Bundeena Floodplain Risk Management Study & Plan

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Australia

Revision 2

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WorleyParsons Group

Project: Bundeena Floodplain Risk Management Study & Plan

Rev	Description	Author	Reviewer	Advisian Approval	Date
A	Draft Report – Issued for Review	WJH WJH	CRT CT	CRT Chris Thomas	20/03/2019
1	Final Draft Report	WJH WJH	CRT CT	CRT Chris Thomas	28/05/2019
2	Final Report for Adoption	WJH WJH	CRT CT	Chris Thomas	13/08/2019

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List of Acronyms and Initialisations

AAD	Average Annual Damages
ABS	Australian Bureau of Statistics
AEP	Average Exceedance Probability
AHD	Australian Height Datum
ALS	Aerial Laser Survey
ARR	Australian Rainfall and Runoff
BCR	Benefit Cost Ratio
BOM	Bureau of Meteorology
DCP	Development Control Plan
DPE	Department of Planning and Environment
DTM	Digital Terrain Model
EMP	Estuary Management Plan
FDM	Floodplain Development Manual
FERP	Flood Emergency Response Plan
FIA	Flood Impact Assessment
FPCC	Flood Planning Constraints Categories
FPA	Flood Planning Area
FPL	Flood Planning Level
HAT	Highest Astronomical Tide
ICOLL	Intermittently Closed and Open Lake or Lagoon
IFD	Intensity Frequency Duration
LEP	Local Environment Plan
LGA	Local Government Area
LiDAR	Light Detection and Ranging
NSW	New South Wales
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PV	Present Value
RCP	Representative Concentration Pathway
SEPP	State Environment Planning Policies
SES	State Emergency Service
VHR	Voluntary House Raising
VHP	Voluntary House Purchase

Acknowledgements

The following report has been prepared by Advisian (*part of the WorleyParsons Group*) for Sutherland Shire Council. The project was overseen by the Sutherland Shire Floodplain Management Committee.

The Floodplain Risk Management Study and Plan is the culmination of many months of investigation, analysis and flood modelling, which has been supported by contributions from representatives of the community of Bundeena, Sutherland Shire Council, NSW State Emergency Services (*SES*) and the Office of Environment & Heritage (*OEH*). These contributions have been critical to identification of the management strategies that have been considered as part of the project and are greatly appreciated.

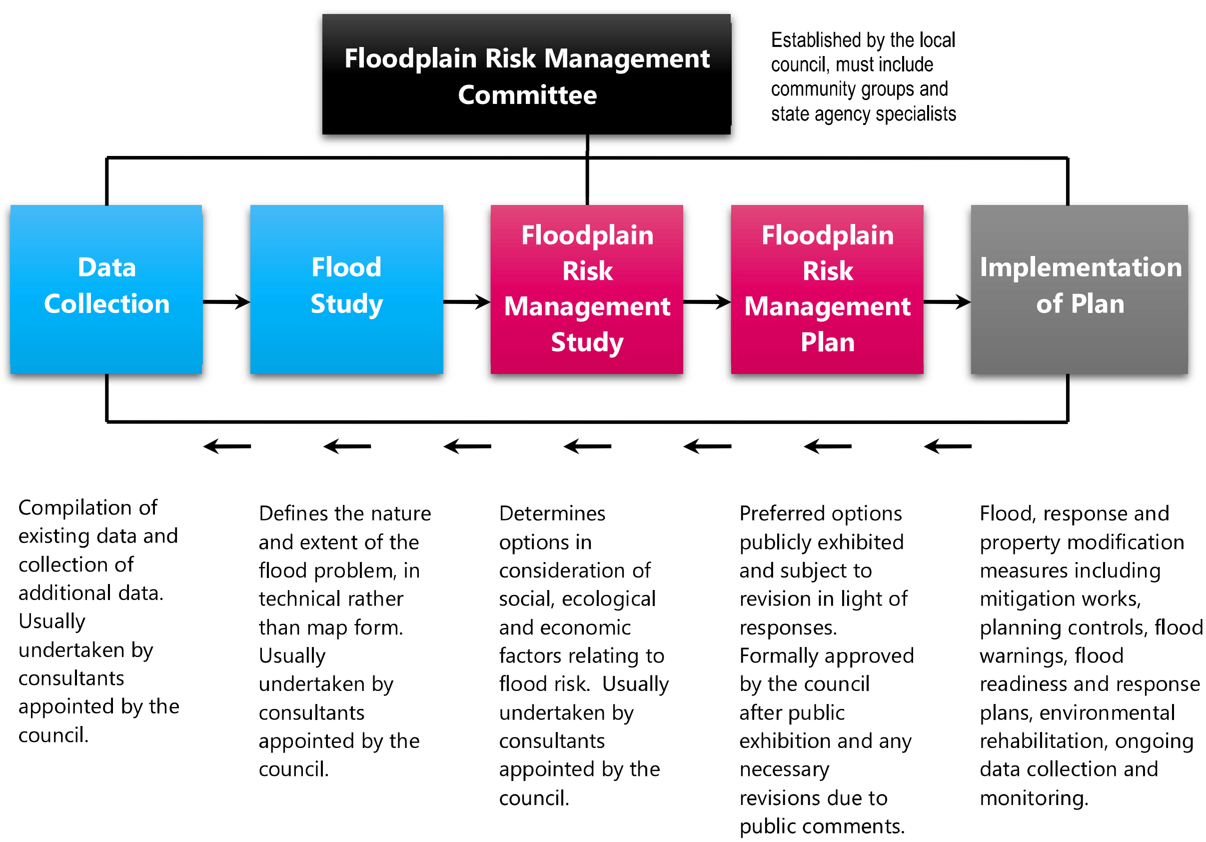
Foreword

The NSW Government's Flood Prone Land Policy is directed towards providing solutions to existing flooding problems in developed areas and ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas. Policy and practice are defined in the Government's Floodplain Development Manual (*2005*).

The primary objective of the Policy is to reduce the impact of flooding on individual owners and occupiers of flood prone land, and to reduce private and public losses caused by flooding. In this regard, the Policy recognises:

- that flood prone land is a valuable resource that should not be sterilised by unnecessarily precluding its development; and,
- that if all applications for development on flood prone land are assessed according to rigid and prescriptive criteria, some proposals may be unjustifiably disallowed or restricted, and equally, quite inappropriate proposals could be approved (*NSW Government, 2005*).

The floodplain risk management process is outlined in the flowchart below.



Source: 'Floodplain Development Manual' (2005)

Under the Policy, the management of flood liable land remains the responsibility of Local Government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Local Government in the discharge of their floodplain risk management responsibilities.

Development of the Bundeena Creek Floodplain Risk Management Study and Plan has built-upon the previous investigations to prepare the Bundeena Creek Flood Study in 2014. The project has been overseen by the Sutherland Shire Floodplain Management Committee comprising representatives from OEH, NSW SES and the local community.

Technical and financial assistance has been provided by OEH through the NSW Government's Floodplain Management Program.

Executive Summary

Setting

Bundeena Creek (also referred to as Bundeena Gully) flows through the township of Bundeena and drains a 2.8 km2 catchment that extends south into the Royal National Park.

The Bundeena Creek catchment has a history of local drainage and flooding issues, particularly in the low-lying areas of the town. Parts of the Bundeena township are susceptible to mainstream flooding from Bundeena Creek, while other parts are susceptible to overland flooding as stormwater runoff drains to the creek.

The lower part of the Bundeena Creek floodplain forms a basin behind the coastal sand dune along Horderns Beach. Areas with terrain less than 2 mAHD represent about 20% of the total catchment. A significant portion of the Bundeena township lies within this low-lying part of the floodplain.

Major flooding of the catchment is documented as having occurred in November 1969, February/March 1977 and November 1984. Numerous other less severe floods have also occurred in the catchment in more recent times, with many residents indicating that roads and properties were inundated during July 2011, March/April 2012, and as recently as June 2016 after relatively minor rainfalls within the catchment.

Project Objectives

The primary objective of the floodplain risk management process is to reduce the risk to life and property from flooding.

The objective of the Bundeena Creek Floodplain Risk Management Study and Plan is to develop a set of cost-effective floodplain risk management actions that can be progressively implemented by Council, SES and others to reduce flood risk for the benefit of flood-affected property owners in Bundeena, as well as the wider community.

Updated Flood Modelling for Bundeena

Advisian completed a Flood Study for the Bundeena Creek catchment for Council in 2014. The Flood Study involved the development of a rainfall-to-runoff computer model for the urban and National Park catchments draining to the creek. The results of this modelling were fed into a two-dimensional hydrodynamic model of the Bundeena Creek floodplain to estimate flood levels, depths and flow velocities.

As a part of preparing the Bundeena Creek Floodplain Risk Management Study and Plan, Advisian has reviewed and updated the computer modelling that was completed for the 2014 Flood Study.

It was agreed with Council that the flood modelling should be updated to:

- Capture the behaviour of flooding along overland flowpaths through the urban areas of Bundeena, including those areas positioned well above the main floodplain of the creek.
- Incorporate the existing stormwater pit and pipe network within the urban areas above the mainstream floodplain.

The updated flood models were calibrated using data collected for the November 1969, November 1984 and March 2012 events, in order to check the reliability of the model results.

Australian Rainfall & Runoff 2016

The 2014 Flood Study was based on the rainfall data and modelling methods outlined in the publication titled, Australian Rainfall & Runoff 1987. An updated version of Australian Rainfall & Runoff was released in 2016, including revised methodologies and updated rainfall Intensity Frequency Duration (IFD) data, the latter accounting for the additional 30 years of rainfall record since the 1987 publication.

The flood modelling for Bundeena was updated to account for Australian Rainfall & Runoff 2016. This involved the simulation of various rainfall temporal patterns, which capture the variation of rainfall intensities during the passage of a storm.

A critical storm duration analysis was also completed which determined that storms with a duration of 6 hours are expected lead to the worst-case flood depths over the lower floodplain of Bundeena Creek. However, noting that the Probable Maximum Flood (PMF) would have a storm duration of 3 hours.

Existing Flood Behaviour in Bundeena

The flood models were used to simulate the 50%, 20%, 10%, 5%, 2%, 1% and 1 in 200 Annual Exceedance Probability (AEP) events and also the PMF.

The model results were used to prepare mapping to show flood levels, depths, velocities and flood hazard.

1% AEP depths across the floodplain are typically less than 0.7 metres to the north of Scarborough Street, but can be deeper across large parts of the floodplain south of Scarborough Street. Velocities across the lower floodplain are typically less than 0.2 m/s except along the creek, which are expected to be highest near the creek mouth at Hordens Beach. The creek channel and immediate overbank areas will be subject to High flood hazard during the 1% AEP storm. 1% AEP velocities along overland flowpaths in the upper catchment can be up to about 1 m/s. Due to the relatively shallow flows, the flood hazard is classified as Low.

PMF depths across the lower floodplain are expected to be greater than 2.2 metres. Velocities in the PMF are typically less than 0.4 m/s across properties in the lower floodplain, with isolated patches up to 0.6 or 0.8 m/s. PMF flooding in the lower floodplain is classified as High hazard. PMF velocities along overland flow paths in the upper catchment can be up to 1.2 m/s, but depths are typically less than 300 mm and hence the hazard classification would be Low.

Hydraulic category mapping was also prepared using the model results to show areas of Floodway, Flood Storage and Fringe. The Flood Risk Precinct mapping for Bundeena has also been updated to account for the latest flood modelling results.

The flood model has been used to assess climate change impacts for the 1% AEP event, accounting for potential sea level rise scenarios to Year 2050, Year 2070 and Year 2100. The results indicate that sea level rise will not have a significant impact on properties at Bundeena until the Year 2100, in which case peak flood levels will be increased by 50 to 100mm across the lower floodplain, but noting there may be some localised areas of increased impact.

The following locations have been identified as key flood problem areas for Bundeena:

- The lower floodplain of Bundeena Creek in general:
  - Deep, high hazard conditions during the PMF, but otherwise generally low hazard in events up to and including the 1 in 200 AEP flood.
  - This flooding is the result of the constriction of flows through the lower reaches of Bundeena Creek, which causes floodwaters to spill across the urban areas within an effective storage area created behind the high beach berm.
- Properties to the north of Bundeena Drive, between Laurence Avenue, Thompson Street and Liverpool Street:
  - Although this area remains low hazard in events up to and including the 1 in 200 AEP event, nuisance flooding starts to inundate properties (below floor level) in the 50% AEP event.
- Properties on the east side of Liverpool Street, with the flood risk generally increasing from south to north:
  - This inundation occurs via breakouts from the creek at the southern end of Liverpool Street.
  - Properties at the southern end of Liverpool Street are not classified as high hazard in events up to and including the 1 in 200 AEP flood according to the Floodplain Development Manual, but they are classified as H3 hazard according to ARR 2016, which is unsafe for vehicles, children and the elderly.
- Properties in the vicinity of the Scarborough Street crossing of Bundeena Creek:
  - This is naturally a low-lying area adjacent to the creek.
  - Water overtops Scarborough Road from the swamp (to the south) even in relatively small events, including the 50% AEP storm.
- Properties at the southern side of Beachcomber Avenue, approximately 80 metres west of its intersection with Eric Street:
  - There is an overland flowpath through two or three properties at this location, which is expected to result in damages to one or two properties in events larger than the 5% AEP storm.
- Overland flow paths through the commercial/residential properties at the northern end of Brighton Street:
  - Up to five properties are affected in the 1 in 200 AEP storm, but only one property is affected in the 5% AEP and lesser storms.
- Overland flow paths through properties at the far eastern side of Bundeena, between Scarborough Street and Baker Street, to Loftus Street and then Neil Street.
  - The flow is shallow and considered nuisance flooding.
  - Below-floor flooding is expected in this area for up to 10 properties.
- Nuisance flooding at properties at the southern end of Brighton Street:
  - Below-floor flooding is expected at four properties in the 1 in 200 AEP event, which is linked to the inundation across the general lower floodplain of the creek.
  - Properties on Brighton Street that back onto the Public School and pathway have flooded in the past.

Existing Flood Damages

Flood damages are adverse impacts that private and public property owners experience as a consequence of flooding. They can be both tangible and intangible, direct and indirect, and are usually measured in terms of a dollar cost.

Tangible damages include direct damages such as the damage to property as a consequence of inundation (*e.g., the cost of replacing carpets*). Tangible damages can also be indirect damages such as the cost to the community of individuals being unable to get to work because they are isolated due to flooding. Intangible damages include impacts such as the trauma felt by individuals as a result of a major flood and the associated health related impacts. It is more difficult to quantify intangible damages, but it is possible they could be as high or higher than the total tangible damage cost.

Flood damages have been calculated according to the flood model results for the PMF, 1 in 200, 1%, 2%, 5%, 10%, 20%, and 50% AEP events. The adopted methodology for Bundeena is in accordance with the Floodplain Risk Management Guideline (*and accompanying spreadsheet*) prepared by OEH in 2007. The level of flooding is compared to the floor level of the dwelling/structure to extract a flood depth relative to floor level. This depth is applied to the relevant depth vs damage curve to determine the dollar value of damage, according to the property type (*residential or commercial*) and the construction type (*slab on ground vs high set vs two-storey*).

A summary of the calculated flood damages is provided below in **Table S1**.

Table S1 Residential and Commercial Flood Damages at Bundeena

EVENT AEP	Number of Properties Subject to Flood Damages *		Flood Damages		
	Residential	Commercial	Residential	Commercial	TOTAL
PMF	461 (245)	14 (14)	$26,513,000	$1,008,000	$27,521,000
1 in 200	112 (38)	9 (6)	$3,136,000	$287,000	$3,422,000
1%	93 (23)	6 (3)	$1,967,000	$115,000	$2,082,000
2%	80 (15)	4 (2)	$1,433,000	$90,000	$1,523,000
5%	74 (14)	4 (2)	$1,235,000	$75,000	$1,310,000
10%	60 (6)	4 (1)	$815,000	$35,000	$850,000
20%	45 (2)	2 (0)	$539,000	$15,000	$554,000
50%	29 (0)	2 (0)	$321,000	$11,000	$332,000

** Number of properties subject to above floor flooding shown in parentheses.*

The relative cost of the potential flood damages is typically expressed in terms of the Average Annual Damage (AAD). The AAD is equivalent to the total damage caused by all floods over a long period of time divided by the number of years in that period. The AAD for Bundeena was calculated to be **$490,000**. That is, funds in the order of $490,000 would need to be put aside each year on average, in order to cover the damage bills that could be incurred as a consequence of flooding.

Proposed Flood Modification Measures

Flood modification measures are physical works that aim to reduce the existing flood risk and damages. The assessment of flood modification measures was completed using a staged approach as follows:

- Stage 1 Assessment:
  - Initial assessment involving modelling of the 1% AEP flood to determine the benefit provided by each option in terms of reduced flood damages.
  - Preliminary assessment of the cost of options, including upfront capital costs and ongoing maintenance costs.
  - Calculation of an indicative Benefit Cost Ratio (BCR) according to the present value of the damage reduction in the 1% AEP event compared to the lifecycle cost of works over 30 years.
  - Triple-Bottom-Line (TBL) assessment to consider additional factors, such as social and environmental impacts/benefits.
- Community consultation to outline the results of the Stage 1 assessment and determine community support for the options (or lack thereof).
- Stage 2 Assessment:
  - Further assessment of the highest scoring option(s) with the most community support, involving flood modelling of the entire range of design events; and,
  - Refinement of the BCR for this option(s).

The options considered are listed in **Table S2**. The Stage 1 modelling assessment of the 1% AEP flood showed that the greatest reduction in flood levels would be afforded by the entrance management works. Whereas options to increase the channel and culvert capacity in the vicinity of Scarborough Street would have little to no benefit in reducing flood levels. A flood protection levee is expected to lead to adverse impacts at properties outside the levee.

The indicative Benefit-Cost Ratio (BCR) for each option is provided in **Table S2**. It should be noted that this indicative assessment can lead to an over-estimate of the overall BCR, but is useful as a relative comparison between options. The highest scoring options are the entrance management works.

The TBL assessment for the options is documented in **Table S3**. It shows that the entrance management options scored the highest and hence are ranked 1 and 2.

Table S2 Indicative Benefit-Cost Assessment of Flood Modification Options

Option	Cost of Works (PV)	1% AEP Damages	Present Value of Damage Reduction	Benefit-Cost Ratio
Existing Conditions	----	***$2.08m***	----	----
F-1A. Entrance widening and deepening	$632k	$1.07m	$3.20m	5.1
F-1B. Entrance berm management (eastern)	$428k	$1.09m	$3.12m	7.3
F-1C. Entrance berm management (central)	$186k	$1.11m	$3.06m	16.4
F-2. Flood protection levee	$788k	$1.59m	$1.55m	2.0
F-3. Creek channel upgrades	$318k	$1.95m	$0.41m	1.3
F-4. Scarborough St culvert upgrade	$281k	$2.07m	$0.03m	0.1
F-5A. One additional outlet to the beach	$820k	$1.87m	$0.66m	0.8
F-5B. Two additional outlets to the beach	$1.13m	$1.74m	$1.10m	1.0
F-6. Scarborough St culvert upgrade + channel upgrade	$705k	$1.95m	$0.41m	0.6

A community information session was held on Friday 15th December 2017 at the Bundeena Community Centre. This session provided opportunity to present the findings of the Stage 1 options assessment in the form of poster displays, one-on-one discussions and a community newsletter with questionnaire. The consultation was focussed on potential flood management measures, but also included general information about the existing flood risk.

A summary of the community feedback is as follows:

- Community support for flood modification works was generally strong, with the exception of the flood protection levee options, particularly when involving encroachment into private property.
- The greatest support was for increasing the frequency of maintenance works in the creek and also stormwater drains, such as debris clearing and vegetation management. Enlargements to the street drainage system were also strongly supported.
- Entrance management works also received relatively strong support.

The Stage 2 assessment of flood modification measures involved further assessment of Option F-1C, which involves periodic lowering the level of the beach berm using an excavator, to allow upstream floodwaters to overtop the berm and erode a temporary channel across the beach.

Table S3 Triple-Bottom-Line Assessment (Flood Modification Measures)

Evaluation Criteria	Weighting	Option – Raw Scores										Option – Weighted Scores								
		1A	1B	1C	2	3	4	5A	5B	6		1A	1B	1C	2	3	4	5A	5B	6
		Entrance Widening and Deepening	Entrance Berm Management (eastern channel)	Entrance Berm Management (central channel)	Flood Protection Levee	Creek Channel Upgrade	Scarborough St Culvert Upgrade	Additional Drainage Outlet to the Beach	Two Drainage Outlets to the Beach	Scarborough St Culvert Upgrade and channel upgrade		Entrance Widening and Deepening	Entrance Berm Management (eastern channel)	Entrance Berm Management (central channel)	Flood Protection Levee	Creek Channel Upgrade	Scarborough St Culvert Upgrade	Additional Drainage Outlet to the Beach	Two Drainage Outlets to the Beach	Scarborough St Culvert Upgrade and channel upgrade
Flood Impacts																				
Impact on hydraulic behaviour	**5**	4	4	4	1	2.5	2.5	3	3	2.5		20	20	20	5	13	13	15	15	13
Reduction in flood damages	**4**	5	5	5	4	2	0	3	4	2		20	20	20	16	8	0	12	16	8
Economic																				
Benefit / Cost Ratio	**4**	5	5	5	5	4	0	3	3	3		20	20	20	20	16	0	12	12	12
Life cycle cost of option	**4**	3	4	5	3	4	5	2	1	3		12	16	20	12	16	20	8	4	12
Social																				
Impact on local community	**4**	1	2	2.5	3	3	3	2	1.5	3		4	8	10	12	12	12	8	6	12
Likely community acceptance	**3**	3	3	3.5	2	2	4	2	1.5	3		9	9	11	6	6	12	6	5	9
Environmental																				
Disruption to the natural character of the area	**3**	1	3	3	2	2	3	2	2	2		3	9	9	6	6	9	6	6	6
Ecological impacts	**4**	2	3	3	2	2.5	2.5	1	1	2.5		8	12	12	8	10	10	4	4	10
											TOTAL SCORE	**96**	**114**	**122**	**85**	**87**	**76**	**71**	**68**	**82**
											RANK	**3**	**2**	**1**	**5**	**4**	**7**	**8**	**9**	**6**

The proposed works were simulated for the entire range of design floods from the 50% AEP storm to the Probable Maximum Flood (*PMF*). The results of the associated flood damages analysis showed the following:

- Option F-1C is most effective at reducing damages during relatively major floods between the 5% AEP and 1 in 200 AEP events. In these events, the existing damages are reduced by about 30% to 45%.
- The benefit is less during smaller events (*50% to 10% AEP*), in which case the existing damages are reduced by only 7% to 10%.
- The BCR for Option F-1C is reduced to 4.8 when accounting for the extended damages analysis, which indicates that the economic benefit will still outweigh the estimated lifecycle costs.

It is recommended that Option F-1C be included in the Bundeena Floodplain Risk Management Plan for further investigation, design and implementation.

Proposed Property Modification Measures

These measures include flood planning controls for future development to ensure that land uses are compatible with flood risk. They can also include voluntary house raising and purchase, or flood-proofing of buildings, which can act to reduce flood damages.

Voluntary house raising (VHR) can be applied to houses of piered construction, which means that single storey high-set dwellings are typically best suited to house raising. Houses of slab-on-ground construction are excluded as raising is not feasible or cost-effective. The inclusion of a house within a proposed VHR scheme does not place any obligation on the owner of the property to raise the house. Landowner participation is voluntary.

VHR was found to be suitable for eight dwellings in Bundeena, resulting in a BCR of 1.3. When considered in the context of the Triple Bottom Line assessment completed for flood modification measures, VHR would be ranked in 4th place. Accordingly, VHR is recommended to be included in the Floodplain Risk Management Plan for Bundeena.

Voluntary house purchase (VHP) would be less cost-effective, with only one dwelling being identified, leading to a BCR of only 0.3.

Council's existing planning controls, instruments and policies have been reviewed in the context of floodplain management and flood related development controls, with the primary objective of identifying ways in which the development preparation and assessment process can be improved across the Sutherland Shire LGA, with Bundeena as an example catchment/floodplain.

Three approaches to flood-related development controls have been suggested, with a recommendation that the Sutherland Shire Development Control Plan (DCP) be updated to incorporate a minimum floor level requirement for Bundeena equivalent to the 1% AEP flood level plus a freeboard of 300mm.

Additional recommendations are as follows:

- Council to update 10.7 planning certificates for properties in Bundeena according to the results of flood modelling for this study.
- Update relevant clauses in the flooding and stormwater drainage sections of the DCP.

- Council to prepare guidance notes to accompany the DCP, including information on requirements for flood impact assessments and the use of Council's consultant(s) for specialist flood modelling.

Flood Emergency Response Considerations

The existing *Local Flood Plan* for Sutherland Shire prepared by SES (*2013*) does not include any specific information or guidance on addressing flood emergency management in Bundeena.

Despite relatively low velocities during events up to and including the PMF (*typically less than 0.2 m/s*), shelter-in-place is not an option for properties without a second storey and evacuation would be required for many properties in the PMF.

The duration of flooding across the lower parts of the floodplain is expected to be 16 to 20 hours in the 1% AEP event. There are currently no water level gauges on Bundeena Creek or local rainfall gauges in the catchment to provide any warning of flooding for Bundeena.

Inundation of properties in the lower floodplain will generally occur from south-to-north as floodwaters breakout into Liverpool Street and Scarborough Street. Residents will need to evacuate north along Liverpool Street towards Bundeena Drive and then east or west towards higher ground, prior to the flood reaching high hazard conditions in these streets. Residents of Liverpool Street south of Scarborough Street will need to mobilise the earliest, as high hazard conditions will start to occur in the 5% AEP event and larger.

Bundeena Drive is expected to be cut during the 5% AEP flood or larger, just east of Liverpool Street and also near Woodfield Avenue, which effectively denotes the timing of when the lower floodplain becomes isolated from the eastern part of Bundeena and from outside areas (*i.e., the National Park entry route from Loftus*). At this point there is still access via Bundeena Drive to the higher flood-free areas at Simpson Road and Short Avenue. However, residents to the north of Bundeena Drive will need to evacuate to this higher ground before flooding reaches the 1% AEP level.

The following emergency response measures are recommended for Bundeena:

- Design and install an automated flood warning, comprising a continuous rainfall gauge and water level gauge linked to a telemetry system for the automated dissemination of flood warnings to the mobile phones of all residents in Bundeena, Council officers and SES.
- Implement a community flood awareness program, comprising educational materials, targeted consultation with particular landowners, running a flood information booth in conjunction with SES outside the shops on Brighton Street or at other public events in Bundeena.
- Provide latest flood modelling results and information for Bundeena to SES.

Implementation Schedule

An Implementation Schedule has been prepared for inclusion in the Floodplain Risk Management Plan (*refer* **Appendix G**), which outlines the recommended actions for implementation of the proposed floodplain risk management options, the capital and ongoing costs for each option, and the indicative timing of commencement for each option according to short term, medium term or longer term priorities.

1 Introduction

1.1 Setting

The township of Bundeena is situated along the southern shore of Port Hacking, which is located at the southern extent of the Greater Sydney Region. Bundeena Creek (*also referred to as Bundeena Gully*) flows through the township of Bundeena and drains a 2.8 km^2 catchment that extends south into the Royal National Park (*refer* **Figure 1.1**).

The Bundeena Creek catchment has a history of local drainage and flooding issues particularly in the low-lying areas of the town. Parts of the Bundeena township are susceptible to mainstream flooding from Bundeena Creek, while other parts are susceptible to overland flooding as stormwater runoff drains to the creek.

Major flooding of the catchment is documented as having occurred in November 1969, February/March 1977 and November 1984. Numerous other less severe floods have also occurred in the catchment in more recent times, with many residents indicating that roads and properties were inundated during July 2011, March/April 2012, and as recently as June 2016 after relatively minor rainfalls within the catchment.

The *'Bundeena Flood Management Study'* (*1993*) identified that over 200 properties in Bundeena have been previously affected by flooding. In 2004, Sutherland Shire Council completed an *'Initial Assessment of Major Flooding'* for all catchments across the Shire in order to prioritise catchments for further investigation. The assessment identified the Bundeena Creek catchment as having the third largest exposure to inundation within the Sutherland Local Government Area (LGA).

1.2 Project Objectives

The primary objective of the floodplain risk management process is to reduce the risk to life and property from flooding.

The objective of the Bundeena Creek Floodplain Risk Management Study and Plan is to develop a set of cost-effective floodplain risk management actions that can be progressively implemented by Council, SES and others to reduce flood risk for the benefit of flood-affected property owners in Bundeena, as well as the wider community.

Accordingly, development of the Plan has considered options for reducing the flood damages that could be experienced by residents within the Bundeena community and to reduce the risk of injury or loss of life.

The Plan is not intended to address small-scale drainage and stormwater management issues or nuisance flooding of less than 100 to 200mm depth.

Although particular flood management measures relate to works at the creek entrance, they are not intended to manage the day-to-day entrance conditions; i.e., opening and closing of the Bundeena Creek ICOLL (*Intermittently Closed and Open Lake or Lagoon*).

1.3 Project Methodology

The following tasks have been completed during the preparation of the Floodplain Risk Management Study and Plan:

- Consultation with Council, OEH and SES stakeholders at Floodplain Management Committee meetings at key stages throughout the project.
- Update to the TUFLOW flood modelling completed for the 2014 Flood Study to reflect Australian Rainfall & Runoff 2016 methodologies and rainfall data, and to incorporate a Direct Rainfall (*rainfall-on-the-grid*) approach.
- Development of flood depth, flood hazard and hydraulic category mapping to assist in the identification of flood problem areas in Bundeena.
- Flood damages analysis using property floor level information to estimate the value of damages expected for a range of design floods, to be used as a base for comparison with the performance of potential flood damage reduction measures.
- Identification and comparative assessment of a range of options to address the existing and potential future flood problems, including flood modification, property modification and response modification measures.
- Consultation with the local community via a newsletter, questionnaire and public workshop to obtain feedback on the potential floodplain management options.
- Development of an implementation schedule which prioritises the preferred floodplain management options and outlines the required actions and potential funding sources for their implementation.

2 Background

2.1 Catchment Description

The Bundeena Creek catchment is approximately 2.8 km^2 in area and is characterised by its valley-like topography with high ground rising within the Royal National Park to the south, west and east (*refer* **Figure 1.1**). The catchment extends south approximately 1.8 kilometres from Bundeena Bay, to a ridgeline that runs parallel to the Big Marley Firetrail. The catchment drains into Bundeena Bay via the outlet at Horderns Beach.

The lower part of the Bundeena Creek floodplain forms a basin behind the coastal sand dune along Horderns Beach. Areas with terrain less than 2 mAHD represent approximately 20% of the total catchment area (*refer* **Figure 1.1**). A significant portion of the Bundeena township lies within this low-lying part of the floodplain.

During storm events runoff is collected along western and eastern branches of Bundeena Creek. The western branch drains forested land and is characterised by a low-lying 3 hectare coastal swamp located to the south-west of the Bundeena Bowling and Sports Club (*refer* **Figure 1.1**).

The eastern branch of the creek drains a combination of forested land to the south and urban area to the east and north. The branches join in an estuarine swamp oak forest located south of Scarborough Street and Liverpool Street. After passing beneath Scarborough Street the Bundeena Creek channel becomes more defined, meandering through the urban area and beneath Bundeena Drive before reaching the outlet at Horderns Beach.

