QUEANBEYAN-PALERANG REGIONAL COUNCIL

QUEANBEYAN
FLOODPLAIN RISK MANAGEMENT
STUDY AND PLAN

DECEMBER 2020

VOLUME 1 – REPORT

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FOREWORD

NSW Government's Flood Policy

The NSW Government's Flood Prone Land Policy is directed at providing solutions to existing flooding problems in developed areas and to ensuring that new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist councils in the discharge of their floodplain risk management responsibilities. The Policy provides for technical and financial support by the State through the following four sequential stages:

1.	Data Collection and Flood Study	Collects flood related data and undertakes an investigation to determine the nature and extent of flooding.
2.	Floodplain Risk Management Study	Evaluates management options for the floodplain in respect of both existing and proposed development.
3.	Floodplain Risk Management Plan	Involves formal adoption by Council of a plan of management for the floodplain.
4.	Implementation of the Plan	Construction of flood mitigation works to protect existing development. Use of Local Environmental Plans to ensure new development is compatible with the flood hazard. Improvements to land use management and flood emergency management procedures.

Presentation of Study Results

The results of an updated flood study that was commissioned by Queanbeyan-Palerang Regional Council as part of the present study (***Updated Flood Study***) are presented in **Appendix C** of this report. Both the *Updated Flood Study* and the *Floodplain Risk Management Study* have been prepared under the guidance of the Floodplain Risk Management Committee comprising representatives from Queanbeyan-Palerang Regional Council, the NSW Office of Environment and Heritage, the NSW State Emergency Service and community representatives.

ACKNOWLEDGEMENT

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ABBREVIATIONS

AEP	Annual Exceedance Probability (%)
AHD	Australian Height Datum
ARI	Average Recurrence Interval (years)
ARR	Australian Rainfall and Runoff
BoM	Bureau of Meteorology
Council	Queanbeyan-Palerang Regional Council
DCP	Development Control Plan
DECC	Department of Environment and Climate Change
DPIE	Department of Planning, Industry and Environment
DWR	Department of Water Resources (now OEH)
FDM	Floodplain Development Manual, 2005
FPL	Flood Planning Level (1% AEP flood level + 0.5 m freeboard)
FPA	Flood Planning Area (area inundated at the FPL)
FRMS	Floodplain Risk Management Study
FRMP	Floodplain Risk Management Plan
FRMS&P	Floodplain Risk Management Study and Plan
LEP	Local Environmental Plan
LP3	Log Pearson Type III (form of probability distribution)
LiDAR	Light Detection and Ranging
MFL	Minimum Floor Level
NSW SES	New South Wales State Emergency Service
PMF	Probable Maximum Flood
VP	Voluntary Purchase

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SUMMARY

S1 Study Objectives

Queanbeyan-Palerang Regional Council (**Council**) commissioned the finalisation of the *Floodplain Risk Management Study and Plan* for the parts of the Queanbeyan that are affected by flooding from the Queanbeyan and Molonglo Rivers (referred to herein as "main stream flooding"). The overall objectives of the *Floodplain Risk Management Study (**FRMS**)* were to assess the impacts of flooding, review existing Council policies as they relate to development of land in flood liable areas, consider options for the management of flood affected land and to develop a *Floodplain Risk Management Plan (**FRMP**)* which:

i) proposes modifications to existing Council policies to ensure that the development of flood affected land is undertaken so as to be compatible with the flood hazard and risk;

ii) proposes *Flood Planning Levels* for the various land uses in the floodplain;

iii) sets out the recommended program of works and measures aimed at reducing over time, the social, environmental and economic impacts of flooding; and

iv) proposes a program for implementation of the proposed works and measures.

As the *FRMS* focuses principally on main stream flooding from the Queanbeyan and Molonglo Rivers, it does not deal with other sources of flooding such as minor tributary flooding and major overland flow which also occurs in other parts of the City.

S2 Study Activities

The activities undertaken in this *FRMS* included:

1. Undertaking a consultation program over the course of the study to ensure that the Queanbeyan community which borders the two river systems was informed of the objectives, progress and outcomes over the course of the study (**Chapter 1** and **3**, as well as **Appendices A** and **B**).
2. Analysis of historic stream flow data to update the flood frequency relationships that have been derived for the Queanbeyan and Molonglo Rivers at Queanbeyan (**Chapter 2** and **Appendix B**).
3. Development of new hydrologic and hydraulic models and the definition of flood behaviour along the Queanbeyan and Molonglo Rivers at Queanbeyan for flood events up to the Probable Maximum Flood (**PMF**). (**Chapter 2** and **Appendix C**).
4. Assessment of the economic impacts of flooding, including the numbers of affected properties and estimation of flood damages (**Chapter 2** and **Appendix D**).
5. Review of current flood related planning controls for Queanbeyan and their compatibility with flooding conditions (**Chapter 2**).
6. Strategic review of potential floodplain risk management works and measures aimed at reducing flood damages, including an economic assessment of the most promising measures (**Chapter 3**).
7. Preparation of draft wording for inclusion in the Queanbeyan Development Control Plan which is aimed at guiding future development in flood prone areas (**Chapter 2** and **Appendix E**).
8. Ranking of works and measures using a multi-objective scoring system which took into account economic, financial, environmental and planning considerations (**Chapter 4**).
9. Preparation of a *FRMP* for the parts of the City that are subject to flooding from the Queanbeyan and Molonglo Rivers (**Chapter 5**).

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S3 Summary of Flood Impacts

The study area comprises the urbanised parts of Queanbeyan which are subject to flooding from the Queanbeyan and Molonglo Rivers. Flooding along these two rivers is of a 'flash flooding' nature, with parts of the Queanbeyan CBD subject to flooding within as little as four hours after the onset of flood producing rain.

Figures 2.2 and **2.3** show the nature of Queanbeyan and Molonglo River flooding for the 1% Annual Exceedance Probability (**AEP**) and PMF events, respectively. In a 1% AEP flood event, floodwater from the Queanbeyan River would inundate parts of the Queanbeyan Central Business District (**CBD**) to depths of up to 3.5 m. The PMF would generate peak flood levels that are about 12 m above the peak 1% AEP flood level at Queanbeyan (**Figure 2.4**).

Water levels in the Queanbeyan River typically rise at a rate of between about 0.5-0.8 m/hour and reach their peak over a period of about 24 hours for floods up to 0.5% AEP in magnitude. During more extreme flood events, water levels in the Queanbeyan River could rise as fast as 4.5 m/hour and reach their peak in about ten hours after the onset of flood producing rain (**Figures 2.5** and **2.6**).

Parts of the Queanbeyan CBD are subject to local catchment flooding during storms which result in the surcharge of the existing stormwater drainage system. **Figure 2.7** shows the nature of local catchment flooding in the Queanbeyan CBD for a 1% AEP storm event.

Relatively minor increases in rainfall intensity associated with future climate change would result in a significant increase in the depth to which floodwater inundates parts of Queanbeyan. For example, a 13% increase in the intensity of a 1% AEP storm event translates to a 1.6 m increase in peak flood levels in the Queanbeyan CBD (**Figure 2.10**).

The threshold for above-floor flooding in existing development at Queanbeyan is a flood with an AEP slightly larger than 5 per cent. At the 1% AEP level of flooding, 260 residential properties would experience above-floor inundation up to a maximum depth of 3.1 m. A large number of these properties comprise residential unit type development. There are 15 residential unit blocks comprising 230 individual units that are located in the High Hazard Floodway area at Queanbeyan.

A total of 239 commercial tenancies and 10 public buildings would also experience above-floor flooding in a 1% AEP flood, the majority of which are located on the western side of the Queanbeyan River within or in close proximity to the Queanbeyan CBD.

The total flood damages at Queanbeyan are $69.6 Million at the 1% AEP level of flooding, increasing to more than $1 Billion for the PMF event.

The "*Present Worth Value*" of damages resulting from all floods up to the magnitude of the 1% AEP at a seven per cent discount rate and a 50 year economic life is $9.8 Million. This number represents the amount of capital spending which would be justified if a particular flood mitigation measure prevented flooding for all properties in Queanbeyan up to the 1% AEP event.

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S4 Freeboard Requirement for Setting Minimum Floor Levels for Residential Development

After accounting for factors which influence flood levels such as wind and wave action, changes in hydraulic roughness, uncertainties in the peak flow estimate and the effects of future climate change, it was concluded that the adoption of a 0.5 m freeboard for setting the minimum floor level of future residential development within parts of the Queanbeyan CBD would not provide the necessary factor of safety to peak 1% AEP flood levels (i.e. because the service life of the multi-storey commercial and residential towers which are permitted in this area is likely to expose them to climate change related impacts on flood behaviour). The findings of a joint probability analysis that was undertaken as part of the present study indicates that the adoption of a 1.2 m freeboard would be more appropriate for setting the minimum floor level for future residential development that is associated with this type of development.

S5 Flood Risk and Development Controls

A draft *Flood Policy* has been prepared to guide future development in areas affected by flooding from the Queanbeyan and Molonglo Rivers (refer **Appendix E**). Controls over development are graded according to the flood risk. The delineation of flood hazard zones is based on the proximity to flow paths, depths and velocities of flow, the rate of rise of floodwaters and ease of evacuation from the floodplain in the event of a flood emergency.

The Flood Planning Level (**FPL**) for main stream flooding at Queanbeyan has been defined as the peak 1% AEP flood level plus 0.5 m freeboard.

Figure E1.1 in the draft *Flood Policy* is an extract from the *Flood Planning Map* relating to flooding along the Queanbeyan and Molonglo Rivers. The extent of the Flood Planning Area (**FPA**) (the area that lies below the FPL) is shown in a solid red colour and has been defined as land which lies at or below the 1% AEP plus 0.5 m freeboard.

Minimum floor level (**MFL**) requirements would be imposed on future development in properties that are identified as lying either partially or wholly within the extent of the FPA shown on the *Flood Planning Map*. The MFLs for all land use types affected by flooding from the Queanbeyan and Molonglo Rivers is the level of the 1% AEP flood event plus 0.5 m freeboard, with the exception of land zoned *B3-Commerical Core* in the Queanbeyan CBD where the MFL of residential development is the 1% AEP flood event plus 1.2 m freeboard, while the MFL of commercial development is the 5% AEP flood level.

Due to the large flood range at Queanbeyan, Essential Community Facilities, Critical Utilities, Schools and Flood Vulnerable type development is not permitted in areas subject to flooding from the Queanbeyan and Molonglo Rivers. **Figure E1.2** in the draft *Flood Policy* shows the areas where this type of development is not permitted in Queanbeyan.

In order to best manage the significant flood risk which is present within the Queanbeyan CBD, the draft *Flood Policy* imposes controls above the FPL. These controls principally relate to the adoption of a shelter-in-place and safe refuge above the PMF level strategy, with the provision for evacuation by boat. As these controls relate to residential development, their adoption will first require Council to apply to the Secretary for "exceptional circumstances" exemption. Note that the adoption of the aforementioned strategy is subject to the completion of the development of a comprehensive floodplain risk management strategy for the Queanbeyan CBD, the requirement for which has been incorporated in the *FRMP*.

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S6 The Floodplain Risk Management Plan

The *FRMP* showing recommended flood management measures for Queanbeyan is presented in **Table S1** at the end of this Summary They have been given a provisional priority ranking, confirmed by the Floodplain Risk Management Committee, according to a range of economic, social, environmental and other criteria set out in **Table 4.1** of the report.

The *FRMP* includes six "non-structural" management measures of a planning nature which could be implemented by both Council and New South Wales State Emergency Service (**NSW SES**), using existing data and without requiring Government funding.

The measures are as follows:

- **Measure 1** - The application of a graded set of planning controls for future development that recognise the location of the development within the floodplain; to be applied through an update the Development Control Plan for Queanbeyan. Recommended wording for inclusion in the Development Control Plan for Queanbeyan is provided in **Appendix E**. Application of these controls by Council will ensure that future development in flood liable areas at Queanbeyan is compatible with the flood risk.
- **Measure 2** – Updating of the wording in Clause 7.2 of *Queanbeyan Local Environmental Plan 2012 (**Queanbeyan LEP 2012**)* titled *Flood planning.* The changes to *Queanbeyan LEP 2012* will permit the inclusion of the recommended set of controls set out in **Appendix E** of this report in the Development Control Plan for Queanbeyan.
- **Measures 3** - Improvements in the NSW SES's emergency planning, including use of the flood related information contained in this study to assist with the update of the *Queanbeyan City Local Flood Plan 2013*. Information in this present report which would be of assistance to NSW SES includes data on the nature and extent of flooding in Queanbeyan, times of rise of floodwaters, duration and depth of inundation at major road crossings for a range of flood events and properties affected by flooding.
- **Measure 4** - Council should take advantage of the information on flooding presented in this report, including the flood mapping, to inform occupiers of the floodplain of the flood risk. This could be achieved through the preparation of a *Flood Information Brochure* which could be prepared by Council with the assistance of NSW SES containing both general and site specific data and distributed with rate notices.
- **Measure 5** – Involves the installation of a telemetered stream gauge on the Queanbeyan River at Queens Bridge. The installation of the telemetered stream gauge will allow NSW SES and others to remotely monitor the water level in the river in real time, rather than rely on intermittent reports from the Local Unit who presently monitor the manual gauge during a flood event.
- **Measure 6** - Involves a review of potential improvements to the existing flood warning system at Queanbeyan. Potential improvements include the establishment of a public address and telephone based flood warning system which is linked to key trigger outflows from Googong Dam and water levels recorded at the telemetered Wickerslack stream gauge which is located about 6 km upstream of Queanbeyan. Depending on the outcomes of **Measure 9**, improvements could also include the development of a flash flood warning system for Queanbeyan.

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Measure 7 comprises the continued management of vegetation along the Queanbeyan River by Council, while **Measure 8** involves the commissioning of a *Voluntary Purchase and House Raising Feasibility Study* for seven residential properties that are located in a High Hazard Floodway area (which are eligible for inclusion in the NSW Government's *Voluntary Purchase Scheme*) and one dwelling that is located in a High Hazard Flood Storage area (which is eligible for inclusion in the NSW Government's *Voluntary House Raising Scheme*). Although subject to the agreement by the affected owners, this measure includes the cost of purchasing the seven properties and the raising of the single dwelling.

While there are 15 unit blocks comprising 230 individual residential units located in the High Hazard Floodway area at Queanbeyan, there would not be sufficient funding within the NSW Government's *Voluntary Purchase Scheme* to acquire all of these unit blocks.

