

Executive Summary

Central Coast Council (Council) commissioned Golder Associates in association with HydroStorm Consulting to undertake a *Floodplain Risk Management Study* and prepare a *Floodplain Risk Management Plan* for the floodplain of Narara Creek and its tributaries. The *Floodplain Risk Management Study* follows a flood study (completed in 2013 and revised in July 2018 (Golder, 2018), which refined the understanding of complex flood behaviour of Narara Creek and its tributaries previously examined in separate studies for the tributary catchments. A *Floodplain Risk Management Plan* will draw upon the results of the assessment carried out for various floodplain management measures presented in the *Floodplain Risk Management Study*.

Study Objectives

The objectives of the Floodplain Risk Management Study are to:

- review Councils existing environmental planning policies and instruments.
- identify works, measures and restrictions aimed at reducing the social, environmental and economic impacts of flooding and the losses caused by flooding on development and the community, both existing and future, over the full range of potential flood events.
- assess the effectiveness of these works and measures for reducing the effects of flooding on the community and development, both existing and future.
- consider whether the proposed works and measures might produce adverse effects (environmental, social, economic or worsened flooding) in the floodplain and whether these effects could be reduced.
- examine the present flood management procedures, community flood awareness and emergency response measures in the context of the NSW State Emergency Service's development and disaster planning requirements.
- examine ways in which the creek and floodplain environment may be enhanced by exploring the possibility of a strategy for vegetation planning that may create a valuable corridor of vegetation without having a detrimental effect on flooding.
- review the flood risk management measures identified in previous studies (refer Appendix E) or implemented as a management action of previous flood risk management plans. The review is required to ensure that those measures, which may have been suitable for flood behaviour established in the previous flood studies, may not be suitable for the flood behaviour established in the current flood study (Golder, 2018).

The Catchment

The Narara Creek catchment lies to the north of the Brisbane Water Estuary. Figure ES1 shows the extent of the catchment boundary and primary sub-catchments. The central and eastern parts of the catchment are densely populated with the primary land use being residential. Since the flood study review (Golder, 2018) a major residential development has occurred within the Narara Creek Catchment, at Research Road, Narara.

In the lower catchment, a major industrial area at West Gosford and a minor one at Glennie St West along with the commercial centres at Brookes Avenue, Wyoming and Lisarow are the primary sources of economic activity in the catchment.

The floodplain widens at the confluence of Brisbane Water Estuary, as the tidal limit extends approximately 5 km upstream of the Central Coast Highway, this significantly influences the flood behavior of the Narara Creek catchment.

The Central Coast Highway, The Pacific Highway, Manns Road, Showground Road and the Narara Valley Drive are the major roads through the catchment.

The Main Northern Railway also passes through the catchment with several stations servicing the area. In April 2015 Transport for NSW (TNSW) completed two passing loops between Gosford and Narara Stations so slow-moving freight trains on the Main North Line can wait while passenger services operate in a timely fashion. The effect of duplication of railway line on the floodplain has been examined further in this study.

Other major infrastructure/utilities in the catchment include the Gosford Hospital, North Gosford Private Hospital, Gosford Golf Club and the Racecourse/The Entertainment Grounds. Narara Valley High School along with several public schools also service this catchment. The critical infrastructure with respect to flood behaviour has been considered as part of emergency management.

The Narara Creek catchment (Figure ES1) has a total area of 46.7 km² and comprises seven major sub-catchments. The Review of the Narara Creek Flood Study (2018) has analysed flood behaviour for each individual tributary as well as the complex interaction at the tributary junctions. Understanding this flood behaviour is key to identifying effective flood risk mitigation options.

The Council has implemented some measures of a Rivercare Plan (Patterson Britton, 1997) in the catchment to improve the health of the waterways and to reduce the sediment load to Brisbane Water. The works carried out under this plan were primarily bank stabilisation works for various creeks in the catchment.

