m AHD)
Existing	5% AEP	1% AEP (1.57 m AHD)
Existing	20% AEP	20% AEP (1.20 m AHD)
2050	1% AEP	MHWS (0.6 m AHD)
2050	1% AEP	5% AEP (1.47 m AHD)
2050	5% AEP	1% AEP (1.57 m AHD)
2050	20% AEP	20% AEP (1.20 m AHD)
2100	1% AEP	MHWS (0.6 m AHD)
2100	1% AEP	5% AEP (1.47 m AHD)
2100	5% AEP	1% AEP (1.57 m AHD)
2100	20% AEP	20% AEP (1.20 m AHD)

7 HYDRAULIC MODELLING

7.1 INTRODUCTION

The hydraulic model developed for the Snug River catchment (as described in Section 5) has been used to simulate design flood events for both existing conditions and future scenarios including climate change parameters. The resulting flood maps are presented in Appendix A, Appendix B and Appendix C.

7.2 HYDRAULIC MODEL CALIBRATION AND VALIDATION

For the Snug River catchment, there are insufficient quantitative historical flood data records and limited qualitative data for historical events. This paucity of data does not permit a conventional calibration of the hydraulic model parameters.

Therefore, for the Snug River hydraulic model, the model parameters have been based on values considered to be suitable for the subject catchment with verification of the model results against the available qualitative flooding observations.

Sensitivity testing of the model parameters has been undertaken, as outlined in Section 8.

7.3 DESIGN FLOOD MODELLING RESULTS – EXISTING CONDITIONS

7.3.1 FLOOD MAPPING

Hydraulic modelling of a range of design flood events (20% AEP, 5% AEP and 1% AEP) has been undertaken using inflow hydrographs generated with the hydrological model. For each of these events, flood mapping has been prepared which is provided in Appendix A, with the maps listed in Table 14.

Table 14: Design Flood Mapping Index – Existing Conditions

Figure No.	Timeframe	Map Type	Catchment Flood Event	Coastal Flood Condition (Water Level Boundary)
A-01	Existing	Water Levels	1% AEP	MHWS (0.6 m AHD)
A-02	Existing	Water Levels	1% AEP	5% AEP (1.47 m AHD)
A-03	Existing	Water Levels	5% AEP	1% AEP (1.57 m AHD)
A-04	Existing	Water Levels	20% AEP	20% AEP (1.20 m AHD)
A-05	Existing	Depths	1% AEP	MHWS (0.6 m AHD)
A-06	Existing	Depths	1% AEP	5% AEP (1.47 m AHD)
A-07	Existing	Depths	5% AEP	1% AEP (1.57 m AHD)
A-08	Existing	Depths	20% AEP	20% AEP (1.20 m AHD)
A-09	Existing	Velocities	1% AEP	MHWS (0.6 m AHD)
A-10	Existing	Velocities	1% AEP	5% AEP (1.47 m AHD)
A-11	Existing	Velocities	5% AEP	1% AEP (1.57 m AHD)
A-12	Existing	Velocities	20% AEP	20% AEP (1.20 m AHD)

7.3.2 FLOOD HAZARD

Flood hazard is a measure of potential harm or a situation with potential to result in loss of property or life under flood conditions. There are numerous factors that can be used to assess flood hazard, but typically it is determined as a measure of flow depth and flow velocity.

Australian Rainfall and Runoff (Ball et al., 2016) provides a set of flood hazard classification curves that relate to the vulnerability of the community when interacting with floodwaters, which has been reproduced in Figure 30. These curves are divided into flood hazard classifications that relate to specific vulnerability thresholds, with the descriptions of the classifications given in Table 15.

Flood hazard for the Snug River study area has been calculated using the hazard classification determined directly in the XPSWMM® model which is calculated based on the depth and velocity values in the model. The 2D solver in XPSWMM® calculates the flood hazard at every simulation timestep, ensuring the true peak flood hazard values are output. The peak flood hazard maps are provided in Appendix A, with the maps listed in Table 16.