2.2 Previous Investigations

A number of previous studies have been undertaken that relate to flooding and waterway management within the study area. A synopsis of those investigations considered relevant to this study is provided in the following.

2.2.1 Bundeena Creek Flood Investigation (1976)

This study, completed by G.J. Cooper, assessed the 1% Annual Exceedance Probability (*AEP*) flood extent for Bundeena using the rational method and the unit hydrograph procedure for peak flows and the Manning's equation to determine levels in Bundeena Creek. The final report proposed the construction of a levee bank to a level of 2.8 m AHD to the south of the township, in order to utilise the swamp area south of Scarborough Street as a flow retarding basin.

2.2.2 Bundeena Flood Management Study (1985)

A detailed flood study for Bundeena was undertaken by Cameron McNamara. A RORB hydrologic model was produced as part of the study to determine peak flows for the 100 year Average Recurrence Interval (*ARI*) event. A HEC-2 steady state analysis then determined 100 year ARI water surface profiles.

Model calibration used data collected from the November 1969, March 1975, February 1977, March 1977 and November 1984 flood events. As there are no streamflow gauges in the catchment, the study relied heavily on interviews with residents of Bundeena and discussions with Council officers.

A floodplain risk management component was also included as part of the study, with potential mitigation options modelled using HEC-2 in order to assess their impact and efficiency in alleviating flooding in Bundeena. Five mitigation measures were investigated with a modified retarding basin (*based on the 1976 proposal*) recommended as the most effective mitigation option. It is understood that this option was not implemented due to issues with funding resources and environmental concerns.

2.2.3 Bundeena Flood Management Study (1993)

An updated Floodplain Risk Management Study was prepared by Kinhill Engineers in 1993. This study involved incorporating new information into the existing flood management study completed by McNamara (1985). The study applied new design rainfall intensities to modelling as per the latest version of '*Australian Rainfall and Runoff – A Guide to Flood Estimation*' (*Institution of Engineers, Australia 1987*). The study recognised new developments within the floodplain and also incorporated Sutherland Shire Council's 1992 topographical survey of the floodplain area. The digital terrain model relied on 2 metre surface contours derived from orthophotos.

A RAFTS hydrologic model was developed in order to determine peak flows entering Bundeena Creek downstream of Scarborough Street for the 20 year and 100 year ARI events as well as the Probable Maximum Flood (*PMF*). A single inflow was extracted and applied to a one-dimensional MIKE-11 hydraulic model that modelled the floodplain using approximately 20 cross-sections taken along Bundeena Creek.

The flood study component of the project identified flood levels of 1.88 m AHD and 1.96 m AHD for the 20 year ARI and 100 year ARI events, respectively, for the area upstream of Scarborough Street.

Flood mitigation options were recommended as part of the floodplain risk management plan. The options included road raising, culvert enlargement, channel formalisation and the construction of earth levees and concrete block walls in the vicinity of Scarborough Street. The study also included recommendations for improving stormwater quality in the Bundeena Creek catchment.

2.2.4 Initial Subjective Assessment of Major Flooding (2004)

Prepared for Council by Bewsher Consulting in 2004, the aim of this study was to assess the designated flood risk areas across the Sutherland Shire and present a prioritised action plan to investigate and manage flood risk.

Council identified 82 major drainage systems for investigation (*defined as those with a pipe diameter greater than or equal to 900 mm*) and 19 waterways, acknowledging there is some overlap between the two. The Georges River and Woronora River (*including Forbes Creek downstream of the Loftus Creek confluence*) were excluded from the study.

The study considered three methods of assessment, including review of Council's complaints database for the major storm that occurred in May 2003, preliminary hydrologic and hydraulic analyses, and the expert advice and experience of previous Council and SES stormwater and flood personnel.

Bundeena Creek was ranked fourth highest on the prioritised action plan for future flood studies and floodplain risk management studies and plans.

The Sylvania Waters and Catchments Flood Study and FRMS was regarded as the highest priority, followed by studies for Kurnell and the combined Botany Bay Catchments area.

2.2.5 Bundeena Creek Estuary Management Plan (2009)

The Estuary Management Plan (*EMP*) was prepared by GHD. It involved a review of relevant legislation and planning controls, community consultation, identification of essential estuary features and management issues, assessment of measures to protect and enhance the estuary, and the development and prioritisation of actions to manage the estuary.

Flooding and the opening of the creek mouth was considered a key management issue, for which it was recommended that non-structural measures be pursued initially, involving protocols for manually opening the entrance once flood levels in the creek reach particular threshold levels. Structural measures were also considered, including the construction of a groyne to create a permanent channel, deepening of the entrance channel, or installing a box culvert. However, it was identified that these options would be costly and involve ongoing maintenance costs.

2.2.6 Sea Level Rise Risk Assessment (2011)

GHD assessed the risk of sea level rise for all coastal areas within the Sutherland Shire LGA. The primary aim was to determine the climate change impacts on sea level rise in the vicinity of coastal catchments for the 2050 and 2100 horizons. The study indicated that the current 100 year ARI tide and storm surge ocean level in the vicinity of Bundeena is 1.51 m AHD. This study assisted in providing contemporary and relevant tailwater levels that have been adopted as part of this study.

Sea level rise is otherwise addressed in Council's Sea Level Rise Policy (2016), which adopts a Representative Concentration Pathway (*RCP*) of 6.0 according to a future scenario involving "intermediate" mitigation of greenhouse gases (*IPCC, 2014*). Further discussion on the implications for Bundeena is included in Section 4.

2.2.7 Sutherland Shire Watercourse Assessment and Rehabilitation Prioritisation (2012)

Applied Ecology completed an assessment and prioritisation of rehabilitation works for watercourses throughout the Sutherland Shire in 2012. The report acknowledges the existing 2006 Plan of Management for Natural Areas in Bundeena, which applies to bushland, wetland, escarpment, watercourses and foreshore.

Bundeena Creek is located in the South-West Arm sub-catchment of the Port Hacking catchment. In the summary of prioritised works the upper eastern and western arms of Bundeena Creek are classified as "Good Condition" and *easy to fix* or *moderately easy to fix*. The reaches immediately upstream and downstream of Scarborough Street are classified as "Fair Condition", but are otherwise considered *easy to fix*. The reach between Bundeena Drive and the creek mouth is classified as "Good Condition" according to its potential impact on the Port Hacking estuary.

The priority of any rehabilitation works is such that the works would be undertaken from upstream to downstream. Key remediation actions would include biotechnical techniques such as the establishment of plantings, water quality improvement techniques to capture pollutants, the improvement of habitats through the removal of invasive species and planting of native species, and other techniques such as channel modifications, riparian buffer management and specific habitat restoration. The report does not provide any further detail in terms of the specific measures that are proposed to be applied to particular reaches of Bundeena Creek.

2.2.8 Bundeena Creek Flood Study (2014)

Advisian/WorleyParsons completed a Flood Study of the Bundeena Creek catchment for Council in 2014. The Flood Study involved the first development of a two-dimensional hydrodynamic model of the Bundeena Creek floodplain using the TUFLOW software package.

Updated aerial photography and terrain data was used to develop a XP-RAFTS hydrologic model of the upstream catchment. The output from the hydrologic model was then applied to the TUFLOW hydrodynamic model. Various data collected for the November 1969, November 1984 and March 2012 events were used to calibrate and validate the hydrodynamic model, to check its reliability.

The hydrodynamic model results were used to prepare flood level, depth, velocity and hazard mapping for the 50%, 20%, 10%, 5%, 2%, 1% and 0.5% AEP events and also the PMF. Provisional flood hazard, provisional hydraulic category and preliminary Flood Planning Area mapping was also prepared as part of the Flood Study.

Sensitivity testing of the Horderns Beach outlet geometry, increased rainfall intensities and testing of sea level rise scenarios for the Year 2050 and Year 2100 were also undertaken.

2.2.9 Horderns Beach Seawall Reconstruction – Flood Impact Assessment (2013)

In parallel with the Flood Study, Advisian/WorleyParsons was also engaged to prepare a flood impact assessment for the reconstruction of the Horderns Beach Seawall. The seawall is situated along the eastern bank of Bundeena Creek at the Horderns Beach outlet and is approximately 70 metres in length. The elevation of the top of the wall varies from 1.77 to 2.77 mAHD.

The assessment determined that there would be limited flood impacts in the vicinity of the works and negligible impact on areas of the floodplain upstream of the seawall. The Horderns Beach Seawall has since been reconstructed.

3 Flood Modelling Update

3.1 Overview

As a part of preparing the Bundeena Creek Floodplain Risk Management Study, Advisian has reviewed and updated the hydrologic and hydrodynamic modelling that was completed for the Bundeena Creek Flood Study (*WorleyParsons, 2014*).

It was agreed with Council early in the project that the flood modelling should be updated to:

- Account for the new methodologies and updated rainfall Intensity Frequency Duration (IFD) data associated with Australian Rainfall & Runoff 2016 (ARR 2016).
- Capture the behavior of flooding along overland flowpaths through the urban areas of Bundeena, including those areas positioned well above the main floodplain of the creek.
- Incorporate the existing stormwater pit and pipe network within the urban areas above the mainstream floodplain.

Accordingly, the following revisions have been made to the modelling:

- The TUFLOW model domain was extended to include all urban areas of Bundeena, which required the definition of suitable downstream boundary conditions for areas that do not discharge to the Bundeena Creek outlet;
- A direct rainfall (*rainfall on the grid*) approach has been applied to the TUFLOW model, which involved a revision to the catchment delineation in the existing XP-RAFTS model for the upper forested catchment and establishment of a suitable interface with the direct rainfall domain;
- Additional stormwater pits and pipes have been incorporated into the 1-dimensional pipe network in the TUFLOW model, using Council's GIS data and survey that was recently undertaken;
- Rainfall temporal pattern ensemble modelling using the updated IFD data has been completed, as per the Australian Rainfall and Runoff (AR&R) 2016 Guidelines.
- A time-varying ocean water level has been adopted as the downstream boundary condition; and,
- Methods of filtering the TUFLOW direct-rainfall model results have been investigated.

The following section outlines the methodology used to update the models, undertake calibration and validation of the models, and presents the associated flood mapping;

3.2 Hydrologic Modelling

An XP-RAFTS hydrologic model was used to simulate catchment runoff draining to Bundeena Creek. The main outputs from the XP-RAFTS model are discharge hydrographs, which define the quantity of runoff, rate of rise, timing and magnitude of peak discharges resulting from a rainfall event.

3.2.1 Sub-Catchment Delineation

The XP-RAFTS model developed for the Flood Study was updated to account for the direct rainfall approach adopted in the TUFLOW hydrodynamic modelling.

This involved revision to the delineation of sub-catchment boundaries, particularly along the southern edge of the TUFLOW model domain (*refer* **Figure 3.1**). Terrain data from the Aerial Laser Survey (ALS) taken in 2005, and Light Detection and Ranging (LiDAR) data provided by GeoScience Australia was also considered.

The discharge hydrographs from these sub-catchments were used as inflows into the upstream extend of the hydrodynamic model domain.

3.2.2 Sub-Catchment Parameters

The updated sub-catchment parameters adopted in the XP-RAFTS model are shown in **Table 3-1**. The update focussed on the sub-catchment areas and slopes, while the catchment roughness and rainfall losses are consistent with the 2014 Flood Study by WorleyParsons.

A catchment roughness of n = 0.1 was adopted for all XP-RAFTS sub-catchments shown in **Figure 3.1** (*non-urban forested catchments*).

Initial and continuing rainfall losses of 10 mm and 2.5 mm/hr, respectively, were adopted for the forested sub-catchments within the study area. These rainfall losses were based on data contained in previous studies of the area, recommendations outlined in the XP-RAFTS User Manual and guidance documented in *Australian Rainfall and Runoff 1987* (ARR 1987).

Under the procedures of *Australian Rainfall and Runoff 2016* (ARR 2016) the concept of 'initial losses' has been refined to account for pre-burst rainfall, or the rainfall which occurs prior to the main storm burst as defined by a standard design duration.

A value of 32 mm is recommended for the initial storm loss for rural areas in the study area according to the ARR 2016 Data Hub. A range of pre-burst rainfall depths are also provided for different storm magnitudes and durations. The average of the median pre-burst depths for the 50%, 20%, 5%, 2% and 1% AEP events was calculated to be about 21 mm for the critical duration storm (6 hours). This also reflects the median pre-burst rainfall for the 1% AEP event.

Accordingly, it is expected that the pre-burst rainfall will effectively reduce the main storm losses in rural areas from 32 mm to a residual of about 11 mm. This depth is similar to the initial loss of 10 mm which has been adopted from the 2014 Flood Study.

The ARR 2016 Data Hub recommends a continuing loss estimate of 2.2 mm/hr for the Bundeena Creek area, which is also similar to the previously adopted loss rate of 2.5 mm/hr.

Therefore, it was determined that the adopted loss rates did not require any adjustment according to ARR 2016 methodologies.

Table 3-1 Sub-catchment Parameters Adopted in XP-RAFTS

Subcatchment Identifier (*refer* Figure 5.1)	Area (ha)	Catchment Slope (%)
West_0	13.36	10.1
West_1	7.98	16.4
West_2	9.84	15.2
West_3	3.85	14.5
West_4.1.1	14.48	11.1
West_4.1.2	23.09	7.2
West_4.1	19.06	15.6
West_4	19.62	10.9
West_5	5.19	16.1
East_1	4.07	11.4
East_2	3.60	19.3
East_3	9.54	16.3
East_4	4.11	12.5
East_5	2.47	20.3
East_6	1.69	15.2
East_7	1.15	16.2
East_8	6.94	4.4
East_9	2.23	3.6
East_3.1	7.25	3.0
East_4.1	11.82	1.7
East_5.1	11.07	1.6
East_6.1	6.94	3.5

3.3 Hydrodynamic Modelling

A two-dimensional TUFLOW hydrodynamic model was used to simulate the passage of floodwater along waterway reaches and across floodplain areas for the 2014 Flood Study. The hydrodynamic model calculated key flooding characteristics such as flood levels, flow velocities, floodwater depths and flood hazard throughout the study area. The results can be used to determine the rate-of-rise of floodwaters and the duration of inundation, which are important considerations for emergency response management.

As part of the Floodplain Risk Management Study the existing TUFLOW model was expanded to include all urban areas within the township of Bundeena (*refer* **Figure 3.1**). It also involved the application of a Direct Rainfall approach to simulation of hydrology for areas within the TUFLOW model domain.

The updated TUFLOW model was calibrated to the same three historic storm events that were modelled as part of the 2014 Flood Study calibration.

3.3.1 TUFLOW Grid Cell Resolution

For the 2014 Flood Study a grid cell resolution of 1 metre was used in the TUFLOW model. However, the use of such a high-resolution grid in combination with the new direct-rainfall approach and extended model domain resulted in excessive model run times.

It was determined that a grid cell resolution of 2 metres would be most appropriate for the updated model, to allow for reasonable model run times while maintaining a suitably accurate representation of topographic details in the study area. The TUFLOW 2D domain configuration includes mid-side nodes on each cell, resulting in the model effectively sampling flood behavior at 1 metre intervals. These mid-side nodes are the mechanism by which TUFLOW controls the conveyance of water from one cell to another and represents the locations where the flow momentum equation terms are centered. Importantly, the mid-side nodes are also able to sample terrain data, enabling the model to define the floodplain to a 1 metre resolution accuracy.

Accordingly, this model cell size is capable of defining areas with narrow overland flow paths less than 2 metres wide, such as between buildings. This was confirmed through a review of initial flood model results. Although the width between buildings is generally 2 metres or greater, there are occasional instances where buildings are more closely spaced with gaps of only 1 metre. The initial flood model results showed that flow was successfully trained through these confined gaps. In part, this is because the TUFLOW model is configured such that flow is able to pass through buildings, albeit with significantly increased roughness.

3.3.2 Digital Terrain Model Data (DTM)

The data used to define the terrain in the hydrodynamic model was sourced from the original 2005 ALS. Through the modelling process and also in light of anecdotal reports received from the community, it became apparent that at the time of the 2005 ALS data capture there had been some earthworks recently undertaken on Bundeena Beach, which resulted in a higher than normal beach berm elevation to the east of Bundeena House.

Additional LiDAR data was sourced from GeoScience Australia (*captured in April 2013 with a 1 metre grid resolution*), which captured a beach berm level approximately 0.6 to 1 metre lower than in the 2005 ALS data.

Accordingly, the lowered berm level is considered more representative of typical beach berm conditions and therefore, the 2013 LiDAR data was applied over the extent of the berm. The adjustments also incorporated a slight narrowing of the entrance channel immediately south of the berm, as reflected in the 2013 LiDAR. It is believed that the reported earthworks at the time of the 2005 LiDAR capture involved excavation of the channel and placement of the material onto the berm.

The revised berm level is still high enough so as not to permit overtopping from the creek in flooding up to and including the 1 in 200 AEP event and therefore, the lowered berm elevation did not result in any impact on peak flood levels during design events up to the 1 in 200 AEP flood.

However, the PMF is expected to overtop the lowered beach berm and the associated TUFLOW results indicate the PMF levels across the wider floodplain would be reduced by about 40 to 50 mm, and with larger reductions in levels closer to the entrance.

In other areas the 2005 ALS data was retained in the TUFLOW model terrain. An exception is at the very north-eastern corner of the Bundeena township where it was required to adopt the 2013 LiDAR where the 2005 ALS was absent.

The DTMs used in the calibration events are shown in **Figure 3.2** and **Figure 3.3** and the DTM used in the simulation of design events is shown in **Figure 3.4**.

The geometry of the Bundeena Creek outlet at Horderns Beach was defined by the 2005 ALS data for all calibration and design events, except for the November 1984 calibration event. The event that occurred during November 1984 showed indications of a fully scoured entrance condition, as discussed in the 2014 Flood Study, and hence the DTM was modified accordingly for this simulation (*refer* **Figure 3.3**).

The Horderns Beach Seawall was constructed in 2016 and was included in the DTM used to simulate the design flood events. The top-of-wall elevations of the seawall were based on Work as Executed drawings provided by Council.

3.3.3 Inflow Locations

Hydrograph outputs from the XP-RAFTS model were used as inflows at the upstream reaches of the TUFLOW model. Direct-rainfall was applied across the TUFLOW model domain in areas downstream of the XP-RAFTS sub-catchments. **Figure 3.1** shows the locations where hydrograph inflows and direct rainfall were applied.

3.3.4 Downstream Boundary Conditions

For the 2014 Flood Study the TUFLOW model was run with a static tailwater level. These tailwater levels were extracted from Council's '*Sea Level Rise Risk Assessment*' (GHD, 2011), which recommended that open boundary conditions for riverine flood analyses should consider the Highest Astronomical Tide (HAT) in combination with an allowance for storm surge.

The peak tailwater levels accounting for HAT and storm surge are shown in **Table 3-2**.

Table 3-2 Adopted Downstream Peak Tailwater Levels

Flood	Peak Tailwater Level (mAHD)
50% AEP	1.25
20% AEP	1.33
10% AEP	1.37
5% AEP	1.41
2% AEP	1.47
1% AEP	1.51
1 in 200 AEP	1.55
PMF	1.65

Although it was recognised that wave setup and wave runup can affect the shoreline and coastal margin, the *2011 Sea Level Rise Risk Assessment* recommended they not be used for flood inundation assessments. The Bundeena Creek entrance is situated in the eastern corner of the beach, suitably sheltered from wave attack by the adjacent headland and the Bundeena Wharf and therefore, it was considered appropriate to exclude the effects of wave setup and runup in the setting of peak tailwater levels.

Furthermore, the TUFLOW model results show that within 30 metres upstream of the entrance the flood levels are already 300 to 400mm higher than at the entrance itself, which indicates that the wave setup estimates of about 100mm (*GHD, 2011*) would be "drowned" by the upstream catchment flows. The relatively steep flood profile immediately upstream from the entrance is attributable to the constrictions created by the narrowing of the creek downstream from Bundeena Drive and the beach berm.

The joint probability methodology outlined in ARR 2016 has not been followed for this study. The methodology involves the consideration of a 'joint probability zone' in which there is overlap between the 'fluvial zone' and 'coastal zone'. In the case of Bundeena Creek, the joint probability zone would be very small due to the relatively steep flood profile immediately upstream of the entrance.

Furthermore, as shown in **Table 3-2** above, the overall variability in tailwater levels between the 50% AEP storm and the PMF is only 400mm. If the PMF and 50% AEP events are ignored, then this variability reduces to about 200mm. Accordingly, joint probability factors are not expected to have a significant impact on flooding other than in the direct vicinity of the entrance and hence, no additional testing of alternate joint probability scenarios was completed (*e.g., testing the 1% AEP catchment storm using a 5% AEP ocean tailwater level*).

Recent best practice guidelines suggest that a time-varying tailwater level should be adopted as the downstream boundary condition at Bundeena Bay (*NSW OEH, 2015*). The OEH guideline prescribes tidal signatures that are to be used as ocean water level boundary conditions. For Bundeena, the tidal signature of a 1% AEP event for a 'Waterway Entrance Type A' was selected, and corresponds to an oceanic embayment or tide dominated estuary (*refer* **Appendix A**).

For smaller and larger events, this tidal signature was shifted lower or higher such that the peak level matches the static tailwater levels shown in **Table 3-2**. The timing of the peak tide level was also shifted to coincide with the timing of the peak catchment flows. The pre-existing TUFLOW modelling results were reviewed to determine this timing.

The layout of the downstream boundary conditions applied in the TUFLOW model are shown in **Figure 3.5**. The ocean tailwater levels and tidal signatures have been applied along the entire coastline included in the TUFLOW model and is not just applied at the Bundeena Creek entrance.

An additional downstream boundary has been applied along the eastern edge of the Bundeena township, at which a normal-depth outflow relationship has been included in the model to simulate any runoff that is expected to discharge freely into the adjacent bushland.

3.3.5 TUFLOW Material Types

Material types in TUFLOW define the roughness of the terrain surface, as well as the initial and continuing rainfall losses applied to the direct rainfall model. The material type delineation is shown in **Figure 3.6** and the corresponding parameters are shown in **Table 3-3**.

Table 3-3 Material Types and Parameters Adopted in TUFLOW

TUFLOW Material Type	Material Type Description	Manning's 'n' (Roughness)	Initial Loss (mm)	Continuing Loss (mm/hr)
1	Urban areas (*excluding buildings*)	0.045	1.5	0
2	Watercourses	0.04	0	0
3	Roads / paved areas	0.025	0	0
4	Short grass / pasture	0.035	10	2.5
5	Forest	0.1	10	2.5
6	Pool-type fencing ^	0.1	0	0
7	Building footprints	Less than 150 mm depth = 0.02 More than 150 mm depth = 1.0	0	0

^ *Only for limited areas of fencing in the direct vicinity of the creek.*

The rainfall losses are similar to those adopted for the original 2014 Flood Study, although applied to the TUFLOW direct rainfall rather than in XP-RAFTS. In the context of ARR 2016 methods, for Material Type 1 (*urban non-roof areas*) the initial loss of 1.5 mm is consistent with applying weighted average losses across impervious and pervious areas according to a split by area of 25% / 75% and accounting for ARR 2016 recommend initial losses and pre-burst rainfalls.

The adopted roughness values are similar to those used in the original 2014 Flood Study, with minor adjustments to urban areas, grassed areas and roads.

A depth-varying roughness parameter was used for Material Type 7 (*building footprints*) in order to prevent the direct rainfall from "ponding" on building roofs. A Manning's 'n' of 0.02 is applied for shallow depths less than 150 mm in order to simulate rainfall flowing freely from building roofs. At depths greater than 150 mm, a higher Manning's 'n' of 1.0 is applied so that the resistance to lateral flow caused by the building is reliably simulated.

3.3.6 Stormwater Pits and Pipes

Stormwater pit and pipe data was surveyed for key areas within the lower floodplain as part of the 2014 Flood Study. Additional stormwater system survey was collected by Sutherland Shire Council for the remainder of the urban area during January 2017 and both data sets were used to develop a 1-Dimensional drainage network within the TUFLOW hydrodynamic model.

The stormwater pit and pipe network incorporated into the TUFLOW model is shown in **Figure 3.7**.

Smaller inlet pits and smaller diameter pipes (*less than 300 mm diameter*) are not expected to have a significant impact on flood behaviour and therefore, have been omitted from the model.

3.3.7 Hydraulic Structures

Several hydraulic structures, such as large box culverts, road bridges and footbridges, along Bundeena Creek were modelled as flow constrictions in TUFLOW. In the case of bridges, flow constrictions simulate the obstruction to flow caused by piers and bridge decks. They also account for a degree of blockage by flood-borne debris.

The following structures were included as flow constrictions in the hydrodynamic model (*refer* **Figure 3.7**):

- The Bundeena Creek culvert crossing at Scarborough Street (2.1 m W x 0.9 m H box culvert);
- A footbridge leading to the property at 26 Bundeena Drive;
- The Bundeena Drive bridge crossing;
- A footbridge leading to the property at 25 Bundeena Drive; and
- The footbridge on Horderns Beach near the creek mouth.

A flow constriction factor of 30% has been applied at all the above structures, which is the same as adopted in the original 2014 Flood Study.

The following assessment has been made in the context of AR&R 2016 methodology for blockage factor analysis:

- The L_{10} length, defined as the average length of the longest 10% of the debris that could arrive at the culvert/bridge is estimated to be between 1.5 and 2 metres. This accounts for potential snagging in the upstream catchment of any larger trees or branches that might be mobilised.
- The debris availability is considered High.
- The debris mobility is considered Medium.
- The debris transportability is considered Low.
- The overall debris potential for the culverts/bridges is therefore classified as Medium.
- The cell size for box culverts at Scarborough Street and Bundeena Drive are between 2 and 3 metres wide.
- The span widths of the footbridges are about 6 to 7 metres.
- Accordingly, the culvert cell width or bridge span generally falls within L_{10} and 3 x L_{10} and hence the blockage factor would be 10% according to AR&R 2016.

The adopted flow constriction factor of 30% for all bridges/culverts is considered appropriate, as this would account for a blockage factor of 10% plus energy losses caused by piers, abutments and deck widths.

3.4 Model Calibration

The updated hydrologic and hydrodynamic models were used to simulate the following three storm events for calibration purposes, which are the same as adopted in the 2014 Flood Study:

- The November 1969 event;
- The November 1984 event; and,
- The March 2012 event.

Further details of the model calibration process are outlined in the original Flood Study report. Re-simulation of these events was essentially a validation of the model updates to confirm that the models are still reliably modelling flood behaviour.

Flood level and depth mapping for the November 1969, November 1984 and March 2012 calibration events are presented in **Figure 3.8** to **Figure 3.13**.

The results for the calibration events were compared to floodmark levels and observations presented in the 2014 Flood Study and shown in **Table 3-4** below. A comparison between the 2014 Flood Study calibration and the current calibration results is also presented.

The modelled peak flood levels using historic rainfall data from the November 1969 event are consistent with previously estimated peak flood levels at the three locations shown in **Figure 3.8**. The modelled peak flood levels are generally greater than levels derived from observations. These differences are limited to approximately 60 mm across all three locations.

The modelled peak flood levels using historic rainfall data from the November 1984 event are shown to be consistent with previously estimated peak flood levels at the three locations shown in **Figure 3.9**. Similar to the November 1969 calibration model results, the modelled peak flood levels are generally greater than levels derived from observations. These differences are limited to approximately 140 mm across all three locations.

Table 3-4 Comparison of Calibration Results to 2014 Flood Study Calibration

Event	Location	Recorded Flood Level (mAHD)	Peak Flood Level (mAHD)		Difference in Model Results (m)
			2014 TUFLOW Model	2018 TUFLOW Model	
14 November 1969	Bundeena Service Station	~ 2.30	2.27	2.24	- 0.03
	Bundeena Drive	2.00 – 2.06	2.02	2.08	+ 0.06
	Downstream of Scarborough Street	2.01 – 2.20	2.13	2.16	+0.03
8 November 1984	Upstream of Bundeena Drive	1.20	1.3	1.31	+0.01
	Downstream of Scarborough Street	1.55 – 1.90	1.90	1.92	+0.02
8 March 2012	Scarborough Street	~ 2.00	2.05	1.91	-0.14

The modelled peak flood levels using historic rainfall data from the March 2012 event are shown to be consistent with previously estimated peak flood levels at Scarborough Street (*refer* **Figure 3.10**). The difference between the modelled flood level and the level derived from observations is less than 100 mm at this location.

As the modelled peak flood levels are generally consistent with observed peak flood levels, with differences limited to a maximum of 140 mm in all three calibration events, the revised hydrodynamic model is considered to be suitably calibrated and reliable for modelling design events and potential flood mitigation options. This comparison also indicates that the model results are not very sensitive to the basic geometrical changes made as part of the modelling update, such as the conversion to a Direct Rainfall approach within the TUFLOW model domain.

3.5 Australian Rainfall & Runoff 2016 Ensemble Modelling

The hydrologic modelling completed for the 2014 Flood Study involved the application of methodologies and rainfall Intensity Frequency Duration (IFD) data and from the industry-standard publication, Australian Rainfall & Runoff 1987 (*AR&R 1987*).

An updated version of Australian Rainfall & Runoff was released in 2016, including revised methodologies and updated rainfall IFD data, the latter accounting for the additional 30 years of rainfall record since the 1987 publication.

Following the flood model updates documented in above sections, the hydrologic analysis was also updated according to the AR&R 2016 IFD data and hydrologic techniques. The most significant component of the hydrology update was the incorporation of storm ensemble modelling techniques.

Previously, the AR&R 1987 guidelines provided only one rainfall temporal pattern for each design event, for each storm duration. The temporal pattern specifies the distribution of rainfall through time during a design storm.

Ensemble modelling according to AR&R 2016 involves applying 10 different temporal patterns to the rainfall data for each design event and storm duration. These 10 patterns are then tested in the hydrologic model to determine which pattern generates closest to (*but not less than*) the average peak flow for a particular design event. This pattern is then adopted for simulation in the hydrodynamic model.

3.5.1 Temporal Pattern Ensemble Modelling

Design events are first sorted into three separate 'bins' based on their Annual Exceedance Probability (AEP), as shown in **Table 3-5**. According to Book 2 Section 5.5 of the AR&R 2016 Guidelines, the bins are defined as follows:

- 'Frequent storms' have an AEP of more than 14.4% (*i.e., more frequent than an approximately 6 year ARI storm*);
- 'Intermediate storms' have an AEP of between 14.4% and 3.2% (*i.e., between approximately 6 and 30 year ARI storm*); and,
- 'Rare storms' have an AEP of less than 3.2% AEP (*i.e., rarer than an approximately 30 year ARI storm*).

For each of these three bins a set of 10 temporal rainfall patterns for each storm duration were obtained from the AR&R Data Hub. Four different storm durations for each AEP event were modelled in order to confirm the critical duration for each design event. Accordingly, a total of 120 temporal patterns and were used in the ensemble modelling for Bundeena (refer Appendix B).

Given that the 1% and 2% AEP events fall within the same temporal pattern bin, the same set of temporal patterns is applied to both events. Bundeena falls within the "East Coast (South)" temporal pattern region, as shown in Figure 2.5.7 in Book 2 Chapter 5 of the AR&R 2016 Guidelines.