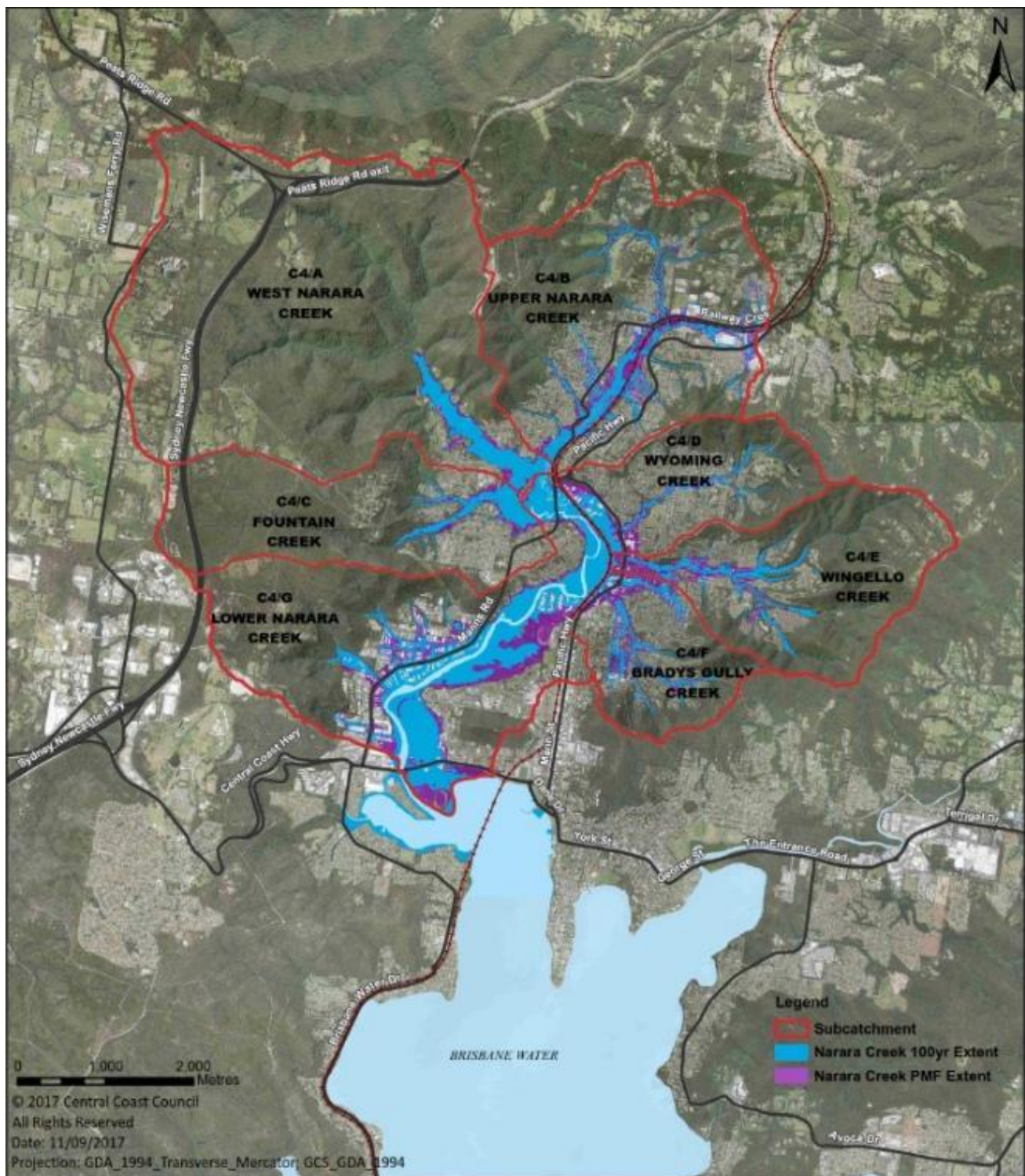


Figure ES1: Narara Creek Catchment

Flood Mechanisms and Behaviour

Narara Creek is the primary channel for conveyance of floodwaters through the catchment. Several large tributaries discharge into the main channel, which ultimately discharges to Fagans Bay in Brisbane Waters.

With the land use ranging from forest to highly urbanised areas within the catchment, the flood producing mechanisms are varied and complex. With concurrent flooding from various tributaries, the existing flood

behaviour in Narara Creek and the low-lying areas of various tributary catchments to a large extent is dependent on flood arrival times at various tributary junctions.