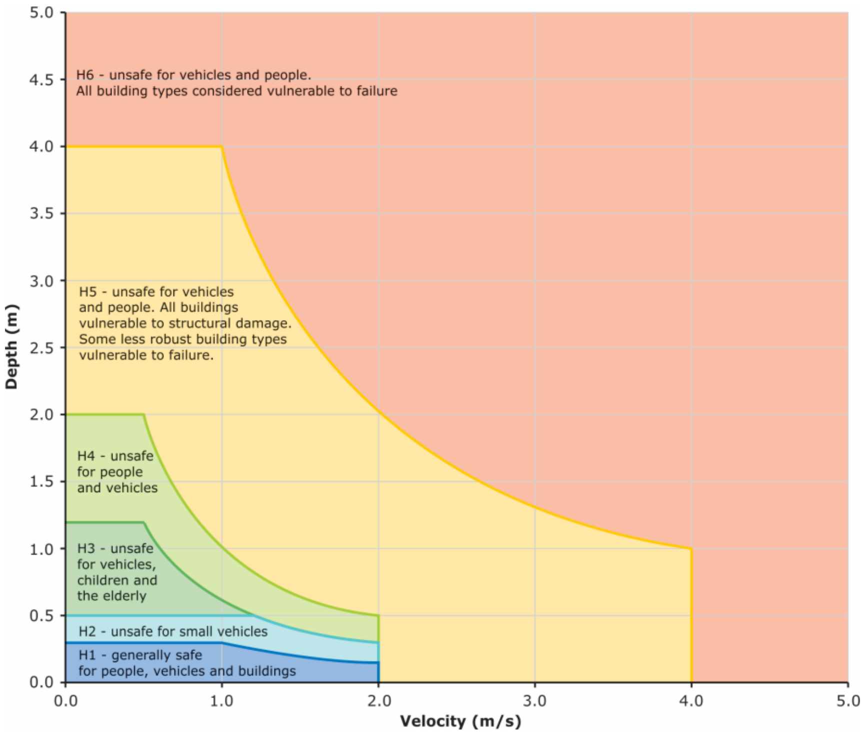


Figure 30: Combined Flood Hazard Curves (Ball et al., 2016)

Table 15: Combined Flood Hazard Curves – Vulnerability Classification (Ball et al., 2016)

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

Table 16: Design Flood Mapping Index for Flood Hazard Categories – Existing Conditions

Figure No.	Timeframe	Map Type	Catchment Flood Event	Coastal Flood Condition (Water Level Boundary)
A-13	Existing	Flood Hazard Category	1% AEP	MHWS (0.6 m AHD)
A-14	Existing	Flood Hazard Category	1% AEP	5% AEP (1.47 m AHD)
A-15	Existing	Flood Hazard Category	5% AEP	1% AEP (1.57 m AHD)
A-16	Existing	Flood Hazard Category	20% AEP	20% AEP (1.20 m AHD)

7.4 DISCUSSION

Upstream of the Channel Highway, flooding is generally contained within the defined river channel and floodplain. This results from a combination of:

- High ground on both sides of the river channel;
- Relatively few obstructions to flow along the river and floodplain corridor; and
- A predicted hydraulic grade of less than 1 in 50 (2%).

Downstream of the Channel Highway where the river widens out to the estuary in the lower reaches, flooding is affected by the combination of tide level and constriction at the river mouth, in addition to the magnitude of fluvial event in the river. There is the potential for flooding to be alleviated in the lower reaches of the Snug River with a wider opening at the mouth of the River. It is therefore recommended that Council considers undertaking further analysis to investigate an entrance management plan for the mouth of the Snug River with the aim of minimising the constriction that currently exists at the river mouth.

8 SENSITIVITY ANALYSIS

The hydrologic and hydraulic models have been used to undertake a range of sensitivity tests to assess the relative significance of the different hydrologic and hydraulic parameters.

Sensitivity tests have been assessed for the 1% AEP design event with a tailwater condition equivalent to mean high water springs (MHWS= 0.60 m AHD). The predicted changes in flooding behaviour are described herein.

8.1 RAINFALL LOSSES

The rainfall losses for design event applied in the hydrologic model have been determined through both event calibration and calibration to flood frequency analysis at the stream gauging station in the Snug River. Sensitivity tests have been undertaken for a 20% decrease and a 20% increase in the initial loss and continuing loss values applied in the hydrologic model. The changes in flooding behaviour are summarised in Table 17.