Table 3-5 Temporal Pattern Bins and Design Events for Bundeena

Temporal Pattern Bin	Design Events
Frequent (More frequent than 14.4% AEP)	• 50% AEP event • 20% AEP event
Intermediate (Between 14.4% and 3.2% AEP)	• 10% AEP event • 5% AEP event
Rare (Rarer than 3.2% AEP)	• 2% AEP event • 1% AEP event • 1 in 200 AEP event • Probable Maximum Flood

Updated 2016 rainfall IFD data for Bundeena was obtained from the Bureau of Meteorology website (*refer* **Appendix C**). This IFD data was used in conjunction with the temporal patterns to generate an ensemble of rainfall hyetographs to be applied in the XP-RAFTS hydrologic model. It should be noted that the average rainfall intensities for sub-daily storm durations for the 1 in 200 AEP event are not provided in the 2016 IFD table (*refer further discussion below*).

Each of the 10 temporal patterns for each design event and storm duration was then modelled in the XP-RAFTS hydrologic model. Flow hydrographs were extracted at a point near the Bundeena Creek outlet.

The hydrograph associated with the upper median temporal pattern (*i.e. the hydrograph with the 5th highest peak flow at the creek outlet*) was selected and applied to their respective inflow points in the TUFLOW hydrodynamic model. The rainfall hyetograph associated with the upper median temporal pattern was also applied to the direct-rainfall polygon in the TUFLOW model.

3.5.2 Estimating Average Rainfall for Short Duration Rare Events

Currently, rainfall data for events rarer than the 1% AEP storm with shorter than 24-hour duration has not been derived for the 2016 IFD curves. Until these design rainfalls have been published, the currently accepted method of deriving an average rainfall for these storms is detailed in Book 8 Section 3.6.3 of the AR&R 2016 Guidelines.

The method involves multiplying the 1% AEP design rainfall by a growth factor shown in the **Table 3-6**, which has been extracted from the AR&R 2016 Guidelines. As such, a growth factor of 1.140 has been used in modelling the 1 in 200 AEP event (*0.5% AEP storm*) for Bundeena.

Table 3-6 Growth Curve Factors for Short Duration Rare Events (AR&R Guidelines, 2016)

AEP (1 in Y)	100	200	500	1000	2000
Growth Factor#	1.00	1.140	1.344	1.513	1.698

Standardised by the 1 in 100 AEP Rainfall Depth

3.5.3 Critical Storm Duration Assessment

The critical storm duration is often adopted as the duration of rainfall that leads to the highest peak flow at the catchment outlet, or other area of interest. It follows that the highest flow rates often produce the highest flood levels.

However, there is potential for flooding across the lower floodplain in Bundeena to be "volume-dominated" (*i.e., where peak flood levels are a function of peak runoff volume rather than peak flowrates*) as runoff is temporarily stored behind the beach berm and fills-up the floodplain. Hence, the critical duration storm that produces the highest peak flow at the creek outlet will not necessarily produce the highest flood levels across the lower floodplain.

Accordingly, in addition to the critical duration assessment completed using the XP-RAFTS hydrologic model, it was also considered worthwhile to confirm the critical duration using the Direct Rainfall simulations in the TUFLOW model. The same four storm durations were simulated in TUFLOW, combining the XP-RAFTS inflows and also the rainfall-on-the-grid.

Peak flood levels were extracted from the TUFLOW model results at various points throughout the main floodplain of Bundeena Creek to assess the critical duration for each event. The results of the assessment are provided in **Table 3-7**, which show that the critical duration storm is expected to be 6 hours for all events except for the PMF.

The smaller 50% and 20% AEP events are heavily constricted by the lower reaches of Bundeena Creek, near the creek outlet, and hence flood levels across the main floodplain are expected to endlessly rise in longer duration storms due to the increased volume of runoff. However, the incremental increases in levels are negligible beyond the 6 hour duration and hence this was selected as the critical duration.

The critical storm duration for overland flow paths through the urban areas above the lower floodplain is expected to be less than 1 hour according to the results of XP-RAFTS modelling.

Table 3-7 Critical Storm Durations for Bundeena Creek

Design Event	Critical Duration
50% AEP	6 hours
20% AEP	6 hours
10% AEP	6 hours
5% AEP	6 hours
2% AEP	6 hours
1% AEP	6 hours
1 in 200 AEP	6 hours
PMF	3 hours

4 Design Flood Behaviour, Hazard and Risk

4.1 Design Flood Modelling

The updated hydrologic and hydrodynamic models were used to simulate the 50%, 20%, 10%, 5%, 2%, 1% and 1 in 200 AEP design events and the Probable Maximum Flood (*PMF*).

The base outputs of any hydrodynamic modelling involving Direct Rainfall (*rainfall-on-the-grid*) will naturally show inundation over almost all grid cells in the model domain, even if the depth of flow is very low. In other words, there will be rainfall onto each model cell and this will result in some depth of runoff (*however small*) and hence the entire model domain will be blanketed in flow.

Accordingly, it is common practice to apply filtering to the flood model results when preparing flood maps to identify 'true' areas of flooding.

4.2 Filter Criteria for Flood Mapping

The flood map filtering applied to mapping of flood levels, depths and hazard has involved the removal of areas that will have less than 20 mm depth of flow and areas of ponding that are less than 300 m^2 in size. This method of filtering removes areas of very low depths that could cause difficulty interpreting the flood mapping and that may also result in overestimated flood damages.

It was also determined that this filter criteria would not remove an excessive amount of flooded areas from the mapping. The areas removed from mapping are associated with low flood hazard, and therefore would not have a significant impact on the flood damages analysis and other assessments.

The flood mapping was also clipped to remove areas of ocean foreshore inundation except at the open beach areas. Although suitable ocean tailwater levels have been adopted in the flood modelling to represent storm surge levels, coastal inundation is not a focus of this study.

Additional manual filtering of the mapping was subsequently undertaken as part of preparing specific flood maps for Council's flood planning purposes, such as for hydraulic categories, flood risk precincts and the Flood Planning Area. Such filtering was focussed on the urban areas of Bundeena that are located above the lower floodplain of the creek, in order to better identify overland flow paths in these areas (*refer* **Section 4.6**).

4.3 Flood Levels, Depths and Velocities

The following mapping has been prepared for each design event:

- Flood level mapping (*refer* **Figures 4.1** to **4.8**);
- Flood depth mapping (*refer* **Figures 4.9** to **4.16**); and,
- Flood velocity mapping (*refer* **Figures 4.17** to **4.24**).

1% AEP flood levels across the mainstream lower floodplain are between 2.2 and 2.3 mAHD to the north of Bundeena Drive and about 50 to 60mm higher to the south of Bundeena Drive. 1% AEP depths across the floodplain are typically less than 700mm to the north of Scarborough St, but can be deeper across large parts of the floodplain south of Scarborough Street. Velocities across the lower floodplain are typically less than 0.2 m/s except along the creek.

The most pronounced increase in creek velocity is expected to occur across the creek mouth at Hordens Beach. Overland flow paths in the upper catchment can be subject to 1% AEP velocities up to about 1 m/s.

Probable Maximum Flood (*PMF*) levels are around 4.3 mAHD across most of the lower floodplain, leading to depths greater than 2.2 metres. Velocities in the PMF are typically less than 0.4 m/s across properties in the lower floodplain, with isolated patches up to 0.6 or 0.8 m/s.

Overland flow paths in the upper catchment can be subject to velocities greater than 1.2 m/s, but depths are typically less than 300 mm.

4.4 Comparison with Previous Studies

Comparison of design flood levels with the flood modelling results of previous studies is included in **Table 4-1**.

Table 4-1 Comparison of Design Flood Levels with Previous Studies

Location	Design Event	Design Flood Levels (mAHD)			
		1985 McNamara	1993 Kinhill	2014 WP	2018 Advisian
Upstream of Bundeena Drive	5% AEP	-	1.43*	1.93	2.18
	1% AEP	1.70	1.50*	2.12	2.26
Upstream of Scarborough St	5% AEP	-	1.88	2.01	2.25
	1% AEP	2.15	1.96	2.19	2.32

** Flood level adopted as tailwater level in Port Hacking*

As shown, the updated flood modelling using Direct Rainfall and AR&R 2016 hydrology has produced flood levels that are higher than all previous studies. The increase in 1% AEP levels relative to the 2014 Flood Study is up to 140mm, while the increase in the 5% AEP event is up to 250mm.

The 1993 Kinhill Engineers study produced flood levels that are significantly lower than the 2-Dimensional modelling completed by WorleyParsons/Advisian, and also lower relative to the original HEC-2 modelling completed by McNamara in 1985.

The 1993 modelling appears to under-recognise the effect of hydraulic controls such as the road crossings and footbridges, in addition to the berm at the beach. The approach to the 1-Dimensional MIKE-11 modelling completed for that study was to assume a tailwater level representing the mean tide level of 0.0 mAHD plus 0.3m storm surge, meaning a tailwater of only 0.3 mAHD for the 1% AEP event.

Whereas the 2D TUFLOW modelling incorporates a higher tailwater level of about 1.5 mAHD and better captures the channel constrictions downstream from Bundeena Drive, including the footbridges, retaining walls and the beach berm. This has the effect to provide a relatively steep flood profile in the first 60m upstream from the beach, over which the 1% AEP levels are expected to rise by about 0.5m.

The 2D TUFLOW model also accounts for the accumulation of storm volume in the lower floodplain of Bundeena, upstream from these constrictions, which is otherwise difficult to capture in a 1D modelling approach like that used in previous studies.

4.5 Provisional Flood Hazard

Provisional flood hazard mapping was prepared according to two sets of hydraulic criteria from the following publications:

- The NSW Floodplain Development Manual (*FDM 2005*), which separates the hazard into High and Low classifications with a transitional classification between (*refer* **Plate 4-1**). The resultant flood hazard mapping is provided in **Figures 4.25** to **4.32**.
- Australian Rainfall & Runoff 2016 (Book 6 Section 7.2.7), which separates the hazard into six different categories (*refer* **Plate 4-2**). The resultant flood hazard mapping is provided in **Figures 4.33** to **4.40**.

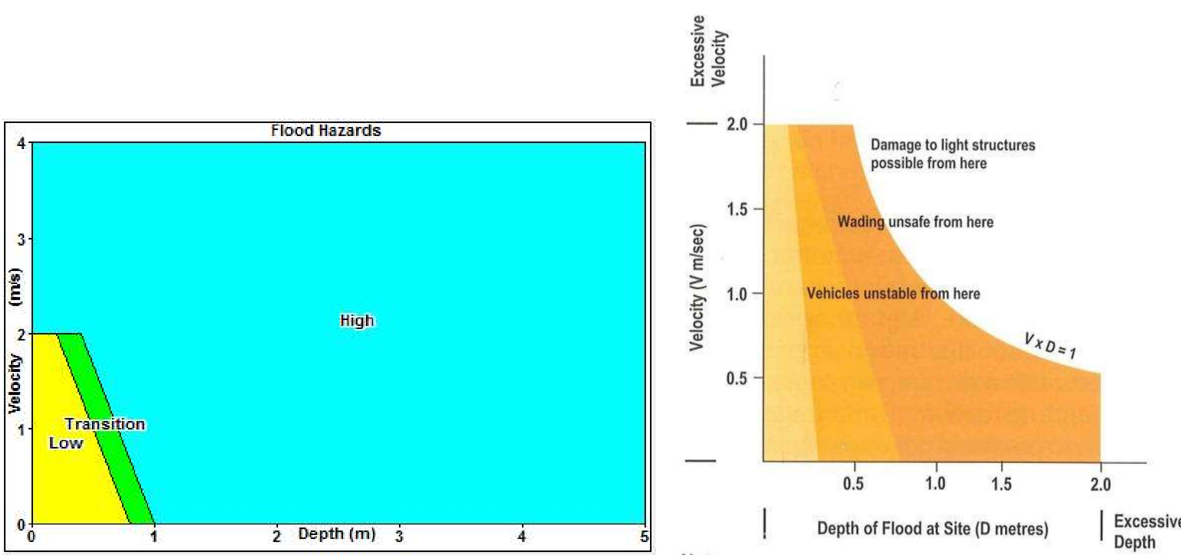


Plate 4-1 Flood Hazard Hydraulic Criteria (NSW Floodplain Development Manual 2005)

Note that the horizontal and vertical axes are reversed when comparing the graphs in **Plate 4-1** and **Plate 4-2**.

A comparison between the two AR&R methods is provided in **Plate 4-3**, which shows that the FDM 2005 classification for High hazard aligns with new AR&R 2016 classification of H5 and higher with respect to a maximum velocity of 2 m/s. However, in terms of maximum depths the FDM 2005 classification of High hazard also includes the new H4 classification and part of the H3 classification.

In this way, the new AR&R 2016 classification system allows for further breakdown of High hazard conditions with regard to maximum depths. It aims to distinguish between when conditions become unsafe for a fit able-bodied adult versus children or the elderly, the threshold being about 1.2 metres depth in lower velocity conditions. It also aims to recognise when flood conditions may begin to impact on the structural integrity of buildings (*H5 and higher*).

The FDM 2005 classification for Low hazard generally aligns with new AR&R 2016 classification of H2 and lower.

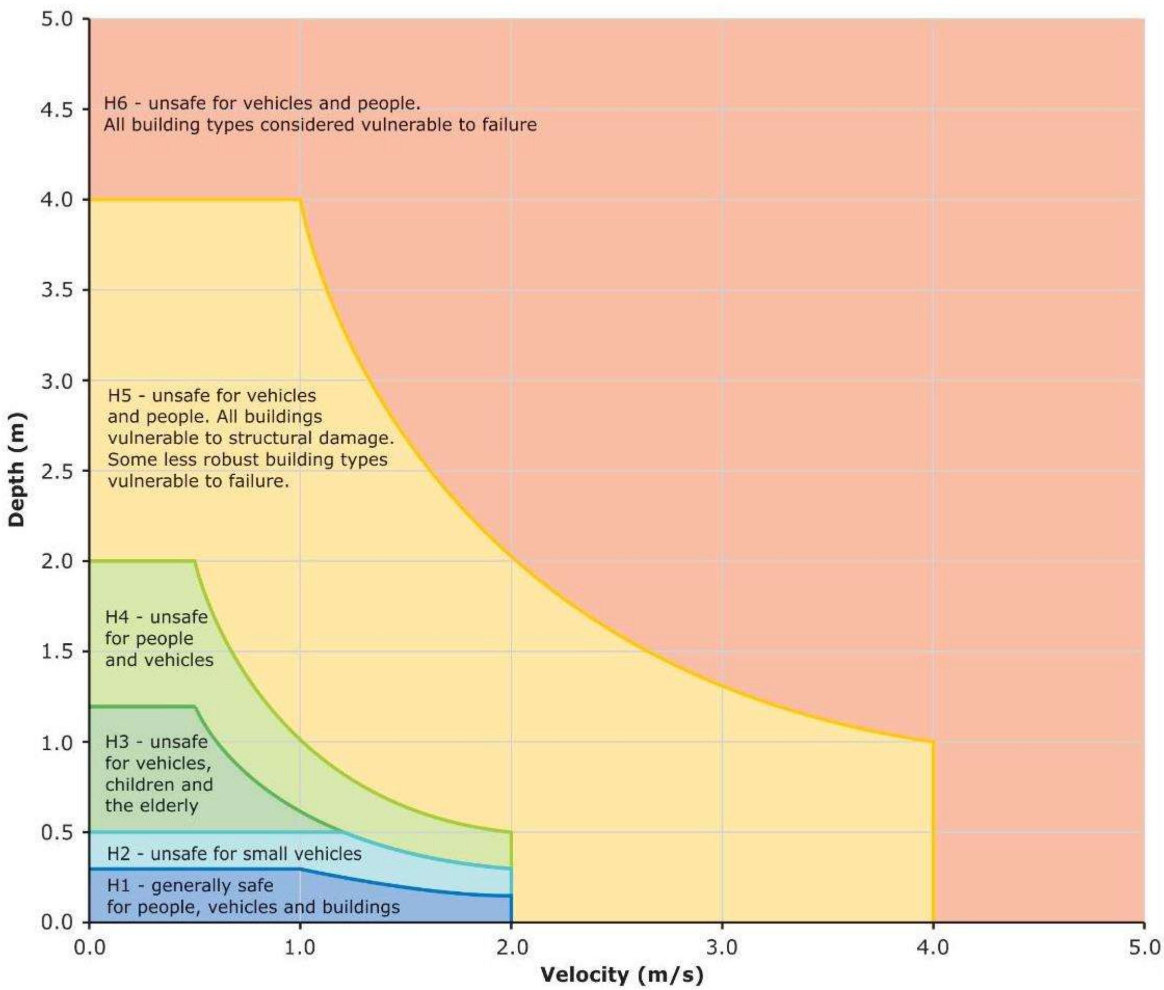


Plate 4-2 Flood Hazard Hydraulic Criteria (Australian Rainfall & Runoff 2016)

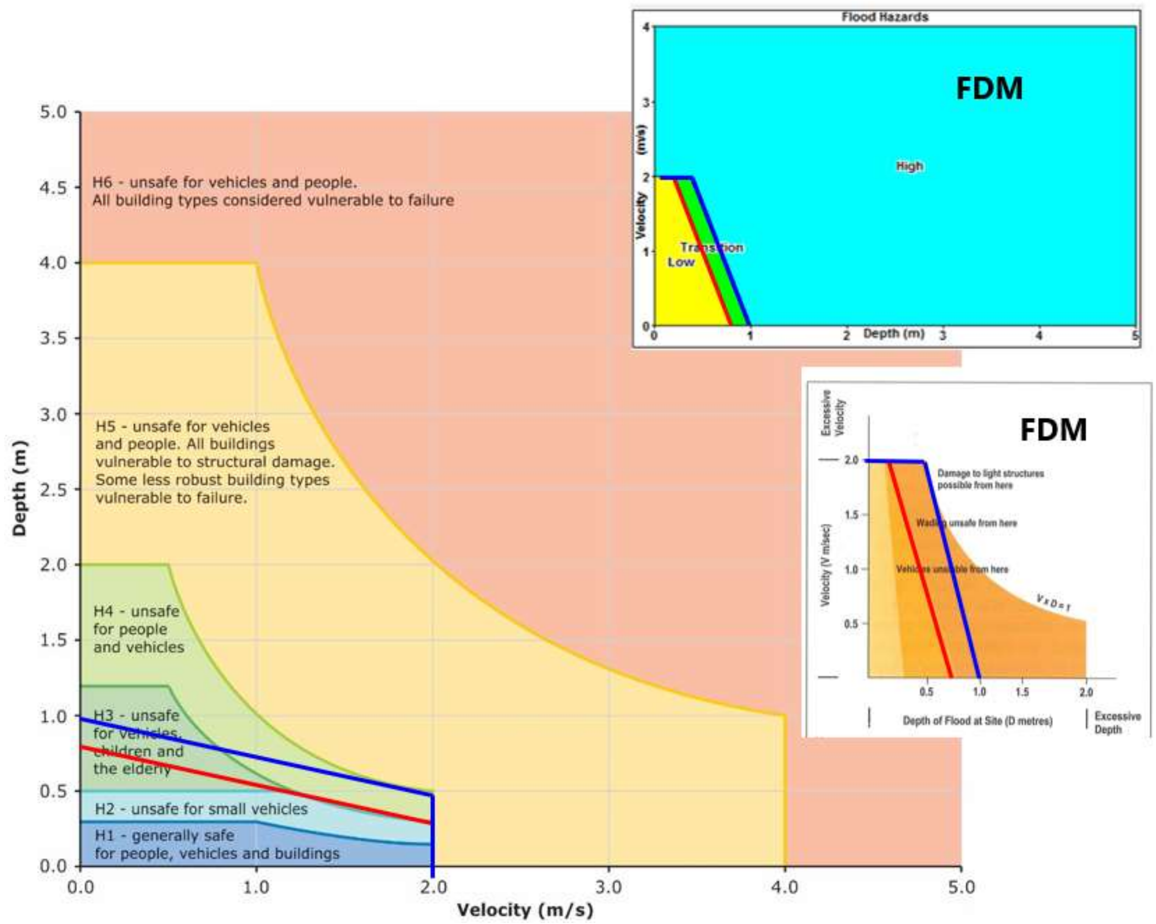


Plate 4-3 Comparison between Flood Hazard Hydraulic Criteria

Figure 4.30 shows that the Bundeena Creek channel and immediate overbank areas are expected to be High hazard during the 1% AEP event. **Figure 4.38** shows the creek channel will be classified as H5 or H4 in areas downstream of Scarborough Street and H4 upstream. Immediate overbank areas will be either H4 or H3 classification. The H3 classification spreads across some properties further from the creek, which are otherwise classified as Low hazard according to the FDM 2005. These areas may be unsafe for children and the elderly.

1% AEP flood hazard generally reduces across the lower floodplain from south to north, with predominantly H3 south of Scarborough St, H1 to H3 between Bundeena Drive and Scarborough Street and H1 to H2 north of Bundeena Drive. 1% AEP hazard is depth-dominated.

The most extreme hazard classification of H6 is only assigned during the PMF, and only within the creek channel areas downstream from Scarborough Street (*refer* **Figure 4.40**). PMF hazard is otherwise consistently H5 or high hazard (FDM) across the majority of the lower floodplain, almost to the edge of the PMF extent. PMF hazard is almost fully depth-dominated.

It should be noted that Council's existing flood planning controls are based on flood risk mapping (*refer* **Section 4.8**). High flood risk areas are generally defined as high hazard areas within the 1%

AEP flood extent (*according to the FDM classification*) as well as Medium flood risk areas with evacuation difficulties. Medium flood risk areas are areas within the 1% AEP flood extent that are not classified as a High risk area. Accordingly, a transition to the new AR&R 2016 hazard classification scheme would require adjustment to the flood risk mapping methodology.

4.6 Rate of Rise of Floodwaters

The response time for Bundeena Creek is relatively fast due to the small catchment area. According to the flood model results, the rate-of-rise of floodwaters will be as follows:

- At the Bundeena Creek crossing at Scarborough Street:
  - Up to 0.4m/hr in the 1% AEP event, taking about 3 hours from the start of the storm to reach an initial peak, and 6 hours to reach the overall peak level about 100 to 200mm higher.
  - About 0.3m/hr in the 5% AEP event, taking about 6 hours to reach the peak level.
  - Up to 1.4m/hr in the PMF, taking only 2.5 hours to reach the peak level.
- At the Bundeena Creek crossing at Bundeena Drive:
  - Up to 1.4m/hr in the PMF, taking only 2 hours to reach the peak level.
- Bundeena Drive at the low point on the evacuation route (near Woodfield Avenue):
  - About 0.3m over 4 hours in the 1% AEP event, taking about 6 hours from the start of the storm to reach the peak level.
  - About 0.2m over 2 hours in the 5% AEP event, taking about 6 hours from the start of the storm to reach the peak level.
  - Up to 1.4m/hr in the PMF, taking only 2.5 hours to reach the peak level.

Accordingly, most of the lower floodplain is expected to be inundated within 2.5 to 3 hours of the start of rainfall in the 1% AEP event and larger. In events smaller than the 2% AEP flood the rate-of-rise is expected to be less aggressive, taking about 6 hours to reach peak levels. This is related to the adopted ARR 2016 rainfall temporal patterns because the 2% and 1% AEP events fall within the "rare" bin, which have both an early and later peak in rainfall intensities during the storm.

Flood level hydrographs at key locations are provided in **Section 5.2**.

4.7 Hydraulic Category Mapping

4.7.1 Overview

The NSW Government's *'Floodplain Development Manual'* (*2005*) categorises flood prone areas as either floodway, flood storage or flood fringe. Each of these hydraulic categories is defined by its unique function during a flood event, as described overleaf in **Table 4-2**.

The Floodplain Development Manual (2005) does not provide explicit quantitative criteria for defining hydraulic categories. This is because the extent of floodway, flood storage and flood fringe areas are largely dependent on the geomorphic characteristics of the floodplain in question such as valley slope and stream sinuosity, as well as topographic features and natural and artificial hydraulic controls within the floodplain.

Although there are no specific procedures for identifying or determining hydraulic categories, a rigorous methodology involving several stages of analysis in conjunction with flood modelling has been developed by Thomas & Golaszewski (*2012*). This methodology was further explored by Thomas et al (2018) to investigate the existence of a link between stability criteria and flow conveyance areas.

Table 4-2 Hydraulic Category Criteria

HYDRAULIC CATEGORY	DESCRIPTION
FLOODWAY	▪ Those areas where a significant volume of water flows during floods ▪ Often aligned with obvious natural channels ▪ They are areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which may in turn adversely affect other areas ▪ They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur.
FLOOD STORAGE	▪ Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood ▪ If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. ▪ Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.
FLOOD FRINGE	▪ The remaining area of land affected by flooding, after floodway and flood storage areas have been defined. ▪ Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels.

The methodology has been applied with success to similar floodplains in NSW and has been shown to provide a robust procedure for defining floodway extent. It has been successfully applied as part of NSW Government funded flood and floodplain management studies for the Hastings River (2012), the Camden Haven River and Lakes System (2014), the Hunter River (Muswellbrook) (2015), South Creek (western Sydney) (2015) and Swamp Creek (Cessnock) (2016), as well as for the towns of Griffith (2014), Bungendore (2016) and Hibbard (Port Macquarie) (2019).

Aspects of this methodology have been applied to determine hydraulic categories for the mainstream floodplain of Bundeena Creek. A similar approach was also used to determine hydraulic categories for major overland flow paths through the urban parts of Bundeena that are elevated above the main floodplain.

4.7.2 Adopted Methodology for Mapping Floodway Corridors

A preliminary floodway extent was firstly determined based on an assessment of aerial photography, topographic data and the 1% AEP flood modelling results. Determination of this extent or "line" considered the following:

- The location of flood storages that are readily identifiable from aerial photography;
- The location and potential impact of hydraulic controls and geomorphic features that could influence floodwater movement and flood characteristics (e.g., velocity);
- Mapping of contours of 'velocity-depth' product (V×D); and,
- Mapping of the variation in peak flow velocity.

The initial extent of the floodway was determined by observing topographic and other physical features of the landscape through both topographic mapping and aerial photography. The distribution of peak velocity and peak velocity-depth product for the 1% AEP event was also considered.

Areas where the velocity-depth product was greater than 0.4 m^2/s or the velocity was greater than about 0.5 m/s were identified and connected in order to provide an <u>initial indication</u> of the floodway extent. It should be noted that the nature of flooding across the Bundeena Creek floodplain during the 1% AEP event is volume-dominated (*particularly upstream from Bundeena Drive*). As a result, areas of significant V×D and higher velocity are typically restricted to the creek channel.

Accordingly, the adopted V×D and velocity thresholds are relatively low compared to those adopted in setting the floodway extent for other river channels and floodplains. Despite this, these criteria are still considered to underestimate the extent of floodway that needs to be preserved in order to avoid significant upstream impact on property and risk to life should blockage occur.

The next step in refining the floodway extent was to determine the width of the corridor required to convey 80% of the peak flow through the floodplain in accordance with the methodology outlined by Thomas & Golaszewski (*2012*).

The peak V×D mapping for the 1% AEP event was reviewed and flow sections were taken across the floodplain, including between the initial floodway lines and also beyond this extent on either side.

The wide storage-dominated nature of flooding across Bundeena meant that taking 80% of flow across the <u>entire</u> floodplain would result in an overestimation of the floodway, which would extend well beyond the creek channel and into areas of slow-moving floodwaters that are typical of flood storages. Accordingly, the flow sections were shortened to span only across the areas immediately either side of the channel where V×D and velocity are greater than about 0.2 m^2/s and 0.1 m^2/s, respectively.

A sample is provided overleaf in **Plate 4-4**, which shows the distribution of V×D, the flow cross-sections taken at regular intervals along the channel and the calculated bounds within which 80% of the flow is conveyed (refer to green dots). These dots were connected to develop the floodway extent shown as the black hatched area.

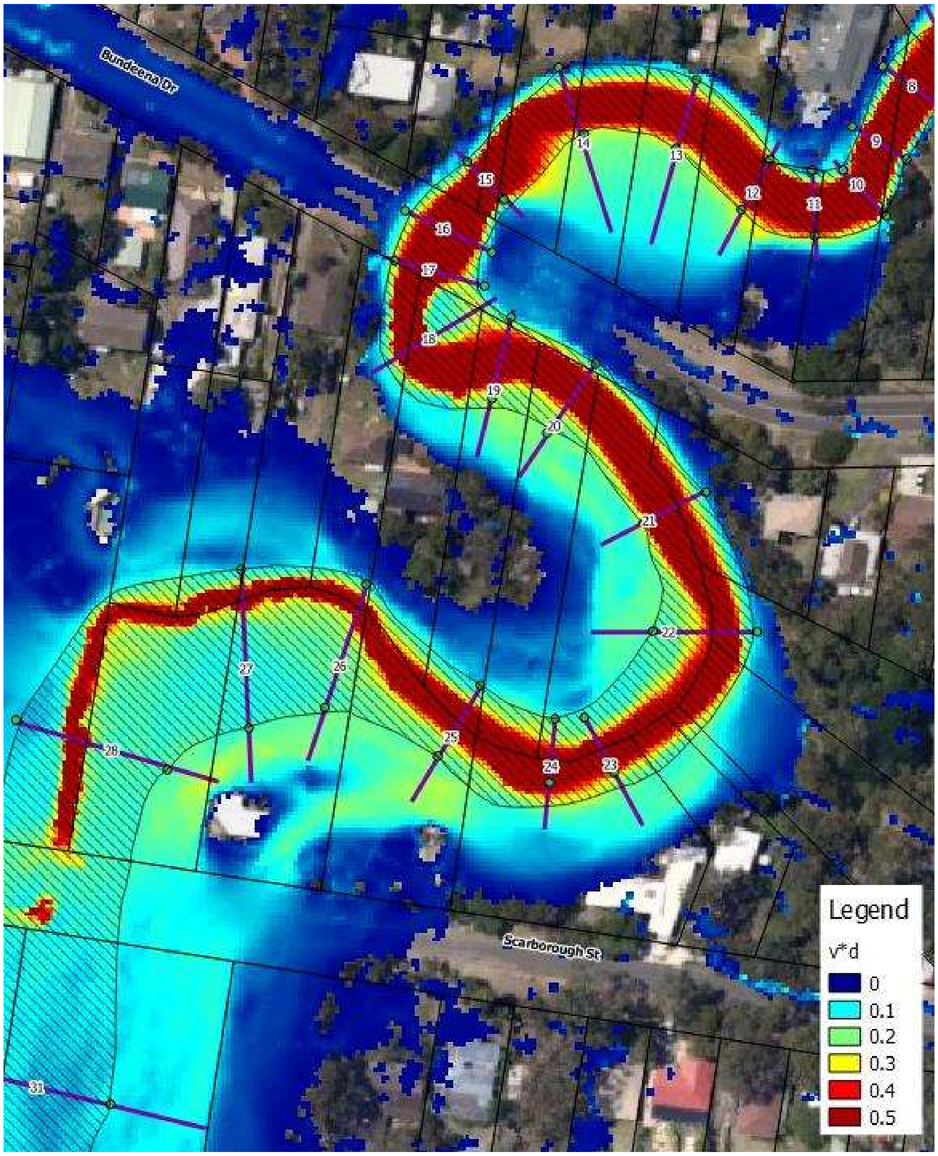


Plate 4-4 Example of Floodway Corridor Delineation

A different approach to delineation of the floodway was adopted for major overland flowpaths that exist across the more elevated areas of Bundeena, which are above the general floodplain of Bundeena Creek. It was recognised that despite being classified as low flood hazard areas (*refer* **Figure 4.30**), it is important to acknowledge and maintain these flowpaths so that floodwaters are not inadvertently diverted onto other properties due to any proposed development.