The upper reaches of various tributaries are independent of the 'backwater' influence of Narara Creek. However, the flood risk in general is low in the upper reaches and it is the lower reaches, where the flood behaviour is complex and a higher flood risk is manifested.

Storm Surge

Storm surge is an abnormal rise in seawater, typical during East Coast Low pressure systems, experienced periodically on the Central Coast and is measured as the height of the water above the normal predicted astronomical tide. A major event, which raised the Brisbane Water levels, occurred in 1974 (1% to 0.5% AEP) and more recently in 2015 (20% AEP).

The lower reaches of the study area are affected by flooding from Brisbane Water. The recent Brisbane Water Foreshore Floodplain Risk Management Study and Plan (Cardno 2015) has investigated this flooding and identified options for managing flood impacts. The reported 1% AEP flood level at the mouth of Narara Creek is 1.64 m AHD (Cardno, 2010). In the absence of creek flooding, the impact of Brisbane Water flooding would extend along Narara Creek to Carrington Street, Narara. On the other hand, the 1% AEP creek flooding (mainstream) is dominant along Narara Creek approximately to Garnet Adcock Memorial Park, downstream of Central Coast Highway bridge. Beyond this point, Brisbane Water flooding is dominant.

It is important to note that the previous flood studies undertaken in the early 1990s for various sub-catchments have potentially underestimated the flood levels along the lower Narara Creek. Those studies did not consider the combined impact of flooding in various sub-catchments nor any allowance was made for the sea level rise or increased rainfall intensity due to climate change. While analysing the major flood event of 1992, a previous study (Kinhill, 1993) has reported that flood levels are potentially underestimated because of the lack of concurrent analysis of all the catchments.

The hydraulic modelling undertaken for the current study included all major structure and major drainage networks above 600 diameter pipes. While representative of flooding more broadly, the modelling was restricted to a grid size of 5m x 5m i.e. the smallest scale on which the flood behaviour is defined within the catchment. This definition of flood behaviour is far more detailed than produced in previous studies. All the major infrastructure, including bridges and culverts, were included in the model for the purposes of modelling flood management options and determining the flood planning area, including sensitivity analysis to climate change.

Mainstream Flooding

Mainstream flooding is associated with runoff generated from the catchment and then travelling through the major creek system within the catchment. Flooding starts when the capacity of the creek is exceeded. The creek gradient plays a major role in defining the floodplain. In the upper reaches of the study area, the gradient of various tributary creeks is steep, and the floodwaters are generally contained within a narrow floodplain. However, overland flow through the developed areas, along with the presence of street drainage, can have a significant impact away from the creek flooding.

In the middle reaches, where the tributaries join the Narara Creek, the flood arrival time from various tributaries plays an important role, as coincident arrival of floods from these tributaries can increase the flood hazard significantly.

In the lower reaches, near the Central Coast Highway, the floodplain widens significantly. The racecourse flood storage contributes significantly to the capacity of wide floodplain at this location and is of critical importance with respect to flood function. The lower parts of the catchment are also affected by coastal flooding. Elevated Fagans Bay levels can enhance the impact of the flooding from the catchment.

Overland Flooding

In addition to the flooding from the creeks, several areas in the catchment are affected by significant overland flow during flood events. The runoff in the catchment starts as the overland flooding and if street drainage is available, would enter the drainage system and would be carried to the nearby creek. However, if the street drainage is not available, or is under capacity, overland flow would occur on the street, and depending on the terrain may travel through the properties or down the street.

The industrial area in West Gosford is a prime example of this behaviour. Properties in this area, which lie west of Manns Road are affected by overland flooding due to the limited capacity of street drainage in this area.

Another significant factor in exacerbating the overland flooding is that the street drainage in the low-lying areas discharges into the nearby creeks, which are also likely to be in flooded conditions, thus limiting discharge from the street drainage.

Erosion

In addition to the direct risk from flooding, erosion and accretion of fluvial deposits due to sediment transport from the catchment or erosion of waterway banks affects the flood behaviour. Bank erosion also affects the stability of adjacent properties. The Council has already investigated a few affected properties along the Showground Road. Council prepared a Rivercare Plan (Patterson Britton, 1997) to improve creek stability in various parts of the study area. Under this program works have been carried out in various creeks such as the works carried out in lower reaches of Wyoming and Wingello Creeks. The Rivercare program was suspended during the process of Pacific Highway Upgrade concept design and community consultation. This program should be restarted to improve the conveyance and health of the creek systems.