Table 17: Summary of changes in flooding behaviour – rainfall losses sensitivity tests

Sensitivity test	Changes in flooding behaviour
Decreased rainfall losses	• Peak flood level increases in the channel and floodplain upstream of the highway of up to 0.04m • Peak flood level increases in the channel and floodplain downstream of the highway of up to 0.12m, transitioning to 0.05m increase in the wider part of the estuary • Negligible change to the extent of flooding upstream of the highway • Minor increase in extent of flooding downstream of the highway
Increased rainfall losses	• Peak flood level reductions in the channel and floodplain upstream of the highway of up to 0.03m • Peak flood level reductions in the channel and floodplain downstream of the highway of up to 0.20m, transitioning to 0.07m reduction in the wider part of the estuary • Negligible change to the extent of flooding upstream of the highway • Minor decrease in extent of flooding downstream of the highway

These changes in flooding behaviour are as expected and indicate there may be some variation in peak flood levels with different rainfall loss values. However, in lieu of suitable calibration data for the hydraulic model, the rainfall loss values adopted for design event modelling are considered to be appropriate for this study.

8.2 HYDRAULIC ROUGHNESS

The Manning's roughness values applied in the hydraulic model are considered to be within typical ranges for the land-use types across the Snug River model. However, there is a degree of uncertainty associated with the delineation of land-use types and associated roughness values, particularly in the absence of extensive calibration data.

Sensitivity tests have been undertaken for a 20% decrease and a 20% increase in the hydraulic roughness values applied in the 2D model domain. The changes in flooding behaviour are summarised in Table 18.

Table 18: Summary of changes in flooding behaviour – hydraulic roughness sensitivity tests

Sensitivity test	Changes in flooding behaviour
Decreased hydraulic roughness	• Peak flood level reductions in the channel and floodplain upstream of the highway of up to 0.03m • Peak flood level reductions in the channel and floodplain downstream of the highway of up to 0.18 • Negligible change to the extent of flooding upstream of the highway • Minor decrease in extent of flooding downstream of the highway
Increased hydraulic roughness	• Peak flood level increases in the channel and floodplain upstream of the highway of up to 0.03m • Peak flood level increase in the channel and floodplain downstream of the highway of up to 0.20m, transitioning to 0.07m increase in the wider part of the estuary • Negligible change to the extent of flooding upstream of the highway • Minor increase in extent of flooding downstream of the highway

These changes in flooding behaviour are as expected and indicate there may be some variation in peak flood levels with different hydraulic roughness value. However, in lieu of suitable calibration data, the hydraulic roughness values adopted for design event modelling are considered to be appropriate for this study.

8.3 BLOCKAGE AT BRIDGES

There are anecdotal records that indicate debris blockage at the highway bridges has occurred in previous flood events. This blockage has the potential to alter flooding behaviour, leading to an increase in peak flood levels and extents of flooding.

A sensitivity test has been undertaken to represent 100% blockage at the bridges while also applying blockage to 1.5m above the bridge deck level. The changes in flooding behaviour are summarised in Table 19.

Table 19: Summary of changes in flooding behaviour – blockage at bridges sensitivity test

Sensitivity test	Changes in flooding behaviour
Fully blocked bridges	• Peak flood level increases immediately upstream of the highway of up to 2.10m for the southern bridge (main channel) and 2.90m for the northern bridge (overflow channel); these significant increases reduce to zero within 100m upstream of the highway • Peak flood level decreases downstream of the highway of up to 0.60m, transitioning to 0.06m decrease in the wider part of the estuary • Increased extents of flooding both upstream and downstream of the highway; upstream of the highway, the changes in extents of flooding generally only affects the floodplain area and open space, whilst downstream of the highway, the changes in flood extents affects properties on both sides of the river channel and floodplain, with up to 55m increase in the extent of flooding on the southern side of the channel and 30m increase on the northern side of the channel

These changes in flooding behaviour are in line with expectations for this sensitivity test and indicate the need to maintain a clear waterway area at the highway bridges.