It was agreed with Council that the standard mapping in these areas for flood depths, levels and hazards (*filtered to remove depths less than 20 mm and ponds less than 300 m^2 in size*) should be further filtered during preparation of mapping of hydraulic categories, flood risk precincts and the Flood Planning Area.

This further filtering involved the manual identification of six significant overland flowpaths for inclusion within the mapping. Areas of shallow ponding within the kerb and gutter of streets were omitted unless linked with upstream and downstream flows through properties.

The results of the 1% AEP and 1 in 200 AEP events and PMF were examined to determine the floodway extent on these overland flowpaths. This was based on consideration of depths, velocities and V×D, to determine where the flows would be most concentrated. Consideration was also given to the way in which floodwaters would likely move around or between buildings, with manual adjustments made where appropriate.

Analysis of the "80% flow corridor" was not completed for the overland flowpaths as the width of floodway was generally narrow.

The resultant floodway extents for both mainstream areas and overland flowpaths have been combined and are shown in **Figure 4.41**.

4.7.3 Flood Storage and Flood Fringe Areas

As outlined in the NSW *'Floodplain Development Manual'* (*2005*), flood storage and flood fringe make up the remainder of the floodplain outside of the floodway corridor.

Flood storage areas are typically defined as those flood prone areas that afford significant temporary storage of floodwaters during a major flood. If filled or obstructed (*e.g., through the construction of levees or road embankments*) the reduction in storage would be expected to result in a commensurate increase in flood levels in nearby areas. The remaining flood prone areas not classified as floodway or flood storage are termed flood fringe.

In accordance with the Floodplain Development Manual (*2005*), the flood fringe represents areas which are unlikely to have any significant impact on the pattern of floodwater distribution through a river and floodplain system and associated flood levels. The boundary between flood storage and flood fringe was defined by a peak 1% AEP flood depth of 0.3 metres (*refer* **Figure 4.41**), which represents a threshold at which flooding over a significant area can typically begin to provide significant volume.

The impact of filling all properties located in the flood fringe areas was assessed for the 1% AEP event using the TUFLOW model. The results showed that flood level increases of up to 40mm would be expected in areas to the north of Bundeena Drive, but otherwise levels would be generally unchanged. This result is largely to be expected considering the proposal represents an aggressive filling scenario which is unlikely to eventuate. For the odd filling of small parts of fringe areas, the flood level impacts are likely to be negligible.

For overland flowpaths above the mainstream floodplain, all inundated areas not included in the floodway extent are effectively classified as flood fringe given the shallow depths of flow less than 300mm (*refer* **Figure 4.41**).

4.7.4 Summary

Floodway is generally confined to the creek and riparian corridor. The residual floodplain is predominantly flood storage to the south of Scarborough Street, a mix of flood storage and flood fringe between Scarborough Street and Bundeena Drive, and predominantly flood fringe north of Bundeena Drive.

4.8 Flood Risk Mapping

The level of flood risk at a property is considered in the application of Council's development controls under the Sutherland Shire Council DCP 2015.

Flood risk is separated into **High**, **Medium** and **Low** flood risk precincts, which are defined as follows:

- High Flood Risk: areas of land below the 1% AEP flood level that is either subject to a high hydraulic hazard or where there are significant evacuation difficulties. On land with high flood risk, there is possible danger to personal safety; evacuation by trucks would be difficult; able-bodied adults would have difficulty wading to safety; and there is a potential for significant structural damage to buildings
- Medium Flood Risk: areas of land below the 1% AEP flood level that is not subject to a high hydraulic hazard and where there are no significant evacuation difficulties. In this precinct there would still be a significant risk of flood damage or risk to life, but these damages and risks can be minimised by the application of appropriate development controls.
- Low Flood Risk: all remaining areas that could potentially be inundated; i.e., outside the 1% AEP extent and bounded by the extent of the Probable Maximum Flood (PMF). All types of development, except *Essential Community Facilities*, would be permitted.

High Risk precincts were mapped according to areas of High or Transitional Flood Hazard during the 1% AEP flood according to the hydraulic criteria outlined in the *NSW Floodplain Development Manual* (2005) (*refer* **Plate 4-1**). Given the relatively shallow depths and low velocities during the 1% AEP event in areas beyond the High/Transitional hazard extent, there would be no significant evacuation difficulties from these areas and hence no additional areas were included in the High Risk classification (*refer* **Figure 4.42**). There are no islands of Low hazard surrounded by High hazard in the 1% AEP or 1 in 200 AEP events or the PMF, which may otherwise create evacuation difficulties.

No overland flowpaths are expected to be of High or Transitional hazard in the 1% AEP event and therefore, the High Risk areas are limited to the mainstream floodplain across the lower part of Bundeena.

The 1% AEP flood extent map, excluding the High/Transitional hazard areas, effectively represents the Medium Flood Risk areas. Between this extent and the extent of the PMF represents the Low Risk areas (*refer* **Figure 4.42**).

4.9 Urban Drainage Network Utilisation

The 1-Dimensional network results from the TUFLOW model were reviewed to determine the smallest design event at which the stormwater pipes become flowing full; i.e., the design event at which the pipes reach capacity. The maximum percentage of total cross-sectional flow area in the pipes occupied during each design storm was extracted from the TUFLOW results, with a 90% threshold adopted as the limit to identify a pipe running full. A threshold of 100% was not used because in this case even if the flow area is lacking by 1%, the pipe would not be tagged as flowing full.

Such a drainage network capacity assessment can be beneficial in identifying parts of the network which may require upgrades to meet industry design standards, as well as the magnitude of any such upgrades.

However, it should be noted that many factors affect the peak capacity of stormwater pipes, including tailwater level, stormwater inlet pit capacity and the alignment of overland flows. Hence, care must be taken when interpreting such mapping and assessing the implications on the urban stormwater network capacity. This mapping is only provided a basis for further investigations at this stage.

The results of this analysis are presented in **Figure 4.43**, which indicate the following:

- The stormwater pipes in the low-lying areas north of Bundeena Drive are expected to be flowing full in the 50% AEP event. However, this result is likely influenced by floodwaters from Bundeena Creek backing-up along the pipes, rather than the actual capacity of the inlet pits and pipes to capture and drain local catchment runoff to the creek. And hence this result does not necessarily mean that the pipes need to be upgraded. To better determine pipe capacity the modelling would need to be refined to consider storms over the catchment area of the pipe network with a low tailwater level in Bundeena Creek.

- The capacity of stormwater pipes in the higher areas of Bundeena can range between the 50% and 1 in 200 AEP event.

- The stormwater pipes down the steep part of Scarborough Street are not running full in the 1 in 200 AEP, which indicates that the TUFLOW model may be under-recognising the ability of inlet pits in the road to capture the runoff, given the steep terrain and limited potential for the TUFLOW model grid to capture small features like road kerbs, leading to a bypass of flows overland. However, it may also represent a "real" deficiency in the inlet capacity of pits or capacity for them to capture runoff along the road or through the public school , which could explain the reports and videos of significant overland flows entering Scarborough street at the downslope side of the school.

With regard to the final point above, the TUFLOW model does not reliably show the observed flow path along the footpath from Rymill Place to Scarborough Street. The properties on the downslope side of the footpath have not reported any significant flows or damage through their properties, which indicates that the overland flow from Rymill Place (and runoff collected across the school) is channelled north along the pathway and into Scarborough Street. It is expected that the flow is channelled along either the rear fences of these properties or along a relatively minor topographic feature that is not captured in the LiDAR data.

It is recommended that Council investigate the option to install additional stormwater inlet pits and pipes along the footpath to capture the overland runoff and direct it into the drainage system in Scarborough Street. However, works of this scale are not typically considered as floodplain risk management options and therefore, have not been investigated further as part of this FRMS & Plan.

4.10 Impact of Potential Sea Level Rise

While the extent of potential climate change impacts is currently uncertain, it is important they be considered when investigating the longer term impacts of flooding and potential flood mitigation works. A major way in which climate change will impact flooding is in terms of potential sea level rise.

The assessment of sea level rise was completed for Bundeena according to Council's Sea Level Rise Policy (2016), which adopts a Representative Concentration Pathway (RCP) of 6.0 according to a future scenario involving "intermediate" mitigation of greenhouse gases (*IPCC, 2014*).

The associated sea level rise projections are as follows, specified also according to the impact on the 1% AEP tailwater level adopted for Bundeena Bay in the TUFLOW model simulations:

- 0.23 m increase in sea level by year 2050, resulting in a peak 1% AEP tailwater level of 1.74 mAHD
- 0.39 m increase in sea level by year 2070, resulting in a peak 1% AEP tailwater level of 1.90 mAHD
- 0.72 m increase in sea level by year 2100, resulting in a peak 1% AEP tailwater level of 2.23 mAHD

The above three planning horizons have been assessed as it is Council's intention to consider how sea level rise might be incorporated into future flood-related development controls. This could involve the development Flood Planning Area maps for each horizon, subject to consultation with Council's Strategic Planners, which would be applied to proposed developments according to their projected life expectancy. For example, a planning horizon of 30 years (*2050*) may apply to residential dwellings, while a planning horizon of 80 years may apply to critical long term infrastructure, such as road bridges.

The impacts of each sea level scenario on 1% AEP flooding in Bundeena was modelled and is shown in **Figure 4.44**, **Figure 4.45**, and **Figure 4.46**, by way of flood level difference mapping.

4.10.1 Year 2050 Sea Level Rise Scenario

In the year 2050 sea level rise scenario there is minimal impact on peak 1% AEP flood levels in Bundeena (*refer* **Figure 4.44**). Due to the increase in water levels modelled in Bundeena Bay there is a slight encroachment of waters at the beach and along the steeper Port Hacking foreshore areas. However, other than along the foreshore there is no impact in terms of increased flood levels or flood extent on private properties.

4.10.2 Year 2070 Sea Level Rise Scenario

Due to the 0.39 metre rise in sea levels in Bundeena Bay, there is some increase in 1% AEP levels backing-up into the Bundeena Creek mouth and throughout the Bonneville Park area (*refer* **Figure 4.45**). The increases in peak flood levels along Bundeena Creek are up to about 10 mm, extending as far south as Bundeena Drive. Near the beach berm the full 390 mm increase in flood levels is realised.

At the rear of properties on the north side of Woodfield Avenue the increase in 1% AEP levels will be up to 100 mm, which may impact on one or two dwellings and several sheds.

4.10.3 Year 2100 Sea Level Rise Scenario

The year 2100 sea level rise scenario is expected to have a more significant impact on peak 1% AEP flood levels across the lower floodplain of Bundeena Creek. Floodwaters back-up to greater depths, impacting much of the floodplain with increases of 30 mm or more (*refer* **Figure 4.46**).

At Bundeena Drive the increase in peak flood level is about 90 mm and at Scarborough Street the increase will be about 50 mm. As in the other sea level rise scenarios the beachfront is where the impacts will be most severe, with increases of up to 600 mm modelled at the mouth of the creek.

At the rear of properties on Woodfield Avenue the increase in 1% AEP levels will be more than 500 mm and may have an increased impact on outbuildings. But the associated increase in flood extent (*i.e., encroachment into the properties*) is typically less than 10 metres and not many primary dwellings are expected to be impacted.

5 The Impacts of Flooding

5.1 Analysis of Existing Flood Damages

5.1.1 What are Flood Damages?

Flood damages are adverse impacts that private and public property owners experience as a consequence of flooding. They can be both tangible and intangible, direct and indirect, and are usually measured in terms of a dollar cost.

Residential, commercial and industrial damages can be separated into direct and indirect damages. Direct damages are the result of the physical contact of floodwaters with the structure and may include the costs associated with repair, replacement or the loss in value of inundated items. Indirect damages represent all other costs not associated with physical damage to property and typically include the loss of income incurred by residents affected by flooding, as well as flood recovery items such as clean-up costs.

Tangible damages include direct damages such as the damage to property as a consequence of inundation (*e.g., the cost of replacing carpets*). Tangible damages can also be indirect damages such as the cost to the community of individuals being unable to get to work because they are isolated due to flooding. These costs can usually be measured and data has been gathered over many years to provide a reliable indication of the likely damage costs that can be incurred by residential, commercial and industrial property owners.

It is more difficult to quantify intangible damages. Intangible damages include impacts such as the trauma felt by individuals as a result of a major flood and the associated health related impacts. Only limited data is available, but it has been stated that intangible damages could be as much or more than the tangible damage cost.

As part of a Floodplain Risk Management Study, it is necessary to determine the total damages that could be incurred as a consequence of flooding. If the total damage cost is significant, it can be argued that works or planning measures to reduce the cost can be justified.

The justification process involves determining an estimate of the flood damage that could be expected to occur over the design life of the works. This damage cost is then compared to the damage cost if no works were undertaken. The difference defines the reduction in flood damage cost, or the net benefit. The net benefit of the works is compared against the cost of the works, thereby generating a benefit-cost ratio for the works.

If the benefit-cost ratio is sufficiently high (*i.e., ideally greater than 1*), the works are typically considered worthwhile from a benefit-cost perspective.

5.1.2 Adopted Methodology for Calculating Flood Damages

The adopted methodology for the calculation of flood damages at Bundeena is in accordance with the Floodplain Risk Management Guideline (*and accompanying spreadsheet*) titled: *Residential Flood Damages* prepared by the Department of Environment and Climate Change (now Office of Environment & Heritage) in 2007.

Flood damages have been calculated according to the latest TUFLOW model results for the PMF, 1 in 200, 1%, 2%, 5%, 10%, 20%, and 50% AEP events. As outlined in **Section 4**, the flood mapping was filtered to remove depths less than 20 mm and ponding less than 300 m^2 in area, in order to provide a more realistic representation of the impact of flooding on the catchment. The filtering effectively removes very shallow flooding in localised depressions in the terrain in the hilly areas of Bundeena (above the main floodplain), which are not likely to contribute significantly to flood damages. This filtering resulted in the removal of most small ponds in the hilly areas.

However, in the PMF the high interconnectivity of the different flowpaths resulted in wide flow areas being retained in the mapping, despite the filtering.

Floor level survey of properties within the mainstream flood extent and those on major overland flowpaths was conducted by Council. The survey also captured additional data such as the construction type employed at each dwelling (*e.g., slab on ground, high set or two-storey*) and the land use type of each property (*e.g., residential or commercial*).

For properties where floor levels were not captured during the survey (*primarily in the areas of widespread overland flows during the PMF*) an approximation of the floor level was made by assuming the building floor level is 400mm above the average ground level at the dwelling, as taken from the LiDAR data. The adopted height of 400mm was derived considering the typical surveyed floor heights above ground, in conjunction with observations from Google Maps Street View.

The calculation of damages at a particular property is only triggered if there are a sufficient number of model grid cells across the structure footprint that get wet during the flood. An example screenshot of a dwelling just passing the minimum threshold for a property to be counted as damaged is shown below in **Plate 5-1**. The yellow polygon represents the footprint of the dwelling in question and the blue shading shows the flood extent. The threshold is defined as a minimum of 30 wet grid cells across the structure footprint. If there is less inundation than this, it is unlikely there will be significant flow into the structure and hence there would be no significant damage.

Once triggered, the level of flooding is compared to the floor level of the dwelling/structure to extract a flood depth relative to floor level. This depth is applied to the relevant damage curve (*refer* **Plate 5-2** *below*) to determine the dollar value of damage, according to the property type (*residential or commercial*) and the construction type (*slab on ground vs high set vs two-storey*).

The residential flood damage curves are based on the 2007 DECC guideline and accompanying spreadsheet, allowing for growth in average wages of 65% according to the ABS since November 2001 (*the baseline date adopted by DECC*).

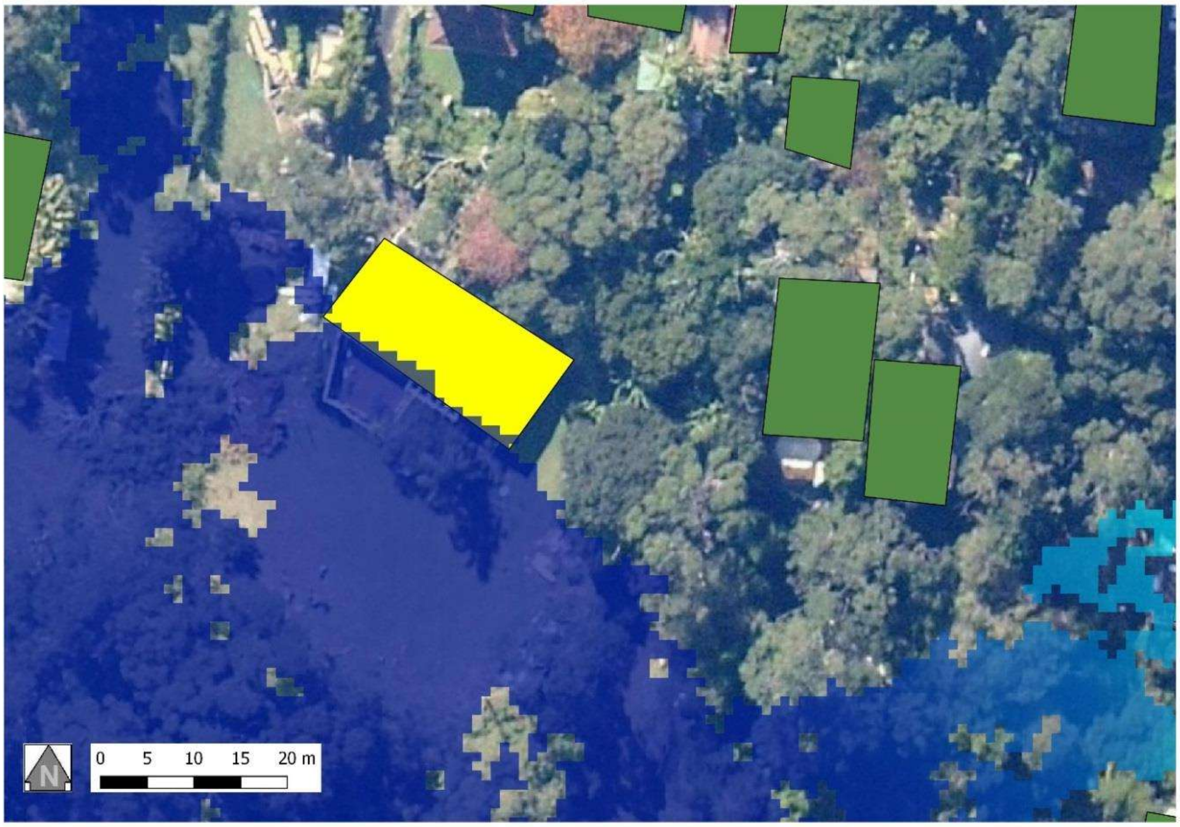


Plate 5-1 Example of Minimum Extent of Dwelling Inundation to Trigger Flood Damages (Yellow Dwelling)

If the level of flooding is less than 500mm below the dwelling floor level it is assumed there would be no flood damage costs. If floodwaters reach higher than 500 below the floor level but do not overtop the floor level, it is expected that a nominal amount of damage will be incurred at the property, accounting for external items.

An estimate of damages associated with the inundation of commercial premises (*such as the service station*) was based on recorded damage costs for similar premises reported in the literature. This literature includes a range of previous floodplain management studies and recorded data presented in intergovernmental reports.

The resultant damage curve is shown in **Plate 5-2**. A similar inflation factor has been applied to ensure that dollar values are relative to 2017.

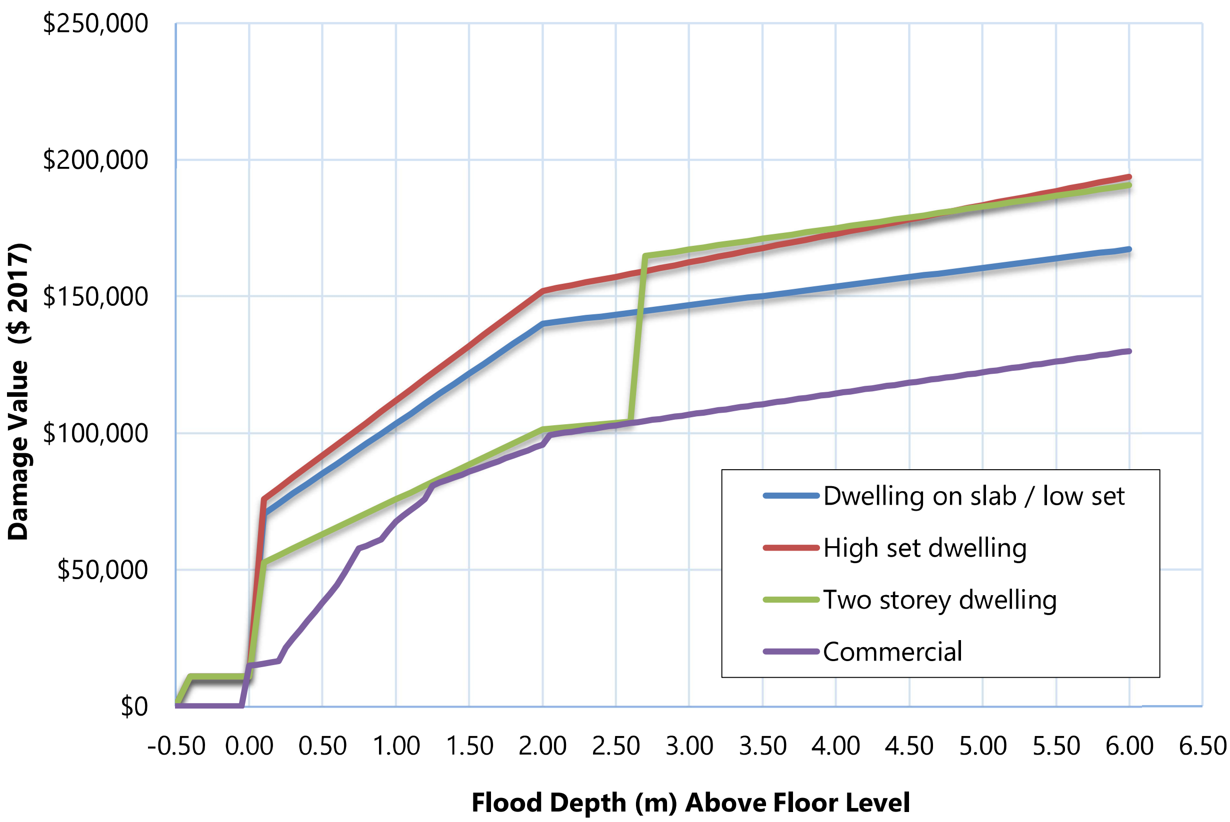


Plate 5-2 Flood Damage Curves for Each Property Type at Bundeena

5.1.3 Calculated Flood Damages

A summary of the calculated flood damages is provided below in **Table 5-1**.

The locations of properties subject to above floor and below floor damages are shown in **Figures 5.1** to **5.7**.

The relative cost of the potential flood damages is typically expressed in terms of the Average Annual Damage (AAD). The AAD is equivalent to the total damage caused by all floods over a long period of time divided by the number of years in that period (*DECC, 2007*). It provides a "base case" measure for comparing the economic benefits of potential flood damage reduction options.

In understanding this concept, there may be years when no floods occur or the floods that do occur cause little significant damage. On the other hand, some floods will be large enough to cause extensive damage. The total cost of damage of these multiple floods, regardless of magnitude, over the period of time in which they occur is represented by a yearly average value of cost known as the AAD.

Table 5-1 Residential and Commercial Flood Damages at Bundeena

EVENT AEP	Number of Properties Subject to Flood Damages *		Flood Damages		
	Residential	Commercial	Residential	Commercial	TOTAL
PMF	461 (245)	14 (14)	$26,513,000	$1,008,000	$27,521,000
1 in 200	112 (38)	9 (6)	$3,136,000	$287,000	$3,422,000
1%	93 (23)	6 (3)	$1,967,000	$115,000	$2,082,000
2%	80 (15)	4 (2)	$1,433,000	$90,000	$1,523,000
5%	74 (14)	4 (2)	$1,235,000	$75,000	$1,310,000
10%	60 (6)	4 (1)	$815,000	$35,000	$850,000
20%	45 (2)	2 (0)	$539,000	$15,000	$554,000
50%	29 (0)	2 (0)	$321,000	$11,000	$332,000

** Number of properties subject to above floor flooding shown in parentheses.*

The Average Annual Damages for Bundeena are calculated to be **$490,000**. That is, funds in the order of $490,000 would need to be put aside each year on average, in order to cover the damage bills that could be incurred as a consequence of flooding. This translates to an AAD of **$1,030** per property, only counting those properties affected by flooding (*in any size event*).

For residential properties the AAD is approximately **$470,000** and of this amount about **$12,000** represents the indirect costs associated with clean-up and finding alternative accommodation.

The Present Value of total damages over an adopted 30 year building design life and applying a discount rate of 7% would be **$6.57 million**.

5.1.4 Intangible Flood Damages

Intangible flood damages are those that are unable to be quantified in monetary terms. These damages are related to the physical and mental health of individuals, environmental concerns, the ability to undertake necessary evacuation measures and disruption to essential community services and operations.

Notwithstanding this, emotional stress and mental illness can stem from a number of experiences associated with damage to family homes and businesses. These include:

- destruction of memorabilia (i.e., family photos);
- death of pets;
- financing the replacement of damaged property;
- living in temporary accommodation;
- children attending a different school;
- loss of business income and potential clients;
- loss of wages; and,
- anxiety experienced by young children.

In general, this type of intangible damage to the well-being of residents can be significant in the event of a major flood. Accordingly, it is possible that the intangible damage cost could be as high or higher than the total tangible damage cost.

The following observations are made about the potential intangible impacts of flooding in Bundeena:

- The significant proportion of residential dwellings subject of over-floor flooding (*about 25% in the 1% AEP event*) may increase the loss of family memorabilia and heirlooms, particular as there is a considerable elderly population in Bundeena.
- Temporary accommodation may be difficult to find in a relatively isolated place like Bundeena, which will place increased toll on people's wellbeing and stamina during the clean-up and rebuilding effort if significant distances need to be travelled each day. The follow-on effect might be further loss of wages due to an extended clean-up period.
- The service station is expected to be affected during major flooding, in which case there is no other source of petrol or vehicle supplies and residents will need to travel back to Sutherland in order to refuel.
- The school is not expected to be impacted and therefore, it is unlikely the local children will need to attend a different school during the recovery period.

5.2 Flood Emergency Response Considerations

The NSW State Emergency Service (SES) is the legislated Combat Agency for floods. It is responsible for coordinating other agencies involved with emergency management.

To allow SES to manage the emergency response to flood risk and undertake evacuation planning the SES, along with NSW Office of Environment and Heritage (OEH), have developed guideline documents which detail their desired outcomes from the Floodplain Risk Management process. These guidelines are titled:

- *'SES Requirements from the Floodplain Risk Management Process'* (*2007*); and,
- *'Flood Emergency Response Planning Classification of Communities'* (*2007*).

The existing *Local Flood Plan* for Sutherland Shire prepared by SES (*2013*) does not include any specific information or guidance on addressing flood emergency management in Bundeena.

As shown in **Table 5-1**, there are expected to be up to 260 residential and commercial properties inundated with over-floor flooding during the PMF. At most risk are properties within the lower floodplain of Bundeena Creek, located predominantly to the west of the creek but also along Scarborough Street and the southern end of Brighton Street.

Despite relatively low velocities during events up to and including the PMF (*typically less than 0.2 m/s*), shelter-in-place is not an option for properties without a second storey and evacuation would be required for many properties in the PMF.

5.2.1 Critical Infrastructure

Critical facilities subject to inundation include:

- The Fire & Rescue NSW Station on the south side of Bundeena Drive, which is expected to be inundated over floor level in the 1 in 200 AEP event.
- The Bundeena service station on Bundeena Drive, which is expected to be inundated over floor level in the 1% AEP event.

There are no known critical utilities in Bundeena (*e.g., water treatment facilities or power sub-stations*) that would be affected by flooding.

There is a supermarket, shops and post office located at the northern end of Brighton Street, which may be subject to overland flows, however the depths are expected to be less than 150mm during events up to and including the 1% AEP storm.

5.2.2 Vulnerable Groups

An assessment has been made to identify vulnerable groups who, due to their age or health, may be more vulnerable to flooding and may need special consideration during a flood.

Students at the Bundeena Public School are considered a potentially vulnerable group. In events up to and including the 1 in 200 AEP event Bundeena Public School will not be subject to significant flooding. Only in the PMF will significant overland flooding occur through the school. The school may require evacuation during the PMF, or at least children and staff should evacuate onsite to higher floor levels.

There are no nursing homes in Bundeena that would constitute a vulnerable group. However, there is a Community and Senior Citizens Centre located at the corner of Bundeena Drive and Liverpool Street. The centre is only used occasionally, but organisers of senior citizen events should be aware of the need to evacuate early during a flood.

The Bundeena Bowling and Sports Club, located at the southern end of Liverpool Street, is also likely to host senior citizens on a regular basis and therefore presents a potentially vulnerable group.

5.2.3 Evacuation Routes

Inundation of properties in the lower floodplain will generally occur from south-to-north as floodwaters breakout into Liverpool Street and Scarborough Street. Residents will need to evacuate north along Liverpool Street towards Bundeena Drive and then east or west towards higher ground, prior to the flood reaching high hazard conditions in these streets. Residents of Liverpool Street south of Scarborough Street (*including staff/patrons of the Bowling Club*) will need to mobilise the earliest, as high hazard conditions (*FDM, 2005*) will start to occur in the 5% AEP event and larger.

According to the ARR 2016 flood hazard categorisation, the hazard will increase most significantly between the 2% and 1% AEP events, leading to H3 conditions in the southern part of Liverpool Street, which becomes unsafe for vehicles, children and the elderly. This indicates that evacuation would need to occur once flooding is expected to increase beyond the 2% AEP event.

A summary of the expected road closures in Bundeena is provided in **Figure 5.8**, which is based on review of flood model results from the range of design storm events. It shows that Scarborough Street would be the first road to be cut, becoming inundated in the 20% AEP event. This finding is in agreement with anecdotal reports and videos that show inundation over Scarborough Street on more than one occasion in recent history.

Bundeena Drive is expected to be cut during the 5% AEP event or larger, just east of Liverpool Street and also near Woodfield Avenue, which effectively denotes the timing of when the lower floodplain becomes isolated from the eastern part of Bundeena and from outside areas (*i.e., the National Park entry route from Loftus*). At this point there is still access via Bundeena Drive to the higher flood-free areas at Simpson Road and Short Avenue.

As flood depths increase at houses to the north of Bundeena Drive these residents will also need to evacuate to the west along Bundeena Drive to the higher ground at Simpson Road and Short Avenue. Flood hazard is expected to remain low along this part of Bundeena Drive during events up to and including the 1 in 200 AEP event, however the number of houses subject to over-floor flooding in this area jumps most dramatically between the 2% and 1% AEP events (*aside from in the PMF*). Residents will need to evacuate to higher ground via Bundeena Drive by the time flooding reaches the 1% AEP level.