Master planning for future development within the Queanbeyan CBD has to date not adequately addressed the management of major overland flow, or the existing, continuing and future flood risk in this area arising from main stream flooding. While the draft *Flood Policy* in **Appendix E** aims to address the flood risk associated with both local catchment and main stream flooding in the Queanbeyan CBD, it is recommended that a comprehensive floodplain risk management strategy be prepared for this area. The preparation of the strategy, which has been included as **Measure 9** in the *FRMP*, will need to address issues such as:

- The suitability of adopting "shelter-in-place" as a flood risk management strategy and/or the provision of elevated walkways linking the proposed buildings with rising ground to the north of the Queanbeyan CBD.
- The management of major overland flow and how gradual infill development can occur without adversely impacting flood behaviour in adjacent development. This may require Council to commit to the construction of a detention basin in Queanbeyan Park to offset the impact future development in areas subject to local catchment flooding would have on flood behaviour. In order to assess the requirements for the temporary storage of major overland flow upstream of the Queanbeyan CBD it will be necessary to extend the hydraulic model that has been developed as part of the present investigation to include the definition of major overland flow in the urbanised catchment which lies to its west.
- The suitability of the improvements which have been recommended as part of this study to the existing flood warning system in regards the safe and timely evacuation of occupiers of the Queanbeyan CBD during a flood on the Queanbeyan River. Based on the findings of the aforementioned major overland flow study, it may also be necessary to develop a flash flood warning system for the Queanbeyan CBD.

It is recommended that a working group be set up to oversee the development of the strategy. The working group should include representatives from Council, the NSW Department of Planning, Industry and Environment (**DPIE**) and NSW SES.

S7 Timing and Funding of FRMP Measures

The total estimated cost to implement the *FRMP* for Queanbeyan is **$6.53 million**, exclusive of Council and NSW SES staff costs. The timing of the measures will depend on Council's overall budgetary commitments and the availability of both Local and State Government funds.

Assistance for funding projects included in the *FRMP* may be available upon application under the Commonwealth and State funded floodplain risk management programs, currently administered by DPIE.

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S8 Council Resolution

Council resolved to endorse the *Queanbeyan Floodplain Risk Management Study and Plan* at its Ordinary Meeting which was held on 16 December 2020 subject to a series of amendments that were considered to balance social, economic, environmental and flood risk parameters, details of which are set out in **Section 1.4** of the *FRMS* report.

Council also resolved that the development controls set out in Chapter E3 of **Appendix E** be considered in any revision of the *Queanbeyan Development Control Plan 2012* which applies to the Flood Planning Area and be referred to the Floodplain Risk Management Committee for comment.

S9 Council Action Plan

1. Council and NSW SES commence work on the "non-structural" measures in the *FRMP (***Measures 1** to **6**).

2. Council continues to maintain vegetation along the banks of the Queanbeyan River (**Measure 7**)

3. Council commissions a *Voluntary Purchase and House Raising Feasibility Study* which deals with the seven residential properties that are located in a High Hazard Floodway area (which are eligible for inclusion in the NSW Government's *Voluntary Purchase Scheme*) and the one dwelling that is located in a High Hazard Flood Storage area (which is eligible for inclusion in the NSW Government's *Voluntary House Raising Scheme*) (**Measure 8**). Depending on the outcome of the feasibility study and the availability of Government funding, Council to proceed with the acquisition/raising of the affected properties/dwellings.

4. Council to develop a comprehensive floodplain risk management strategy for the Queanbeyan CBD in close consultation with DPIE and NSW SES (**Measure 9**).

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TABLE S1
RECOMMENDED MEASURES FOR INCLUSION IN
QUEANBEYAN FLOODPLAIN RISK MANAGEMENT PLAN

Measure	Required Funding	Features of the Measure	Priority
1. Incorporate recommended set of controls into the Development Control Plan for Queanbeyan.	(Council's staff costs)	▪ Control development in floodplain as presented in **Appendix E** of the *Queanbeyan Floodplain Risk Management Study and Plan 2019*. ▪ Graded set of flood controls based on the type of development and their location within the floodplain, defined as land inundated by the Probable Maximum Flood. ▪ Floodplain divided into six hazard zones: **Inner Floodplain (Hazard Category 1)**, **Inner Floodplain (Hazard Category 2A)**, **Inner Floodplain (Hazard Category 2B)**, **Inner Floodplain (Hazard Category 2C)**, **Intermediate Floodplain** and **Outer Floodplain**. ▪ Flood controls for residential development located on land which lies below the Flood Planning Level (1% AEP flood plus 0.5 m freeboard), with no new residential development in **Inner Floodplain (Hazard Category 1)** zone. ▪ Floor levels of commercial development in **Inner Floodplain (Hazard Category 2B)** zone at or above the 5% AEP level. Minimum floor level for new residential development in this zone to be the 1% AEP flood plus 1.2 m freeboard. ▪ Provision to be made for the safe and timely evacuation of occupiers of commercial tenancies and residential unit towers located in the **Inner Floodplain (Hazard Category 2B)** zone. ▪ Controls for Essential Community Facilities, Critical Utilities and Flood Vulnerable development based on the Probable Maximum Flood.	**Priority 1: t**his measure has a high priority in view of continuing development in Queanbeyan. It does not require Government funding.
2. Update of *Queanbeyan LEP 2012*	Council's staff costs	➢ Update wording in clause 7.2 of Queanbeyan *LEP 2012* titled *Flood planning* to reflect the recommended approach to defining the FPL.	**Priority 1**: this measure is designed to reduce the flood risk to future development and has a high priority for inclusion in the *FRMP*. It does not require Government funding.
3. Ensure flood data in *this Floodplain Risk Management Study and Plan* are available to the NSW SES for improvement of flood emergency planning.	NSW SES costs	➢ NSW SES should update the *Queanbeyan City Local Flood Plan 2013* using information on flooding patterns, times of rise of floodwaters and flood prone areas identified in this report.	**Priority 1**: this measure would improve emergency response procedures and has a high priority. It does not require Government funding.
4. Implement flood awareness and education program for residents bordering the Queanbeyan and Molonglo Rivers.	Council staff costs	➢ Council to inform residents of the flood risk, based on the information presented in the *FRMS*. (e.g. displays of flood mapping at Council offices, preparation of *Flood Information Brochure* for distribution with rate notices, etc).	**Priority 1**: this measure would improve the flood awareness of the community and has a high priority. It does not require Government funding.
5. Installation of a telemetered stream gauge on Queanbeyan River at Queens Bridge.	$20,000(1)	➢ The installation of a telemetered stream gauge on Queens Bridge by WaterNSW will assist NSW SES and others in remotely monitoring water levels in the Queanbeyan River, noting that this task is presently undertaken by the Local Unit via the manually read gauge.	**Priority 1**: this measure would improve flood emergency response at Queanbeyan and has a high priority.
6. Review of Existing Flood Warning System	$50,000	▪ NSW SES to review potential improvements to the existing flood warning system at Queanbeyan and consider developing a public address and telephone based system which utilises the findings of the *Updated Flood Study* and the *FRMS* to set key trigger flows and levels.	**Priority 1**: this measure would improve emergency response procedures and has a high priority.
7. Vegetation Management Program	Council staff costs	▪ Council to continue with the ongoing management of vegetation along the Queanbeyan River.	**Priority 2**: this measure would maintain the aesthetics of the river corridor at Queanbeyan and reduce the risk that floating debris will accumulate on the overbank area of the river during a flood event.
8. Commission *Voluntary Purchase and House Raising Feasibility Study* at an estimated cost of $30,000 for seven residential properties that are located in a High Hazard Floodway area and raise one dwelling that is located in a High Hazard Flood Storage area (Allocated amount of $6.34 Million assumes all affected property owners opt into the two schemes)	$6.37 Million	▪ Council to approach the owners of the seven properties that are located in the High Hazard Floodway area to assess their willingness to participate in the NSW Government's *Voluntary Purchase Scheme*. Upon gaining agreement, Council to seek grant funding from the NSW Government to purchase the relevant properties. ▪ Council to approach the owner of the property which is located in a High Hazard Flood Storage area to assess their willingness to have the floor level of their dwelling raised to the 1% AEP flood level plus 0.5 m freeboard. Upon gaining agreement, Council to seek grant funding from the NSW Government to raise the dwelling to the required level.	**Priority 2**: this measure would reduce flood risk within existing development.

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TABLE S1 (Cont'd)
RECOMMENDED MEASURES FOR INCLUSION IN
QUEANBEYAN FLOODPLAIN RISK MANAGEMENT PLAN

Measure	Required Funding	Features of the Measure	Priority
9. Develop comprehensive floodplain risk management strategy for the Queanbeyan CBD	$120,000	▪ The strategy would address issues such as: ○ the suitability of adopting a "shelter-in-place" strategy and/or the adoption of an elevated walkway arrangement for evacuating occupiers of the Queanbeyan CBD to rising ground to its north; ○ the management of overland flow through the Queanbeyan CBD and the measures which would be required to mitigate gradual infill development on this type of flooding; ○ the freeboard which should be adopted for setting the residential FPL for the Queanbeyan CBD. ○ the suitability of the existing flood warning system in combination with the potential improvements set out under **Measure 6** to safely evacuate occupiers of the Queanbeyan CBD during a flood emergency**.** ▪ If the strategy includes controls above the residential Flood Planning Level then it will be necessary for Council to apply for "exceptional circumstances" approval from the NSW Government nominees. ▪ Depending on the findings of the assessment, it may also be necessary to develop a flash flood warning system for the Queanbeyan CBD.	**Priority 1**: this measure is designed to reduce the existing, continuing and future flood risk in the Queanbeyan CBD and has a high priority for inclusion in the *FRMP*.
Total Estimated Cost	**$6.53 Million**		

1. Excludes ongoing operation and maintenance costs.

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1 INTRODUCTION

1.1 Study Background

Queanbeyan-Palerang Regional Council (**Council**) commissioned the finalisation of the *Floodplain Risk Management Study and Plan* (***FRMS&P***) for Queanbeyan where it borders the Queanbeyan and Molonglo Rivers in accordance with the New South Wales Government's *Flood Prone Land* policy. This report sets out the findings of the investigation which utilised new flood models that were developed as part of the present study (***Updated Flood Study***) to review and update the findings of the draft *Queanbeyan Flood and Floodplain Risk Management Study and Plan* which was prepared by Lyall & Associates in 2008 (Lyall & Associates, 2008).

The *Floodplain Risk Management Study (**FRMS**)* reviewed baseline flooding conditions, including an assessment of the economic impacts and the feasibility of potential measures which are aimed at reducing the impact of Queanbeyan and Molonglo River flooding on both existing and future development. This process allowed the formulation of the *Floodplain Risk Management Plan* (***FRMP***) for Queanbeyan.

1.2 Background Information

The following documents were used in the preparation of this report:

- *Queanbeyan River Corridor Plan of Management* (Queanbeyan City Council, 1999)
- *Floodplain Development Manual* (New South Wales Government (New South Wales Government (**NSWG**), 2005)
- *Draft Queanbeyan Flood and Floodplain Risk Management Study and Plan* (Lyall & Associates, 2008)
- *Queanbeyan Local Environmental Plan 2012*
- *Queanbeyan Development Control Plan 2012* (Queanbeyan-Palerang Regional Council, 2012)
- *Initial Assessment of Potential Flood Mitigation for Communities Downstream of Googong Dam* (Jacobs, 2015)
- *Googong Dam Dam Safety Emergency Plan* (Icon Water, 2020)

1.3 Overview of FRMS Report

The results of the *FRMS* and the *FRMP* are set out in this report. The contents of each Chapter of the report are briefly outlined below:

- **Chapter 2**, **Baseline Flooding Conditions**. This Chapter includes a description of the drainage system and a review of both historic and design flood behaviour at Queanbeyan, the latter as derived by the *Updated Flood Study*. The Chapter also summarises the economic impacts of flooding on existing urban development, reviews Council's existing flood related planning controls and management measures, as well as NSW State Emergency Service's (**NSW SES's**) flood emergency planning. The Chapter concludes with an assessment of the impact future urbanisation in the vicinity of the Queanbeyan Central Business District (**CBD**) as envisaged by the *Queanbeyan Local Environmental Plan,* 2012, and potential increases in rainfall intensities linked to future climate change would have on flood behaviour.

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- **Chapter 3**, **Potential Floodplain Risk Management Measures**. This Chapter reviews the feasibility of floodplain risk management options for their possible inclusion in the *FRMP.* The list of measures considered is based on input from the Community Consultation process, which sought the views of residents and business owners at Queanbeyan in regard to potential flood management measures which could be included in the *FRMP*. The measures are investigated at the strategic level of detail.
- **Chapter 4**, **Selection of Floodplain Risk Management Measures**. This Chapter assesses the feasibility of potential floodplain risk management strategies using a multi-objective scoring procedure which was developed in consultation with the Floodplain Risk Management Committee and outlines the preferred strategy.
- **Chapter 5** presents the ***Floodplain Risk Management Plan****.* The *FRMP* comprises a number of non-structural measures which are aimed at increasing the flood awareness of the community and ensuring that future development is undertaken in accordance with the local flood risk. One structural measure was also included in the *FRMP* to further reduce flood risk and damages to existing development.
- **Chapter 6** contains a glossary of terms used in the study.
- **Chapter 7** contains a list of References.

Five appendices provide further information on the study results:

Appendix A – Community Consultation summarises residents' and business owners' views on potential flood management measures which could be incorporated in the *FRMP*.

Appendix B – Historic Flood Data contains a brief description of previous studies which have been undertaken to define the nature of flooding at Queanbeyan, as well as an analysis of the available rainfall and stream flow record. Also included in the Appendix are a series of plates showing the nature of flooding at Queanbeyan for major floods that occurred in July 1922, August 1974, October 1976 and December 2010. Tables comprising the annual series of maximum peak flows recorded by the *Queanbeyan River at Googong* (GS 410701), *Queanbeyan River at Wickerslack* (GS 410760) and *Molonglo River at Burbong* (GS 410705) stream gauges are also contained in the Appendix.

Appendix C – Hydrologic and Hydraulic Modelling Update deals with the development and calibration of new computer models, as well as their use to more accurately define the nature of flooding along the Queanbeyan and Molonglo Rivers at Queanbeyan for design flood events up to the Probable Maximum Flood.

Appendix D – **Flood Damages** is an assessment of the economic impacts of flooding to existing residential, commercial and industrial development, as well as public buildings that are located on the floodplains of both the Queanbeyan and Molonglo Rivers at Queanbeyan. The damages have been assessed using the results of the *Updated Flood Study,* both surveyed and estimated floor levels, the latter which were derived from a combination of a "drive-by" property survey, as well as data from LiDAR survey.