8.4 DOWNSTREAM WATER LEVEL

Modelling of design flood events that does not include tidal surge levels has applied a downstream water level equivalent to a mean high water springs (MHWS) tide level of 0.60 m AHD. Sensitivity tests have been undertaken for a change in the assumed tidal boundary (excluding surge) by assessing both a highest astronomical tide (HAT) of 0.80m AHD and lowest astronomical tide (LAT) of -0.90 m AHD. The changes in flooding behaviour are summarised in Table 20.

Table 20: Summary of changes in flooding behaviour – downstream water level sensitivity tests

Sensitivity test	Changes in flooding behaviour
Increased tide level (HAT=0.80 m AHD)	Peak flood level increases do not propagate further upstream than the mouth of the Snug River due to the constricted channel at this location
Decreased tide level (LAT=-0.90 m AHD)	Peak flood level decreases do not propagate further upstream than the mouth of the Snug River due to the constricted channel at this location

These changes in flooding behaviour indicate that the tide level (excluding tidal surge) applied in conjunction with fluvial runoff events has negligible effect on flooding characteristics of the Snug River. Therefore, the tidal condition adopted for design event modelling is considered to be appropriate for this study.

8.5 AR&R RAINFALL PARAMETERS

As discussed in Section 6.4, the design rainfall estimates and temporal patterns have been derived using the methodology described in Australian Rainfall and Runoff 2016 (Ball et al., 2016). A sensitivity test has been undertaken using the design event modelling methodology described in Australian Rainfall and Runoff 1987 (Pilgrim, 1987).

The changes in flooding behaviour are summarised in Table 21.

Table 21: Summary of changes in flooding behaviour – downstream water level sensitivity tests

Sensitivity test	Changes in flooding behaviour
ARR1987 Rainfall Parameters	• Peak flood level increases upstream of the highway of up to 0.15m • Peak flood level increases downstream of the highway of up to 0.16m, transitioning to a 0.12m increase in the wider part of the estuary • Minor increases in the extents of flooding both upstream and downstream of the highway

These changes in flooding behaviour indicate that the application of design rainfall parameters from ARR2016 yields less conservative flood levels and flooding behaviour compared with ARR1987. This indicates the need for calibration and validation of the model for future rainfall and flood events (requiring data to be collected at the time of any future event), and for application of freeboard to the predicted flood levels for the purpose of setting design levels for future development.

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9 CLIMATE CHANGE ANALYSIS

9.1 ADOPTED CLIMATE CHANGE PARAMTERS

The potential impacts of predicted climate change have been considered for future flood events in the years 2050 and 2100. Climate Futures for Tasmania modelling (White et al., 2010) indicates that the 24-hour 1% AEP event rainfall intensities may increase by 10% to 30% in south-eastern Tasmania. Potential changes in rainfall intensity may vary for different duration events.

Sea level rise due to climate change has been derived from the 2015 report *Sea-Level Rise Planning Allowances for Kingston Beach, Tasmania* (Hunter, 2015). This report advocates the following sea level rise allowances summarised in Table 22.

Table 22: Sea Level Rise Allowances for Years 2050 and 2100 (Hunter, 2015)

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

Based on the above predictions for increased rainfall intensities and sea level rise, the climate change analysis for this study has been undertaken by applying the following:

Table 23: Rainfall intensities and sea level rise for climate change scenarios

Year	Change in rainfall/sea level rise
2050	• 10% increase in rainfall intensities • 0.30 m sea level rise
2100	• 30% increase in rainfall intensities • 1.00 m sea level rise

9.2 FLOOD MAPPING AND DISCUSSION OF RESULTS

Flood mapping for these climate change scenarios has been prepared, as provided in Appendix B for year 2050 and Appendix C for year 2100. Flood maps have been prepared for each climate change scenario, with separate maps for peak water levels, depths, velocities and flood hazard categories. Additional mapping has been prepared showing the differences in peak water levels compared with the equivalent existing climate model results.

Table 24 provides an index of the flood mapping for the year 2050 (Appendix B), whilst Table 25 provides an index of the flood mapping for the year 2100 (Appendix C).