5.2.4 Flood Warning

The Bureau of Meteorology (*BOM*) does not issue flood warnings for flash flood catchments with a response time of less than 6 hours. There are currently no water level gauges on Bundeena Creek or local rainfall gauges in the catchment to provide any warning of flooding for Bundeena.

5.2.5 Duration of Flooding

According to the TUFLOW model results the duration of inundation in the 1% AEP event is expected to be about 16 hours over Scarborough Street at the creek crossing (*refer* **Plate 5-3**), while the PMF is expected to be one or two hours longer.

The duration of inundation over Bundeena Drive at the creek during the 1% AEP event will be less than 1 hour given the level of the road is about 2.2 mAHD (*refer* **Plate 5-4**). The duration of inundation during the PMF will be about 9 hours.

The low point on the Bundeena Drive evacuation route (*near Woodfield Avenue*) is expected to be inundated for up to 8 hours during the 1% AEP event (*refer* **Plate 5-5**). During the PMF the model results indicate that this location could be inundated for up to 12 hours.

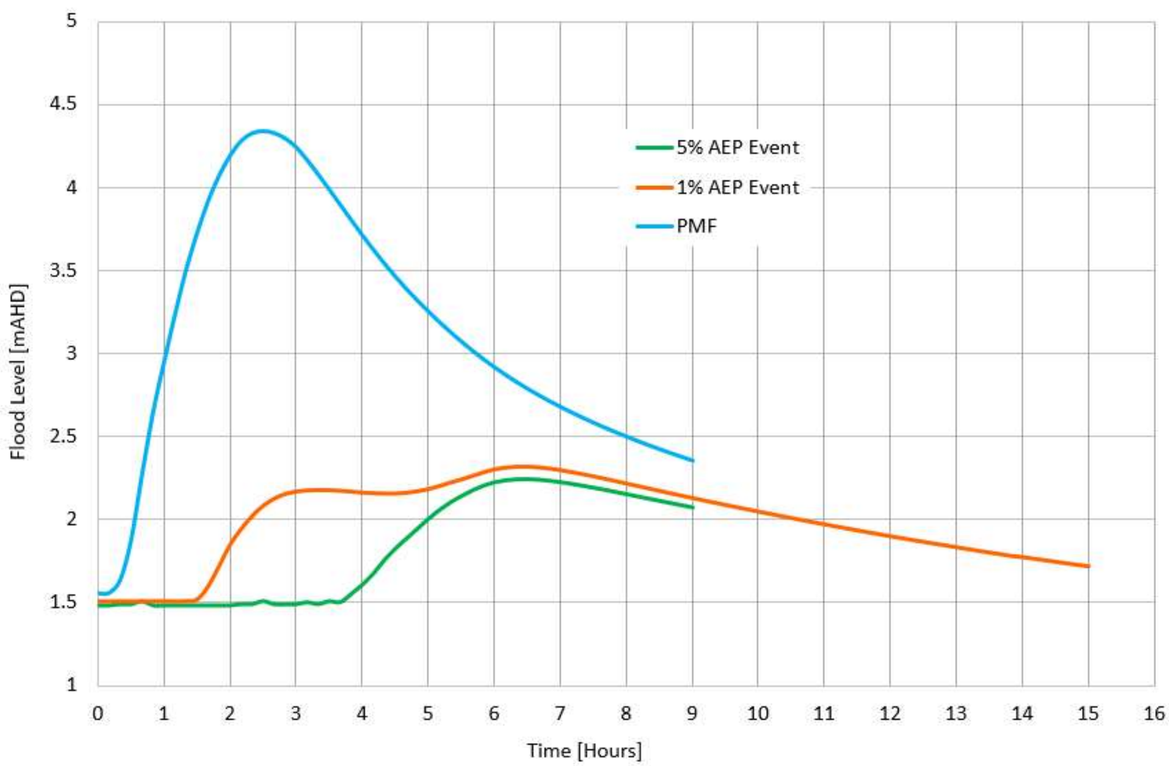


Plate 5-3 Flood Level Hydrographs at Scarborough Street (at Bundeena Creek)

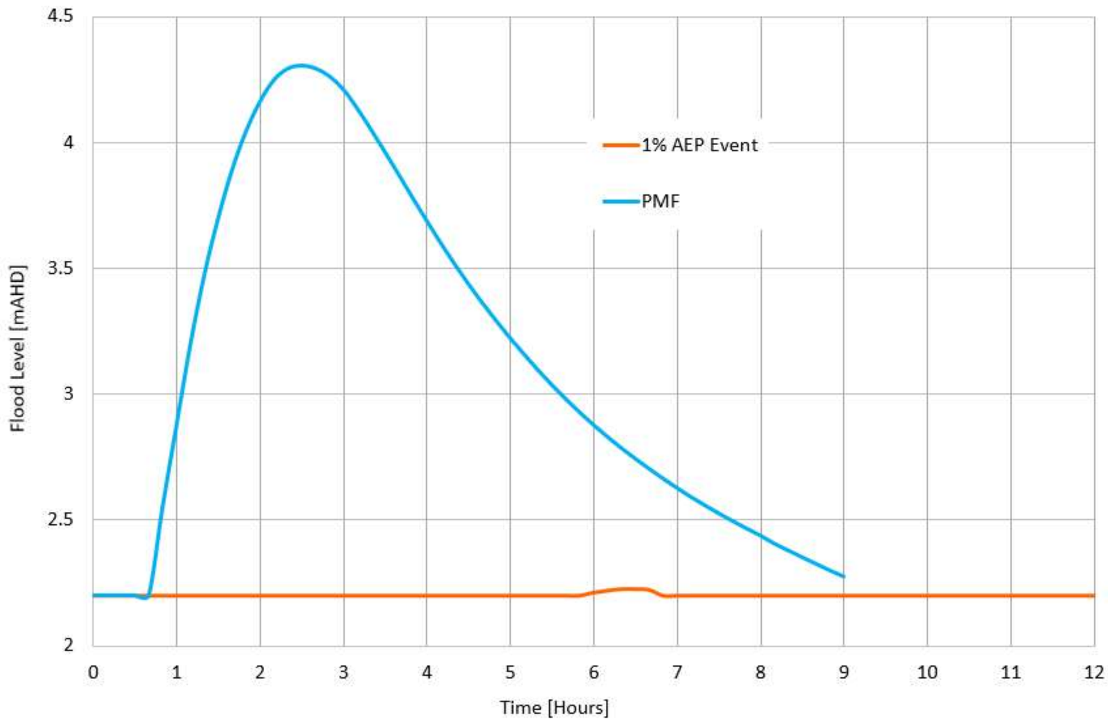


Plate 5-4 Flood Level Hydrographs at Bundeena Drive (above creek channel)

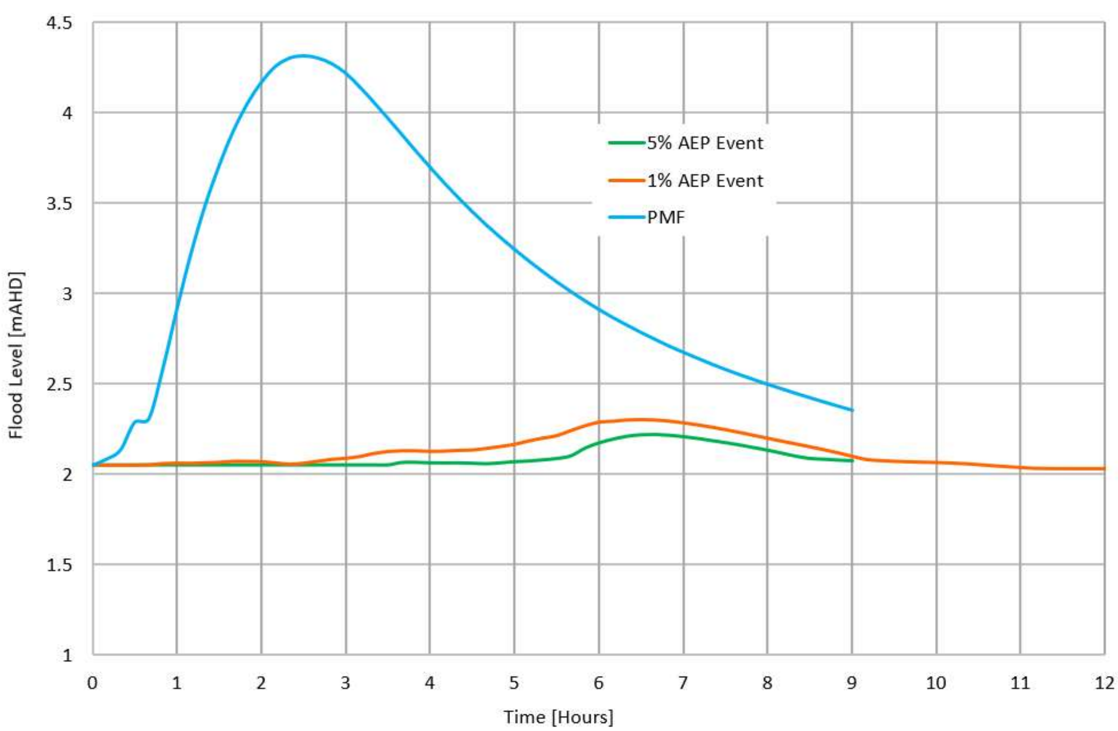


Plate 5-5 Flood Level Hydrographs at Bundeena Drive near Woodfield Avenue

5.2.6 Classification of Flood Emergency Response Communities

Given the relatively early timing of Bundeena Drive being cut near Woodfield Avenue, at a time when the majority of houses are not yet experiencing over-floor flooding, it is expected that most residents in the lower floodplain would become trapped in Bundeena. However, there will be access to the higher areas at Simpson Road and Short Avenue, which are considered large enough to provide temporary refuge for residents.

According to the OEH guideline titled, *Flood Emergency Response Planning Classification of Communities*, the lower floodplain areas to the west of Bundeena Creek would be classified as a *High Flood Island* (*refer* **Plate 5-6**)).

In this context, the areas of high ground at Simpson Road and Short Avenue have been classified as "habitable areas", without relying on the availability of habitable rooms within dwellings.

This is considered appropriate, as the OEH guideline gives the following definition of a High Flood Island:

> *The flood island includes enough land higher than the limit of flooding (i.e. above the PMF) to cope with the number of people in the area. During a flood event the area is surrounded by floodwater and property may be inundated. However, there is an opportunity for people to retreat to higher ground above the PMF within the island and therefore the direct risk to life is limited.*

Note that resupply insitu or transport by air/boat is not likely to be required given the relatively short duration of flooding at Bundeena (*less than 24 hours*).

The eastern part of Bundeena is classified as a *High Trapped Perimeter* area. The two available routes for evacuation from the lower floodplain are Scarborough Street and Bundeena Drive, for properties to the east of the creek and east of the low point in Bundeena Drive (*as indicated in* **Figure 5.8**). Residents on Bundeena Drive will need to cross the creek prior to the road being cut in this area, which is expected to occur during the 1 in 200 AEP event.

Note that residents on Woodfield Avenue may be able to evacuate to the National Park and Loftus until the 1% AEP event is reached. This area is also classified as a *High Trapped Perimeter Area*.

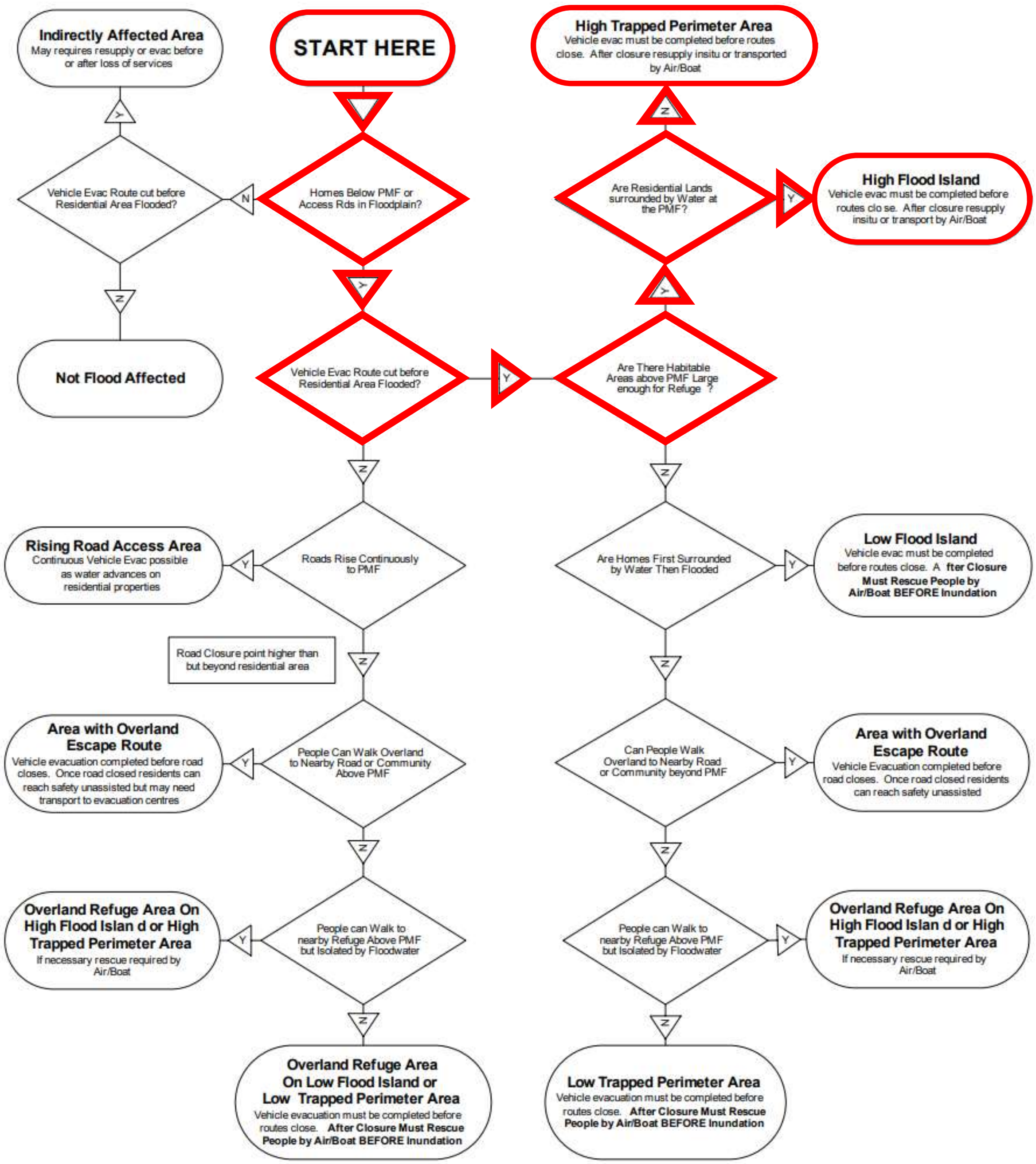


Plate 5-6 Process for Classification of Communities for Flood Emergency Response Planning
(Red illustrates assessment for Bundeena)

5.3 Summary of Flood Problem Areas in Bundeena

According to general flood behaviour, flood hazard, risk and emergency management considerations outlined in sections above, the following locations have been identified as key flood problem areas for Bundeena, and have therefore been considered in the formulation of potential flood mitigation options and the review of emergency response protocols and flood planning controls:

- The lower floodplain of Bundeena Creek in general:
  - Deep, high hazard conditions in the PMF, but otherwise generally low hazard in events up to and including the 1 in 200 AEP flood.
  - This flooding is the result of the constriction of flows through the lower reaches of Bundeena Creek, which causes floodwaters to spill across the urban areas within an effective storage area created behind the high beach berm.
  - Most properties would be subject to over-floor inundation in the PMF, meaning that shelter-in-place is not an option for houses without a second storey, and hence evacuation to higher ground is required.
- Properties to the north of Bundeena Drive, between Laurence Avenue, Thompson Street and Liverpool Street:
  - Although this area remains low hazard in events up to and including the 1 in 200 AEP event, nuisance flooding starts to inundate properties (below floor level) in the 50% AEP event.
  - Flooding of this area occurs due to the inability of local runoff to drain away to Bundeena Creek given the elevated tailwater levels in the creek. In events up to and including the 1% AEP storm the peak level of flooding is not directly linked to the peak level of flooding to the south of Bundeena Drive (*i.e., the flood level is a little lower on the north side*).
  - There are seven properties subject to over-floor damages in 1% AEP event, which represents one of the most dense areas of properties affected.
- Properties on the east side of Liverpool Street, with the flood risk generally increasing from south to north:
  - This inundation occurs via breakouts from the creek at the southern end of Liverpool Street.
  - These properties are not classified as high hazard in events up to and including the 1 in 200 AEP flood according to the Floodplain Development Manual, but they are classified as H3 hazard according to ARR 2016, which is unsafe for vehicles, children and the elderly.
  - Residents at the southern end of Liverpool Street provided anecdotal reports of being cut-off by floodwaters in their front yard, in which case they need to wade through this area to reach higher ground further north on Liverpool Street.
- Properties in the vicinity of the Scarborough Street crossing of Bundeena Creek:
  - This is naturally a low-lying area adjacent to the creek.
  - Water overtops Scarborough Road from the swamp (to the south) even in relatively small events, including the 50% AEP storm.
  - Properties either side of the creek are affected, with three to four dwellings with over-floor flooding in the 10% and 5% AEP events.

- The flood mapping shows that flood levels are elevated on both the upstream and downstream side of the road, meaning that an increase in the capacity of the box culvert beneath Scarborough Street is unlikely to improve flood conditions in the area.

- Properties at the southern side of Beachcomber Avenue, approximately 80 metres west of its intersection with Eric Street:
  - There is an overland flowpath through two or three properties at this location, which is expected to result in damages to one or two properties in events larger than the 5% AEP storm.
- Overland flow paths through the commercial/residential properties at the northern end of Brighton Street:
  - Up to five properties are affected in the 1 in 200 AEP storm, but only one property is affected in the 5% AEP and lesser storms.
  - The most recent development in this area and within the lots behind/above may have alleviated the actual damage threat, provided that appropriate overland flow paths have been incorporated into the designs.
- Overland flow paths through properties at the far eastern side of Bundeena, between Scarborough Street and Baker Street, to Loftus Street and then Neil Street.
  - The flow is shallow and considered nuisance flooding. It may benefit from further investigation into blockages caused by fencing and buildings, but is not considered a priority for floodplain management investigations.
  - Below-floor flooding is expected in this area for up to 10 properties.
- Nuisance flooding at properties at the southern end of Brighton Street:
  - Under-floor flooding is expected at four properties in the 1 in 200 AEP event, which is linked to the inundation across the general lower floodplain of the creek.
  - Properties on Brighton Street that back onto the Public School and pathway from Rymill Place have flooded in the past. A portion of the runoff is also directed north along the rear fences of these properties and into Scarborough Street. The flood model has a resolution that does not capture the effect of localised small features like fences.

6 Floodplain Management Approach

6.1 Types of Floodplain Risk Management Measures

Floodplain risk management measures can be separated into the following categories (*Floodplain Development Manual, 2005*):

- **Flood modification measures**. These are typically structural works, such as flood protection levees, flood detention basins or bypass floodways, which act to reduce flood damages.
- **Property modification measures**. These measures include flood planning controls for future development to ensure that land uses are compatible with flood risk. They can also include voluntary house raising and purchase, or flood-proofing of buildings, which can act to reduce flood damages.
- **Response modification measures**. These typically include emergency response management measures, flood predictions and warnings and community flood awareness and preparedness.

6.2 Approach to Addressing the Flood Problem

The flooding problem at Bundeena can be broken up into three major components, namely:

- the existing flooding problem;
- the potential future flooding problem; and,
- the residual, or continuing flooding problem.

Each component is discussed in the following sections, along with the recommended types of mitigation measures to address them.

6.2.1 Existing Flooding Problem

The existing flooding problem relates to those areas where flood damages are likely to arise as a consequence of flooding occurring today. It concerns existing dwellings, industrial complexes and commercial premises that would be inundated during flooding generally up to the 1% AEP level, as well as all associated infrastructure within the floodplain, including roads and utility services. In this context, the existing flooding problem is usually addressed by structural measures which aim to modify flood behaviour and thereby reduce flood damages.

There has been an historic focus on flood modification measures in Bundeena, such as the potential upgrades to the culvert beneath Scarborough Street. As outlined in previous flood management studies for Bundeena, there has also been proposals for channelisation of the creek and the construction of earth levees to mitigate flood impacts.

The key flood problem areas at Bundeena have been outlined in **Section 5.3**. These have been considered in the identification of potential flood modification measures for assessment using the TUFLOW flood model (*refer* **Section 7**).

Particular property modification measures, such as voluntary house raising or purchase, can also help to reduce existing flood damages.

6.2.2 Future Flooding Problem

The potential *future* flooding problem refers to those areas of the floodplain that are likely to be proposed for future development or to be the subject of rezoning applications. It also relates to the potential redevelopment of existing lots within the floodplain.

As land resources for development become increasingly scarce, pressures mount to allow new development or redevelopment within floodplain areas where it might otherwise be avoided. Future development can also lead to increased impervious areas that lead to increased runoff and hence flooding.

Council has a duty of care to ensure that its current planning instruments recognise the potential future flood risk. Council also has a responsibility to ensure that appropriate flood-related development controls can be used to support decisions to approve or reject development proposals in flood affected parts of the LGA.

Council has been applying such controls for several years that seek not only to reduce future flood risk but also the existing flood risk through controlled redevelopment of existing flood prone properties. In this regard, in addressing the potential future flood problem, Council is seeking to refine and improve its existing floodplain risk management practices.

Potential sea level rise also needs to be considered as part of future floodplain management (*see* **Section 4.10**).

The effectiveness of flood-related development controls versus proposed flood modification works should be considered in the context of the current rate of redevelopment in Bundeena, which is relatively low.

6.2.3 Residual Flooding Problem

Unless the Probable Maximum Flood (*PMF*) is adopted as the basis for determining structural and planning measures aimed at reducing flood damages, there will always be a residual or continuing flooding problem.

However, the adoption of the PMF as the 'planning flood' is not realistic or practical because it would sterilise a large area of land, thereby forcing development to areas of higher ground which may not historically be serviced, or which could introduce unrealistically high infrastructure costs.

Hence, a lesser flood standard is adopted. Most councils in NSW, including Sutherland Shire Council, have adopted the 1% AEP level plus a freeboard of 500 mm as the Flood Planning Level. As a result, measures that are put in place to control flood damage will ultimately be overwhelmed by a flood that is larger than that adopted as the threshold for the planning control of land use, or as the limiting flood for the design of structural measures.

Accordingly, it is incumbent upon Council to consider the implications of floods greater than the adopted planning flood, for all events up to the PMF, and to work with the State Emergency Service (*SES*) to develop a contingency plan for such events.

As discussed above, SES' *Local Flood Plan* covers the entire Sutherland Shire LGA, but does not incorporate any specific response actions for the township of Bundeena.

Council's DCP currently incorporates controls that require the developer to consider flood evacuation, warnings and flood refuge areas for any proposed development. However, Council would like to standardise the approach for development applications, making it more straight-forward for flood emergency response to be addressed.

7 Assessment of Flood Modification Measures

7.1 Assessment Methodology

The assessment of flood modification measures was completed using a staged approach as follows:

- Identification of options based on noted flood problems, as shown in the model results (*refer* **Section 5.3**) and also based on community consultation completed as part of previous investigations for the 2014 Bundeena Flood Study.
- Stage 1 Assessment:
  - Initial assessment involving modelling of the 1% AEP flood to determine the benefit provided by each option in terms of reduced flood damages. This involved some refinement to particular options during the investigations.
  - Preliminary assessment of the cost of options, including upfront capital costs and ongoing maintenance costs. Note that all cost estimates represent a total present value of costs over a 30 year design life assuming a real discount rate of 7%. All cost estimates also include an allowance for further design and approvals.
  - Calculation of an indicative Benefit Cost Ratio (BCR)
  - Triple-Bottom-Line (TBL) assessment to consider additional factors, such as social and environmental impacts/benefits.
- Community consultation to outline the results of the Stage 1 assessment and determine community support for the options (or lack thereof).
- Stage 2 Assessment:
  - Further assessment of the highest scoring option(s) with the most community support, involving flood modelling of the entire range of design events; and,
  - Refinement of the BCR for this option(s).

7.2 Identification of Flood Modification Measures

The potential flood mitigation options that have been identified and investigated as part of the Stage 1 Assessment are listed in **Table 7-1**.

Figure 7.1 depicts the locations of proposed management options, and **Figures 7.2** and **7.3** shows the entrance management options in greater detail. Note that the options were assessed individually as part of the Stage 1 Assessment, with the exception of Option F-6 which involves both upgrade of the culvert beneath Scarborough Street and upgrade of the downstream channel.

Table 7-1 Potential Flood Mitigation Options

Option	Description	Objective
Option F-1	Increasing the flood conveyance through the creek entrance	Reduce flood levels across the lower floodplain of Bundeena Creek
Option F-2	Flood protection levee	Deflect floodwaters around the residential areas to the west of Bundeena Creek
Option F-3	Creek channel upgrade	Reduce the extent of inundation between Scarborough Street and Bundeena Drive, and across upstream areas
Option F-4	Scarborough Street culvert upgrade	Reduce the frequency and extent of overtopping of Scarborough Street
Option F-5	Additional stormwater outlet(s) to the beach	Reduced incidence of nuisance flooding between Laurence Avenue and Liverpool Street, north of Bundeena Drive
Option F-6	Scarborough Street culvert upgrade + channel upgrade	Refer Options F-3 and F-4 above

Within Options F-1 and F-5 up to two or three variations were also considered as follows:

- Option F-1:
  - F-1A: Creek entrance widening and deepening
  - F-1B: Entrance berm management (eastern channel)
  - F-1C: Entrance berm management (central channel)
- Option F-5:
  - F-5A: Single additional stormwater outlet to the beach
  - F-5B: Two additional stormwater outlets to the beach

7.3 Stage 1 Assessment of Flood Modification Measures

7.3.1 Option F-1A: Creek Entrance Widening and Deepening

The *Bundeena Creek Estuary Management Plan* (*EMP*) (GHD, 2009) identified potential creek mouth management options for Bundeena Creek, including structural options and non-structural options. These options were investigated from an estuary management and flood management perspective.

Option F-1A is a combination of two structural options suggested in the EMP, involving widening and deepening of the creek channel near the mouth, in conjunction with a training wall on the western side of the creek mouth.

The additional conveyance capacity of the creek mouth is to allow upstream floodwaters to escape into the bay more readily. The following creek entrance conditions were modelled to reflect the proposed widening and deepening of the channel (*refer* **Figure 7.2**):

- A 20m wide channel;
- Excavation depth between 0.8m and 1.5m below existing conditions to obtain a channel bed level of approximately 0.2 mAHD.

As outlined in the Bundeena Creek EMP, the average sediment movement along Hordens Beach results in net transport of sand from west-to-east towards the creek mouth.

Accordingly, this option would also require the installation of large geofabric containers (*refer* **Plate 7-1**) to create a training wall on west side of the excavated entrance channel, which would trap the sand transported from the west and protect the creek mouth from blockage.

The existing 20m long footbridge over the creek would need to be replaced with a 35m bridge in order to span the widened creek.

Plate 7-1 Example of large Geofabric Containers to create a training wall

Hydraulic Assessment

The proposed channel geometry was incorporated into the TUFLOW flood model, which was used to simulate the 1% AEP event.

The impact of Option F-1A on existing 1% AEP flood levels is shown in **Figure 7.4**, which indicates that there will be a wide-spread reduction in flood levels across Bundeena. The most significant reductions are expected along the creek north of Bundeena Drive, with reductions in the order of 400 mm to 560 mm.

There are also significant flood level reductions to the south, ranging from 400mm at Bundeena Drive to 200 mm at the northern side of Scarborough Street. The reductions in flood level across the remainder of the lower floodplain are up to about 140 mm. There is expected to be a marginal reduction in the extent of flooding in some areas.

The overall reduction in 1% AEP flood damages was calculated to be about $1.01m, which represents almost a 50% reduction in damages relative to existing conditions.

Cost Estimate

The cost of implementing Option F-1A is estimated to be about $632,000 (*refer* **Appendix D**) which represents the total present value of upfront costs and maintenance costs with a 20% contingency.

The capital cost includes an allowance for excavation of the channel, installation of the geofabric containers and replacement of the foot bridge. Ongoing maintenance costs include periodic maintenance dredging of the channel once every 3 years over a design life of 30 years, in addition to an allowance for replacement of the geofabric containers after 15 years, which represents the nominal design life for these units.

Environmental Factors

Bundeena Creek is classified as an Intermittently Closed and Open Lake or Lagoon (ICOLL), with the typically closed entrance opening during periods of high rainfall / stream flows, large tidal events, or through physical intervention (*GHD, 2009*).

ICOLLs are typically very sensitive to human intervention or influence. The artificial opening of estuary entrances can create an interruption to the natural hydraulic regime of the ICOLL, resulting in increased tidal flushing which may affect the existing water quality balance.

Accordingly, there is potential for the Option F-1A permanent entrance channel to impact on the ecology of Bundeena Creek. The proposed geofabric container training wall may also interfere with the natural balance of sediment movement along Hordens Beach and in the nearshore zone of Bundeena Bay.

7.3.2 Option F-1B: Entrance Berm Management (Eastern Channel)

The flood model results for Option F-1A (*refer* **Figure 7.4**) indicate that works to maintain an open entrance during flooding will be effective in reducing 1% AEP flood levels across the lower parts of Bundeena. To reduce the potential environmental impacts and also the cost of construction, a softer option to increase the capacity of the entrance was also considered. The term "softer" is used to describe on-ground works that are not considered hard structural works, and typically involve measures to blend into the natural environment.

Option F-1B would involve the implementation of a berm management program to periodically excavate the beach berm at the entrance down to a level of approximately 1.5 mAHD. Floodwaters within Bundeena Creek are expected to overtop this lowered berm level and hence trigger a scouring of the entrance channel, even during an event as small as the 50% AEP storm. This scoured entrance will provide additional capacity for floodwaters to escape the creek and thereby reduce upstream flooding.

The beach berm excavation protocols would require the natural beach berm level to be excavated from a level of approximately 2.5 mAHD down to 1.5 mAHD over a 40m width at the eastern end of Hordens Beach (*refer* **Figure 7.2**).

It is assumed that the 40m section of lowered berm will erode down to a level of about 0.8 mAHD during a flood, which represents the lowest part of the existing channel, based on the LiDAR data. According to the Hjulstrom curve shown in **Plate 7-2**, velocities of more than 0.25 to 0.6 m/s are required in order to mobilise medium to coarse sand, which is the typical grain size expected at Hordens Beach (*between 0.3 and 2 mm*).