Culvert Blockage

Culvert/Bridge blockage due to natural and anthropogenic debris has also occurred in the past in a major flood event. Private bridges in Brady Gully catchment were washed away and lodged at the culvert entrance downstream, causing flooding of the nearby properties. Natural debris such as uprooted vegetation, slumped creek banks etc., can also result in blockage of culverts.

These flood mechanisms both in isolation and in combination are the basis for floodplain management of this catchment. Sensitivity analysis has been completed within the flood study to gain an understanding of blockage on nearby properties.

The major areas of historical flooding in the Narara Creek catchment are highlighted in Figure ES4 & ES5.

Historic Flooding

Significant flooding events occurred within the Narara Creek catchment between October 1985 and February 1990, with flooding occurring mostly in the lower floodplain. During the 1985 event, 41 residences and 21 commercial /industrial premises were inundated above floor level (PWD Report No87045). The most

severely affected areas, where flood depths were up to one meter above the floor level, were in the Rowena Road and Showground Road areas.



Figure ES2: A Flooded Property at Showground Road Narara-14 October 1985

There was a significant flood event in February 1992, which resulted in widespread flooding across the upper and lower catchments. Subsequent analysis estimated that this event was slightly rarer than a 1% Annual Exceedance Probability (AEP) and it was generally agreed that it was the worst flood event on record (Patterson Britton, 1995).



Figure ES3: Gavenlock Oval Flood level mark 3 bricks under bottom of window – February 1992

The two historic events illustrated in Figures ES2 & ES3 highlight the severity of flooding that needs to be addressed in this floodplain risk management study. Figures ES4 and ES5 show the flood extent during the February 1992 flood event.

Several major floods in the past have been observed in the catchment. Historic flood levels recorded on Narara Creek at Showground Road are presented in the following table. The 1% AEP design flood for the present study is also presented in this table for comparison purposes.

Historical Flooding (AHD Range) Recorded on Narara Creek at Showground Road								1% AEP Design Flood Level (2018 Study)
Year	1949	1956	1974	1977	1978	1985	2007	
Height AHD (M)	3.0 to 4.1	2.9*	2.4 to 3.0	2.2 to 2.7	2.2 to 2.8	3.3 to 3.8	3.0*	3.90

* denotes adopted level

Years 1949 to 1985 - Source Lower Narara Creek Flood Study December 1988, Public Works Report 87045