Appendix E – **Draft Flood Policy** presents guidelines for the control of future urban development in areas subject to main stream flooding along the Queanbeyan and Molonglo Rivers.

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1.4 Community Consultation

Following the Inception Meeting of the Floodplain Risk Management Committee which included Council, the NSW Department of Planning, Industry and Environment (**DPIE**) and NSW SES, a *Community Newsletter* was prepared by the Consultants and distributed by Council to residents and business owners who are located on the floodplains of the Queanbeyan and Molonglo Rivers. The *Community Newsletter* contained a *Community Questionnaire* seeking details from the community of flood experience and attitudes to potential floodplain risk management measures. Community responses are summarised in **Chapter 3** of the report, with supporting information is contained in **Appendix A**.

While the responses to the *Community Questionnaire* provided information on historic floods and flow patterns, in particular those resulting from the flood that occurred in December 2010, the data were mainly of a qualitative nature. The views of the community on potential flood management measures to be considered in the study were also taken into consideration in the assessment presented in **Chapter 3** of the report.

The Floodplain Risk Management Committee reviewed the potential flood management measures developed in **Chapter 3** and assessed the measures using the proposed scoring system of **Chapter 4**. The *FRMS* and accompanying *FRMP* were also reviewed by the Floodplain Risk Management Committee and amended prior to public exhibition.

The draft *FRMS&P* report was placed on public exhibition over a six week period commencing 9 August 2019. A community information session was also held on 27 August 2019 where the Consultant presented the key findings of the study, as well as the key components of the *FRMP*. Two written submissions were received from the community, as well as one written submission from Natural and Built Character of Council. A set of written responses were prepared which addressed these comments, several of which were discussed during a Floodplain Risk Management Committee meeting that was held on 8 September 2020.

At its Ordinary Meeting held on 16 December 2020 Council resolved to endorse the *FRMS&P* subject to the following amendments that were considered to balance social, economic, environmental and flood risk parameters:

"a. Flooding impacts referred to in S10.7 Planning Certificates apply to land within the Flood Planning Area and the Outer Floodplain.

b. That residential development which is replacing existing residential development on land within the Inner Floodplain (Category 2C) be considered, subject to it not increasing the density of persons resident on a site and meeting other requirements which are also applicable to residential land in the Intermediate Floodplain as shown in Annexure 2 Development Controls Matrix at page E-17 and that this Matrix be altered to reflect both the limitation on site density and the other requirements which will need to be met.

c. That Essential Community Facilities, Critical Utilities and Flood Vulnerable development as defined in the Plan at Annexure 1 (page E-16) "not be encouraged" on land within the Outer Floodplain as shown in Figure E1.2 (Sheet 2 of 2) of the Plan and that Annexure 2 Development Controls Matrix at page E -17 be altered to reflect this."

Council also resolved that the development controls set out in Chapter E3 of **Appendix E** be considered in any revision of the *Queanbeyan Development Control Plan 2012* which applies to the Flood Planning Area and be referred to the Floodplain Risk Management Committee for comment.

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1.5 Flood Frequency and Terminology

In this report, the frequency of floods is referred to in terms of their Annual Exceedance Probability (**AEP**). The frequency of floods may also be referred to in terms of their Average Recurrence Interval (**ARI**). The approximate correspondence between these two systems is:

Annual Exceedance Probability (AEP) – %	Average Recurrence Interval (ARI) – years
0.2	500
0.5	200
1	100
5	20
20	5

The AEP of a flood represents the percentage chance of it being equalled or exceeded in any one year. Thus a 1% AEP flood, which is equivalent to a 100 year ARI, has a 1% chance of being equalled or exceeded in any one year and would be experienced, on the average, once in 100 years; similarly, a 20 year ARI flood has a 5% chance of exceedance, and so on.

The 1% AEP flood (plus freeboard) is usually used to define the Flood Planning Level (**FPL**) and Flood Planning Area (**FPA**) for the application of flood related planning controls over residential development. While a 1% AEP flood is a major flood event, it does not define the upper limit of possible flooding. Over the course of a human lifetime of, say 70 years, there is a 50 per cent chance that a flood at least as big as a 1% AEP event will be experienced. Accordingly, a knowledge of flooding patterns in the event of larger flood events up to the Probable Maximum Flood (**PMF**), the largest flood that could reasonably be expected to occur, is required for floodplain and emergency management purposes. In the present study, flooding patterns were assessed for design floods ranging between a 20% AEP event and the PMF.

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2 BASELINE FLOODING CONDITIONS

2.1 Catchment Description

The city of Queanbeyan is located on the Queanbeyan River immediately upstream of its confluence with the Molonglo River. The catchment area of the Queanbeyan River at its confluence with the Molonglo River is approximately 970 km^2, of which 80 km^2 comprises the sub-catchment downstream of Googong Dam. The catchment area of the Molonglo River at its confluence with the Queanbeyan River is approximately 580 km^2. The topography of the catchment ranges from mountainous terrain to flat floodplain areas. The catchment is characterised by broad areas of undulating country from 600 to 900 m elevation in which the rivers are incised in narrow valleys ranging from 30 to 120 m deep. The catchment is flanked by the Tinderry Mountains to the west and the Great Dividing Range to the east.

Both the Queanbeyan and Molonglo Rivers are exposed to similar hydro-meteorological conditions, and so tend to flood simultaneously. However, the timing and severity of the floods in both rivers varies from flood to flood, which can influence flood levels at Queanbeyan. The Molonglo River can cause a backwater effect on the flood levels in the Queanbeyan River. This can be significant and may extend upstream at least as far as the Queens Bridge area.

2.2 Googong Dam and its Effects on Flooding at Queanbeyan

Googong Dam in located about 10 km upstream of Queanbeyan on the Queanbeyan River and comprises an ungated earth and rock fill embankment which incorporates a clay core. Construction of the dam commenced in 1975 and was completed in 1978. The dam is owned and operated by Icon Water, with its primary function being to supply drinking water to the population of Canberra and Queanbeyan. The dam stores 121 GL of water at full supply level.

The existing infrastructure has limited capacity to release water quickly for flood control purposes, with the release capacity limited to a maximum rate of 790 ML/d or 9.1 m^3/s when the dam is at full storage level (Jacobs, 2015). That said, DWR, 1992 demonstrated that the storage effects of the dam achieve a reduction in peak flood level at Queanbeyan of about 0.7 m for the flood with an annual exceedance probability (**AEP**) of 1 per cent.

2.3 Land Use in Queanbeyan Area

The population of the Queanbeyan City area was about 36,350 at the time of the 2016 Census. Queanbeyan has experienced steady and sustained growth at an average annual rate of population growth of 1.2 per cent according to the 2016 Census.

There are three crossings of the river within the environs of the City. The most important is the Queens Bridge road crossing which links the more developed western floodplain with the eastern shore. This crossing links Monaro Street with Bungendore Road. Monaro Street in the commercial heart of the City is located at relatively high levels and is only affected by the 1% AEP flood. Whilst the high point in the deck of the Queens Bridge is above the 1% AEP flood level, Bungendore Road on the eastern side is located in a sag known as the Big Dipper and is flood affected during medium flood events in excess of 10% AEP. A low level crossing is located a short distance downstream of Queens Bridge at Morisset Street. This crossing is cut by minor freshes in the river. A high level railway bridge crosses the river about 4 km downstream of Queens Bridge.

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A new ring road is soon to be built to the south of Queanbeyan which will link Ellerton Drive on the eastern side of the Queanbeyan River to Edwin Land Parkway on its western side (denoted herein as the "**Ellerton Drive Extension project"**). The deck of the new bridge crossing of the Queanbeyan River will be set above the peak 0.05% AEP flood level.

The study area extends along the 9 km reach of the Queanbeyan River from the *Queanbeyan River at Wickerslack stream gauge* (GS 570983) (**Wickerslack stream gauge**) to the junction with the Molonglo River. Over most of this length the Queanbeyan River corridor which is the City's most important natural asset winds its way through the centre of the City. A 28 km reach of the Molonglo River is also included in the investigation extending from the *Molonglo River at Burbong stream gauge* (GS 410705) (**Burbong stream gauge**) to Lake Burley Griffin in Canberra.

Residential development abuts the western side of the Queanbeyan River corridor from a location a short distance upstream of where the Ellerton Drive Extension project will cross the river to a point a short distance upstream of Queens Bridge. Commercial development is located downstream of this point with the Queanbeyan Leagues Club, shopping centres and motel development being located in flood prone areas. Residential development in low lying areas in the vicinity of Campbell Street and Lowe Street are also affected by river flooding in excess of 5% AEP. High flows generated by the local catchment to the west of this area can also cause flooding problems due to surcharge of the local stormwater drainage system. Downstream of Queens Bridge the Queanbeyan Riverside Tourist Park is located on the western bank of the river between Collett and Morisset Street and is inundated by river flooding in excess of 20% AEP.

Residential development on the eastern floodplain is concentrated in the Trinculo Place and Macquoid Street areas, which is affected by a 5% AEP river flood. Several large home unit developments are located on flood prone land in this area.

Residential development has also occurred in recent years abutting Buttles Creek. The watercourse crosses the Yass Road and several local road crossings before joining the Queanbeyan River near Morisset Street. The Yass Road is above major river flood levels, but could be inundated for short periods by local catchment flooding.

Council has recently prepared the *Queanbeyan Development Control Plan 2012* (***Queanbeyan DCP 2012***) to guide future development in the portion of the Queanbeyan CBD which is bounded by Lowe, Antill, Collett and Rutledge Streets. The Queanbeyan CBD is located in a flood prone area in the vicinity of Queens Bridge and includes the Queanbeyan Leagues Club. Both the *Queanbeyan Local Environmental Plan 2012* (***Queanbeyan LEP 2012***) and the *Queanbeyan DCP 2012* allows for mixed commercial and high-rise residential development in the Queanbeyan CBD.

2.4 Flood History

2.4.1 General

Table 2.1 over relates historic floods to predicted design floods of various return periods. The gauge heights corresponding with Minor, Moderate and Major Floods, as defined by NSW SES in the *Queanbeyan City Local Flood Plan 2013* are also shown. PMF and dam-break flood levels derived in hydrologic studies carried out for Icon Water are also shown in **Table 2.1**. **Annexure A** in **Appendix B** of this report contains a series of plates showing the nature of flooding at Queanbeyan for major floods that occurred in July 1922, August 1974, October 1976 and December 2010.

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TABLE 2.1
FLOOD HISTORY AND DESIGN FLOOD LEVELS[1]
QUEENS BRIDGE STREAM GAUGE

Flood Event	Height on Queens Bridge Gauge (m)[2]
Googong Dam failure during PMF event[3]	29.6
Sunny Day failure of Googong Dam[3]	24.2
PMF Event without Dam Failure	23.4
0.2% AEP	14.8
0.5% AEP	13.0
1% AEP	11.4
May 1925[4]	10.7 (approx.)
2% AEP	10.0
August 1974[4]	9.5
October 1976[4]	9.2 (approx.)
1891 (Month Unknown)[4]	8.9
December 2010[4]	8.4
July 1922[4]	8.3
5% AEP	8.3
Major Flood[4]	8.2
July 1988[4]	7.6
Moderate Flood[4]	7.4
July 1991[4]	6.9
10% AEP	6.8
April 1989 / January 1984[4]	6.2
20% AEP	5.6
Minor Flood[4]	4.2

1. Unless otherwise stated, peak flood levels were derived as part of present study.
2. Gauge zero on Queens Bridge gauge = 564.10 m AHD
3. Source: Icon Water, 2020
4. Source: *Queanbeyan City Local Flood Plan 2013*

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2.4.2 Floods Prior to August 1974

The flood of record occurred in May 1925 and reached a peak height of about 10.7 m on the Queens Bridge stream gauge, which is about 0.7 m below the peak 1% AEP flood level at this location. During this event, the superstructure of the railway bridge over the Queanbeyan River downstream of the city was swept away by floodwater.

Annexure B of **Appendix B** contains a copy of a newspaper article that appeared in *The Queanbeyan Age* on Friday 29 May 1925. The article describes how floodwaters rose quickly on the evening of Tuesday 26 May 1925 and isolated a number of residents but remarkably did not cause any loss of life. The article also notes that the largest floods prior to 1925 occurred in 1891 (month unknown) and July 1922, when the water level in the river respectively peaked about 6 feet (1.8 m) and 8 feet (2.4 m) below the level reached during the May 1925 flood.

2.4.3 August 1974 Flood

The highest flood experienced in Queanbeyan since the 1925 flood occurred on 29 August 1974 when the water level at the Queens Bridge stream gauge peaked at 9.5 m.[1] This event occurred prior to the construction of Googong Dam and was a 5% AEP flood under pre-dam conditions. Under post-dam conditions it would be a much rarer flood, estimated to have a return period of about 2.5% AEP.

During the August 1974 flood, 400 people were evacuated, mainly from flats and home units on the eastern bank of the Queanbeyan River in the vicinity of Trinculo Place. The flood was characterised by 'rapid river rises' which caught the community off guard.

An operation on Collett Street to evacuate residents from home units had to be abandoned when floodwater (up to 1.5 m deep in places) made the operation too dangerous, leaving some people trapped in the building. About 250 evacuees from the eastern side of Queanbeyan were accommodated at the RSL Memorial Bowling Club on Yass Road, while on the western side of the river the Salvation Army Hall on Morisset Street was used as an evacuation centre. Power was lost overnight on 28 August for approximately 1.5 hours on the western side of Queanbeyan and until mid-morning on 29 August on the eastern side, affecting the operation of the evacuation centres.

Elderly residents on the western side of Queanbeyan were taken to the Queanbeyan District Hospital, while furniture was stored in the grand stand of the showground on Lowe Street. On the eastern side, furniture was stored at the Seiffert Park Pavilion on Thurralilly Street. Council provided trucks and drivers to assist with evacuation and the elocation of furniture.

Access between the Queanbeyan CBD and east Queanbeyan via Queens Bridge was cut at the Big Dipper and an advance headquarters for all emergency services was set up on the eastern side of the river in Macquoid Street. The railway line was used to supply east Queanbeyan.

Other flood impacts reported by NSW SES included:

- Floodwaters inundated the CBD extending to the intersection of Monaro and Lowe streets.
- Council Chambers on Crawford Street were inundated.
- The bridge over the Molonglo River on Yass Road may have closed.

[1] Note that the Queens Bridge was under construction, with only the bridge piers in place at the time of the August 1974 flood (refer **Plates B2.3** to **B2.5** in **Annexure A** of **Appendix B**).