Table 24: Climate Change Analysis Flood Mapping Index – Year 2050

Figure No.	Map Type	Catchment Flood Event	Coastal Flood Condition (Water Level Boundary)
B-01	Water Levels	1% AEP + 10% rainfall intensity	MHWS +0.3m SLR (0.90 m AHD)
B-02	Water Levels	1% AEP + 10% rainfall intensity	5% AEP +0.3m SLR (1.77 m AHD)
B-03	Water Levels	5% AEP + 10% rainfall intensity	1% AEP +0.3m SLR (1.87 m AHD)
B-04	Water Levels	20% AEP + 10% rainfall intensity	20% AEP +0.3m SLR (1.50 m AHD)
B-05	Depths	1% AEP + 10% rainfall intensity	MHWS +0.3m SLR (0.90 m AHD)
B-06	Depths	1% AEP + 10% rainfall intensity	5% AEP +0.3m SLR (1.77 m AHD)
B-07	Depths	5% AEP + 10% rainfall intensity	1% AEP +0.3m SLR (1.87 m AHD)
B-08	Depths	20% AEP + 10% rainfall intensity	20% AEP +0.3m SLR (1.50 m AHD)
B-09	Velocities	1% AEP + 10% rainfall intensity	MHWS +0.3m SLR (0.90 m AHD)
B-10	Velocities	1% AEP + 10% rainfall intensity	5% AEP +0.3m SLR (1.77 m AHD)
B-11	Velocities	5% AEP + 10% rainfall intensity	1% AEP +0.3m SLR (1.87 m AHD)
B-12	Velocities	20% AEP + 10% rainfall intensity	20% AEP +0.3m SLR (1.50 m AHD)
B-13	Hazard	1% AEP + 10% rainfall intensity	MHWS +0.3m SLR (0.90 m AHD)
B-14	Hazard	1% AEP + 10% rainfall intensity	5% AEP +0.3m SLR (1.77 m AHD)
B-15	Hazard	5% AEP + 10% rainfall intensity	1% AEP +0.3m SLR (1.87 m AHD)
B-16	Hazard	20% AEP + 10% rainfall intensity	20% AEP +0.3m SLR (1.50 m AHD)
B-17	Differences	1% AEP + 10% rainfall intensity	MHWS +0.3m SLR (0.90 m AHD)
B-18	Differences	1% AEP + 10% rainfall intensity	5% AEP +0.3m SLR (1.77 m AHD)
B-19	Differences	5% AEP + 10% rainfall intensity	1% AEP +0.3m SLR (1.87 m AHD)
B-20	Differences	20% AEP + 10% rainfall intensity	20% AEP +0.3m SLR (1.50 m AHD)

Table 25: Climate Change Analysis Flood Mapping Index – Year 2100

Figure No.	Map Type	Catchment Flood Event	Coastal Flood Condition (Water Level Boundary)
C-01	Water Levels	1% AEP + 30% rainfall intensity	MHWS +1.0m SLR (1.60 m AHD)
C-02	Water Levels	1% AEP + 30% rainfall intensity	5% AEP +1.0m SLR (2.47 m AHD)
C-03	Water Levels	5% AEP + 30% rainfall intensity	1% AEP +1.0m SLR (2.57 m AHD)
C-04	Water Levels	20% AEP + 30% rainfall intensity	20% AEP +1.0m SLR (2.20 m AHD)
C-05	Depths	1% AEP + 30% rainfall intensity	MHWS +1.0m SLR (1.60 m AHD)
C-06	Depths	1% AEP + 30% rainfall intensity	5% AEP +1.0m SLR (2.47 m AHD)
C-07	Depths	5% AEP + 30% rainfall intensity	1% AEP +1.0m SLR (2.57 m AHD)
C-08	Depths	20% AEP + 30% rainfall intensity	20% AEP +1.0m SLR (2.20 m AHD)