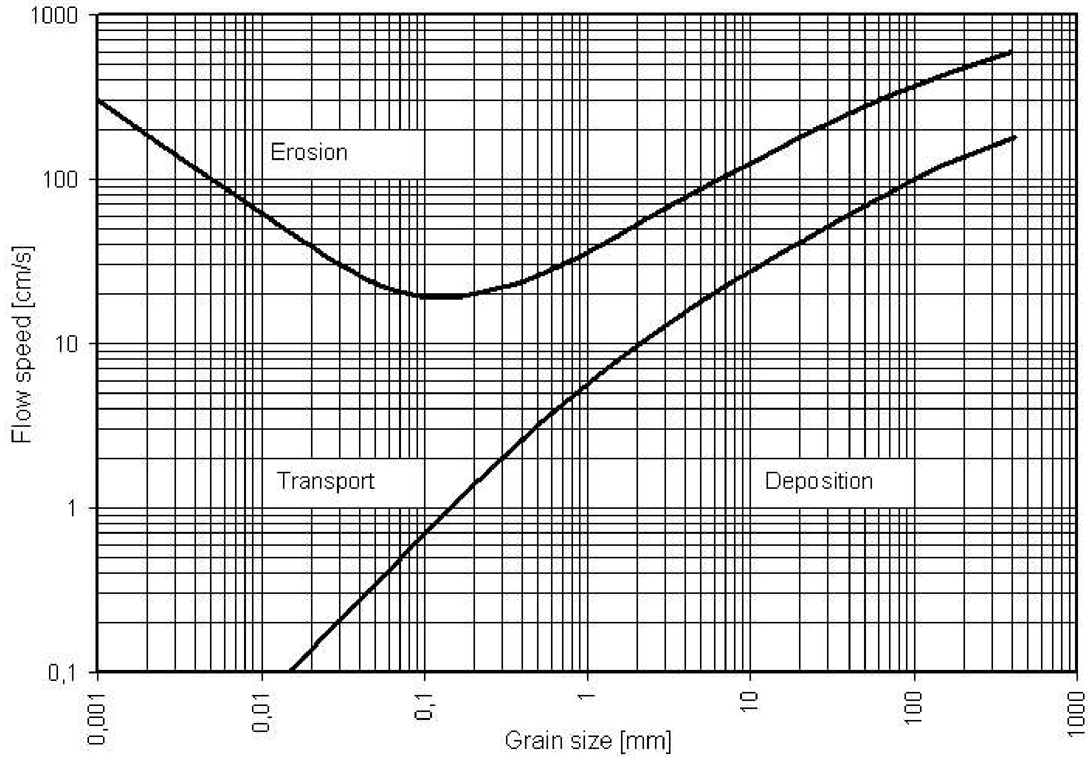


Plate 7-2 Hjulstrom Curve (*source: Wikipedia*)

The 1% AEP time-series model results for Option F-1B were reviewed to determine that the velocity across the berm would rise quickly following commencement of the berm erosion, with the 0.6 m/s threshold for the largest sand particles being reached once the berm has eroded by 200 to 300mm. The subsequent maximum velocity will be about 0.8 m/s according to the TUFLOW results, indicating that sufficient erosion potential will exist to create the channel.

Option F-1B would require removal and replacement of the existing footbridge with a longer bridge with span of about 50m.

Hydraulic Assessment

The proposed berm and channel geometry were incorporated into the TUFLOW flood model as follows:

- An initial berm elevation of 1.5 mAHD is adopted, representing the excavated berm.
- When a trigger flood level of 1.6 mAHD is reached on the upstream side of the berm, it commences to reduce in height from 1.5 to 0.8 mAHD over a period of 30 minutes, representing the time taken for floodwaters to erode the berm and create the widened channel.

The impact of Option 1B on existing 1% AEP flood levels is shown in **Figure 7.5**, which indicates that there will be a wide-spread reduction in flood levels across Bundeena. The result is similar to that for Option F-1A, albeit the benefit is slightly reduced.

The most significant reductions are expected along the creek north of Bundeena Drive, with reductions in the order of 400 mm to 500 mm.

South of Bundeena Drive the reduction in 1% AEP levels is up to 360 mm and in the remainder of the lower floodplain reductions are similar to that observed in the modelling of Option F-1A, with less than a 10 mm difference when comparing the two mitigation options.

The overall reduction in 1% AEP flood damages was calculated to be about $0.99m relative to existing conditions.

Cost Estimate

The cost of implementing Option F-1B is estimated to be $428,000 (*refer* **Appendix D**), which represents the total present value of upfront costs and maintenance costs with a 20% contingency.

The capital cost includes an allowance for initial excavation of the berm and replacement of the foot bridge. An ongoing maintenance cost is included to account for the periodic excavation of the berm once every year over a design life of 30 years to maintain it at the 1.5 mAHD level.

Environmental Factors

The typical creek entrance bed level is about 0.8 mAHD according to the captured LiDAR data, which is about 700mm below the proposed berm excavation level of 1.5 mAHD. Accordingly, Option F-1B will not have a material impact on how Bundeena Creek functions as an ICOLL under existing conditions.

Nor is this option expected to have any impact on sand transport along Hordens Beach over the longer term. Immediately following a flood event there may be increased scour and deposition of sediments into the nearshore zone, however this sediment would be slowly worked back onto the beach via normal wave action.

Under a sea level rise scenario the 1.5 mAHD berm would be sufficiently high as to not allow flow into the creek under normal tidal conditions. The effectiveness of berm management may be reduced in a sea level rise scenario given the damping effect of a raised tailwater level. The berm management protocols could be reviewed periodically as required.

7.3.3 Option F-1C: Berm Management (Central Channel)

Option F-1C is similar to Option F-1B and will involve periodically lowering the level of the beach berm down to 1.5 mAHD to allow upstream floodwaters to overtop the berm and erode a temporary channel across the beach.

However, an alternative location for the berm excavation was considered given the need to replace the existing footbridge as part of Option F-1B. Replacement of the footbridge can be avoided if the berm excavation is positioned centrally in the space between Bundeena House and the eastern end of the beach (*refer* **Figure 7.3**).

The central location of the resultant channel through the beach berm would also allow a more streamlined discharge from the creek into the bay, thereby providing additional benefit in reducing upstream flood levels. The location of berm excavation was not pushed any further westward for fear of eroding the area adjacent to Bundeena House.

A similar flood modelling approach to Option F-1B was adopted.

Hydraulic Assessment

The impact of Option F-1C on existing 1% AEP flood levels is shown in **Figure 7.6**, which indicates that there will be a wide-spread reduction in flood levels across Bundeena.

The result is similar to that for Option F-1B. However, Option F-1C will be slightly more effective in reducing flood levels to the north of Scarborough Street, and slightly less effective in areas immediately surrounding Scarborough Street and to the south of Scarborough Street. Generally, the flood level reductions afforded by Option F-1C will be within 30mm of those for Option F-1B.

The overall reduction in 1% AEP flood damages was calculated to be about $0.97m relative to existing conditions.

Cost Estimate

The cost of implementing Option F-1C is estimated to be $186,000 (*refer* **Appendix D**), which represents the total present value of upfront costs and maintenance costs with a 20% contingency.

The capital cost includes an allowance for initial excavation of the berm and distribution of the sand along Hordens Beach. An ongoing maintenance cost is included to account for the periodic excavation of the berm once every year over a design life of 30 years to maintain the berm at the 1.5 mAHD level.

Environmental Impacts

The environmental considerations are similar to those discussed above for Option F-1B.

A lowered beach berm level at 1.5 mAHD will still be above ocean tide levels, even in a king tide or ocean storm surge situation. Accordingly, this option is not expected to increase the risk of coastal inundation or flooding to residents along the creek.

But note that tidal inflows or storm surge would still be able to travel up the normal creek channel and thereby cause erosion of the natural berm from the side. The major storm event in June 2016 created severely high ocean levels which overtopped/eroded the entire beach berm, as shown in photographs and video by a continuous water surface between the sea wall and Bundeena House. Option F-1C would have no material impact in an extreme event like June 2016.

The periodic berm excavation would not affect the visual or recreational amenity of the beach. The section provided in **Figure 7.3** is an engineering sketch and incorporates an exaggerated vertical scale to clearly show key features. In reality, the side slopes at either end of the lowered berm will be very gradual and will not be noticeable; nor will they affect recreational access to the beach.

7.3.4 Option F-2: Flood Protection Levee

Option F-2 comprises the construction of a flood protection levee across the western part of the lower floodplain between properties in Bundeena and the Royal National Park (*refer* **Figure 7.1**).

The levee would be intended to protect properties to the north of the levee, including those further north near Bundeena Drive. Given the space constraints at the rear of properties to the north of Scarborough Street the initially tested levee only extends south from Scarborough Street. The western end of the levee would tie-in to the higher terrain at Bundeena Drive, above the level of flooding.

The proposed levee would be constructed as a grassed earthen levee according to the following geometry:

- Crest elevation of 2.4 mAHD (approximately 100mm above the 1% AEP flood level).
- Total length of approximately 780m.
- Typical height of approximately 0.7m, with side batters of 1(V):4(H) to facilitate mowing maintenance.
- Base width of approximately 8m, allowing for side batters and a 2m wide crest.

Hydraulic Assessment

The proposed levee was incorporated into the TUFLOW model and simulated for the 1% AEP event. The impact on 1% AEP flood levels due to Option F-2 is illustrated in **Figure 7.7**.

As shown, the levee is expected to reduce the level of flooding in areas to the north of the levee by between 20 and 30 mm. The benefit in these areas is somewhat limited because floodwaters are expected to travel around the eastern end of the levee across Scarborough Street and through properties to the north of the street. If the levee was to be extended further north, across Scarborough Street, along the rear of Liverpool Street properties and tie-in with higher ground near Bundeena Drive then the reduction in flood levels behind the levee may be improved.

However, as shown in **Figure 7.7**, the levee as modelled is expected to increase 1% AEP flood levels to the south of the levee, which is the result of floodwaters building-up against the levee. Within the National Park the increases in peak flood level will be up to 45 mm. In areas south of Scarborough Street and east of the creek some residential lots will experience an increase in 1% AEP flood levels of up to 30 mm due to the levee.

Such adverse impacts are typically not acceptable as part of best-practice floodplain management. And it is expected this adverse impact would be exacerbated in the scenario that the proposed levee is extended further north across Scarborough Street towards Bundeena Drive. Accordingly, it was not considered worthwhile to pursue this option any further.

Cost Estimate

The cost of implementing Option F-2 is estimated to be $788,000 (*refer* **Appendix D**), which represents the total present value of upfront costs and maintenance costs with a 20% contingency.

The capital cost includes allowances for construction of the levee and appropriate surface treatments. Ongoing maintenance costs allow for inspections and maintenance activities once every three years.

Environmental Factors

Construction of the proposed levee would disrupt the existing vegetation along the fringe of the Royal National Park. It would also cause a disruption to affected residents on the east side of Liverpool Street, particularly the southern-most lot as the existing creek cuts across the corner of this property. These residents would lose part of their rear yard due to the geometry of the levee with an 8 metre base width.

7.3.5 Option F-3: Creek Channel Enlargement

Opportunities for creek upgrades were investigated, with a view to increasing the capacity of the creek and thereby reducing upstream flood levels. Upstream and downstream of Bundeena Drive the creek is relatively incised and optimised within the constraints of existing houses and topography, thereby limiting the potential for any upgrade works in this area.

However, the section of creek stretching approximately 120m downstream from Scarborough Street appears to have a relatively low capacity when reviewing the available LiDAR and creek bathymetry data, as compared to the existing and proposed drainage easements at the rear of properties along the creek.

Accordingly, this stretch of the creek was identified for channel widening and deepening. The proposed works would involve widening the creek base from about 2m to 8m and widening the top-of-channel from about 10m to 20m (*refer* **Figure 7.1**), thereby utilising the full width of existing and proposed drainage easements. The overall bed level of the creek would not be lowered because of the need to tie-in with upstream and downstream bed levels.

Hydraulic Assessment

The proposed channel works were incorporated into the TUFLOW model and tested for the 1% AEP event. In addition to the geometry changes outlined above, the material roughness of n = 0.04 associated with in-channel areas was extended to cover the widened footprint of the channel. This represents a reduction in roughness relative to the original roughness of 0.10 (*forested floodplain*).

The resultant impact on 1% AEP flood levels is shown in **Figure 7.8**. The maximum reduction in flood levels is expected to occur upstream from Scarborough Street and is only 10 to 20mm, which is not significant.

Downstream from the proposed channel works there is predicted to be a minor increase in peak 1% AEP flood levels of about 5 to 6 mm.

The overall reduction in 1% AEP flood damages was calculated to be about $131,000 relative to existing conditions, which represents a reduction of about 6%.

Cost Estimate

The cost of implementing Option F-3 is estimated to be $318,000 (*refer* **Appendix D**), which represents the total present value of upfront costs and maintenance costs with a 20% contingency.

The capital cost includes allowances for temporary piping to bypass flows during construction, the excavation works and removal of material in addition to surface treatments and bush regeneration works. Ongoing maintenance costs allow for maintenance dredging once every five years and vegetation management once every three years.

7.3.6 Option F-4: Scarborough Street Culvert Upgrade

Option F-4 would involve the upgrade and realignment of the box culvert that runs beneath Scarborough Street, which conveys floodwaters accumulated in the southern swamp area into the top of the defined Bundeena Creek channel. The upgrade of this culvert has long been favoured by local residents who see these works as being critical in reducing the instances of floodwaters overtopping Scarborough Street. The existing culvert is skewed relative to the downstream creek channel and therefore, there is a perception that the hydraulic efficiency will be improved if the culvert is realigned to be perpendicular to Scarborough Street.

The culvert upgrade has been investigated in the past, including the preparation of design drawings by WorleyParsons. It was discovered at the time that there is a sewer main and large water supply main (*300mm diameter*) positioned along the north side of Scarborough Street, which would need to be relocated as part of the culvert upgrade works.

The proposed upgrades to the culvert, as tested with the TUFLOW model, would include:

- Replacing the existing 2.1m W x 0.9m H box culvert with a wider 3.6m x 0.9m box culvert.
- Realigning the culvert to follow the creek channel direction. The existing box culvert is skewed eastward, towards a retaining wall on the northern side of Scarborough Street.

Hydraulic Assessment

The widened and realigned box culvert was incorporated into the TUFLOW model and tested for the 1% AEP event.

The impact of the culvert on 1% AEP flood levels is illustrated in **Figure 7.9**, which shows that the culvert works will provide minimal to no benefit during such flooding and therefore, the overall reduction in flood damages was calculated to be only $11,000.

The 5% AEP event was also simulated, to test if the proposed works would provide a benefit during more frequent, smaller floods. However, the TUFLOW results again showed minimal benefit.

This result is largely due to the low elevation of the Scarborough Street roadway (*~1.7 mAHD*) relative to the tailwater level modelled in Bundeena Bay (*1.51 mAHD for the 1% AEP event*). The invert of the culvert beneath the road is about 0.7 mAHD, which means that the culvert will be largely drowned-out by the tailwater and therefore, won't provide any significant conveyance capacity unless there is sufficient head upstream (*i.e., elevated flood levels*) to drive the flow through.

Even in the smallest event modelled (50% AEP) the tailwater level in Bundeena Bay is 1.25 mAHD, which would inundate the culvert to a depth of 550mm and thereby reduce the equivalent free-draining capacity by more than 50%.

Notwithstanding this, it is also recognised that the constriction of the creek near the entrance, downstream from Bundeena Drive, will cause a backing-up of floodwaters that would overtop Scarborough Street and drown the box culvert irrespective of the tailwater level adopted in Bundeena Bay. For example, in the March 2012 event despite having a tailwater recorded and modelled as 1.16 mAHD, the results of the calibration simulations showed a steep flood profile up to 1.8 mAHD directly behind the beach berm but then a relatively flat flood profile upstream to Scarborough Street at 1.9 mAHD.

As shown by the indicative long-section of the creek in **Plate 7-3**, the backing-up of floodwaters due to constrictions downstream of Bundeena Drive has an impact up to Scarborough Street and beyond. Accordingly, any upgrade of the Scarborough Street culvert will have minimal benefit in reducing flood levels as it will not help floodwaters to escape the entrance.

The constriction in the creek near the entrance appears to have a more pronounced backwater effect in lower tailwater scenarios relative to higher tailwater scenarios, meaning that upgrade to the culvert beneath Scarborough Street is expected to provide minimal benefit in either situation. This has been confirmed by detailed flood modelling.

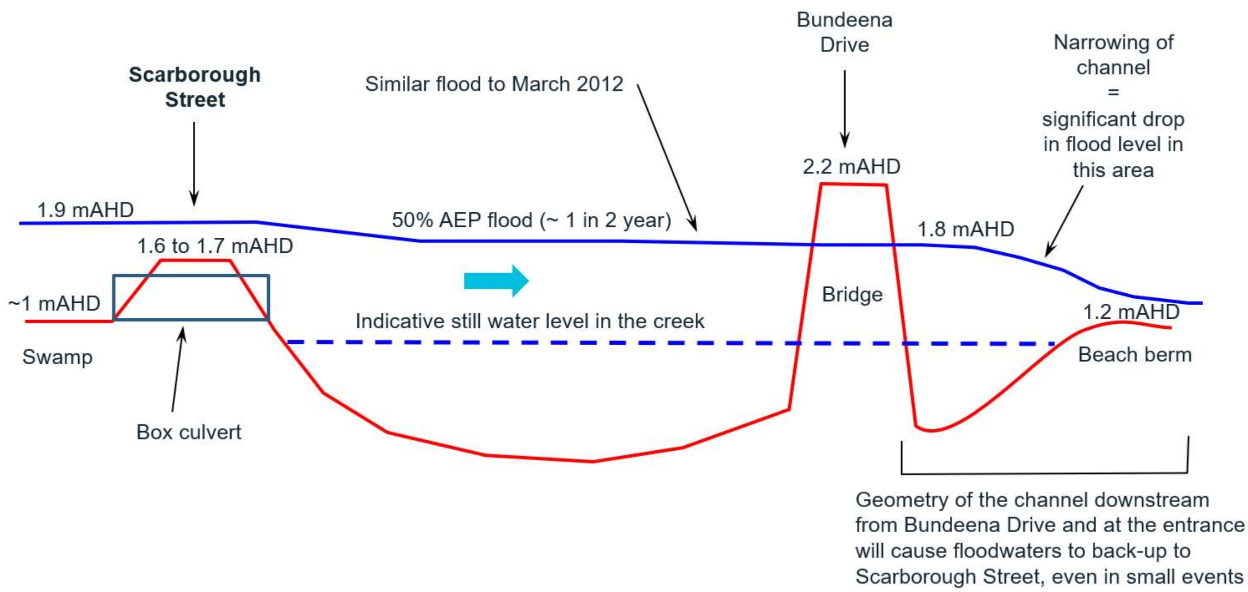


Plate 7-3 Indicative Longitudinal Section of Bundeena Creek Flooding

Cost Estimate

The cost of implementing Option F-4 is estimated to be $281,000 (*refer* **Appendix D**), which represents the total present value of upfront costs with a contingency of 20%.

The capital cost includes allowances for temporary piping to bypass flows during construction, demolition and trenching of the roadway, culvert installation, reinstatement of the pavement and relocation of water and sewer services. No additional maintenance costs were included as it is expected the existing culvert is already part of Council's maintenance regime.

7.3.7 Option F-5A: Stormwater Outlet to Hordens Beach

Option F-5A would involve the installation of a new stormwater outlet to Hordens beach (*refer* **Figure 7.1**), with the intention of facilitating the escape of floodwaters ponding in the area between Laurence Avenue, Thompson Street and Liverpool Street.

This option would involve the installation a 600mm diameter stormwater pipe from Hordens Lane to the beach through an existing access reserve positioned opposite to the northern end of Thompson Street. It would also require the construction of additional stormwater pipes (*600mm diameter*) along Hordens Lane and within the northern parts of Laurence Avenue and Thompson Street, in order to connect the existing street drainage to the new stormwater line to the beach (*compare* **Figures 3.7** *and* **7.1**). The entire additional length of piping that would be required is approximately 430m.

The proposed outlet at the beach would need to extend sufficiently beyond the surf zone to minimise potential for the outlet to become blocked with beach sand. The works would also involve the construction of geofabric container groynes above the outlet pipe at Hordens Beach in order to protect the pipe from wave attack.

Hydraulic Assessment

The additional stormwater pipe network and beach outlet was incorporated into the TUFLOW model, which was then used to simulate the 1% AEP event.

The impact of Option F-5A on 1% AEP flood levels is shown in **Figure 7.10**. The benefit in terms of reduced flood levels is limited to areas north of Bundeena Drive, between Laurence Avenue and Liverpool Street. Reductions in 1% AEP flood levels would be up to 75 mm in this area, resulting in some minor reduction in the flood extent. Flood levels in other areas of Bundeena would be largely unaffected by the proposed drainage works.

The reduction in 1% AEP flood damages was calculated to be about $210,000 relative to existing flood conditions.

Cost Estimate

The cost of implementing Option F-5A is estimated to be $820,000 (*refer* **Appendix D**), which represents the total present value of upfront costs and future maintenance costs with a contingency of 20%.

The capital cost includes allowances for site establishment, demolition of the roadways and trenching, installation of the stormwater pipes, reinstatement of the pavements, construction of beach groynes and site clean-up. Ongoing maintenance costs include replacement of the geofabric containers after 15 years, which represents the nominal design life for these units.

Environmental Factors

The installation of the proposed stormwater pipes within Hordens Lane and adjacent streets will cause some disruption to local traffic during construction.

There is expected to be impact on the amenity of Hordens Beach during construction of the stormwater outlet and groyne at the beach, and potentially an impact on the water quality and ecology of the nearshore zone unless appropriate management measures are employed.

Following construction, the groyne may have an ongoing impact on sediment movement along the beach. A stormwater quality improvement device might also be needed on the new stormwater line to minimise any discharge of gross pollutants and nutrients to the bay.

7.3.8 Option F-5B: Two Stormwater Outlets to Hordens Beach

Option F-5B is identical to Option F-5A, however with the addition of a second stormwater outlet to Hordens Beach. The additional outlet would pass to the beach through the existing boat ramp reserve at the northern end of Liverpool Street (*refer* **Figure 7.1**). The second outlet would provide additional capacity to drain the low-lying areas north of Bundeena Drive.

The total length of additional 600mm diameter stormwater pipe required for Option F-5B is approximately 540m. This option would require the construction of two geofabric container groynes to provide protection to both outlets.

Hydraulic Assessment

The impact of Option F-5B on 1% AEP flood levels is shown in **Figure 7.11**. Similar to Option F-5A, the benefit is limited to areas north of Bundeena Drive, between Laurence Avenue and Liverpool Street. Reductions in 1% AEP flood levels would be in the order of 90 to 200mm, with the greatest reductions expected along the northern part of Liverpool Street. Flood levels in other areas of Bundeena would be largely unaffected by the proposed drainage works.

The reduction in 1% AEP flood damages was calculated to be about $350,000 relative to existing flood conditions.

Cost Estimate

The cost of implementing Option F-5B is estimated to be $1,127,000 (*refer* **Appendix D**), which incorporates similar allowances to that provided for Option F-5A plus the cost of the additional stormwater outlet and geofabric container groyne.

Environmental Factors

The potential impact on the environment would be similar to that for Option F-5A, with potentially increased impacts due to the additional stormwater outlet and groyne at Hordens Beach.

7.3.9 Option F-6: Scarborough Street Culvert and Channel Upgrade

The widening of the Scarborough Street culvert from 2.1m to 3.6m was demonstrated to have little impact in reducing 1% or 5% AEP flood levels in Option F-4 (refer **Section 7.3.6**), including in the case of high or low tailwater levels in Bundeena Bay.

However, the local community has expressed again its long-standing preference for upgrading the Scarborough Street culvert because of the perceived benefit in reducing flood levels both upstream and downstream. Accordingly, it was decided to investigate the impact of a theoretical maximum widening of the culvert in combination with enlargement of the creek channel downstream of the culvert (*as in Option F-3*).

This option would involve replacement of the existing single 2.1m x 0.9m box culvert with three 3.0m x 0.9m box culverts, thereby representing a total width of culverts of 9 metres. The downstream creek channel would be enlarged to match the width of culverts and otherwise works would be similar to Option F-3. This option was tested as a best-case scenario which would return the maximum possible benefit for such works.

Hydraulic Assessment

The impact of Option F-6 on 1% AEP flood levels is shown in **Figure 7.12**. There is expected to be only minor reductions in peak flood levels of up to 10 mm to the south of the proposed works. However, minor increases in flood levels of up to 6mm are expected to the north of the upgrades.

The reduction in 1% AEP flood damages was calculated to be about $130,000 relative to existing flood conditions.

The impacts on 1% AEP flood levels are similar to those observed in the model results for Option F-3, suggesting that the channel works are responsible for more of the reduction in peak flood levels than the Scarborough Street culvert upgrades, at least for the 1% AEP storm.

In addition to the 1% AEP event, this option was modelled for the 50% AEP storm to assess if there would be any benefit in reducing nuisance flooding during smaller events. The 50% AEP flood levels are expected to decrease by up to 14mm to the south of Scarborough Street (*refer* **Figure 7.13**).

In the vicinity of Scarborough Street 50% AEP flood levels are expected to decrease by up to 30mm. However, downstream from the channel enlargement works flood levels are expected to be increased by 5 to 6mm, which is similar to what is expected in the 1% AEP event. The reduction in 50% AEP flood damages was calculated to be only $11,000 relative to existing flood conditions.

Cost Estimate

The cost of implementing Option 8 is estimated to be $705,000 (*refer* **Appendix D**), which represents the total present value of upfront costs and ongoing maintenance costs with a contingency of 20%. The capital cost and maintenance costs include allowances for the same items outlined above for Options F-3 and F-4.

7.4 Indicative Benefit-Cost Analysis of Flood Modification Options

A benefit-cost analysis was undertaken to assess the economic viability of implementing the identified flood mitigation options. The estimated cost of construction/implementation was compared with the predicted monetary benefit offered by each option in terms of the potential reduction in flood damages.

Because the full range of design flood events was not simulated as part of the Stage 1 assessment, the Average Annual Damage (AAD) for each option was approximated by comparing damages calculated for the 1% AEP storm for each option to the damages calculated for the 1% AEP storm under existing conditions (*base case*). The AAD was estimated according to the ratio of the option 1% AEP damages to the base case 1% AEP damages.

There is potential for this approach to over-estimate the overall benefit-cost because the options may provide a lesser benefit in smaller storm events. However, given the 100 year ARI event is a typically adopted design objective for floodplain management measures, it is considered appropriate to use this methodology in order to undertake a relative comparison between options.

The 'benefit' was calculated over a design life of 30 years as the present value of the reduction in AAD for each management option relative to the AAD that would be incurred under existing conditions. A real discount rate of 7% was adopted, which is the same used to determine the present value of the cost of options.

In this way, an indicative Benefit-Cost Ratio (BCR) was determined for each flood modification option, which is useful for purpose of comparison between options (*refer* **Table 7-2**). As shown, the options involving creek entrance works are expected to have a BCR higher than the other options.

Table 7-2 Indicative Benefit-Cost Assessment of Flood Modification Options

Option	Cost of Works (PV)	1% AEP Damages	Present Value of Damage Reduction	Benefit-Cost Ratio
Existing Conditions	----	***$2.08m***	----	----
F-1A. Entrance widening and deepening	$632k	$1.07m	$3.20m	5.1
F-1B. Entrance berm management (eastern)	$428k	$1.09m	$3.12m	7.3
F-1C. Entrance berm management (central)	$186k	$1.11m	$3.06m	16.4
F-2. Flood protection levee	$788k	$1.59m	$1.55m	2.0
F-3. Creek channel upgrades	$318k	$1.95m	$0.41m	1.3
F-4. Scarborough St culvert upgrade	$281k	$2.07m	$0.03m	0.1
F-5A. One additional outlet to the beach	$820k	$1.87m	$0.66m	0.8
F-5B. Two additional outlets to the beach	$1.13m	$1.74m	$1.10m	1.0
F-6. Scarborough St culvert upgrade + channel upgrade	$705k	$1.95m	$0.41m	0.6

7.5 Triple Bottom Line Assessment of Mitigation Options

In addition to assessment of the economic benefit for each flood mitigation option, further assessment was undertaken to compare the options according to a range of additional criteria, including social and environmental factors.

The assessment criteria and their weighting are outlined in **Table 7-3**.

It is acknowledged that there will be some overlap between the flood impact criteria and the criteria for economic assessment. For example, an impact on flooding is likely to affect the cost of flood damages and therefore, impact on the benefit-cost ratio. However, in light of the primary objectives of this floodplain risk management study and plan, and the relevance of the associated flood modelling results, it is considered appropriate to give additional weighting to direct flood impacts and also the indirect consequences.

Table 7-3 Triple-Bottom-Line Assessment Criteria

Evaluation Criteria	Scoring Approach (0 to 5)	Weighting
Flood Impacts		
Impact on hydraulic behaviour	Worst/adverse=0, neutral=2.5, best=5	x 5
Reduction in flood damages	<$0.2M=0, >$0.2M=1, >$0.4M=2, >$0.6M=3, >$1M=4, >$2M=5 (present value)	x 4
Economic		
Benefit / Cost Ratio	<0.2=0, <0.3=1, <0.5=2, <1= 3, ≥1=4, >1.5=5	x 4
Life cycle cost of option	>$5M=0, >$1M=1, >$0.8M=2, >$0.5M=3, >$0.3M=4, <$0.3M=5	x 4
Social		
Impact on local community	Worst/adverse=0, neutral=2.5, best=5	x 4
Likely community acceptance	Least support=0, neutral=2.5, most support=5	x 3
Environmental		
Disruption to the natural character of the area	Worst/adverse=0, neutral=2.5, best=5	x 3
Ecological impacts	Worst/adverse=0, neutral=2.5, best=5	x 4

Each flood modification option was assigned a score of 0 to 5 against each criterion; 5 being the best score indicating the most beneficial impacts and zero being the lowest score or negative impacts. For the more qualitative criteria, such as ecological impacts and disruption to the natural character of the area, a median score of 2.5 was applied in the case of neutral impacts.

Where possible, the criteria were scored quantitatively; for example, the life cycle cost for each option was scored according to the present dollar value of the total life cycle costs.

The Triple-Bottom-Line assessment for all potential mitigation options is summarised in **Table 7-4**. Additional information and justification of the individual scores is provided in **Appendix E**.

As shown in **Table 7-4**, the highest scoring options were the creek entrance management options. The lowest scoring options were the stormwater outlets to Hordens Beach, and the flood protection levee. Upgrade of the Scarborough Street culvert also scored relatively low despite the obvious community support for this option.