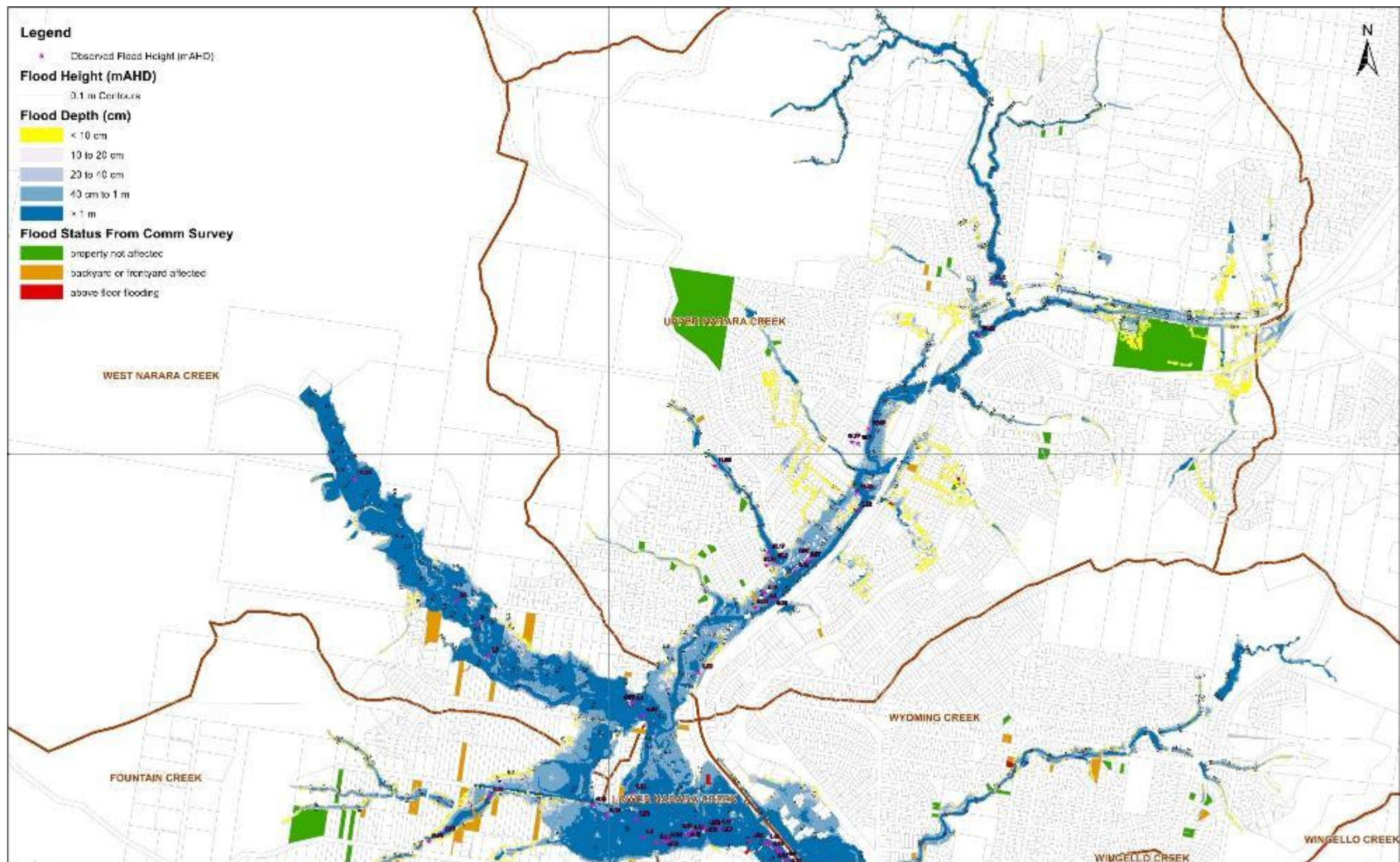


Figure ES4: Upper Narara Creek Peak Historical Flooding February 1992

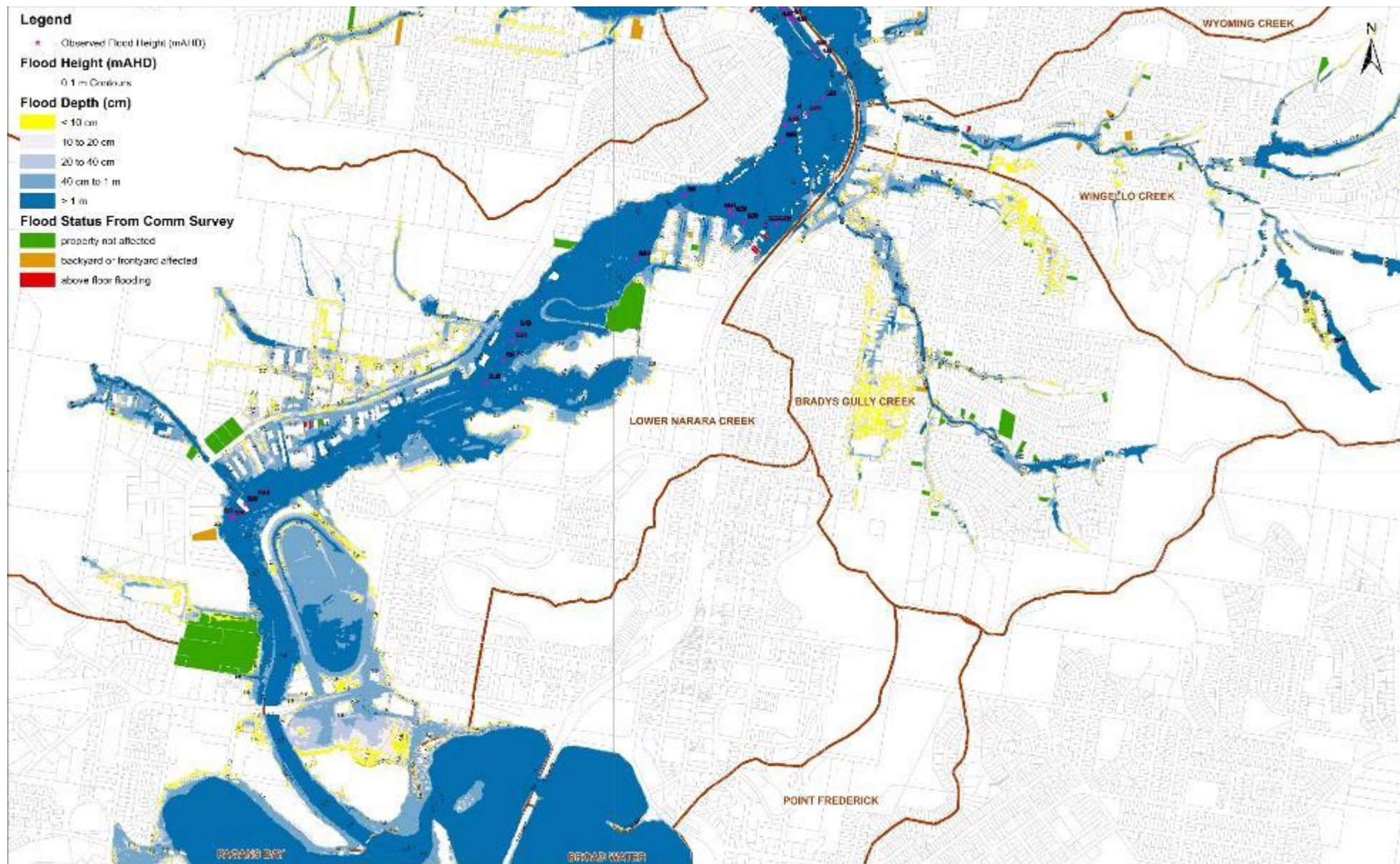


Figure ES5: Lower Narara Creek Peak Historical Flooding February 1992

Past Flood Mitigation Options

Following the major flood event in 1992, the Central Coast Council initiated a series of flood management studies that culminated in flood risk management plans for various creek systems in the study area. Several flood management options were investigated as part of those studies and a number of them have been implemented in the catchment. A sketch showing the implemented options is presented in Appendix B. The hydraulic model developed for the catchment has incorporated all those options.

All previous options were identified by studies undertaken for only a part of the larger Narara Creek catchment. Hydraulic assessment carried out in past studies for the options located in the upper reaches of the catchment, such as the Pecan Close Basin, is likely to be robust and the impact of the option would be relatively well defined. However, assessment of those options, which lie at or near the confluence with Narara Creek did not consider the dynamic flow behaviour with various flood arrival times from various parts of the larger catchment. Hence these options are likely to be assessed as less effective in the current study, where a whole-of-catchment modelling approach has been undertaken. As an example, the flood mitigation works undertaken on Wyoming Creek near Pacific Highway *appear to be less effective* than shown in the previous study (Floodplain Management Plan for Wyoming Creek, Kinhill, 1993).

It is noted that the options in the previous studies were assessed based on existing catchment conditions at that time. Generally, a separate assessment or reassessment of the previous options was not undertaken in the current study. The options that have been implemented in the study area were, however, included in the modelling and were considered to be a part of the existing conditions for the catchment.

The Lower Narara Creek Floodplain Management (1993) identified specific properties as high risk. Under the Voluntary Purchase (VP) program, and with assistance from the NSW Government's Floodplain Management Program, 39 properties in the Rowena Road / Showground Road area have been acquired over a period of approximately 20 years. The Plan was amended in February 2002 to include a further two properties in the voluntary purchase scheme, these properties have been reviewed as part of this study.

Impact of Transport Infrastructure Upgrade

The Pacific Highway upgrade through the catchment by TfNSW is a major infrastructure development within the floodplain.

As part of the adopted eastern route by TfNSW, it was necessary to close Carrington Street and investigate the option of a link road to connect Pandala Rd to Reeves Street.