Figure No.	Map Type	Catchment Flood Event	Coastal Flood Condition (Water Level Boundary)
C-09	Velocities	1% AEP + 30% rainfall intensity	MHWS +1.0m SLR (1.60 m AHD)
C-10	Velocities	1% AEP + 30% rainfall intensity	5% AEP +1.0m SLR (2.47 m AHD)
C-11	Velocities	5% AEP + 30% rainfall intensity	1% AEP +1.0m SLR (2.57 m AHD)
C-12	Velocities	20% AEP + 30% rainfall intensity	20% AEP +1.0m SLR (2.20 m AHD)
C-13	Hazard	1% AEP + 30% rainfall intensity	MHWS +1.0m SLR (1.60 m AHD)
C-14	Hazard	1% AEP + 30% rainfall intensity	5% AEP +1.0m SLR (2.47 m AHD)
C-15	Hazard	5% AEP + 30% rainfall intensity	1% AEP +1.0m SLR (2.57 m AHD)
C-16	Hazard	20% AEP + 30% rainfall intensity	20% AEP +1.0m SLR (2.20 m AHD)
C-17	Differences	1% AEP + 30% rainfall intensity	MHWS +1.0m SLR (1.60 m AHD)
C-18	Differences	1% AEP + 30% rainfall intensity	5% AEP +1.0m SLR (2.47 m AHD)
C-19	Differences	5% AEP + 30% rainfall intensity	1% AEP +1.0m SLR (2.57 m AHD)
C-20	Differences	20% AEP + 30% rainfall intensity	20% AEP +1.0m SLR (2.20 m AHD)

The changes in flooding behaviour for modelling of the predicted 2050 climate are summarised in Table 26.

Table 26: Changes in flooding behaviour – 2050 climate

Floodplain location	Changes in flooding behaviour
Upstream of the Channel Highway	• Flood levels are predicted to increase by up to 0.10m for a 1% AEP fluvial event (Figure B-17 and Figure B-18) and up to 0.16m for a 20% AEP fluvial event (Figure B-20) • Relatively minor increase in the extents of flooding • Flood levels upstream of the Channel Highway are generally not affected by sea level rise
In the vicinity of the Channel Highway bridges	• Flood level increases of up to 0.13m for all climate change scenarios modelled • Relatively minor increase in the extents of flooding

Downstream of the Channel Highway (i.e. wider reach of the estuary)	• Peak flood levels in the lower reach of the Snug River estuary are significantly affected by the hydraulic control formed by the constriction at the mouth of the river
	• Flood levels in the wider part of the estuary are predicted to increase by up to
	  ○ 0.10m for 1% AEP +10% fluvial event with MHWS +0.3m SLR (Figure B-17)
	  ○ 0.22m for 1% AEP +10% fluvial event with 5% AEP +0.3m SLR (Figure B-18)
	  ○ 0.28m for 5% AEP +10% fluvial event with 1% AEP +0.3m SLR (Figure B-19)
	  ○ 0.29m for 20% AEP +10% fluvial event with 20% AEP +0.3m SLR (Figure B-20)
	  ○ These results indicate that the magnitude of change in flood level is greater for more frequent events
	• Relatively significant increases in the extent of flooding for all four climate change scenarios, where this is most likely due to the effect of sea level rise

The changes in flooding behaviour for modelling of the predicted 2100 climate are summarised in Table 27.

Table 27: Changes in flooding behaviour – 2100 climate

Floodplain location	Changes in flooding behaviour
Upstream of the Channel Highway	• Flood levels are predicted to increase by up to 0.30m for a 1% AEP fluvial event (Figure C-17 and Figure C-18) and up to 0.43m for a 20% AEP fluvial event (Figure C-20) • Relatively minor increase in the extents of flooding • Flood levels upstream of the Channel Highway are generally not affected by sea level rise
In the vicinity of the Channel Highway bridges	• Flood level increases of up to 0.42m for all climate change scenarios modelled • Relatively minor increase in the extents of flooding
Downstream of the Channel Highway (i.e. wider reach of the estuary)	• Peak flood levels in the lower reach of the Snug River estuary are affected by the hydraulic control formed by the constriction at the mouth of the river, though to a lesser degree compared with 2050 climate • Flood levels in the wider part of the estuary re predicted to increase by up to o 0.40m for 1% AEP +30% fluvial event with MHWS +1.0m SLR (Figure C-17) o 0.82m for 1% AEP +30% fluvial event with 5% AEP +1.0m SLR (Figure C-18) o 0.97m for 5% AEP +30% fluvial event with 1% AEP +1.0m SLR (Figure C-19) o 0.96m for 20% AEP +30% fluvial event with 20% AEP +1.0m SLR (Figure C-20) o These results indicate that the magnitude of change in flood level is greater for more frequent events • Relatively significant increases in the extent of flooding for all four climate change scenarios, where this is most likely due to the effect of sea level rise