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- Most of the Queanbeyan Riverside Tourist Park was inundated.
- Floodwater caused extensive damage to the Queanbeyan Leagues Club.

2.4.4 October 1976 Flood

On 16 October 1976, a flood with an estimated peak of 9.2 m, which is about 0.9 m higher than a 5% AEP event occurred in Queanbeyan. The peak flood level was not recorded at the Queens Bridge stream gauge for this event, but it appears to have been about 0.3 m below the August 1974 flood based on nearby flood marks.

The 1976 flood occurred during the construction of Googong Dam. The crest of the partially constructed dam wall had an elevation of about RL 629.6 m AHD at the time of the flood, which is about 33 m below its current level of RL 663.0 m AHD. There was some concern that the dam wall may fail during the event as the depth of flow over the spillway at the peak of the flood was between about 2.2 and 2.5 m (refer **Plates B3.1** to **B3.7** in **Annexure A** of **Appendix B**). An evacuation warning for low-lying areas of Queanbeyan was issued approximately 24 hours before the flood peak arrived.

Approximately 5,000 people were evacuated in Queanbeyan, mainly from the CBD and residential areas. Around 400 dwellings were reported to have suffered some flood damage. Damage to Council property was also extensive.

Many major roads in and around Queanbeyan were cut, including the road through Dairy Flat in the Australian Capital Territory (**ACT**). The only access to the area was by way of Yass.

Other flood impacts included:

- Approximately 1.5 m of water inundated the carparks and storage areas in the lower level of flats on Trinculo Place, while road access to the flats was cut. Floodwater also cut access to flats on Wanniassa Street.
- The ground floors of Old Kent House, the Leagues Motel and the Art Gallery on Trinculo Place were inundated.
- Floodwater was over the road and in the yards of houses in the vicinity of Crawford and Morisset Streets up to the level of the Woolworths carpark on Crawford Street.
- The Queanbeyan Riverside Tourist Park was flooded to just below the roof of the amenities block.
- A number of residences along Thorpe Avenue were inundated in the vicinity of Glebe Park.
- Floodwater reached road level at the junction of Collett Street and Morisset Street.
- The Marco Polo Club in Morisset Street had water over the ground floor of the club.
- Deep water covered the intersection of Collett and Antill Streets.
- Approximately 1.0 – 1.5 m of water covered the site of the Riverside Plaza and there was approximately 1.8 m of water in the basement of the Leagues Club at the peak of the flood.
- Bungendore Road was closed at the Big Dipper for approximately two days.

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2.4.5 January 1984 and April 1989

Floods reaching a peak of 6.2 m on the Queens Bridge gauge (Minor Flood level), which is about 0.6 m higher than a 20% AEP event occurred on both 26 January 1984 and 3 April 1989 in Queanbeyan. Whilst floodwater remained within the banks of the Queanbeyan River during the 1984 event, water entered the lower levels of the Queanbeyan Riverside Tourist Park on Morisset Street and the lower level of the Riverside Plaza carpark on Collett Street during the flood in 1989.

The differences in the effects of flooding of the same level on the Queens Bridge gauge may have been caused by different influences of the Molonglo River which may cause backwater flooding in the Queanbeyan River. In the 1989 flood, it appears the Molonglo and the Queanbeyan River were both in flood during this event.

2.4.6 July 1988

A flood which peaked at 7.6 m on the Queens Bridge gauge, which is about 0.8 m higher than a 10% AEP event occurred on 6 July 1988. The peak occurred at 7 pm and the flow at the spillway of Googong Dam was 500 m^3/s at 5:30 pm. Road closures occurred at the low level bridge at Morisset Street, Bungendore Road at the Big Dipper, as well as Waniassa and Collett Streets. The only evacuations were from Queanbeyan Riverside Tourist Park.

2.4.7 July 1991

A flood which peaked at 6.9 m on the Queens Bridge gauge, which is about 0.1 m higher than a 10% AEP flood occurred on 11 July 1991. During this event the NSW SES sandbagged the Big Dipper in order to keep the main traffic route to the CBD open, as floodwater started to back up stormwater drains on either side of the dip and inundated the eastern approach to the Queens Bridge.

During the event, floodwater inundated the Riverside Plaza carpark and the lower floor of the Queanbeyan Leagues Club.

2.4.8 December 2010

The flood event that occurred at Queanbeyan on the morning of 9 December 2010 was preceded by a period of consistent rainfall across the preceding month which gradually filled Googong Dam from 80% capacity on 8 November 2010 to about 85% on 30 November 2010. Heavy rainfall that fell across the Queanbeyan River catchment on 1 and 2 December 2010 rapidly filled the dam resulting in the spillway commencing to operate at about 11:30 hours on 3 December 2010.

Severe localised rainfall on the rain days of 9 and 10 December 2010 produced rainfall depths in excess of 120 mm in the Queanbeyan River catchment upstream of Googong Dam generating a peak flow in the Queanbeyan River of about 1,100 m^3/s at the U/S Googong Dam stream gauge.

The maximum depth of flow over the Googong Dam spillway was about 1.8 m at 07:25 hours on 9 December 2010. At this level, the peak flow over the spillway was about 660 m^3/s (a reduction of about 440 m^3/s when compared with the peak flow recorded at the U/S Googong Dam stream gauge).[2]

[2] Without Googong Dam and the attenuating effects that it has on flows in the Queanbeyan River, it is likely that the December 2010 storm event would have resulted in flooding patterns at Queanbeyan that would have been similar to those experienced during the October 1976 flood.

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On the morning of 9 December 2010, flood levels at the Queens Bridge gauge rose at a rate of about 1.2 m/hour, from 5.0 m at 06:00 hours to 8.0 m at 08:30 hours. The flood peaked at the gauge at 8.4 m on the gauge between 10:05 and 10:40 hours on 9 December 2010 (i.e. 3 hours after the peak at Googong Dam) before receding at a rate of about 0.25 m/hour. The flood was equivalent to about a 5% AEP design flood event. Flood levels eventually dropped below the minor flood level (i.e. 4.2 m on the Queens Bridge gauge) at 14:30 hours on 10 December 2010.

The floodwater transported large amounts of woody debris (refer **Plate B4.13** in **Annexure A** of **Appendix B**) which was caught in vegetation located along the banks of the Queanbeyan and Molonglo Rivers (refer **Plates B4.19**, **B4.20**, **B4.35** and **B4.36** in **Annexure A** of **Appendix B**). A large amount of debris was also deposited in the vicinity of the Morisset Street bridge (refer **Plates B4.37** to **B4.40** in **Annexure A** of **Appendix B**).

Other flood impacts included:

- Evacuations of Trinculo Place, Riverside Caravan Park, Riverside Plaza and Queanbeyan Leagues Club.
- Approximately 1.5 m of water inundated the Riverside Plaza carpark.
- Floodwater inundated the tennis courts, car yard and McDonald's carpark in the vicinity of the intersection of Morisset Street and Waniassa Street.
- Bungendore Road was closed at the Big Dipper until late 9 December 2010.

Evacuation centres were established at Queanbeyan TAFE, Queanbeyan High School and Karabar High School.

2.5 Design Flood Behaviour

2.5.1 Background

The present study defined the nature of flooding along the Queanbeyan and Molonglo Rivers at Queanbeyan, as well as patterns of local catchment flooding in the vicinity of the Queanbeyan CBD. The study involved computer modelling of the catchment and floodplain to assess flooding patterns and indicative extents of inundation for design floods ranging from 20% AEP up to the PMF. The design storms used to determine flows in the drainage system for events with AEPs of between 20 and 0.2 per cent were determined using procedures set out in the 2016 edition of *Australian Rainfall and Runoff* (Geoscience Australia, 2016), while estimates of Probable Maximum Precipitation were made using the *Generalised Short Duration Method* as described in BoM, 2003.

Extents of inundation were defined from Light Detection and Ranging (**LiDAR**) survey data which were used to develop the hydraulic model of the drainage system. The hydraulic analysis comprised of a two-dimensional geometric model of the floodplain which was based on grid points of natural surface levels at 4 m spacing. The extents of inundation shown in the flood study are "indicative" reflecting the accuracy of the LiDAR survey data (95 per cent of the points lie within +/- 150 mm of the true elevation).

In order to create realistic results, anomalies caused by inaccuracies in the LiDAR survey data were removed. To do this, a filter was applied to remove depths of inundation over the natural surface less than 100 mm. This had the effect of removing the very shallow depths which are more prone to be artefacts of the model, but at the same time giving a reasonable representation of the various overland flow paths.

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As far as flooding in the Queanbeyan and Molonglo Rivers is concerned, the filtering process did not have a significant effect on the representation of the areal extent of flooding. It is to be noted that while the flood level and velocity data derived from the analysis are consistent throughout the model, the flood extent diagrams should not be used to give a precise determination of depth of flood affectation in individual allotments.

Four historic floods (May 1925, August 1974, October 1976 and December 2010) were used to calibrate the hydraulic model. Discharge hydrographs recorded at the Wickerslack and Burbong stream gauges were used as inflows for the hydraulic model for the floods that occurred in 1974, 1976 and 2010, while a steady state approach was adopted for modelling the May 1925 flood. The derived flows and flood levels were compared with historic flood marks and recorded observations of flooding along the Queanbeyan River and were found to be in good agreement. **Appendix C** contains further details on the model development and calibration process.

2.5.2 Flooding Patterns on the Queanbeyan and Molonglo Rivers

Figures 2.2 and **2.3** show the nature of main stream flooding at Queanbeyan for the 1% AEP and PMF events, respectively, while **Figures C4.1** to **C4.6** in **Appendix C** show similar information for the 20%, 10%, 5%, 2%, 0.5% and 0.2% AEP flood events. These diagrams show the indicative extents and depths of inundation, as well as peak water surface elevation contours in the vicinity of Queanbeyan.

Figure 2.4 shows water surface profiles along the Queanbeyan and Molonglo Rivers for the full range of design flood events, while **Table 2.2** sets out the design flood levels at the Wickerslack, Queens Bridge and A.C.T. Border stream gauges on the Queanbeyan River, as well as the Oaks Estate stream gauge on the Molonglo River.

TABLE 2.2
DESIGN PEAK FLOOD LEVELS

AEP (%)	Wickerslack Stream Gauge(1)		Queens Bridge Stream Gauge(2)		A.C.T. Border Stream Gauge(3)		Oaks Estate Stream Gauge(4)	
	Water Level (m AHD)	Gauge Height (m)	Water Level (m AHD)	Gauge Height (m)	Water Level (m AHD)	Gauge Height (m)	Water Level (m AHD)	Gauge Height (m)
20	578.38	3.93	569.67	5.57	568.41	-	567.72	6.93
10	579.62	5.17	570.89	6.79	569.83	-	569.05	8.26
5	581.09	6.64	572.42	8.32	571.53	-	570.76	9.97
2	583.15	8.7	574.06	9.96	573.18	-	572.18	11.39
1	584.94	10.49	575.49	11.39	574.55	-	573.32	12.53
0.5	586.89	12.44	577.12	13.02	576.07	-	574.6	13.81
0.2	589.01	14.56	578.88	14.78	577.76	-	575.98	15.19
PMF	601.7	27.25	587.47	23.37	585.67	-	584.39	23.6

1. Gauge zero = 574.45 m AHD (assumed).
2. Gauge zero = 564.10 m AHD (based on survey provided by Council).
3. Gauge zero not maintained by gauge operator.
4. Gauge zero = 560.79 m AHD (provide by gauge operator).

The key features of main stream flooding at Queanbeyan for the various design flood events are as follows:

20% AEP Flood

- Floodwater is generally confined to the inbank area of the Queanbeyan and Molonglo Rivers.
- The Morisset Street Bridge would be overtopped by about 2 m.
- The Oaks Estate Road crossing of the Molonglo River would be overtopped by about 5 m.

10% AEP Flood

- Floodwater commences to surcharge the western bank of the Queanbeyan River immediately upstream of the Morisset Street bridge where it partially inundates the northern end of the Queanbeyan Riverside Tourist Park.
- Floodwater commences to surcharge the eastern bank of the Queanbeyan River immediately upstream of the Morisset Street bridge where it inundates a short length of Wanniassa Street south of its intersection with Morisset Street.

5% AEP Flood

- Floodwater commences to surcharge the eastern bank of the Queanbeyan River in the vicinity of the Queanbeyan Golf Course and Trinculo Place.
- Access between the eastern and western sides of Queanbeyan is cut as floodwater backs up across Wanniassa Street and inundates Bungendore Road at The Big Dipper to a depth of about 1.8 m.
- Direct vehicular access via Ford Street to existing residential development that is located on the eastern bank of the Queanbeyan River downstream of Morisset Street is cut.
- Floodwater commences to surcharge the western bank of the river where it enters the Riverside Plaza carpark.
- Queanbeyan Riverside Tourist Park will be completely inundated to a minimum depth of about 0.3 m.
- Floodwater inundates the intersection of Morisset Street and Carinya Street to a depth of about 1.2 m.
- Floodwater backs up the trunk stormwater drainage line that runs through the Queanbeyan CBD and commences to surcharge the open channel that is located on the western side of Collett Street.

2% AEP Flood

- Floodwater surcharges the western bank of the Queanbeyan River onto Woodger Parade, inundating existing residential development that is located on its eastern side by up to 1.2 m.
- Floodwater surcharges the eastern bank of the Queanbeyan River and inundates Thorpe Avenue immediately north of its intersection with Hirst Avenue to a depth of about 0.8 m.
- Floodwater backs up through the Queanbeyan CBD and inundates existing commercial development to depths up to about 1.2 m.
- Existing residential development that is located in the vicinity of the intersection of Morisset Street and Carinya Street will be inundated to depths of up to about 1.8 m.

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- Floodwater surcharges the southern bank of the Molonglo River and inundates Yass Road to a depth of less than 0.1 m.
- Floodwater surcharges the southern bank of the Molonglo River and partially inundates the Sewage Treatment Plant.

1% AEP Flood

- Floodwater inundates Collett and Crawford Street in the Queanbeyan CBD to depths of up to 3.5 and 2.5 m, respectively.
- Floodwater inundates existing residential development that is located on the western side of Campbell Street to depths of up to 1.6 m.

0.5 and 0.2% AEP Floods

- Flood behaviour is generally similar to that described for the 1% AEP flood.
- Peak 0.5 and 0.2% AEP flood levels in the Queanbeyan CBD are respectively 1.6 m and 3.4 m higher when compared to the peak 1% AEP flood level.

PMF

- The peak flow in the Queanbeyan and Molonglo Rivers for the PMF is about 7.5 and 8.2 times that of the 1% AEP flood, respectively. As a results, the peak flood levels are about 12 m higher in the PMF when compared to a 1% AEP flood.