This link road was deemed to provide traffic benefits and potentially provide a flood evacuation route for the local area. However, during community consultation by TfNSW, objections were raised by sections of the local community. Consequently, TfNSW removed this link road from the final option. The details of community consultation undertaken by the TfNSW are presented in Appendix F.

The link from Pandala Road to Reeves Street is an effective solution in terms of cost and flood risk management perspectives. It is recommended that the option for the provision of this link road be further explored, and the community re-engaged with the sole objective of highlighting the flood risk and the possible reduction of this risk for the area.

Flood Impacts and Damages

Floods have direct as well as indirect impacts on society. The direct impacts primarily include damage to properties and other financial impacts whereas indirect damages include social and psychological impacts on society. Consequently, some damages are tangible whereas others cannot be quantified.

The Narara Creek Flood Study Review (Golder, 2018) hereafter described as *The Flood Study* has provided the opportunity to assess the impact of the entire catchment in a single hydraulic model and hence the outcomes are considered more robust. The model is also able to accommodate three different types of flooding mechanisms in the catchment, namely overland flooding in the upper reaches of the catchment, fluvial flooding resulting from major waterways in the catchment and coastal flooding from Brisbane Waters. This Floodplain Risk Management Study considers the flood damages as a result of fluvial and overland flooding only. Damages assessment from coastal flooding have been estimated in the Brisbane Water Foreshore Floodplain Risk Management Study and Plan (Cardno, 2015).

Flood modelling indicates that flood impacts are widespread when various flooding mechanisms are considered. In a 1% AEP flood event, more than 650 properties are affected by above-floor flooding with an estimated flood damage of approximately \$70 million. The Average Annual Damage (AAD) for the study area is approximately \$24 million. The AAD is estimated from the probability of occurrence of flood events of different severity and the associated damages. It provides a long term average of flood damages in a catchment.

Table ES1 summarises the number of properties that would be flooded in different design flood events together with the tangible and intangible flood damage that is likely to occur in the study area.

Table ES1: Number of Flood Affected Properties and Associated Damages for Various Design Flood Events

Event	No of Houses Affected by Flooding	No of Houses with Over-Floor Flooding	Tangible Flood Damage	Intangible Costs (25% of Tangible Costs)	TOTAL
PMF	1673	1,560	\$162,143,164	\$40,535,791	\$202,678,955
500 Year ARI	949	781	\$67,545,307	\$16,886,327	\$84,431,634
200 Year ARI	949	781	\$62,200,622	\$15,550,155	\$77,750,777
100 Year ARI	861	664	\$56,466,705	\$14,116,676	\$70,583,381
50 Year ARI	792	585	\$50,226,874	\$12,556,718	\$62,783,592
20 Year ARI	721	527	\$44,847,713	\$11,211,928	\$56,059,641
10 Year ARI	657	482	\$40,504,378	\$10,126,094	\$50,630,472
5 Year ARI	562	416	\$34,641,868	\$8,660,467	\$43,302,335
2 Year ARI	187	166	\$13,141,528	\$3,285,382	\$16,426,910

The flood damage estimates have been derived for the state of the catchment circa 2009. Although the study area is almost fully developed as per the land zoning current at that time, any future changes in land zoning to intensify development can potentially have significant impact on the flood behaviour. The impact of re-zoning should be investigated on a catchment wide basis where cumulative impacts of all the possible/future land re-zonings are considered. Piecemeal assessment of development or rezoning should be avoided.

Flood Management Options

At project inception, the flood study results were presented to the Council's Coast and Flood Committee. Several flood management options were identified, and a preliminary list of flood management options was also presented in the meeting.

The identified options can be classified as:

- **Flood Modification (FM)** measures
- **Property Modification (PM)** measures
- **Emergency Response Modification (EM)** measures

Option identification and assessment is discussed in Section 9.