9.3 SUMMARY OF CLIMATE CHANGE ANALYSIS

The predicted changes in flooding behaviour due to climate change indicate that increases in peak water levels and flood extents are likely to occur. The increases in peak water levels upstream of and in the general vicinity of the Channel Highway bridges are generally caused by the increased rainfall intensities (fluvial events), while the peak water level increases in the wider part of the estuary are the result of both increased rainfall intensities and sea level rise. It is likely that sea level rise is the major factor affecting the peak water level increases in the lower reach of the estuary.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 CONCLUSIONS

The purpose of this study has been to undertake a detailed flooding assessment of the lower Snug River through the establishment of appropriate hydrological and hydraulic models. The key activities undertaken in preparing this study are as follows:

- Collection and compilation of available data considered relevant for understanding and describing the Snug River catchment and flooding characteristics;
- Engagement with the local community was undertaken via distribution of a questionnaire, aimed at raising general awareness of the study and to garner flood intelligence;
- Development of a hydrological model of the Snug River catchment using XPSWMM®, deriving inflows for the Snug River only (i.e. excluding local stormwater catchments);
- Development of a hydraulic flood model of the lower Snug River using XPSWMM®;
- Calibration of the hydrological model using historic rainfall and gauged flow data, with additional determination of model parameters using a flood frequency analysis for the Snug River streamflow gauging station;
- Analysis of a range of design flood events, with preparation of flood mapping;
- Sensitivity tests for a range of model parameters; and
- Climate change analysis, applying predicted increases in rainfall intensities and sea levels for the years 2050 and 2100.

The results of the hydraulic modelling of design flood events indicate the flooding behaviour summarised in Table 28.

Table 28: Summary of general flooding behaviour in the lower Snug River

Floodplain location	Changes in flooding behaviour
Upstream of the Channel Highway	Flooding is generally contained within the defined river channel and floodplain. This results from a combination of: • High ground on both sides of the river channel; • Relatively few obstructions to flow along the river and floodplain corridor; • A predicted hydraulic grade of less than 1 in 50 (2%)
Downstream of the Channel Highway	Where the river widens out to the estuary in the lower reaches, flooding is affected by the combination of tide level and constriction at the river mouth, in addition to the magnitude of fluvial event in the river

The sensitivity tests undertaken for this study indicate that the various model parameters adopted for design event modelling are appropriate for use in this study. Regarding debris blockage at the Channel Highway bridges, both historic data and sensitivity modelling indicate that flooding may be exacerbated by the accumulation of debris (typically large woody debris) at the Channel Highway bridges. This indicates the need to maintain the bridges as blockage-free to minimise impacts of flooding due to debris blockage.

Modelling of the climate change scenarios indicates that increased peak flood levels and extents of flooding are likely due to increased rainfall intensities and sea level rise. The increases in peak water levels upstream of and in the general vicinity of the Channel Highway bridges are generally caused by the increased rainfall intensities (fluvial events), while the peak water level increases in the wider part of the estuary are the result of both increased rainfall intensities and sea level rise. It is likely that sea level rise is the major factor affecting the peak water level increases in the lower reach of the estuary.

10.2 RECOMMENDATIONS

The recommendations provided in Table 29 have been prepared to address both future uses of the tools developed in preparing the study and the study outcomes.

Table 29: Recommendations for future management of flood risk in the Snug River

Recommendations	
1	That Council further enhance the modelling tools developed for this study, primarily to include local catchments inflows and associated stormwater drainage infrastructure in Snug.
2	That Council collects flood data during and immediately following future flood events to assist with recalibration and/or on-going validation of the modelling tools.
3	That Council develop a long-term strategy for the management of flood risk in the low-lying areas of Snug.
4	That Council investigates an entrance management plan for the mouth of the Snug River with the aim of minimising the constriction that currently exists at the river mouth.
5	That the flood mapping for the 1% AEP, year 2100, developed for this study be endorsed by Council and incorporated into the Kingborough Interim Planning Scheme as a flood overlay for the area (noting that stormwater flooding has not been addressed in this study).
6	That Council establishes and promotes a community education program in conjunction with the SES to provide information on what to do before, during and after a flood event, and to facilitate the communication of existing flood risks at flood-prone properties.

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