Given the large flood range at Queanbeyan, there is a need to consider the freeboard which is to be applied to future development, as the commonly adopted value of 500 mm may not provide the required factor of safety on peak 1% AEP flood levels. Further consideration of the components which are typically used to assess the freeboard requirements at a given location and how they apply to Queanbeyan are set out in **Section 3.5.1.2** of this report.

2.5.3 Times and Rates of Rise

Figure 2.5 shows the stage hydrographs for the modelled design flood events at the location of bridge crossings, while **Figure 2.6** shows the rate of rise and fall of water levels in the Queanbeyan River at Queens Bridge.

Flood levels in the Queanbeyan River at Queanbeyan generally rise at a maximum rate of between about 0.5-0.8 m/hour, but could rise at a rate of up to 4.5 m/hour during an extreme flood.

While water levels take a little over 24 hours to reach their peak once they commence to rise for the critical 48 hour storm event, flood levels could surcharge the southern bank of the river and commence to inundate parts of the Queanbeyan CBD within as little as 6 hours after the onset of flood producing rain.

2.5.4 Travel Times

Hydraulic modelling undertaken as part of the present study shows that it takes between about 30 minutes and one hour for the flood wave to travel between the Wickerslack stream gauge and Queens Bridge (a distance about 6 km by river). Based on this finding, it would take between about one and two hours for the flood wave to travel between Googong Dam and Queanbeyan, noting that the dam lies about 4.5 km upstream of the Wickerslack stream gauge.

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2.5.5 Flooding Patterns in the Queanbeyan CBD

Figure 2.7 shows the nature of local catchment flooding in the vicinity of the Queanbeyan CBD for a storm event with an AEP of 1 per cent.

On the western side of the Queanbeyan River, local catchment runoff that surcharges the existing piped drainage system discharges overland through the Queanbeyan CBD in an easterly direction at depths generally no greater than about 0.9 m.

Overland flow in the Queanbeyan CBD is generally confined to the area bounded by Antill Street to the north and Morisset Street to the south due to this area forming the natural low point in the off-river embayment. The majority of the runoff which surcharges the existing stormwater drainage system to the west of the Queanbeyan CBD in a 1% AEP storm event is able to re-enter the underground system via the short section of channel which is located on the western (upstream) side of Collett Street.

2.6 Existing Flood Mitigation Measures

Apart from the storage effects of Googong Dam (refer **Section 2.2** for further details), there are no other existing flood mitigation measures located along the Queanbeyan or Molonglo Rivers at Queanbeyan.

2.7 Economic Impacts of Flooding

The economic consequences of floods are discussed in **Appendix D**, which assesses flood damages to residential, commercial and industrial property, as well as public buildings in areas affected by main stream flooding on the Queanbeyan and Molonglo Rivers at Queanbeyan. There were only limited data provided by respondents to the *Community Questionnaire* on historic flood damages to the urban sectors in the study area. Accordingly, it was necessary to use data on damages experienced as a result of historic flooding in other urban centres. The residential flood damages were based on the publication *Floodplain Risk Management Guideline No. 4, 2007* (**Guideline No. 4**) published by the Department of Environment and Climate Change (**DECCW**) (now DPIE). Damages to industrial and commercial development, as well as public buildings were evaluated using data from previous floodplain risk management investigations in NSW.

It is to be noted that the principal objectives of the damages assessment were to gauge the severity of urban flooding likely to be experienced along the Queanbeyan and Molonglo Rivers at Queanbeyan and also to provide data to allow the comparative economic benefits of various flood modification measures to be evaluated in **Chapter 3** of the report. As explained in **Appendix D**, it is not the intention to determine the depths of inundation or the damages accruing to *individual properties*, but rather to obtain a reasonable estimate of damages experienced over the extent of the urban area in the City for the various design flood events. The estimation of damages using *Guideline No. 4* (in lieu of site specific data determined by a loss adjustor) also allows a uniform approach to be adopted by Government when assessing the relative merits of measures competing for financial assistance in flood prone centres in NSW.

Damages were estimated for the design flood levels determined from the hydraulic modelling undertaken as part of the present investigation. Elevations of the ground floors of 493 affected properties were surveyed in 2006, while the floor levels of the remainder of the flood affected properties in Queanbeyan were estimated by a “drive-by” survey which assessed the height of the

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floor above local natural surface elevations. These natural surface elevations in this case were derived from the LiDAR survey data used to construct the aforementioned hydraulic model. The number of properties predicted to experience “above-floor” inundation as a result of main stream flooding together with estimated flood damages is listed in **Table 2.3**.

TABLE 2.3
FLOOD DAMAGES AT QUEANBEYAN

Design Flood Event (% AEP)	Number of Properties						Total Damage ($ Million)
	Residential		Commercial/ Industrial		Public		
	Flood Affected	Flooded Above Floor Level	Flood Affected	Flooded Above Floor Level	Flood Affected	Flooded Above Floor Level	
20	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0
5	0	0	5	5	0	0	0.3
2	116	93	72	65	2	2	17.8
1	313	260	271	239	20	10	69.6
0.5	563	529	340	336	30	28	177
0.2	907	853	351	351	41	39	311
PMF	3,032	3,003	391	388	73	73	1,111

The threshold for above-floor flooding in existing development at Queanbeyan is a flood with an AEP slightly larger than 5 per cent. At the 1% AEP level of flooding, 260 residential properties would experience above-floor inundation up to a maximum depth of 3.1 m. A large number of these comprise residential unit type development.

There are two second storey residential units that would be above-floor inundated in a 1% AEP flood, increasing to 82 and 166 for floods with AEPs of 0.5 and 0.2 per cent, respectively. No third storey residential units would be above-floor inundated during a 0.2% AEP flood event. During a PMF event, more than 270 second, 150 third, five fourth and five fifth storey residential units would experience above-floor inundation.

A total of 239 commercial tenancies and 10 public buildings would experience above-floor flooding in a 1% AEP flood, the majority of which are located on the western side of the Queanbeyan River within or in close proximity to the Queanbeyan CBD.

The total flood damages at Queanbeyan are $69.6 Million at the 1% AEP level of flooding, increasing to more than $1 Billion for the PMF event.

The “*Present Worth Value*” of damages resulting from all floods up to the magnitude of the 1% AEP at a seven per cent discount rate and a 50 year economic life is $9.8 Million. This number represents the amount of capital spending which would be justified if a particular flood mitigation measure prevented flooding for all properties in Queanbeyan up to the 1% AEP event.

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The *"Present Worth Value"* of flood damages is relatively small compared to the total flood damages that would be incurred during floods larger than about 2% AEP. This is a function of the relatively high threshold at which flood damages commence to be experienced at Queanbeyan.

Additional information on flood damages at Queanbeyan is presented in **Section D8** of **Appendix D** and in **Figure D8.1** bound in Volume 2 of this report.

2.8 Impact of Flooding on Vulnerable Development and Critical Infrastructure

Figure 2.8 (2 sheets) shows the location of vulnerable development and critical infrastructure relative to the extent of inundation for floods ranging between 20% AEP and the PMF, while **Table 2.4** over the page summarises the impact that flooding has on this type of development/infrastructure at Queanbeyan.[3]

Apart from the Queanbeyan Riverside Tourist Park that is impacted by floods larger than 20% AEP, all vulnerable development with the exception of the Queanbeyan District Health Service Revival Unit which is located on the northern side of Antill Street between Crawford and Collett Streets is located on land which lies above the 1% AEP flood event.

The Fire and Rescue NSW Station located at the corner of Campbell Street and Albert Street is located on land which lies below the 1% AEP flood level, while the Police Station on the Kings Highway is located on land which lies below the 0.5% AEP flood level. The NSW SES headquarters is located at the eastern end of Erin Street on the edge of the Queanbeyan River floodplain.

2.9 Potential Impacts of Future Urbanisation

Future infill development has the potential to increase the rate and volume of runoff conveyed along the major overland flow path which runs in an easterly direction through the Queanbeyan CBD, as well as in Buttles Creek.

An assessment of the potential impact future development in the catchments which contribute to runoff in these two areas was undertaken as part of the present investigation. This involved increasing the fraction impervious in the hydrologic model to reflect an increase in hard stand areas and then running the hydraulic model to assess the change that could potentially occur to local catchment flood behaviour.[4]

Given the relatively high level of development that is present in the catchments which contribute to runoff in the Queanbeyan CBD and Buttles Creek, future infill development will only have a relatively minor impact in peak 1% AEP flood levels, as shown on **Figure 2.9**. The largest impact is shown to occur in an existing unit development that is located on the eastern side of Collette Street, where peak 1% AEP flood levels would be increased by a maximum of about 0.1 m.

[3] Critical infrastructure has been split into two categories; community assets and emergency services.

[4] A global 50% fraction impervious was applied to residential zoned areas, while a global 90% fraction impervious was applied to commercial and industrial zoned areas.

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TABLE 2.4
IMPACT OF FLOODING ON VULNERABLE DEVELOPMENT AND CRITICAL INFRASTRUCTURE AT QUEANBEYAN

Type	Development/Structure	Location Identifier[1]	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5%	0.2%	PMF
Vulnerable Development	Hospital (Queanbeyan District Hospital & Health Service)	-	O	O	O	O	X	X	X	X
	Educational Facility (Queanbeyan East Public School)	EF1	O	O	O	O	O	O	O	X
	Educational Facility (St Gregorys Primary School)	EF2	O	O	O	O	O	X	X	X
	Educational Facility (St Gregorys Primary School Lowe Street Campus)	EF3	O	O	O	O	O	O	O	X
	Educational Facility (Queanbeyan Public School)	EF4	O	O	O	O	O	O	O	X
	Educational Facility (Queanbeyan South Public School)	EF5	O	O	O	O	O	O	O	O
	Educational Facility (Queanbeyan West Public School)	EF6	O	O	O	O	O	O	O	O
	Educational Facility (Queanbeyan High School)	EF7	O	O	O	O	O	O	O	O
	Educational Facility (Karabar High School)	EF8	O	O	O	O	O	O	O	O
	Queanbeyan TAFE	EC4	O	O	O	O	O	O	O	X
	Child Care Facility (Kindy Patch Queanbeyan)	CC1	O	O	O	O	O	O	O	X
	Child Care Facility (Crest Road Early Learning Centre)	CC2	O	O	O	O	O	O	O	O
	Child Care Facility (Crestwood World of Learning)	CC3	O	O	O	O	O	O	O	O
	Child Care Facility (Precious Momentz)	CC4	O	O	O	O	O	O	O	O
	Child Care Facility (Queanbeyan Family Day Care)	CC5	O	O	O	O	O	O	O	O
	Child Care Facility (Create Imagine Learn)	CC6	O	O	O	O	O	O	O	O
	Child Care Facility (KU Queanbeyan South Early Learning Centre)	CC7	O	O	O	O	O	O	O	O
	Child Care Facility (Waratah Pre-School)	CC8	O	O	O	O	O	O	O	O
	Child Care Facility (Go Kindy)	CC9	O	O	O	O	O	O	O	O
	Child Care Facility (Campbell Street Children's Centre)	CC10	O	O	O	O	O	X	X	X
	Child Care Facility (Harris Park Preschool)	CC11	O	O	O	O	O	O	O	X
	Caravan Park / Camping Ground (Queanbeyan Riverside Tourist Park)	-	O	X	X	X	X	X	X	X
	Aged Care Facilities (Queanbeyan Aged Care Facility)	AC1	O	O	O	O	O	O	X	X
	Aged Care Facilities (Baptistcare George Forbes House Aged Care Centre)	AC2	O	O	O	O	O	O	O	O
	Aged Care Facilities (Warrigal Care Queanbeyan)	AC3	O	O	O	O	O	O	O	X

Cont'd Over

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TABLE 2.4 (Cont'd)
IMPACT OF FLOODING ON VULNERABLE DEVELOPMENT AND CRITICAL INFRASTRUCTURE AT QUEANBEYAN

Type	Development/Structure	Location Identifier[1]	20% AEP	10% AEP	5% AEP	2% AEP	1% AEP	0.5%	0.2%	PMF
Emergency Services	NSW SES Headquarters	-	O	O	O	O	O	O	O	X
	RFS Brigade (Station)	RFS1	O	O	O	O	O	O	O	X
	RFS Brigade (Control Centre)	RFS2	O	O	O	O	O	O	O	O
	Police Station	-	O	O	O	O	O	X	X	X
	Fire & Rescue NSW Station	-	O	O	O	O	X	X	X	X
	Ambulance	-	O	O	O	O	O	O	O	X
	Evacuation Centre (Queanbeyan High School)	EC1	O	O	O	O	O	O	O	O
	Evacuation Centre (Karabar High School)	EC2	O	O	O	O	O	O	O	O
	Evacuation Centre (Queanbeyan East Public School)	EC3	O	O	O	O	O	O	O	X
	Queanbeyan TAFE	EC4	O	O	O	O	O	O	O	X
Community Assets	Telephone Exchange	-	O	O	O	O	X	X	X	X
	Sewage Treatment Plant	-	O	O	O	X	X	X	X	X
	Major River Crossing (Queanbeyan Suspension Bridge)	RC1	O	O	O	O	X	X	X	X
	Major River Crossing (Bungendore Road at "The Big Dipper")	RC2	O	O	X	X	X	X	X	X
	Major River Crossing (Morisset Street)	RC3	O	O	O	O	O	X	X	X
	Major River Crossing (Goulburn-Queanbeyan Railway Line)	RC4	O	O	O	O	O	X	X	X
	Major River Crossing (Yass Road)	RC5	O	O	O	X	X	X	X	X
	Major River Crossing (Oaks Estate Road)	RC6	X	X	X	X	X	X	X	X

1. Refer **Figure 2.7** (2 sheets) for location of vulnerable development and critical infrastructure

"O" = Infrastructure not impacted by flooding.

"X" = Infrastructure impacted by flooding.

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2.10 Potential Impacts of Climate Change

Consideration was given to the impacts on design flood levels of future climate change when estimating freeboard requirements on minimum floor levels of future development.

DPIEs guideline titled *Practical Consideration of Climate Change, 2007* was used as the basis for examining climate change on flood behaviour along the Queanbeyan and Molonglo Rivers at Queanbeyan. The guideline recommends that until more work is completed in relation to the climate change impacts on rainfall intensities, sensitivity analyses should be undertaken based on increases in rainfall intensities ranging between 10 and 30 per cent. On current projections, the increase in rainfalls within the service life of developments or flood management measures is likely to be around 10 per cent, with the higher value of 30 per cent representing an upper limit which may apply near the end of the century. Under present day climatic conditions, increasing the 1% AEP design rainfall intensities by 10 per cent would produce about a 0.5% AEP flood; and increasing those rainfalls by 30 per cent would produce about a 0.2% AEP event.