Table 7-4 Triple-Bottom-Line Assessment (Flood Modification Measures)

Evaluation Criteria	Weighting	Option – Raw Scores										Option – Weighted Scores								
		1A	1B	1C	2	3	4	5A	5B	6		1A	1B	1C	2	3	4	5A	5B	6
		Entrance Widening and Deepening	Entrance Berm Management (eastern channel)	Entrance Berm Management (central channel)	Flood Protection Levee	Creek Channel Upgrade	Scarborough St Culvert Upgrade	Additional Drainage Outlet to the Beach	Two Drainage Outlets to the Beach	Scarborough St Culvert Upgrade and channel upgrade		Entrance Widening and Deepening	Entrance Berm Management (eastern channel)	Entrance Berm Management (central channel)	Flood Protection Levee	Creek Channel Upgrade	Scarborough St Culvert Upgrade	Additional Drainage Outlet to the Beach	Two Drainage Outlets to the Beach	Scarborough St Culvert Upgrade and channel upgrade
Flood Impacts																				
Impact on hydraulic behaviour	**5**	4	4	4	1	2.5	2.5	3	3	2.5		20	20	20	5	13	13	15	15	13
Reduction in flood damages	**4**	5	5	5	4	2	0	3	4	2		20	20	20	16	8	0	12	16	8
Economic																				
Benefit / Cost Ratio	**4**	5	5	5	5	4	0	3	3	3		20	20	20	20	16	0	12	12	12
Life cycle cost of option	**4**	3	4	5	3	4	5	2	1	3		12	16	20	12	16	20	8	4	12
Social																				
Impact on local community	**4**	1	2	2.5	3	3	3	2	1.5	3		4	8	10	12	12	12	8	6	12
Likely community acceptance	**3**	3	3	3.5	2	2	4	2	1.5	3		9	9	11	6	6	12	6	5	9
Environmental																				
Disruption to the natural character of the area	**3**	1	3	3	2	2	3	2	2	2		3	9	9	6	6	9	6	6	6
Ecological impacts	**4**	2	3	3	2	2.5	2.5	1	1	2.5		8	12	12	8	10	10	4	4	10
											TOTAL SCORE	**96**	**114**	**122**	**85**	**87**	**76**	**71**	**68**	**82**
											RANK	**3**	**2**	**1**	**5**	**4**	**7**	**8**	**9**	**6**

7.6 Community Consultation

Community consultation was undertaken in Bundeena during preparation of the 2014 *Bundeena Creek Flood Study* (*WorleyParsons*). This prior consultation was aimed at informing local residents of the potential flood risk, as shown in the flood mapping produced as part of the Flood Study. However, the community feedback also included recommendations for reducing the impact of flooding, such as upgrade of the Scarborough Street culvert and entrance management works.

7.6.1 Information Session, Newsletter and Questionnaire (Stage 1)

A community information session for the Floodplain Risk Management Study was held on Friday 15th December 2017 at the Bundeena Community Centre. This session provided opportunity to present the findings of the Stage 1 options assessment in the form of poster displays, one-on-one discussions and a community newsletter with questionnaire. The consultation was focussed on potential flood management measures, but also included general information about the existing flood risk.

The information session was well attended, with between 20 and 30 people passing through the exhibits during the course of the afternoon. The age demographic of attendants was typically between middle-aged and the elderly. One-on-one discussions during the session were focussed around creek entrance conditions and the historic flooding observed across Scarborough Street.

The newsletter and questionnaire were also letter-box dropped to 450 households and businesses in Bundeena identified as being on flood prone land (*i.e., within the PMF extent*). The purpose of the questionnaire was to:

- Understand the community's perception of flood risk;
- Identify whether or not their local area or current address had experienced flooding, and if so, when and under what circumstances it flooded;
- Identify areas where priority should be placed for any future flood management work; and
- Ask community members for their opinions on potential flood mitigation measures and whether they would support them.

7.6.2 Consultation Outcomes

A total of 15 questionnaire responses were received along with two additional email submissions. While this represents a response rate of less than 5%, when considered alongside the decent attendance at the information session, the overall community interest in flooding and floodplain management is relatively strong for a catchment of this size.

12 of the respondents have lived in the area for more than 20 years, with five having lived in the area for more than 40 years. The majority of respondents perceive the greatest cause of flooding in the catchment to be related to blockage of the creek channel, bridges and stormwater drains, which was followed closely by overland flow impediments (*fences and other obstacles*).

In response to the question on where action is most urgently needed to minimise flooding, 10 of the 15 questionnaire respondents identified Scarborough Street in the vicinity of the creek crossing as being the priority. Other priority areas included between Laurence Avenue, Thompson Street and Liverpool Street, and also the walkway between Rymill Place and Scarborough Street.

A summary of the responses on potential flood mitigation measures is outlined in **Table 7-5**. More detailed information on the questionnaire responses, including responses to other questions, are compiled in **Appendix F**.

Table 7-5 Community Opinion on Mitigation Strategies

Flood Mitigation Option	Support	Neutral	Oppose
Flood Protection Levees (on public land)	44%	25%	31%
Flood protection levees (some of which may encroach onto private property)	13%	44%	44%
Creek Channel works (e.g., channel widening, straightening, concrete lining)	56%	31%	13%
Entrance management works (e.g., regular works to maintain a wider entrance channel)	56%	25%	19%
Raising of dwellings or voluntary purchase of properties situated in high hazard areas of the floodplain	56%	31%	13%
Road raising to allow for improved evacuation	33%	47%	20%
Increasing the size of street stormwater pipes and inlet pit capacities	56%	44%	0%
Increasing the frequency of maintenance works of the creek channel (e.g., debris cleaning, vegetation control)	82%	18%	0%
Increasing the frequency of maintenance works of stormwater pipes and inlet pits (e.g., leaf and debris clearing)	87%	13%	0%

7.6.3 Discussion

Key findings from the information contained in **Table 7-5** are as follows:

- Community support for flood modification works was generally strong, with the exception of the flood protection levee options, particularly when involving encroachment into private property.
- The greatest support was for increasing the frequency of maintenance works in the creek and also stormwater drains, such as debris clearing and vegetation management . This suggests that the residents may not fully appreciate the mechanisms that cause major flooding in the catchment, or otherwise prefer options that involve relatively less structural works and hence less disruption. The culvert beneath Scarborough Street was often identified as a target for clearing or upgrade.
- Enlargements to the street drainage system were also strongly supported.
- Entrance management works also received relatively strong support.
- There was a relatively high combined "neutral" and "opposed" responses for road raising to allow improved evacuation, which may be related the overall perception that flood risk is low despite the relatively frequent nuisance flooding.

7.7 Stage 2 Assessment

According to the results of the Stage 1 Triple-Bottom-Line assessment and community feedback received during the information session and in questionnaire responses, entrance berm management was selected for further investigation.

Specifically, Option F-1C, involving a centrally located channel, was chosen for the Stage 2 assessment due to the advantages it offers, such as reduced overall cost and avoiding the need to replace the existing footbridge to the beach.

7.7.1 Refinement of Option F-1C Flood Damages Assessment

The Stage 2 assessment involved simulation of Option F-1C for the entire range of design events from the 50% AEP storm to the Probable Maximum Flood (*PMF*). This allows refinement of the flood damages analysis and the Benefit-Cost Ratio to account for smaller, more frequent events which can have a greater relative impact on the overall economic performance of an option.

It is confirmed that the 50% AEP flood (*smallest event tested*) will lead to a flood level of about 1.7 mAHD on the upstream side of the berm and hence will overtop the proposed berm level of 1.5 mAHD.

However, the TUFLOW modelling approach for more frequent floods (*50%, 20% and 10% AEP events*) adopted a slower rate of erosion for the beach berm, recognising that scour of the entrance channel would occur over a longer duration because the flow is not as great. For these events it was assumed the berm would be eroded from 1.5 to 0.8 mAHD over a period of about 1.5 hours.

The results of the extended flood damages analysis showed the following:

- Option F-1C is most effective at reducing damages during relatively major floods between the 5% AEP and 1 in 200 AEP events. In these events, the existing damages are reduced by 30% to 45%.
- The benefit is less during smaller events (*50% to 10% AEP*), in which case the existing damages are reduced by only 7% to 10%.
- There is almost negligible damages reduction in the PMF (*less than 1%*).
- The Present Value of the damage reduction is expected to be about $890,000, which is considerably less than the Stage 1 estimate based solely on the 1% AEP event (*refer* **Table 7-2**).

The BCR for Option F-1C is reduced to 4.8 when accounting for the extended damages analysis, which indicates that the economic benefit will still outweigh the estimated lifecycle costs.

7.7.2 Recommendations

It is recommended that Option F-1C be included in the Bundeena Floodplain Risk Management Plan for further investigation, design and implementation.

It is envisaged that further investigation and design would involve:

- Assessment of erosion potential at the beach berm to confirm that a channel base level of 0.8 mAHD is a realistic assumption, including sediment size analysis and the calculation of shear stresses. This should involve investigations to reduce the width of the lowered berm if at all possible, which would limit the excavation volume.

- Further assessment of coastal processes, including aeolian sediment transport, to confirm the expected frequency of maintenance works to bring the berm back down to 1.5 mAHD. This information would feed into an implementation plan for the works containing protocols to trigger the periodic excavation of the berm.
- Development of a sand distribution plan, for placement of excavated material along Hordens Beach, including a Review of Environmental Factors (REF).
- Additional consultation with residents and landowners in the vicinity of the works.
- Preparation of a *Beach Berm Management Feasibility Assessment* report to document the findings of the above investigations. This would include assessment of opportunities to incorporate entrance management works to address day-to-day blockage of the creek entrance.

8 Property Modification Measures

8.1 Background

Flooding is a significant naturally occurring hazard to the utilisation of land. Since the early days of European settlement of New South Wales, development has occurred within the floodplain which has not fully appreciated the implications of the nature and extent of the flood hazard. Development of these areas has occurred due to the proximity of transport corridors such as the rivers flowing through the floodplain, the flatness of floodplain lands which rendered them easier to build on, and more recently, the relatively lower cost per hectare.

In this context, appropriate floodplain management needs to recognise the full flood risk. That is, it must relate to the whole of the floodplain and not just to one isolated component of the floodplain defined by a particular flood occurrence, such as the area inundated in the 1% AEP flood.

This, however, does not mean that there should be restrictions on development within the entire floodplain. Instead, there should be a holistic approach to the management of the floodplain commencing from its broadest extent and progressively focusing inwards to more critical aspects of the use of the floodplain, such as development on land frequently affected by floods. This holistic approach may in some cases, reveal the capacity for more intense development for certain types of land-uses, as opposed to the rigid application of a global flood standard.

Generally, the management of a floodplain is approached by the imposition of either structural or non-structural measures. Traditionally, structural measures have played a major role to address the existing flood problem. In addition to flood modification works, such as those investigated in **Section 7**, there are structural property modification works that can be implemented, such as voluntary house raising or purchase.

Contemporary thinking in floodplain management is also focussed toward the implementation of non-structural measures. Non-structural measures include increased public awareness, the establishment of flood emergency response procedures and more recently, there has been an increased emphasis on developing floodplain management plans that recommend changes to planning controls contained within council planning instruments such as Development Control Plans (DCPs).

8.2 Structural Measures

8.2.1 Option P-1: Voluntary House Raising

Voluntary house raising has been considered as a property modification measure with the objective of reducing existing flood damages. This measure can be applied to houses of piered construction, which means that single storey high-set dwellings are typically best suited to house raising. Houses of slab-on-ground construction are excluded as raising is not feasible or cost-effective.

The inclusion of a house within a proposed voluntary house raising (VHR) scheme does not place any obligation on the owner of the property to raise the house. Landowner participation is voluntary (*OEH, 2013a*).

OEH requires any potential VHR to consider the following:

- The full range of design flood events and their impacts;
- VHR is generally excluded in floodway and high hazard areas;
- Cost-effectiveness of the proposed house raising scheme, with the aim of damages reductions outweighing the house raising costs (*i.e., a BCR > 1.0*);
- The viability of the scheme and its prioritisation;
- The support of the affected community, as determined through consultation.

The OEH grant funding criteria also includes the following:

- Funding is only available for residential properties and not commercial or industrial properties;
- Dwellings constructed after 1986 are not eligible, as this is the date of gazettal of the original Floodplain Development Manual which includes construction principles to avoid flood damage;
- Properties already substantially benefited by other floodplain mitigation measures are not eligible for VHR funding;
- VHR should involving raising dwellings above a minimum design level, such as Council's Flood Planning Level (*i.e., 1% AEP level plus 500mm freeboard*).

The TUFLOW model results were reviewed against eligible properties to determine which houses would benefit from house raising. A range of design events and depth criteria were considered through an iterative approach to obtain the highest Benefit-Cost Ratio (*BCR*), while also limiting the VHR scheme to a manageable overall cost.

The results of this testing indicate that VHR would be suitable for dwellings with floor levels subject to depths of 0.1m or greater during the 1% AEP event. Adopting this criterion resulted in the selection of eight dwellings for raising, as shown in **Figure 8.1**. The identified houses are not located within floodway or high hazard areas.

It was determined that the BCR is optimised when raising these dwellings by about 0.7m on average. This would mean the dwellings are raised to approximately 600mm above the 1% AEP level and hence above the Flood Planning Level.

Flood Damages Reduction

The raising of the eight identified properties is expected to result in a reduction in 1% AEP flood damages of approximately $635,000. In comparison, during the 5% AEP event the reduction in damages would be about $320,000.

Cost Estimate

The cost of implementing Option P-1 is estimated to be about $100,000 per house raised (*refer* **Appendix D**), which includes alternative accommodation while houses are being raised, an allowance for removalists to assist with temporary removal of home contents for the raising, plus a contingency of 20%.

If it is assumed that the eight houses are raised over the course of 5 years, the total present value of costs would be $826,000, which includes allowances to further develop the VHR Scheme, consult with landowners and a yearly administration cost.

8.2.2 Option P-2: Voluntary House Purchase

Voluntary house purchase has also been considered as a property modification measure with the objective of reducing existing flood damages.

Guidance from OEH outlines that voluntary purchase (VP) is effective for properties in situations where there are highly hazardous flood conditions, where the property is to be removed from a floodway, or when purchase of the property enables other flood mitigation works to be implemented (*OEH, 2013b*). OEH also specifies that VP will only be considered where no other feasible risk management options are available to address the risk to life at the property.

Flood depths above dwelling floor levels were considered for a range of design events to identify the number of properties for purchase that leads to the highest Benefit-Cost Ratio (*BCR*), while also trying to limit the overall cost.

It was determined that voluntary purchase would be suitable for one house subject to flood depths of 0.2m and greater during 1% AEP event (*refer* **Figure 8.1**). Note that this property is also identified for voluntary house raising. It should also be noted that this property is not located in a high hazard area, except during the PMF.

Flood Damages Reduction

The purchase of the identified property is expected to result in a reduction in flood damages of approximately $150,000 in the 1% AEP event. During the 5% AEP event the reduction in damages would be about $80,000.

Cost Estimate

The cost of implementing Option P-2 is estimated to be $1,020,000 including all costs associated with purchase and demolition (*refer* **Appendix D**). It includes allowances for stamp duty and legal fees, as well as rehabilitation of the dwelling footprint once demolition is complete and a contingency of 20%.

If it is assumed that the house is purchased in 2 or 3 years' time (*once funding is obtained*), the total present value of costs would be $1,086,000, which includes allowances to document the VP Scheme, consult with the landowner and administration costs.

8.2.3 Benefit-Cost Analysis

Average Annual Damages (AAD) for Options P-1 and P-2 were calculated according to the reduction in flood damages across the entire range of design events, from the 50% AEP to the PMF. The reduction in AAD over a standard 30 year design life was brought back to a present value using a real discount rate of 7%.

The present value of costs were compared to the present value of the benefit to determine the Benefit-Cost Ratios (BCR) presented in **Table 8-1**. Voluntary house raising is considered an economically viable option because returns a BCR greater than 1.0.

Table 8-1 Benefit-Cost Assessment of Property Modification Measures

Option	Cost of Works (PV)	1% AEP Damages	Present Value of Damage Reduction	Benefit-Cost Ratio
Existing Conditions	----	***$2.08m***	----	----
P-1 Voluntary house raising (x8)	$826k	$1.45m	$1.07m	1.3
P-2 Voluntary house purchase (x1)	$1.09m	$1.93m	$0.36m	0.3

8.2.4 Triple Bottom Line Assessment

A Triple-Bottom-Line assessment for the structural property modification options is summarised in **Table 8-2**. Additional information and justification of the individual TBL scores is provided in **Appendix E**.

As shown in **Table 8-2**, the weighted score for VHR would rank this option fourth behind the entrance management options. VP would be ranked in last place with a weighted score of only 65.

Table 8-2 Triple-Bottom-Line Assessment for Structural Property Modification Measures

Evaluation Criteria	Weighting	Raw Scores			Weighted Scores	
		P-1	P-2		P-1	P-2
		Voluntary House Raising	Voluntary House Purchase		Voluntary House Raising	Voluntary House Purchase
Flood Impacts						
Impact on hydraulic behaviour	**5**	2.5	2.5		13	13
Reduction in flood damages	**4**	4	1		16	4
Economic						
Benefit / Cost Ratio	**4**	4	2		16	8
Life cycle cost of option	**4**	2	1		8	4
Social						
Impact on local community	**4**	3	3		12	12
Likely community acceptance	**3**	2.5	2		8	6
Environmental						
Disruption to the natural character of the area	**3**	2.5	2.5		8	8
Ecological impacts	**4**	2.5	2.5		10	10
				TOTAL SCORE	**91**	**65**
				RANK *	**4**	**11**

** Rank is relative to TBL assessment for flood modification options (refer Table 7-4)*

8.2.5 Recommendations

There was generally good community support for house raising or purchase options, with only 13% of respondents to the questionnaire voicing their opposition. However, it was noted that of the identified properties for raising/purchase, only one landowner responded to the questionnaire.

Given the BCR greater than 1 and relatively high TBL score, it is recommended that voluntary house raising be included in the Floodplain Risk Management Plan for Bundeena. It is recommended that further investigations be undertaken to confirm the particular houses to be raised based on flood modelling with the Option F-1C berm management works in place, including any further refinement to that modelling. Affected property owners will need to be consulted and a VHR scheme developed to seek OEH funding.

Voluntary purchase is not recommended due to the low BCR and because alternative risk management measures can be considered to address the high hazard conditions in the PMF, such as appropriate flood warning and community awareness.

8.3 Flood Related Development Controls (Option P-3)

8.3.1 Review of Existing Flood Related Development Controls

Council's existing planning controls, instruments and policies have been reviewed in the context of floodplain management and flood related development controls, with the primary objective of identifying ways in which the development preparation and assessment process can be improved across the Sutherland Shire LGA, with Bundeena as an example catchment/floodplain.

The following instruments and policies have been reviewed:

- Sutherland Shire Local Environmental Plan 2015 (*LEP*);
- Sutherland Shire Development Control Plan 2015 (*DCP*):
  - Chapter 38 – Stormwater and Groundwater Management
  - Chapter 40 – Environmental Risk c) Flood Risk Management
- Sutherland Shire Specification Stormwater Management 2009
- Sutherland Shire Council Sea Level Rise Policy 2016

Key findings of this review at an overarching level are as follows:

- The LEP is a statutory document which needs to include standard flood-related clauses adopted by the NSW Department of Planning & Environment (*DPE*), without modification to ensure consistency across all council areas in NSW. This includes the requirement to define the Flood Planning Area according to the Flood Planning Level, which is adopted as the 1% AEP flood level plus a freeboard of 500mm. Properties outside the Flood Planning Area and within the PMF extent are not subject to any flood related development controls under the LEP.
- Council would need to apply to the DPE for exceptional circumstances in order to make any changes to the LEP regarding controls that apply to properties beyond the Flood Planning Area.

- Chapter 40 of Council's DCP comprises development controls based on the Flood Risk Precinct mapping approach adopted by Council, which covers all properties within the PMF extent (*in the case of Low Risk areas*).
- This current incongruity between the LEP and the DCP controls can make it difficult for Council to apply the full DCP requirements in the assessment of development applications; e.g., flood evacuation requirements for properties outside the FPA but within the PMF extent.

The Flood Planning Area (FPA) for Bundeena is shown in **Figure 8.2**. The extent of the FPA is difficult to determine for the overland flowpaths in the higher parts of Bundeena due to technical issues encountered when automatically applying 500mm freeboard to 1% AEP flood levels in steep areas. Accordingly, the FPA mapping contained in this report is considered preliminary and will be subject to further investigation (*refer recommendations in following sections*).

8.3.2 Approach to Flood Related Development Controls

In light of the issues outlined above, Council has investigated the application of a revised approach to the establishment and application of DCP controls on a catchment-by-catchment basis across the Sutherland Shire, which would look to align the DCP with the LEP controls in as many cases as possible, where appropriate.

The Bundeena Creek catchment and floodplain has been investigated as a case study for this approach, but it is possible that a different outcome would be appropriate for other catchments.

Note that the following sections of the FRMS & Plan have been prepared by Advisian in conjunction with input from Council's engineering and planning officers.

The following three methods have been considered:

1. Controls applied only to properties within the residential Flood Planning Area, as defined by the 1% AEP flood level plus 500mm freeboard.
2. Controls applied only to properties within the residential Flood Planning Area, as defined by the 1% AEP flood level plus 300mm freeboard (*i.e., reduced freeboard*).
3. Controls applied to all properties within the PMF extent.

Further discussion of the implications of these approaches is contained in the following, and in sections further below.

Method 1 – Controls Applied to Lots within the FPA based on 500mm Freeboard

In this method flood related development controls would be applied to properties within the 1% AEP flood extent, in addition to the area between the 1% AEP flood extent and the FPA.

No flood related development controls would be applied to residential development located outside the FPA.

General considerations:

- This method would be consistent with the Department of Planning & Environment's Section 117 Direction and there would be no need to apply for exceptional circumstances to modify the LEP to refer to properties outside the FPA (*within the PMF*).
- Adoption of 500 mm freeboard is consistent with other mainstream floodplains in the Sutherland Shire
- 500 mm freeboard may be too conservative and onerous to apply to development along overland flow paths, but it does provide means to account for the unknown impact of flow obstructions along these flow paths.

Considerations for Bundeena:

- Flood Planning Area mapping criteria – Islands of raised ground above the 1% AEP level may be fully surrounded by flooding in the 1% AEP event. However, these islands are not expected to be 500 mm higher than the 1% AEP level and hence would be subsumed into the FPA extent.
- Minimum habitable floor levels of new dwellings within the FPA north of Scarborough Street would need be raised up to of 1.1 metres above the existing ground, which is a significant height on relatively flat ground across the lower floodplain.
- Minimum ground floor levels for new development would not be sufficient to allow shelter-in-place during the PMF, which will result in a depth above FFL of about 1.5 metres. A second storey would be required for shelter-in-place.
- Only a relatively small number of properties are situated wholly above the FPL and also within the PMF (*Low Risk*) extent (*refer* **Figure 8.2**), located mainly at the north-western end of Hordens Lane, behind the beach. This means only a very small proportion of all flood affected properties within the Bundeena Creek floodplain would be exempt from flood related development controls.

<u>Method 2 – Controls Applied to Lots within the FPA based on 300mm Freeboard</u>

In this method flood related development controls would be applied to properties within the 1% AEP flood extent, in addition to the area between the 1% AEP flood extent and the FPA. However, the freeboard applied to determine the FPA would be reduced from 500mm to 300mm.

It is recommended that this method be considered for Bundeena given the following:

- The maximum 1% AEP flood depth in areas north of Scarborough Street is generally no more than 700 mm and no more than 150 mm along overland flow paths in the upper catchment.
- The TUFLOW model offers a relatively conservative approach to flood modelling across the lower floodplain in terms of rainfall losses, tailwater levels and in treating the floodplain as a volume-dominated system.
- Being a volume-dominated system, there is low potential for afflux or flow diversions caused by obstructions in the lower floodplain.
- Requiring new developments to be wet flood-proofed up to 500 mm above 1% AEP level (*i.e., 200 mm above minimum floor level*) can compensate for the lower design floor level.

General considerations:

- Council would not need to apply for exceptional circumstances to modify the LEP to refer to a freeboard of 300 mm (*for Bundeena and other nominated floodplains*), because this does not involve the application of any controls above the standard Flood Planning Level comprising 500 mm freeboard (*i.e., outside the FPA*).
- Adoption of 300 mm freeboard would not be consistent with other mainstream floodplains in the Sutherland Shire.
- 300 mm freeboard is considered more realistic for overland flow paths, compared to the standard 500 mm freeboard.

Considerations for Bundeena:

- Improved urban design outcomes - New dwellings within the FPA north of Scarborough Street would need floor levels be raised by up to only 0.9 metres above existing ground level.
- The adoption of 300 mm freeboard instead of 500 mm will mean that the number of flood control lots in Bundeena is reduced by only 5 lots, from 355 to 350 (*refer* **Figure 8.3**). This assessment is based on properties being tagged if encroached by the FPA, which need only be a partial encroachment.
- Adopting the same freeboard of 300 mm for mainstream and overland flow floodplains would make the FPL easier to calculate, understand and apply across Bundeena township.
- Being a volume-dominated system, the TUFLOW model is not overly sensitive to variations in model parameters, which provides confidence in the reduction of freeboard. However, it is recommended that the sensitivity of the model be tested further to confirm.

Method 3 – Controls Applied to all Lots within the Probable Maximum Flood Extent

This method reflects the current DCP situation in that floor level controls remain limited to lots within the FPA and evacuation controls also apply to lots beyond the FPA up to the PMF extent. In other words, development of properties outside the FPA would only need to satisfy the evacuation controls; e.g., preparation of a flood emergency response plan.

To better align this existing system with the LEP, Council would need to apply to DPE for exceptional circumstances to modify the LEP to include reference to lots up to the PMF extent, which may be difficult to justify given the small number of properties affected (*less than 10*), which represents less than 5% of all flood-affected properties in Bundeena. It is generally not considered useful to pursue the application of flood related controls for lots up to the PMF extent.

8.3.3 Flood Risk Precinct Mapping

The implications of the three methods outlined above on the existing Flood Risk Precinct mapping in Bundeena have been investigated, which has also considered the use of ARR 2016 flood hazard categorisation and Flood Planning Constraints Categories (FPCC).

The Flood Risk Precincts for Bundeena could be updated to reflect the separation of the current Low Risk areas into areas within versus outside the FPA extent. This is further investigated in **Table 8-3**.

ARR 2016 hazard categories are one possible means of redefining the High flood risk precinct. These hazard categories are commonly being used in the definition of FPCCs, in which case H5 and H6 areas correspond to FPCC 2 and FPCC1, respectively, which together could be broadly considered as the High flood risk precinct.

The suitability of the ARR 2016 hazard categories is discussed further in **Table 8-3**. According to this assessment, it was concluded that the FPCC categories, which are based on a combination of hydraulic categories and ARR 2016 hazard categories, are not appropriate for the Bundeena Creek floodplain for the following reasons:

- Use of the H3 to H6 hazard categories in the 1% AEP event (*in lieu of the FDM categories*) to restrict development would either not reduce the risk sufficiently or be too conservative, not meaningful and act to sterilise large parts of the floodplain.
- Flood Planning Constraint Categories relate only to development matters and not to overall flood risk that should be considered by existing property owners (*who may not be redeveloping*) or prospective purchasers who want to broadly understand flood risk and understand flood emergency response implications.
- This approach maintains consistency with the current DCP approach and also the approach used for the Gwawley Bay floodplain.

Accordingly, it is recommended that the 2005 FDM hazards are retained in assigning flood risk precincts for the DCP.

The incorporation of a new *Very Low* risk category into the Flood Risk Precinct mapping has also been considered as part of the assessment in **Table 8-3**. It is concluded that a Very Low flood risk precinct is not warranted for the Bundeena Creek floodplain. However, it may be useful for other floodplains in the Shire.

Table 8-3 Review of Flood Risk Precincts for Bundeena

Flood Risk Precinct	Current Definition	Possible New Definition	Comments/ Implications
High	High and Provisional flood hazard in the 1% AEP event, as defined in Figure L2 of the 2005 FDM, or where there are significant evacuation difficulties	H6 category in the 1% AEP event or PMF	There is no H6 area in the 1% AEP or 1 in 200 AEP flood events, and H6 only appears within the creek channel in the PMF. H6 is unsuitable for defining the high flood risk precinct.
		1% AEP >= H5 category	1% AEP H5 category is centred on the creek and riparian corridor but is extremely narrow and is therefore, unsuitable for defining the high flood risk precinct.
		1% AEP >= H4 category	1% AEP H4 area generally does not extend far beyond the H5 category. It is suggested that H4+ areas do not sufficiently capture the high risk areas.
		1% AEP >= H3 category	1% AEP H3 category would fit well for the lower creek reaches north of Bundeena Drive but it gradually widens to the south to occupy a large proportion of the floodplain to the south of Scarborough Street. Use of H3+ areas as a high risk precinct would act to sterilise part of existing residential properties and is inconsistent with the FPCC definitions currently being considered by councils. Although H3 is defined as unsafe for vehicles and vulnerable people, it would provide an overly conservative representation of high risk, particularly in cases where depths are less than 0.8 metres and velocities less than 0.5 m/s (refer **Plate 4-3**) .
		1% AEP floodway	The 1% AEP floodway is considered too narrow along the creek. Floodways have been assigned to the major overland flow paths in the upper catchment in order to keep them free of obstructions, but these areas otherwise do not represent high hazard conditions. The high risk flood precinct shown in **Figure 4.42**, particularly in the lower creek reaches, does not extend significantly beyond the 1% AEP floodway, and should not adversely impact redevelopment potential.
		1% AEP flood storage	1% AEP flood storage shown in **Figure 4.41** occupies a very large proportion of the floodplain and is not a realistic representation of high hazard/risk.

Flood Risk Precinct	Current Definition	Possible New Definition	Comments/ Implications
Medium	Area between the high flood risk precinct and the 1% AEP flood extent (or expressed alternatively as area below 1% AEP flood extent where there are no evacuation difficulties)	Would be retained as current	
Low	Area between the 1% AEP flood extent and the PMF	Area between the 1% AEP flood extent and the FPA	Same controls as for Medium flood risk precinct would apply. Distinguishing between Medium and Low risk areas is still required for community awareness/education purposes. This category provides a more explicit recognition of the residential FPL within the flood risk precinct mapping and hence provides better link to the flood related development controls.
Very Low	N/A	Area between the FPA and the PMF	Incorporation of this new category would reflect Approaches 1 and 2 outlined above, whereby lots between the FPA and PMF extent would not be subject to flood related controls. Alternatively, only evacuation controls would be applied (*which would involve applying to DPE for exceptional circumstances to incorporate the PMF extent into the LEP definition of flood control lot*). Addition of this category would provide a more refined assessment of risk. This approach is being pursued by Fairfield City Council in their planning proposal. This new category may not be particularly useful for the Bundeena Creek floodplain given that, for the majority of the floodplain, there is only a small difference between the 1% AEP and PMF extents and the low and very low risk precincts would show only as narrow slivers.

8.3.4 Proposed Update to Development Controls

Further to the revised approach of applying development controls and the implications on Flood Risk Precincts outlined above, **Table 8-4** provides a list of specific updates to be considered for *Chapter 40 Part C (Flood Risk Management)* of the Sutherland Shire Development Control Plan (DCP).

The recommended modifications are listed generally in the order they currently appear in the DCP, followed by additional general controls to be inserted where appropriate.

Recommendations are also provided in **Table 8-5** for modification of specific clauses of Council's stormwater management controls, as contained in Chapter 38 of the DCP (*Stormwater and Groundwater Management*) and the Sutherland Shire Environmental Specification – Stormwater Management (2009).

It is also recommended that Council undertake the following:

- Update 10.7 planning certificates for properties in Bundeena according to the results of flood modelling for this study.
- Review the preliminary Flood Planning Area map for Bundeena considering the planning work underway as part of the *Woolooware Floodplain Risk Management Study & Plan* and the proposed changes put forward by the NSW Department of Planning.
- Consider updating the LEP to remove specific reference to Flood Planning Area maps. Flood Planning Levels would still apply, but this would save the need to continually produce and update specific FPA maps for each catchment and floodplain in the LGA. This would be subject to further investigation.