The **Flood Modification Options** identified for the study area and assessed were:

- West Gosford Industrial Area levee
- Raising the Siletta Road Basin storage level
- Racecourse storage area with accompanying levee
- Raising Central Coast Highway
- Creating detention basin in Brooks Avenue Industrial Area
- Filling of Caravan Park above the 1% AEP flood
- Upgrade of Narara Valley Drive Bridge

- Provision of a levee along the northern end of Koninderie Parade

The **Property Modification Options** identified for the study area and assessed were:

- Planning and development controls
- House Raising
- Voluntary Purchase
- On Site Detention Policy

The following **Emergency Response Modification Options** were found suitable for the study area:

- Revision of Central Coast Local Flood Plan (a sub-plan of DISPLAN)
- Information Transfer to SES by Council
- Public Awareness and Education by SES (FloodSafe Brochure for the study area)
- Public Awareness and Education by SES (Schools Package)
- Business Awareness and Education by SES
- Depth markers at major road crossings
- Flood Emergency Response Plan for Large Establishments
- Data Collection Strategies
- Flood Warning Systems
- Flood Mapping Information Council Website

The Council undertook an Early Warning Flood Forecasting Study (MHL, 2017) to explore the possibility of flood forecasting for the Narara Creek catchment. A flood forecasting tool (MHLFIT) was identified in the study as a suitable predictive flood tool. Following testing, the MHLFIT tool is now operational and currently in use by the Council and SES. The MHLFIT tool utilises the flood model results for forecasting flooding in the catchment based on the rainfall data from the local and regional rain and level gauges. This tool is specifically designed to assist SES and Council officers with predictive flood intelligence using real time data for flood forecasting in short duration catchments, such as Narara Creek.

Options Assessment

A preliminary assessment of the flood management options was undertaken and discussed in a meeting with the Council's Technical Sub-committee for the project. The options were assessed against the existing planning policies, possible effectiveness, community acceptability etc. before short-listing the options for further assessment.

The final assessment of options was carried out against a range of criteria, including technical, economic, environmental and social.

Hydraulic modelling was undertaken for several flood modification options. The results (refer Section 12) of this assessment were used to determine the reduction in flood damages as a result of the implementation of the options.

A detailed economic analysis was undertaken for those flood modification options for which hydraulic modelling was undertaken. Several property modification options (such as house raising and voluntary purchase programs) were also assessed for their economic feasibility. The economic assessment included a damages assessment and a benefit-cost ratio analysis.

A multi-criteria matrix assessment approach was adopted for the comparative assessment of all options identified using a similar approach to that recommended in the Floodplain Risk Management Manual (2023). This approach of assessing the merits of various options uses a subjective scoring system. The principal merits of such a system are that it allows comparisons to be made between alternatives using a common index. In addition, it makes the assessment of alternatives “transparent” (i.e. various important factors are discussed and included in the analysis). However, this approach does not provide an absolute “right” answer as to what should be included in the Flood Risk Management Plan and what should be omitted. Rather, it provides a method by which stakeholders can re-examine options and, if necessary, debate the relative scoring assigned.

Each option is given a preliminary score according to how well the option meets specific considerations. In order to keep the scoring simple a system was developed for each criterion.

The following criteria were adopted for the matrix assessment:

- **Technical**
 - Likely Overall Hydraulic Improvement
- **Economic**
 - Capital and Operating Costs
 - Reduction in Risk to Property
- **Social**
 - Reduction in Social Disruption
 - Reduction in Risk to Life
- **Environmental**
 - Flow and Water Quality Objectives
 - Fauna/Flora
- **Community**
 - Community Support
- **Authority**
 - Council/Agency/SES Support
- **Policy/Legislation**
 - Compatible with Policies and Plans.

The score for each option is presented in this report (Section 15.3). Primarily, all options related to development control scored highly among all the options. Major flood modification options such as flood retarding basins are not feasible in the study area due to the developed nature of the catchment. The flood modifications therefore are of smaller magnitude and provide only localised benefits. However, those benefits are significant and can be adopted in the Flood Risk Management Plan. The Narara Valley Drive Bridge Upgrade along with the Koninderie Parade Levee and filling of Caravan Park are examples of the options that provide significant benefits, both tangible and non-tangible.

The final stage of the flood risk management process is to prepare a flood risk management plan for the study area. The findings of this report, including scoring of different options, would be taken into consideration while recommending various flood management options in the plan.

The draft Narara Creek Floodplain Risk Management Study and Plan would be placed on public exhibition to gather community feedback.