For the purpose of the present investigation, the impact a 10% increase in design rainfall intensities would have on flood behaviour was assessed by comparing the peak flood levels which were derived from the flood modelling for design events with AEPs of 1 and 0.5 per cent.

Figure 2.10 (2 sheets) shows the afflux data (i.e. increase in peak flood levels compared with present day conditions for the 1% AEP event) derived from the hydraulic modelling that was undertaken as part of the present investigation. The potential impact of a 10% increase in rainfall intensity on flooding patterns at Queanbeyan may be summarised as follows:

- Peak 1% AEP flood levels along the Queanbeyan River would generally be increased in the range 1.5-2.0 m. By reference to **Table 2.1**, the peak 1% AEP flood level at Queens Bridge would be increased by 1.6 m.
- The resulting increase in peak flood levels would result in a significant increase in the extent of inundation on both sides of the Queanbeyan River in the vicinity of the Queanbeyan CBD.
- Floodwater would surcharge the western bank of the Queanbeyan River upstream of Rutledge Street, where it would combine with floodwater which would have backed up into the Queanbeyan CBD during the rising limb of the flood.
- While peak flood levels on the Molonglo River would generally be increased in the range 1.0-1.5 m, the extent of flooding would not increase significantly.
- Based on the values set out in **Table 2.3**, an additional 269 dwellings comprising mainly unit type development, 97 commercial properties and 18 public buildings would experience above-floor inundation, resulting in the total flood damages at Queanbeyan increasing from $69.6 Million to $177 Million at the 1% AEP level of flooding.

Figure 2.11 shows the afflux data derived from the hydraulic modelling for the 1% and 0.2% AEP events. The potential impact of a 30% increase in rainfall intensity on flooding patterns at Queanbeyan may be summarised as follows:

- Peak 1% AEP flood levels along the Queanbeyan River would generally be increased in the range 3.0-4.0 m. By reference to **Table 2.1**, the peak 1% AEP flood level at Queens Bridge would be increased by 3.4 m.

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- The resulting increase in peak flood levels would result in an even greater increase in the extent of inundation on both sides of the Queanbeyan River in the vicinity of the Queanbeyan CBD when compared to a 10% increase in rainfall intensities, with floodwater shown to inundate the Queanbeyan Showground.
- Floodwater would surcharge the western bank of the Queanbeyan River upstream of Rutledge Street, where it would combine with floodwater which would have backed up into the Queanbeyan CBD during the rising limb of the flood.
- Peak flood levels on the Molonglo River would generally be increased in the range 2.0-3.0 m, with floodwater shown to extend into the industrial area which is located on the southern side of the Goulburn-Queanbeyan Railway Line. It would also impact existing development in Oaks Estate.
- Based on the values set out in **Table 2.3**, an additional 593 dwellings comprising mainly unit type development, 112 commercial properties and 29 public buildings would experience above-floor inundation, resulting in the total flood damages at Queanbeyan increasing from $69.6 Million to $311 Million at the 1% AEP level of flooding.

The large flood range poses a significant problem, especially when considering the freeboard requirements for potential flood modification measures and also future development that is planned on the floodplain at Queanbeyan. While there are uncertainties in the estimation of increased rainfalls resulting from climate change and its timeframe, it cannot be ignored and must be given careful consideration in regards its implications on the continuing and future flood risk at Queanbeyan. Further discussion on this issue is contained in **Section 3.5.1.2** of the report.

2.11 Flood Hazard and Hydraulic Categorisation of the Floodplain

2.11.1 General

According to Appendix L of NSWG, 2005, in order to achieve effective and responsible floodplain risk management, it is necessary to divide the floodplain into areas that reflect:

1. The impact of flooding on existing and future development and people. To examine this impact it is necessary to divide the floodplain into *"flood hazard"* categories, which are provisionally assessed on the basis of the velocity and depth of flow. A *final determination* of hazard was then undertaken which involved consideration of a number of additional factors which are site specific to the Queanbeyan and Molonglo Rivers at Queanbeyan. **Section 2.11.2** below provides details of the procedure adopted.
2. The impact of future development activity on flood behaviour. Development in active flow paths (i.e. *"floodways"*) has the potential to adversely re-direct flows towards adjacent properties. Examination of this impact requires the division of flood prone land into various *"hydraulic categories"* to assess those parts which are effective for the conveyance of flow, where development may affect local flooding patterns. Hydraulic categorisation of the floodplain was undertaken as part of the *Updated Flood Study*. **Section 2.11.3** below summarises the procedure adopted.

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2.11.2 Flood Hazard Categorisation

As mentioned above, flood prone areas may be *provisionally* categorised into *Low Hazard* and *High Hazard* areas depending on the depth of inundation and flow velocity. A flood depth of 1 m in the absence of significant flow velocity represents the boundary between *Low Hazard* and *High Hazard* conditions. Similarly, a flow velocity of 2.0 m/s but with a small flood depth around 200 mm also represents the boundary between these two conditions. Interpolation may be used to assess the hazard for intermediate values of depth and velocity. Flood hazards categorised on the basis of depth and velocity only are *provisional*. They do not reflect the effects of other factors that influence hazard.

These other factors include:

1. Size of flood – major floods though rare can cause extensive damage and disruption.
2. Effective warning time – flood hazard and flood damage can be reduced by sandbagging entrances, raising contents above floor level and also by evacuation if adequate warning time is available.
3. Flood awareness of the population – flood awareness greatly influences the time taken by flood affected residents to respond effectively to flood warnings. The preparation and promotion by Council of the *Flood Study Update* and *FRMS&P* increases flood awareness, as does the formulation and implementation of a response plan by NSW SES (*Local Flood Plan*) for the evacuation of people and possessions.
4. Rate of rise of floodwaters – situations where floodwaters rise rapidly are potentially more dangerous and cause more damage than situations in which flood levels increase slowly.
5. Duration of flooding – the duration of flooding (or length of time a community is cut off) can have a significant impact on costs associated with flooding. This duration is shorter in smaller, steeper catchments.
6. Evacuation problems and access routes – the availability of effective access routes from flood prone areas directly influences flood hazard and potential damage reduction measures.

Provisional hazard categories may be reduced or increased after consideration of the above factors in arriving at a final determination. A qualitative assessment of the influence of the above factors on the *provisional flood hazard* (i.e. the hazard based on velocity and depth considerations only) is presented in **Table 2.5** over the page.

After consideration of the above factors, it was considered that there was no reason to adjust the provisional flood hazard for main stream flooding and that the final determination of hazard in the floodplains could reasonably be based on depth and velocity considerations. **Figure 2.12** shows the division of the floodplain into high and low hazard areas following consideration of the factors set out in **Table 2.5**.

While the overall score for local catchment flooding was slightly higher than for main stream flooding, this was mainly a result it being short duration in nature. However, given its relatively shallow and slow moving nature, it was considered reasonable to base the hazard classification for local catchment flooding on depth and velocity considerations. **Figure 2.13** shows the division of the floodplain into high and low hazard areas following consideration of the factors set out in **Table 2.5**.

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TABLE 2.5
INFLUENCE OF FLOOD RELATED PARAMETERS ON PROVISIONAL FLOOD HAZARD

Parameter	Flood Characteristics	Influence on Provisional Hazard	
		Main Stream Flooding	Local Catchment Flooding
Size of flood	The river channel has a comparatively high hydraulic capacity and is capable of conveying major flood events. However, substantial depths of ponding occur in the embayment area on the western bank occupied by the Queanbeyan CBD. Depths of ponding in excess of 2 m could occur, which would tend to increase the hazard in those areas. Local catchment flooding in the Queanbeyan CBD is generally limited to the area bounded by Antill Street to the north, Collett Street to the east, Morisset Street to the south and Lowe Street to the east. While the extent and depth of major overland flow would increase with storm intensity, it would generally not extend beyond this area. Floodwater is also largely confined to the inbank area of Buttles Creek near its confluence with the Queanbeyan River.	+1	0
Effective warning time	BoM maintain an effective and proven Flood Warning System for the Queanbeyan River. The target minimum warning time of a particular flood height is about 6 hours. While BoM maintains a storm warnings service which would provide some warning for short-duration ‘flash flooding’ in the vicinity of the Queanbeyan CBD, there would be limited effective warning time to take action against local catchment flooding.	-1	+1
Flood awareness	Flood awareness is likely to be low due to the comparatively long duration since the last major flood which inundated existing development at Queanbeyan. Similarly, awareness of the potential for local catchment flooding to impact parts of the Queanbeyan CBD would also be low. This would tend to increase the hazard when a flood eventually occurs.	+1	+1
Rate of rise and velocity of floodwaters	During major flood events, flooding rises to a peak over a 24 hour period, at a maximum rate of about 0.8 m/hr. In conjunction with the Flood Warning System, this would allow residents to raise contents to about 900 mm above floor level and evacuate from the floodplain. While the rate of rise would be quite fast, the velocity of major overland flow in the Queanbeyan CBD and on the overbank area of Buttles Creek would be relatively mild.	0	0
Duration of flooding	Flood levels of medium to major events would be maintained within 2 m of their respective peak levels for 12 to 24 hours. Local catchment flooding would generally be of a short duration nature, with the ponding of stormwater not likely to exceed a few hours.	0	-1
Evacuation problems	Although access to eastern Queanbeyan is cut during floods in excess of 10% AEP due to inundation of the Big Dipper, there is evacuation out of the flooded areas to higher ground bordering the Queanbeyan River. Egress from property that is impacted by local catchment flooding in the Queanbeyan CBD would generally not be possible during a storm event.	0	+1
	OVERALL SCORE	**+1**	**+2**

Legend 0 = neutral impact on provisional hazard
+ 1 = tendency to increase provisional hazard
– 1 = tendency to reduce provisional hazard

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2.11.3 Hydraulic Categorisation of the Floodplain

According to the NSWG, 2005, the floodplain may be subdivided into the following zones:

- ***Floodways*** are those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if partially blocked, would cause a significant increase in flood level and/or a significant re-distribution of 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*** areas are 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*** is 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.

Floodplain Risk Management Guideline No. 2 Floodway Definition, offers guidance in relation to two alternative procedures for identifying floodways. They are:

- **Approach A**. Using a *qualitative approach* which is based on the judgement of an experienced hydraulic engineer. In assessing whether or not the area under consideration was a floodway, the qualitative approach would need to consider; whether obstruction would divert water to other existing flow paths; or would have a significant impact on upstream flood levels during major flood events; or would adversely re-direct flows towards existing development.
- **Approach B**. Using the hydraulic model, in this case TUFLOW, to define the floodway based on *quantitative experiments* where flows are restricted or the conveyance capacity of the flow path reduced, until there was a significant effect on upstream flood levels and/or a diversion of flows to existing or new flow paths.

One quantitative experimental procedure commonly used is to progressively encroach across either floodplain towards the channel until the designated flood level has increased by a significant amount (for example 0.1 m) above the existing (un-encroached) flood levels. This indicates the limits of the hydraulic floodway since any further encroachment will intrude into that part of the floodplain necessary for the free flow of flood waters – that is, into the floodway.

The *quantitative assessment* associated with **Approach B** is technically difficult to implement. Restricting the flow to achieve the 0.1 m increase in flood levels can result in contradictory results, especially in unsteady flow modelling, with the restriction actually causing reductions in computed levels in some areas due to changes in the distribution of flows along the main drainage line.

Accordingly the *qualitative approach* associated with **Approach A** was adopted, together with consideration of the portion of the floodplain which conveys approximately 80% of the total flow and also the findings of *Howells et al, 2004* who defined the floodway based on velocity of flow and depth. Howells et al suggested the following criteria for defining those areas which operate as a "floodway" in a 1% AEP event:

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- Velocity x Depth greater than 0.25 m^2/s **and** Velocity greater than 0.25 m/s; or
- Velocity greater than 1 m/s.

Flood storage areas are identified as those areas which do not operate as floodways in a 1% AEP event but where the depth of inundation exceeds 0.3 m and 1 m in areas subject to local catchment and main stream flooding, respectively. The remainder of the flood affected area was classified as flood fringe.

Figure 2.12 (2 sheets) shows the division of the Queanbeyan River and Molonglo River floodplains into floodway, flood storage and flood fringe areas at the 1% AEP level of flooding. While the majority of the flood affected areas function as floodways due to the relatively steep sided nature of the floodplain at Queanbeyan, high hazard flood storage areas are present on both sides of the Queanbeyan River in the vicinity of the Queanbeyan CBD. A high hazard flood storage area is also present on the western overbank of the Queanbeyan River upstream of the Queanbeyan CBD in the vicinity of Woodger Parade and Malcolm Road.

Figure 2.13 shows the division of the area within the vicinity of the Queanbeyan CBD which is subject to local catchment flooding into floodway, flood storage and flood fringe areas. The extent of the floodway that was defined using the Howells et al criteria was expanded to align with the allotment boundaries, as it will be necessary to maintain an unobstructed flow path through this part of the Queanbeyan CBD as part of any future development proposal of the area.[5]

2.12 Council's Existing Planning Instruments and Policies

2.12.1 General

The *Queanbeyan Local Environmental Plan, 2012* (***Queanbeyan LEP 2012***) is the principal statutory planning document used by Council for controlling development by defining zoning provisions, establishing permissibility of land use and regulating the extent of development in the town.

The *Queanbeyan Development Control Plan 2012* (***Queanbeyan DCP 2012***) supplements *the Queanbeyan LEP 2012* by providing general information and detailed guidelines and controls which relate to the decision making process.

2.12.2 Land Use Zoning – Queanbeyan LEP 2012

Figure 2.14 shows the zonings incorporated in *Queanbeyan LEP 2012* at Queanbeyan. The Queanbeyan CBD is zoned *B3 - Commercial Core*, while the area along the western bank of the Queanbeyan River upstream of its location is generally zoned *R2 – Low Density Residential*. Land zoned *R2 – Low Density Residential* is also located directly to the west of the Queanbeyan CBD on the western side of the Queanbeyan River and directly to the east of a strip *of R4 – High Density Residential* zoned land that is located along Trinculo Place on the eastern side the river. *R4 – High Density Residential* zoned land is also located immediately to the north of the Queanbeyan CBD.

[5] Note that the alignment and width of the floodway could be altered as part of a future development proposal provided that major overland flow is conveyed between the adjacent streets and the proposed development will not adversely impact flood behaviour in adjacent development.