Table 8-4 Proposed Modification to Flood Related Controls in the DCP (Chapter 40 Part C – Flood Risk Management)

Relevant Clause	Description	Details	Comments/ Recommendations
Preamble	General introduction		Preamble needs to be reviewed and updated, particularly with regard to the risk management hierarchy. It should acknowledge how controls interact with and support other Floodplain Risk Management measures. It should also acknowledge there is one residential FPL referred to in the LEP but multiple FPLs provided in the DCP; e.g., for non-habitable areas, car parking and for different development types.
Section 1	Clause 1	Refers to Clause 5.2 Controls for Development on Land Mapped as *Initial Assessment Potential Flood Risk*. But in doing so calls the classification "potentially flood affected".	The wording is not consistent, as the Risk Management Maps refer to this area as just "Initial Assessment". The terminology is not consistent and could also be misleading. It is recommended to simply identify properties as flood-affected, and assign a degree of confidence to the assessment based on the source of flood information; e.g., initial subjective assessment, adopted flood study, site-specific study etc.
Section 2	Dictionary	There is currently no definition of "non-habitable"	Related to floor level controls, it would help to clarify the definition of 'habitable' and 'non-habitable'. Based on the Building Code of Australia definition, a habitable area is used frequently and/or for extended periods for normal domestic or commercial activities and where fittings, fixtures, contents or stored goods are susceptible to flood damage. Non-habitable areas are not used frequently and/or for extended periods, do not contain fittings, fixtures, contents or stored goods susceptible to flood damage, and that can be wet flood-proofed, for example, bathrooms, toilets, pantries, corridors, lobbies, laundry, utility room, deck, etc.
Section 3	Land Use Categories	Child care centres and health service facilities are currently listed under the Commercial or Industrial category	It is recommended that child care centres and health service facilities be moved into the list of Sensitive Uses and Facilities, given that children and health care patients are more vulnerable to flooding.

Relevant Clause	Description	Details	Comments/ Recommendations
Section 4	Objectives	Objective 7 – Prevent intensification of development on land that is subject to a high risk of flood.	Review wording of this objective to account for potential redevelopment opportunities to reduce the existing flood risk (*refer to General Controls below*).
		Additional objectives	Include additional objectives to capture ongoing floodplain management projects and interaction with other floodplain risk management measures.
Sections 5.1 and 5.2	Overarching controls	Existing format includes background information, the process for determining which controls apply, and also some specific development controls.	It is recommended these sections be reviewed. Information on how to determine which controls apply should be moved to Section 1 of the chapter and also supplemented by a process flow-chart. Controls that are currently in Sections 5.1 and 5.2 (e.g., related to floodways) should be moved into subsequent sections of the DCP that contain the controls and matrices.
Floor Level	Controls 2 and 3	Commercial and industrial developments	Delete reference to residential vs commercial/industrial development in setting minimum habitable floor levels. Both should be related to FPL. Floor level requirement relating to PMF level should only apply to Sensitive Uses and Facilities.
	Controls 1 to 5	Habitable vs non-habitable floor levels	Minimum design floor levels should be specified for both habitable and non-habitable areas within the proposed development for different development types (including concessional development). Habitable and non-habitable design floor levels to continue to be based on the 1% AEP level plus freeboard and 5% AEP level, respectively (*subject to assessment of visual impact*), and should be no lower than the existing dwelling floor level for concessional development.
	Control #6	Undercroft areas	Condition 6 regarding under-croft or sub-floor areas to be moved to Flood Effects controls.

Relevant Clause	Description	Details	Comments/ Recommendations
		Additional guidance	It is recommended to provide guidance within the DCP (or as guidance notes) on meeting floor level controls; for example: Floor levels to be set based on highest flood level measured around the building perimeter, floor levels can vary with varying flood levels across the property, and incorporation of sea level rise into floor level requirements based on development type and design life (*refer* **Section 4.10**). It is also recommended to update the DCP to incorporate a minimum floor level requirement of 1% AEP level plus 300 mm freeboard for Bundeena.
Structural Soundness	Controls	Engineers report required to confirm structural soundness up to 1% AEP level or PMF, subject to circumstances.	Controls are usually conditioned by Council within the DA consent. The application of controls to structures with floor levels above the PMF will be triggered by the proponent's decision to allow for vertical evacuation / shelter-in-place.
Flood Effects	Control #1	Engineer's report of flood impacts	It is recommended this condition be updated to include reference to the level of assessment required, such as: ▪ No assessment required where proposed development is fully within 1% AEP flood fringe area; ▪ Minimal assessment is required where proposed development is located partly or fully within the 1% AEP flood storage area, but is elevated such that there is no significant loss of flood storage; ▪ Detailed assessment required where proposed development requires filling of 1% AEP flood storage area. Provide guidance within the DCP (or as separate guidance notes) for addressing flood effects, for example: ▪ No more than 10 mm increase in flood levels is allowed on neighbouring properties; ▪ No change allowed to AR&R 2016 hazard categories on roadways; ▪ Consideration and balancing of positive and adverse off-site impacts ▪ Assess impacts on evacuation and critical / sensitive facilities.

Relevant Clause	Description	Details	Comments/ Recommendations
			It is also recommended to add controls for obtaining a positive covenant on maintaining open sub-floor space, regardless of height of floor above ground.
Car parking and driveway access	Controls	Levels of open carparking, carports, garages and crests to basement car parks to be based on a specified design flood. Driveway to be designed such that flood depth and hazard is not increased. Vehicle barriers to be provided for car parking areas that are at less than the 1% AEP flood level.	It is recommended that an assessment be undertaken to confirm if the minimum design level of carparking in Bundeena should continue to be based on the current 1% AEP flood level or should be reduced to, say, the 5% AEP flood level. Considerations: ▪ Compare increased risk of flood damage to cars as well as external properties if cars float off-site, to the benefit of achieving a potentially better urban design outcome. ▪ In the context of Bundeena flooding, there is not a significant difference in flood depths and extents between the 5% and 1% AEP events. ▪ There is some reduction in capacity to evacuate if carparking is set at a lower level, but in the context of Bundeena the peak 5% AEP level is reached only about 1 hour earlier in the 1% AEP event. In some circumstances it may not be practicable to provide car parking elevated to the design flood level; e.g., due to lack of space, unacceptable driveway slopes, adverse off-site flood impacts etc. If an applicant attempts to demonstrate, but cannot feasibly achieve, compliance then allowing carparking to be provided as high as practicable can be considered, but provided it is no lower than existing ground levels and is not leading to intensification of vehicles; i.e., no additional car parking spaces above the current number of spaces. Damage to cars in basement car parking by floodwaters overtopping the entrance crest can often be more significant than damage to cars parked in open carparking, at the same flood level for the same design event. Some councils consider raising driveway crest levels to the PMF level, but in the local Bundeena context this would be impracticable given PMF depths are typically greater than 2 metres. 1% AEP flood depths are typically less than 0.6 m, and therefore it is recommended to retain existing Condition 6 for Car Parking and Driveway Access. Although implied by current Condition 5, it is recommended to include specific text to indicate that vehicle barriers are not required if carparking is at the 1% AEP level or higher.

Relevant Clause	Description	Details	Comments/ Recommendations
Evacuation	Controls	Two options are available for evacuation: ▪ Horizontal evacuation from the property to outside the PMF extent. ▪ Vertical evacuation within the property to above the PMF level i.e. shelter-in-place / deliberate entrapment. Flood emergency response planning by SES and development proponents should acknowledge the variation in hazard across the floodplain and also according to the size of flood. With regard to the latter, although overbank flooding commences across the lower floodplain in small events, the hazard across most of this area does not become high (i.e., H3 and above) until flooding is at the 2% AEP level or greater. Flood hazard in the overland flow catchments is generally very low; i.e., H1.	Vertical evacuation only viable if Structural Soundness conditions can be satisfied and if safe refuge can be provided above the PMF level; i.e., in a two storey building. Vertical evacuation may be preferable to horizontal evacuation given: ▪ Requires less reliance on SES. ▪ Relatively short flood duration (PMF duration above FPL = ~6 hours). ▪ External hazards potentially greater than internal hazards. ▪ Allows property owners to stay to defend home, raise furniture and belongings to second storey. ▪ More realistically reflects community behaviour during a flood. Given the high hazard conditions across the lower parts of Bundeena in the PMF, it is recommended that new DCP controls requiring the preparation of a flood emergency response plan be considered. In the context of Bundeena, it is recommended that the current controls to be tailored for residential development, particularly low-density; e.g., less emphasis on flood signage and exits which might apply to apartments or commercial premises, and more emphasis on flood emergency response planning encompassing preparation, flood warning and evacuation. It is recommended the DCP incorporate guidance on the preparation of emergency response plans and a potential pro-forma emergency response plan(s), which will need to reference the flood information contained in this FRMS&P and SES materials. Council planners, SES and the Floodplain Risk Management Committee should be consulted on the best approach to updating the DCP.

Relevant Clause	Description	Details	Comments/ Recommendations
Management & Design	Controls	Controls should be retained as per the current DCP but with some amendments.	It is recommended to move Control #2 of this clause (site emergency response flood plan) to the Evacuation conditions and delete reference to below minimum floor level requirement. A new control is to be added that requires flood compatible fencing within the high flood risk precinct or a floodway (which captures the overland flow catchment), with a positive covenant applied. Control #3 is to be modified to refer to "building" (which could be a dwelling or other premises). Update the matrices so that Control #4 also be applies to Concessional Development at Essential Community Facilities and Sensitive Uses & Facilities that are already flood affected.
General Controls		Items and issues currently omitted from the DCP or not covered in sufficient detail	Redevelopment in the high flood risk precinct only allowed where the redevelopment will act to reduce flood risk; e.g., replacing an existing building in the high flood risk precinct that is subject to over-floor flooding with a new building not subject to over-floor flooding and leading to an increase in flood storage, provided evacuation controls can be met. Objective 7 in Section 4 is to be updated to reflect this. Otherwise, continue to restrict new development in high flood risk precincts.
			As outlined in Section 4.7, floodways in the upper, overland flow catchments have been defined according to different criteria compared to floodways in the lower, mainstream floodplain. It would be problematic to identify the overland floodways as high risk areas because they are essentially low hazard. The DCP needs to state specifically that development in floodways (whether mainstream or overland) is generally inappropriate and that the floodways should be maintained.

Table 8-5 Proposed Modification to Council's Stormwater Management Controls

Instrument	Relevant Clause	Details	Comments/ Recommendations
Sutherland Shire DCP Chapter 38 – Stormwater and Groundwater Management	On-Site Detention Section 5.2 Clause 1	No OSD is required for new single dwellings where a rainwater tank of minimum 5000L is provided and connected to toilets, laundry and irrigation for reuse.	Other councils often require OSD even if a rainwater tank is proposed for stormwater reuse. If a dwelling is being constructed under the Complying Development Code (SEPP 2008), the property can include up to 70% impervious area and avoid OSD if a rainwater tank is proposed. This could lead to increased runoff and downstream flood impacts. It is recommended that OSD controls be updated to consider the proposed impervious area for a development. They should also consider whether the property is located in the floodplain. Typically OSD is not required for properties within the 1% AEP extent, so that runoff can escape to downstream areas and thereby avoid coincidence with the timing of flows from the upstream catchment.
	On-Site Detention Section 5.2 Clause 4 and Section 5.3 Clause 3.	"The **volume** of stormwater to be detained on-site shall be calculated from the **volume** of water from a 5% AEP event less the **volume** of runoff established by Clause 1.2, less any **volume** infiltrated onsite, and less a third of the **volume** of any tank used for rainwater reuse"	The calculation of detention volume is based on peak <u>flow rates</u> during a storm rather than volumes. It is recommended that this clause be amended as follows: *The volume of stormwater to be detained on-site is to be calculated as that required to reduce the peak post-development flow rate in a 5% AEP event to the equivalent pre-development flow rate. The flow rate discharged to any proposed infiltration system can be considered in this analysis. The required OSD volume can be offset by up to one third of the volume of any rainwater tanks for reuse.*

Instrument	Relevant Clause	Details	Comments/ Recommendations
Sutherland Shire Environmental Specification – Stormwater Management 2009	Section 5.6 Stormwater Management Controls for Land Affected by Flooding	"b) For hospitals, civil defence headquarters or other essential services finished floor levels shall be a minimum 500mm above the following flood levels: Hospitals and civil defence headquarters - 0.2% AEP, Other essential services - 0.5% AEP."	Hospitals are classified as an Essential Community Facility within the DCP, which according to the assessment matrices are not permitted in Low, Medium or High Risk areas. Accordingly, they are not permitted within the PMF extent (Low Risk area). In most situations the PMF level will be more than 500mm higher than the 0.2 or 0.5% AEP events, and hence these controls relating to 0.2 or 0.5% AEP levels are largely irrelevant. In Bundeena the PMF level is about 1.9m higher than the 0.5% AEP level (1 in 200 AEP). It is recommended that Council remove this clause from the 2009 Specification and incorporate such controls into DCP Chapter 40, and also relating to the Low, Medium or High Risk classifications.

8.3.5 Relationship with Complying Development Code (2008)

Advisian has reviewed the State Environmental Planning Policy (*Exempt and Complying Development Codes*) 2008, otherwise known as the Codes SEPP or CDC, in the context of flood related controls that are relevant for development or redevelopment in Bundeena.

The Codes SEPP outlines particular development that is either exempt or complying, thereby not requiring a Development Application to be submitted to the local council. The intention is to relieve local councils of a portion of the development assessment load.

According to the definition in the Codes SEPP, a *Flood Control Lot* means a lot to which flood related development controls apply in respect of development for the purposes of industrial buildings, commercial premises, dwelling houses, dual occupancies, multi dwelling housing or residential flat buildings (*other than development for the purposes of group homes or seniors housing*).

According to the LEP, this would refer to lots within the Flood Planning Area (*i.e., the extent of the 1% AEP level plus freeboard*).

The Codes SEPP stipulates that development is 'complying' provided that it is <u>not</u> carried out on any part of a Flood Control Lot that is classified as:

- A Flood Storage area;
- A Floodway area;
- A flow path;
- A high hazard area;
- A high risk area.

But in undertaking such development there are flood related criteria to be met, such as:

- Minimum floor levels;
- Flood proofing below FPL;
- Structural soundness of buildings;
- Engineers report to confirm no flood impacts (but cumulative impact assessment is not required);
- Evacuation requirements;
- Minimum carparking levels.

The Flood Fringe hydraulic category is excluded from the CDC list above, meaning that complying development could be completed in these areas without Council approval. In this regard, refer to **Figure 8.4** for areas/lots identified in Bundeena as being outside the Flood Storage area and within the Flood Planning Area. The mapping indicates that about 100 lots could be considered under complying development provisions, which represents about 30% of the total number of flood control lots in Bundeena.

The TUFLOW flood model has been used to test the impact of cumulative development (*filling*) in flood Fringe areas of Bundeena on the 1% AEP flood. It is considered a conservative assessment because it involves filling of more than half of the existing 1% AEP floodplain in the area north of Bundeena Drive.

According to the TUFLOW results, flood level increases of up to 40mm are expected at existing dwellings in areas to the north of Bundeena Drive (*refer* **Figure 8.5**). This is not an insignificant impact, but is not surprising considering the large number of lots and significant area assumed to be filled. In reality such a fill scenario is unlikely to eventuate. The offsite impacts of any single development in the Fringe area are expected to be less than Council's unofficial standard of 10 mm maximum allowance increase.

It is noted that the Codes SEPP does not refer to Medium or Low risk areas, which on face value, could mean that complying development can be completed in these areas without Council approval. In Bundeena these areas are effectively the 1% AEP Low Hazard area and the PMF extent, respectively.

However, Flood Storage areas constitute a significant portion of the Medium Risk areas and these are not classified as complying by the Codes SEPP and therefore DA's in these areas would need to be submitted to Council.

The impact of cumulative development in the Low Risk precinct has not been tested because it can only be tested for the PMF (*by definition of Low Risk*). The impact of development on flooding is typically only tested for events up to the 1% AEP flood (*even if cumulative*), whereas the PMF is only considered from an emergency response perspective.

8.4 Guidelines for DA Preparation and Assessment (Option P-4)

It is recommended that Council develop and publish guidelines to assist developers and their consultants in the preparation of flood impact assessment reports for Development Applications. The guidelines could be incorporated within the DCP or published as separate guidance notes.

The guidelines would contain information on the details required to be included in flood impact assessments, and also guidance on using Council's consultants to undertake the flood modelling for these assessments.

8.4.1 Requirements for Flood Impact Assessment Reports

The guidance notes for flood impact assessment (FIA) reports would include:

- The level of assessment required; e.g., no assessment, desktop assessment, or detailed assessment with hydraulic modelling.
- The required format and structure of the flood impact assessment report.
- The scope of flood emergency response planning to be addressed.
- Information on the use of flood compatible fencing.
- Information on flood compatible building components and materials.

- Information on the preferred design of driveways to reduce flood hazard across or property or in the street.
- The application of controls to Concessional Development, which is considered important for Bundeena given that the majority of redevelopment would involve retaining the original building.
- Guidance on the use of Council's nominated flood modelling experts for assessment of flood impacts, where modelling is required (*refer next section*).
- Methodology for assessing the change to effective impervious area due to either:
  - New development, for a vacant site or where the existing building is replaced; e.g., knock down and rebuild; or,
  - Redevelopment where the existing building is retained; e.g., alterations and additions.

Flood evacuation procedures should be addressed as part of the FIA to be submitted with a Development Application. Development consent conditions would include the need for the proponent to prepare a Flood Emergency Response Plan (*FERP*) for private certification prior to receiving the Occupation Certificate (*OC*). The detail of the FERP should be commensurate with the type of development and level of flood risk.

Given most development in Bundeena will be associated with single residential dwellings subject to Low or Medium flood risk, it is recommended that a single page pro-forma FERP will be sufficient.

The FERP pro-forma template should be completed and attached as part of the FIA at the DA stage. Council could then include a condition in the development consent to prepare a laminated or weather-proof sticker version of the FERP and attach it to the outside of the electricity box as an OC requirement.

8.4.2 Flood Modelling for Development Applications

It is recommended that Council consider including a requirement for any flood modelling for FIAs to be undertaken by Council's consultant(s) under the commission and direction of the Applicant and their consultant.

The flood model results would be interpreted by the applicant and their consultant as part of preparing the FIA report. Advantages of this approach would be:

- It ensures that modelling is undertaken by flood modelling specialists using a consistent approach to modelling and flood map preparation.
- Ongoing modelling work using a consistent and standardised approach can offer time and cost savings to applicants.
- Updates and improvements to the flood model suggested by Council's consultant(s) can be quickly acted upon.
- Council's consultant(s) would be able to act as an expert witness on behalf of Council.

8.5 Summary

It is recommended the following Property Modification measures be included in the Floodplain Risk Management Plan for Bundeena:

- Option P-1: Voluntary House Raising
- Option P-3: Flood related development controls, comprising the following items:
  - Further development of a revised approach to determine DCP controls on a catchment-by-catchment basis, considering freeboard requirements and whether to adopt the Flood Planning Area or PMF extent as the limit for tagging flood control lots.
  - Retain the existing Flood Risk Precinct classification for Bundeena, but alternative methods are to be considered for other catchments, including the introduction of a Very Low risk category.
  - Update the Sutherland Shire DCP Chapter 40 Part C according to the recommended changes contained in **Table 8-4** and subject to consultation with Council planning and engineering officers.
  - Update Council's stormwater management controls according to the recommended changes contained in **Table 8-5** and subject to consultation with Council planning and engineering officers.
  - Update 10.7 planning certificates for properties in Bundeena according to the results of flood modelling for this study.
  - Review the preliminary Flood Planning Area map for Bundeena considering the planning work underway as part of the Woolooware Floodplain Risk Management Study & Plan and the proposed changes put forward by the NSW Department of Planning.
  - Consider updating the LEP to remove specific reference to Flood Planning Area maps, subject to further investigation.
- Option P-4: prepare guidance notes to accompany the DCP, including information on flood impact assessment requirements and the use of Council's consultant(s) for specialist flood modelling.

9 Response Modification Measures

Flood emergency response considerations are outlined in **Section 5.2**, including a summary of the properties affected in the PMF and the expected flood hazard conditions along evacuation routes to higher ground. The locations where roads are cut by floodwaters, the proposed evacuation routes and Flood Emergency Response Communities are shown in **Figure 5.8**.

To address the "residual" flooding problem in Bundeena, which cannot be readily addressed by flood modification or property modification measures, the following response modification options were investigated:

- Option R-1: Automated Flood Warning System.
- Option R-2: Community Flood Awareness Program.
- Option R-3: Provision of Flood Data to SES to inform the *Local Flood Plan*.
- Option R-4: Road raising at the low point in Bundeena Drive to allow evacuation.

9.1 Option R-1: Automated Flood Warning System

As outlined in **Section 5.2**, shelter-in-place is not an option for properties in the lower floodplain which do not have a second storey. In the case of future redevelopment, there is opportunity to reduce the flood risk by the implementation of relevant flood planning controls (*refer* **Section 8.3**).

However, the existing properties that do not have a second storey will need to evacuate prior to floodwaters along streets becoming unpassable (*i.e., high hazard conditions or depths greater than 200 to 300mm*).

The most vulnerable residents will be at the southern end of Liverpool Street. Floodwaters would begin to cut the road within 1 hour of the commencement of the 2% or 1% AEP storms. The flood hazard category increases most significantly between the 2% and 1% AEP events, leading to H3 conditions, which becomes unsafe for vehicles, children and the elderly. This indicates that evacuation would need to occur once flooding is expected to increase beyond the 2% AEP event, otherwise residents may be trapped in their homes by rising floodwaters.

As flood depths increase at houses to the north of Bundeena Drive these residents will also need to evacuate to the west along Bundeena Drive to the higher ground at Simpson Road and Short Avenue. Flood hazard is expected to remain low along Bundeena Drive during events up to and including the 1 in 200 AEP event, however the number of houses subject to over-floor flooding in this area jumps most dramatically between the 2% and 1% AEP events (*aside from in the PMF*). Residents will need to evacuate to higher ground via Bundeena Drive by the time flooding reaches the 1% AEP level.

The Bureau of Meteorology (*BOM*) is able to issue a general Flood Watch in the case that significant rainfall is forecast in the Bundeena area and surrounding catchments. However, the BOM does not issue Flood Warnings for flash flood catchments with a response time of less than 6 hours. Furthermore, there are currently no water level gauges on Bundeena Creek or local rainfall gauges in the catchment to provide any warning of flooding for Bundeena.

It is also recognised that the SES would have limited capacity to respond to a major flood situation in Bundeena due to the quick response time of the catchment and given the remoteness of the township.

Accordingly, it is recommended that an automated local flood warning system be installed for the Bundeena Creek catchment. It would involve the following:

- A pluviometer rainfall gauge to take continuous rainfall readings in the catchment.
- A water level gauge to monitor the level of flooding in the swamp area south of Scarborough Street and Liverpool Street, upstream from the urban areas.
- A telemetry system for automatic logging of rainfall and river levels, linked to an automated system for dissemination of flood warnings to the mobile phones of all residents in Bundeena. Warnings would also be sent to SES and Council representatives.
- Flash flood warnings would be triggered once rainfall exceeds the 2% AEP event (*for a range of storm durations*), or once water levels have reached the 5% AEP level.

It is suggested the rainfall and water level gauge could be combined into the one weather station unit, which would be most cost-effective in terms of installation and future maintenance. It is also recognised there is limited access to the steep upper catchment areas in the Royal National Park, which would otherwise have been an ideal location for the rainfall gauge. Given the relatively small size of the catchment, a rainfall gauge located centrally in the catchment would be appropriate, such that could be combined with a water level gauge beside the creek at the southern end of Liverpool Street.

It is recommended that further investigations be completed to confirm appropriate rainfall and water levels triggers for the dissemination of flash flood warnings. This should involve assessment of rainfall and water level combinations. If warnings are issued too early and lead to a false alarm, then this will lead to reduced community and SES confidence in the warning system.

It is estimated the upfront cost of the system would be about $90,000, which includes an allowance for design and installation of the rainfall gauge, water level gauge and telemetry/warning system.

The ongoing maintenance cost for the system is expected to be about $3,000 per year, which translates to a present value of about $35,000 assuming a real discount rate of 7% over a 30 year design life. This would include testing and review of the system operation on a yearly basis.

9.2 Option R-2: Community Flood Awareness Program

Many residents in the lower floodplain of Bundeena Creek are aware of the potential for flooding, particularly at the southern end of Liverpool Street and in the vicinity of the creek alignment. Residents north of Bundeena Drive, between Laurence Avenue and Liverpool Street are also likely aware of nuisance flooding that has occurred in the past.

However, it is expected that some local residents are not aware of the flood risk, particularly those new to the area, or otherwise do not fully appreciate the depths and hazards associated with a major flood, such as the 5% AEP event or larger.

Accordingly, it is recommended that Council develop and implement a flood awareness program, working with SES using the flood mapping from the TUFLOW model in conjunction with the SES FloodSafe educational materials.

Possible methods of engagement with the community would include:

- Further dissemination of flood information brochures;
- Inclusion of educational materials with rates notices in the mail;
- Targeted consultation with particular landowners, such as the Bundeena Bowling and Sports Club and businesses at the northern end of Brighton Street (*overland flows*);
- Running a flood information booth in conjunction with SES on a Saturday morning outside the shops along Brighton Street, or setup an information booth at other public events in Bundeena.

It is estimated that the flood awareness program would cost about $30,000, which includes allowance for the present value of ongoing awareness events/meetings/mailouts over 30 years.

9.3 Option R-3: Provision of Flood Data to SES

The NSW SES is currently preparing a Local Flood Plan (*LFP*) for the Georges River basin, which is to include an increased level of detail relative to the existing FLP for Sutherland Shire.

It is recommended that the emergency response considerations documented in this FRMS and Plan be provided to SES for the update of their flood intelligence information for Bundeena, so that appropriate emergency response protocols can be developed and incorporated into the Local Flood Plan.

The flood mapping contained in this report should also be provided to SES in digital format. Appropriate systems should be established for the transfer of the data in order to maximise the practical usability for SES. The procedures should be established in a way that they could also be applied to other catchments/floodplains where flood studies have been recently completed or are being undertaken by Council.

It is also recommended that a system be established for the transfer of information on new developments from Council to SES, so that SES can review and update their flood intelligence and response protocols as required. This should include information on two storey buildings that have been approved by Council for shelter-in-place.

It is estimated that the SES data compilation and handover for Bundeena would cost in the order of $10,000, including an allowance to consult with SES on the most appropriate digital format of flood intelligence and mapping.

9.4 Option R-4: Road Raising at Bundeena Drive Low Point

As outlined in **Section 5.2** and shown in **Figure 5.8**, there is a low point on Bundeena Drive to the north of the intersection with Woodfield Avenue which will be cut in the 5% AEP flood, thereby preventing evacuation from Bundeena towards the National Park and Loftus.

The centreline of the road in this area would be inundated for a length of about 120 metres at the peak of the 1% AEP flood with depths up to 300mm.

Raising of this low point in Bundeena Drive by 300mm would provide flood-free access from Bundeena for residents at Short Avenue and Simpson Road. However, Bundeena Drive is also relatively low in locations further to the east, near Laurence Avenue and Thompson Street, thereby limiting the evacuation benefit offered to the lower floodplain areas, which are of most concern.

Furthermore, the raising of Bundeena Drive in this area will block the existing relief path for floodwaters towards Bonnie Vale Park along Sea Breeze Lane, which is likely to have an impact on flood conditions during the 5% AEP and larger events. Blocking this flow path may increase the level of flooding in properties immediately east of Bundeena Drive and also across the wider lower floodplain.

Other considerations for potential road raising:

- Even though only requiring a vertical lift of 300mm, the road would be raised relative to the terrain in the properties either side of the road (*up to 12 properties would be affected*), thereby causing disruption to driveways and requiring additional drainage works.
- The works are expected to create disruption to local traffic during construction, being the only route from the township.
- Road raising works will attract minimal support according to responses to the community questionnaire, with only the flood protection levee option attracting less support.

Given the limited evacuation benefit, potential flood impacts, construction considerations and lack of community support, it is not recommended that this option be pursued as part of the Floodplain Risk Management Plan.

10 Floodplain Risk Management Plan

10.1 Proposed Floodplain Risk Management Options

It is recommended that the Floodplain Risk Management Plan for Bundeena include the following options:

- **Option F-1C**: Entrance berm management (central channel)
- **Option P-1**: Voluntary house raising for up to 8 dwellings located in areas identified as having overfloor flooding greater than 0.1 m in the 1% AEP event.
- **Option P-3**: Flood related development controls, comprising the following items:
  - Further development of a revised approach to determine DCP controls on a catchment-by-catchment basis, considering freeboard requirements and whether to adopt the Flood Planning Area or PMF extent as the limit for tagging flood control lots.
  - Retain the existing Flood Risk Precinct classification for Bundeena, but alternative methods are to be considered for other catchments.
  - Update the Sutherland Shire DCP Chapter 40 Part C according to the recommended changes contained in **Table 8-4** and subject to consultation with Council planning and engineering officers.
  - Update Council's stormwater management controls according to the recommended changes contained in **Table 8-5** and subject to consultation with Council planning and engineering officers.
  - Update 10.7 planning certificates for properties in Bundeena according to the results of flood modelling for this study.
  - Review the preliminary Flood Planning Area map for Bundeena considering the planning work underway as part of the Woolooware Floodplain Risk Management Study & Plan and the proposed changes put forward by the NSW Department of Planning.
  - Consider updating the LEP to remove specific reference to Flood Planning Area maps, subject to further investigation.
- **Option P-4**: prepare guidance notes to accompany the DCP, including information on flood impact assessment requirements and the use of Council's consultant(s) for specialist flood modelling.
- **Option R-1**: Automated flood warning system for Bundeena.
- **Option R-2**: Community flood awareness program.
- **Option R-3**: Provision of flood intelligence data to NSW State Emergency Services.

10.2 Implementation Schedule

An Implementation Schedule has been prepared for inclusion in the Floodplain Risk Management Plan and is provided in **Appendix G**. The schedule outlines the following.

- The recommended actions for implementation of the proposed floodplain risk management options.
- Capital and ongoing costs for each option.
- The indicative timing of commencement for each option according to short term, medium term or longer term priorities.

10.3 Responsibilities and Funding

Implementation of the Floodplain Risk Management Plan will be the responsibility of Council.

Funding for the implementation of options will be coordinated by Council, using Council funds and also monies from grant applications to the Office of Environment & Heritage (OEH) under the NSW Floodplain Management Program.

It is envisaged that NSW State Emergency Services would contribute funding towards initiatives involving community awareness and the handover of flood intelligence information.

10.4 Public Exhibition of the Draft Floodplain Risk Management Study and Plan

Public exhibition of the draft of this report occurred in June 2019. The draft study and plan was made available to the public who were encouraged to review and provide comment. Materials to assist in the review of the draft plan were also made available to the public. These included:

- An information brochure;
- Frequently asked questions (FAQs) list; and,
- A community summary.

Residents were encouraged to comment on the draft plan either by email or through an online survey on Council's *'Join the Conversation'* webpage.

Additionally, a public meeting was held at Bundeena Community Centre on 19th June 2019, at which around 40 residents, Council staff, Councillors, and representatives from Advisian were in attendance.

Following public exhibition, submissions were compiled and reviewed by Council. Further information on the consultation process and its findings are included in **Appendix H**.

Finalisation of this Plan and its recommendations have considered and addressed the feedback from the community wherever possible.

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