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Land zoned *B5 - Business Development* is located along Crawford Street immediately north of the Queanbeyan CBD and along the northern side of the Kings Highway between Queens Bridge and Yass Road on the eastern side of the Queanbeyan River.

Land zoned *IN1 – General Industrial* is located on the southern side of the Goulburn-Queanbeyan Railway Line east of its crossing of the Queanbeyan River.

2.12.3 Flood Provisions – Queanbeyan LEP 2012

Clause 7.2 of *Queanbeyan LEP 2012* entitled “Flood Planning” outlines Council’s objectives in regard to development of land that is at or below the FPL. The FPL referred to is the 1:100 ARI (or 1% AEP) flood plus an allowance for freeboard of 500 mm. The area encompassed by the FPL (i.e. the FPA) denotes the area subject to flood related development controls, such as locating development outside high hazard areas and setting minimum floor levels for future residential development. It is now standard practice for the residential FPL to be based on the 1% AEP flood plus an appropriate freeboard unless exceptional circumstances apply.

Queanbeyan LEP 2012 would need to be supported by an update of *Queanbeyan DCP 2012* which would set out specific requirements for development in flood liable areas based on the flood extent and hazard mapping which has been developed as part of the present investigation. Recommendations for minor amendments to the wording in Clause 7.2 of *Queanbeyan LEP 2012* are set out in **Section 3.5.1.4**.

2.12.4 Flooding and Stormwater Controls – Queanbeyan DCP 2012

Part 2 – ‘All Zones’ of *Queanbeyan DCP 2012* (**Part 2**) sets out the controls that apply to all land located with the Queanbeyan local government area. Chapter 2.5 – ‘Flood Management’ of *Queanbeyan DCP 2012* specifies the objectives and corresponding controls for flood management in areas that are subject to flooding in Queanbeyan.

Queanbeyan DCP 2012 uses the definition of floodway and flood fringe areas that were developed as part of Lyall & Associates, 2008 for the 1% AEP flood for setting flood related development controls in Queanbeyan. Tables of peak flood levels for the 20% and 1% AEP flood events based on the HEC-RAS modelling that was also undertaken as part of Lyall & Associates, 2008 are contained in Chapter 2.5 of *Queanbeyan DCP 2012*.

While *Queanbeyan DCP 2012* does not permit new residential development in the floodway area, it does permit new commercial development provided it is elevated above the peak 1% AEP flood and permits the flow of floodwater beneath it.

In areas which lie outside the floodway area, the floor level of commercial development is permitted to be set at least 2 m below the FPL provided that a floor area equivalent to 25% of the whole floor area of the building is sited at or above the FPL. *Queanbeyan DCP 2012* requires that a means of escape is to be provided from any floor that is sited less than 4.5 m above the FPL by means of a large window opening onto an area of external wall away from electricity connection to the building and free of projections which may prevent a rescue boat from approaching the escape window.

For residential development including motels, *Queanbeyan DCP 2012* requires floor levels to be set no lower than the FPL. Access to all residential dwellings and units is to be set no lower than 0.8 m below the FPL to firm ground that is rising toward flood free land. In the event that a raised path is provided, a guide rail or handrail is to be provided.

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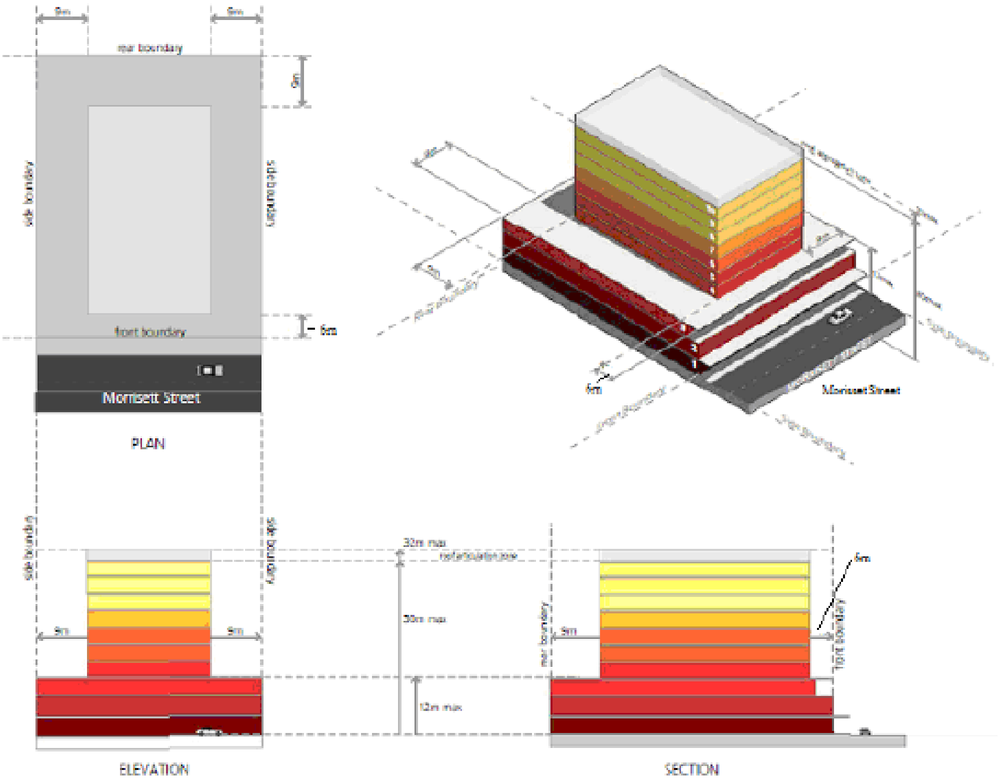
Queanbeyan DCP 2012 states that in the event of a dwelling or residential flat building located within floodway areas being destroyed by fire or flood, Council will consider an application for the rebuilding of the building only if sufficient funds are not available to enable purchase of the subject land by Council.

Section 2.2.7 of *Queanbeyan DCP 2012* titled 'Basement Parking' states that basement parking must be constructed to prevent the entry of floodwater at the FPL. It also states that provision must be made for a failsafe means of evacuation, as well as a pump-out system to remove floodwater.

2.12.5 Planning Provisions for Queanbeyan CBD

Queanbeyan LEP 2012 allows buildings of up to 30 m in height to be constructed on land zoned *B3 - Commercial Core*. Part 6 – 'Central Business District and Other Business Zones' of *Queanbeyan DCP 2012* (**Part 6**) outlines the requirements for development within areas zoned *Business* under *Queanbeyan LEP 2012*, noting that its primary focus is on development within the Queanbeyan CBD.

One of the stated objectives of Part 6 is to facilitate shop top housing in the Queanbeyan CBD. The illustration below is taken from Part 6 showing the required setbacks for a residential tower arrangement above commercial development along Morisset Street.



Part 6 acknowledges that there may need to be consideration to a number of clauses in *Queanbeyan LEP 2012* which may need to be considered when developing in the Queanbeyan CBD, the flood planning clause being one. Based on the controls set out in Part 2 of *Queanbeyan DCP 2012*, the ground floor level of any new commercial development within the Queanbeyan CBD could be set a maximum of 2 m below the 1% AEP plus an allowance of 0.5 m freeboard, with the residential component set at or above this level.

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As the minimum floor level controls are linked to Queanbeyan River flooding, there is the potential for ground floor commercial development to be impacted by local catchment flooding, especially in the area bounded by Antill Street to the north, Collett Street to the east, Morisset Street to the south and Lowe Street to the west.

Section 3.5.1.3 sets out the recommended approach to managing the flood risk in the Queanbeyan CBD, while **Appendix E** sets out the flood related controls which should be applied to this area.

2.13 Flood Warning and Flood Preparedness

2.13.1 Flood Response Planning in Queanbeyan

The NSW SES is nominated as the principal combat and response agency for flood emergencies in NSW. NSW SES is responsible for the issuing of relevant warnings (in collaboration with BoM), as well as ensuring that the community is aware of the flood threat and how to mitigate its impact.

The *Queanbeyan City Local Flood Plan, 2013* (herein referred to as the ***Local Flood Plan***) published by NSW SES covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures for all levels of flooding within the Queanbeyan City area. The *Local Flood Plan* is administered by the NSW SES Queanbeyan Local Controller who controls flood operations within the Queanbeyan City area and is based in Queanbeyan. . The NSW SES Queanbeyan unit is located at No. 34 Erin Street, Queanbeyan.

The main body of the *Local Flood Plan* follows the standard NSW SES template and is divided into the following sections:

- ***Introduction;*** this section of the *Local Flood Plan* identifies the responsibilities of the NSW SES Local Controller, Unit Controllers and NSW SES members, as well as supporting services such as the Police, BoM, Ambulance, Fire Brigades, Department of Community Services, Council, Icon Water, etc. The *Local Flood Plan* identifies the importance for NSW SES and Council to coordinate the development and implementation of a public education program to advise the population of the flood risk.
- ***Preparedness;*** this section deals with activities required to ensure the *Local Flood Plan* functions during the occurrence of the flood emergency. The Plan will devote considerable attention to flood warning and emergency response.
- ***Response***. The NSW SES maintains an operation centre at the NSW SES Local Headquarters in Erin Street, Queanbeyan. Response operations will commence: on receipt of a Preliminary Flood Warning, Flood Warning, Flood Watch, Severe Thunderstorm Warning or a Severe Weather Warning for flash flooding from BoM, on receipt of a dam failure or when other evidence leads to an expectation of flooding within the Queanbeyan City area.

  The *Local Flood Plan* states that the Queanbeyan High School on Agnes Avenue in Queanbeyan, Karabar High School on Donald Road in Karabar and the Queanbeyan TAFE on Macquoid and Buttle Streets in Queanbeyan East are suitable flood evacuation centres. The location of the nominated flood evacuation centres are shown on **Figure 2.8** (2 sheets).

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- ***Recovery***, involving measures to ensure the long term welfare for people who have been evacuated, recovery operations to restore services and clean up and de-briefing of emergency management personnel to review the effectiveness of the *Local Flood Plan.*

Annexes A and B of the *Local Flood Plan* describe the flood threat and impact that flooding has on the community in the Queanbeyan City area, respectively. Annex C of the *Local Flood Plan* lists the stream gauges that are monitored in the area, with the 'Minor', 'Moderate' and 'Major' flood levels on the Queens Bridge gauge given as 4.2 m, 7.4 m and 8.2 m, respectively. Annex G of the *Local Flood Plan* sets out the evacuation arrangements for the Queanbeyan City area. The nominated key trigger levels on the Queens Bridge gauge are 6.4 m which relates to the inundation of the Queanbeyan Riverside Tourist Park and 8.2 m which relates to low lying areas along Thorpe Avenue.

2.13.2 Flood Warning System for Queanbeyan

BoM operates an effective and proven Flood Warning System for the Queanbeyan River, with river heights and rainfall information issued via its Flood Warning Centre. The Googong Dam weather and stream flow gauge system which is operated by IconWater also provides information on water levels in the dam, as well as recorded inflows and outflows. **Figure B1.1** in **Appendix B** shows the network of rainfall and stream flow gauges that are used to monitor a flood emergency in the Queanbeyan and Molonglo River valleys.

Flood Watches are issued by BoM warning of potential flooding on the Queanbeyan and Molonglo Rivers based on forecast weather patterns and stream flows. An example of a Flood Watch that was issued by BoM on 1 December 2017 for the Queanbeyan area is given below:

> *"**Flood watch for Queanbeyan and Molonglo, Bell, Belubula, Murrumbidgee, Upper Murray and Snowy Rivers:** Local and minor to moderate riverine flooding may develop along the Murrumbidgee River from Friday onwards. Southern and central districts forecast to receive the most rain, with some areas likely to receive heavy to very heavy rainfall during Friday and Saturday. The Upper Murrumbidgee catchment is wet following rainfall in the last two weeks. Potential to cause minor to moderate riverine flooding as well as local flooding from Friday onwards."*

Flood Warnings are issued by NSW SES for the Queanbeyan and Molonglo Rivers based on gauge specific forecasts of actual or imminent flooding. Flood Warnings would typically specify the river valley, the locations expected to be flooded, the likely severity of flooding and when it will occur.

Evacuation Warnings are issued by the NSW SES to warn the community of the need to prepare for a possible evacuation. An Evacuation Warning will be issued when time permits and/or if there is some uncertainty regarding flood timing, heights or ongoing rainfall.

An Evacuation Order will be issued by the NSW SES in order to instruct the community to immediately evacuate in response to an imminent threat.

While the *Local Flood Plan* states that Evacuation Warnings and Orders may be distributed via public address and telephone based systems, there is presently no such systems in place which would enable NSW SES to alert residents and business owners at Queanbeyan of an imminent flood threat in this way.

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2.14 Environmental Considerations

The Queanbeyan River is one of the City's most valuable natural environmental assets. In recognition that its high ecological, social and hydrologic values required ongoing management to ensure that those values are maintained at a sustainable level, Council adopted the *Queanbeyan River Corridor Plan of Management* in 1999. The *Queanbeyan River Corridor Plan of Management, 1999* primarily deals with the defined corridor of land along the river and within the limits of the City. This area is defined as the "Main River Corridor" adjacent to the central thread of the channel, and an "Outer Corridor Area" which includes land within the City, but not immediately adjacent to the river. The reach of the river within Council's boundaries was divided into four 'Management Units' and management strategies for each Unit contained in an Action Plan.

Figure 4 of the *Queanbeyan River Corridor Plan of Management, 1999* titled "Threats and Opportunities" shows the extents of the Management Units. The Plan nominates the presence of weeds and willows along the extent of the Management Units as one of the main threats to the riverine environment. Although willow trees may have aesthetic value along waterways, they are of concern due to their ability to rapidly colonise watercourses and reduce areas of native habitat, alter stream flows and restrict waterway conveyance capacity. Council and the *River Corridor Steering Committee* endorsed the removal of willows along the Queanbeyan River and tributaries. The implementation of a willow reduction program is contained in the Action Plan for all areas. This program is relevant to the *FRMS* in the maintenance of conveyance capacity of the stream and its floodplains.

Another item in the *Queanbeyan River Corridor Plan of Management, 1999* of relevance to the *FRMS* is the stated goal of preserving the views and scenic quality of the Main River Corridor through the conservation of bushland and other natural features as well as minimising the effects of urban development. This goal would militate against the adoption of a levee scheme along the Main River Corridor to protect the City from flooding.

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3 POTENTIAL FLOODPLAIN RISK MANAGEMENT MEASURES

3.1 Range of Available Measures

A variety of floodplain risk management measures can be implemented to reduce flood damages. They may be divided into three categories, as follows:

Flood modification measures change the behaviour of floods in regard to discharges and water surface levels to reduce flood risk. This can be done by the construction of levees, detention basins, channel improvements and upgrades of piped drainage systems in urban areas. Such measures are also known as "structural" options as they involve the construction of engineering works. Vegetation management is also classified as a flood modification measure.

Property modification measures reduce risk to properties through appropriate land use zoning, specifying minimum floor levels for new developments, voluntary purchase of residential property in high hazard areas, or raising existing residences in the less hazardous areas. Such options are largely planning (i.e. "non-structural") measures, as they are aimed at ensuring that the use of floodplains and the design of buildings are consistent with flood risk. Property modification measures could comprise a mix of structural and non-structural methods of damage minimisation to individual properties.

Response modification measures change the response of flood affected communities to the flood risk by increasing flood awareness, implementation of a flood warning system and the development of an emergency response plan for property evacuation.

3.2 Community Views

Comments on potential flood management measures were sought from the Queanbeyan community by way of the *Community Questionnaire*, which was distributed at the commencement of the study. The responses are summarised in **Appendix A** of this *FRMS* report. Question 7 in the *Community Questionnaire* outlined a range of potential flood management options. The number of responses for and against each measure are set out in **Table 3.1**. A number of the measures are discussed in more detail in later sections of this Chapter.

The following measures were the most favoured by the Community:

- Updating *Queanbeyan LEP 2012*, *Queanbeyan DCP 2012* and the *Local Flood Plan*
- Consideration of flood related issues associated with high density development in the Queanbeyan CBD
- Implementation of a flood education program and flash flood warning system at Queanbeyan
- Management of vegetation along the Queanbeyan River corridor
- Improvements to the local stormwater drainage system in the Queanbeyan CBD

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TABLE 3.1
COMMUNITY VIEWS ON POTENTIAL FLOOD MANAGEMENT MEASURES

Flood Management Measure		Classification[1]	Respondent's Views	
			Yes	**No**
a)	Update Local Environmental Plan and Development Control Plan documents.	PM	160	17
b)	Consider flood related issues associated with future high density development in the CBD of Queanbeyan.	PM	169	15
c)	Implement a Flash Flood Warning System for the local catchment draining through the Queanbeyan CBD.	RM	154	26
d)	Updates to existing Queanbeyan City Local Flood Plan to include recent flood level information in Flood Warning System.	RM	157	18
e)	Program of flood education to raise awareness amongst the local community.	RM	143	24
f)	Voluntary purchase of residential property in high hazard areas.	PM	69	92
g)	Raise the Flood Planning Level for residential properties to account for climate change.	PM	79	72
h)	Investigate the possibility of using Queanbeyan Park and Showground as flood detention basins during large storms.	FM	111	35
i)	Raise the road level at the Big Dipper on Bungendore Road north of Queens Bridge.	FM	121	26
j)	Management of vegetation along creek corridors to provide flood mitigation, stability, aesthetic and habitat benefits.	FM	155	7
k)	Widening of watercourses.	FM	84	46
l)	Removal of floodplain obstructions.	FM	125	17
m)	Improve the stormwater system within the Queanbeyan CBD.	FM	141	14
n)	Construct permanent levees along the river to contain floodwaters.	FM	75	57
o)	Provide funding or subsidies to raise houses above major flood level in low hazard areas.	PM	43	88
p)	Provide a Planning Certificate to purchasers in flood prone areas, stating that the property is flood affected.	PM	122	26

1. FM = Flood Modification Measure
   PM = Property Modification Measure
   RM = Response Modification Measure

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3.3 Outline of Chapter

A number of the measures set out in **Table 3.1** were examined at the strategic level of detail in this Chapter and where appropriate, tested for feasibility on a range of assessment criteria in **Chapter 4**. Following consideration of the results by the Floodplain Risk Management Committee, selected measures were included in the *FRMP* in **Chapter 5**.

While a number of flood modification measures were considered at Queanbeyan, the large flood range coupled with the adverse impact that they would have on flood behaviour in existing development meant that their inclusion in the *FRMP* could not be justified.

The property modification measures considered as part of this study include controls over future development, voluntary purchase of residential properties and house raising. Response modification measures such as improvements to the flood warning system through the development of an automated flood alert system which is linked to flood levels at the Wickerslack stream gauge, improvements to emergency planning and responses, and public awareness programs have been considered for Queanbeyan.

3.4 Flood Modification Measures

3.4.1 Channel Works and Willow Reduction Program for Queanbeyan River

The hydraulic capacity of a stream may be increased by widening, deepening or straightening the channel and by clearing the banks of obstructions. The scope of such improvements can vary from minor works such as de-snagging and bank clearing, which do not increase the waterway area but reduce hydraulic roughness, to major channel excavations.

Careful attention to design is required to ensure stability of the channel is maintained and scour or sediment build up is minimised. A degree of sinuosity is often provided in the channel route for these and aesthetic reasons. The potential for channel improvements to increase downstream flood peaks also needs to be considered. In general, channel improvements need to be carried out over a substantial stream length to have any significant effect on flood levels.

Projects identified in the *Queanbeyan River Corridor Plan of Management, 1999* include the removal of sediment, woody weeds and willows and revegetation of the river corridor with native species. Those measures would have a beneficial, but limited, impact on the conveyance capacity of the river. Closer to the Queanbeyan CBD, it is proposed to maintain the existing height and location of the weirs on the downstream side of Queens Bridge.

The implementation of large scale improvements to the hydraulic capacity of the river which would in turn significantly reduce major flood levels is counter to the objectives of the *Queanbeyan River Corridor Plan of Management, 1999*. In view of the limited room available it would require substantial deepening of the channel and adoption of a uniform waterway area to maximise hydraulic capacity and therefore would not be environmentally acceptable.

3.4.2 Levees

Levees are an effective means of protecting flood affected properties up to the chosen design flood level. In designing a levee it is necessary to take account of potential redistribution of flood flows, the requirements for disposal of internal drainage from the protected area and the consequences of overtopping the levee in floods greater than the design event.

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Levees are usually constructed of compacted soil won from local sources and carefully placed to strict engineering standards. Reinforced concrete and concrete block walls are often used in situations where there is insufficient land available for earth banks. Such walls are provided with reinforced concrete footings of sufficient width to withstand overturning during flood events. A recent example of this form of construction is the levee scheme for the town of Lismore which protected the town from a severe flood a short time after its opening.

A major difficulty with levee schemes is the provision of facilities for the temporary storage and disposal of local runoff originating within the protected area. In some situations, evacuation of runoff by pumping over the levee has been adopted where there is insufficient area available to store runoff for later disposal by gravity as the flood recedes.

Potential for Levees on Queanbeyan River Floodplain

The present worth value of damages for flood events up to the 1% AEP magnitude in Queanbeyan is quite significant, amounting to $9.8 million at a 7% discount rate. Consequently, development of a levee scheme with a 1% AEP hydrologic standard and costing up to this amount could be justified on economic grounds.

However, the following technical factors militate against a levee scheme:

(1) There is a large local sub-catchment to the west of the Queanbeyan CBD which presently drains through it (see discussion of local catchment flooding in **Section 2.5.5**). Stormwater runoff would pond behind any levee and would be unable to escape by gravity until floodwaters receded. Due to the absence of suitable storage areas, high capacity pumps would be required to evacuate runoff. There is also the possibility of failure of the electricity supply resulting in excessive ponding behind the levee. Floodgates would also need to be installed and maintained on existing drainage lines to prevent the back flooding of protected areas from the river.

(2) There are ridges of high ground available on the western floodplain at the northern (Antill Street) and southern (Isabella Street) ends of the Queanbeyan CBD area which could form the upstream and downstream boundaries of a levee scheme. However as the route providing protection for the Queanbeyan CBD is along the river frontage, the levee could be up to 6.6 m high in places and hence, visually obtrusive.

Several levee alignments have been considered. Their routes are shown on **Figure 3.1**. Due to their adverse visual impact, disruption to the local road system (which would need to grade over the top of the levee at intersection points) and difficulties associated with the management of stormwater from the local catchments upstream of the protected areas, they are not viewed as feasible mitigation options. They have been included in this review for the sake of completeness.

Levee 1 would extend from Isabella Street northwards to Antill Street, protecting the low lying Queanbeyan CBD and residential area on the western overbank. The levee would be about 1,100 m in length and up to 6.6 m in height allowing 500 mm of freeboard on the 1% AEP peak water surface level.

As shown on **Figure 3.1**, the levee would run along the riverbank to Morisset Street before turning eastwards to run along the southern side of that street for about 200 m and turn northwards to run along Carinya Street to tie in with high ground a short distance to the south of Antill Street. **Figure 3.2** includes a profile of the natural surface along the route of the levee and also shows peak water levels along its length for a range of flood events.

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Whilst the levee would exclude river flooding from the western floodplain, it would not protect development on the eastern floodplain. In addition, there may be a re-direction of flows formerly conveyed along the western bank towards the eastern floodplain.

Levee 2 would follow the route of Levee 1 as far north as the intersection of Collett Street and Morisset Street, but would continue along Collett Street to Antill Street. The length of levee is about 70 m shorter than the Levee 1 route, but it would not protect the commercial developments to the east of Collett Street in the block between Morisset Street and Antill Street. **Figure 3.2** includes a profile of the natural surface along the levee route.

Levee 3 would be designed to protect development to the west of Collett Street against flooding up to the 2% AEP. In the event of larger floods, the levee which would extend from Morisset Street to Antill Street would be outflanked by floodwaters leaving the west bank and flowing over Monaro Street into the protected area. In order to provide 500 mm of freeboard over the 2% AEP flood, the levee would extend over a distance of 650 m and would have a maximum height of 5 m. **Figure 3.2** includes a profile showing natural surface levels along the levee route.

Levee 4 would be a 2% AEP levee running along the eastern side of Crawford Street between Monaro Street and Antill Street. The levee would run along the river side of Crawford Street and would therefore protect properties on both sides of that street. As shown on **Figure 3.2**, the levee would be about 350 m long and up to 2 m high near its intersection with Morisset Street.

From the above considerations, protection of the Queanbeyan CBD area and the residential area to the west of Campbell Street from river flooding by a levee is not considered technically feasible and has not been adopted for further consideration.

It may be practicable to protect one or more of the commercial properties by low block walls or temporary flood gates around the entrances. Such localised flood proofing measures would be of a private nature and outside the ambit of Council funded works discussed in this present study.

3.4.3 Upgrading Bungendore Road at the Big Dipper

A separate investigation was carried out by Lyall & Associates on behalf of Council in May 2016 which assessed the impact the raising of the Kings highway at the location of the Big Dipper would have on flood behaviour. The assessment included the development of the two-dimensional (in plan) hydraulic model using the TUFLOW software (**Kings Highway TUFLOW Model**). The Kings Highway TUFLOW Model formed the basis of the Queanbeyan TUFLOW Model which was developed as part of the present investigation, details of which are set out in **Appendix C** of this report.

Two options for raising the Kings Highway at the location of the Big Dipper were assessed as part of the earlier investigation. Option 1 involved raising the road up to or slightly above the 5% AEP backwater level from the Queanbeyan River and incorporating a 15 cell 3600 mm wide by 900 mm high box culvert arrangement at the location of the existing low point. The Kings Highway TUFLOW Model was run adopting minimum road levels of RL 572.0 m AHD, RL 572.1 m AHD and RL 572.2 m AHD to test the sensitivity of flood levels upstream of the road corridor to minor differences in road level. These runs of the model were denoted Options 1A, 1B and 1C, respectively. A fourth run of the model, denoted Option 1D was also undertaken where the minimum road level was raised above the 2% AEP flood level.

Figure 3.3 includes a cross section of the Queanbeyan River at the location of the Kings Highway crossing showing details of the existing Queens Bridge and the four assessed road heights. The investigation found that increasing the level of immunity of the road to 5% AEP (i.e. as per Options 1A, 1B and 1C) would not adversely impact flooding conditions for floods up to 1% AEP

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in magnitude. However, as shown on **Figure 3.4**, the investigation found that increasing the level of flood immunity of the road to 2% AEP (i.e. as per Option 1D) would result in peak flood levels being increased in existing development that is located on the southern (upstream) side of the corridor.

The second option that was investigation as part of the earlier investigation (i.e. Option 2) comprised a 160 m long six span bridge, the elevation of which is shown on **Figure 3.3**. While the bridge option increased the waterway area beneath the road, the investigation found that it would impact peak 1% AEP flood levels in adjacent development due to the blocking effects of the western abutment.

Given the adverse impacts that the upgrade of the Big Dipper would have on flood behaviour in existing development, improvements to its hydrologic standard beyond that of a 5% AEP flood cannot be justified. As mentioned in **Section 2.3** of this report, the Ellerton Drive Extension project while circuitous in nature, will facilitate access across the Queanbeyan River for floods with AEPs as low as 0.05 per cent. Based on the above, the upgrade of the Kings Highway at the Big Dipper has not been included in the *FRMP*.

3.4.4 Detention Storage Upstream of Queanbeyan CBD

The merits of a scheme which would involve the provision of additional flood storage in Queanbeyan Park and the Showground which is aimed at mitigating the impacts of local catchment flooding in the Queanbeyan CBD were assessed as part of the present investigation.

Figure 2.7 shows the indicative depth of inundation in the Queanbeyan CBD resulting from a 1% AEP local catchment flood event under present day conditions.

While overland flow is presently stored on the surface of the Showground during a 1% AEP storm event, where it is slowly released back into the downstream stormwater drainage system, there is limited scope to divert additional overland flow which approaches from the west toward the existing flood storage area. For example, while a large amount of overland flow discharges to the intersection of the Kings Highway and Campbell Street from the west, significant modifications would need to be made to the existing road network in order to divert overland flow into the Showground. It is questionable whether this would be technically feasible given the Kings Highway is a major arterial road and would be subject to minimum/maximum grade requirements.

There is merit in increasing the volume of temporary flood storage in Queanbeyan Park as the flood modelling shows that about 50% of the total flow which discharges to the intersection of the Kings Highway and Campbell Street presently discharges toward the open area. In order to ensure that the overland flow which discharges in a northerly direction from the Kings Highway enters Queanbeyan Park it would be necessary to modify road levels in Campbell Street, as well as raise ground levels in the park itself.

While a set of hydrologic and hydraulic models have been developed as part of the present study to assess the nature of local catchment flooding in the Queanbeyan CBD, it is recommended that as part of any assessment of the temporary flood storage requirements in Queanbeyan Park, a more detailed investigation be undertaken to define the nature of overland flooding in the whole of the catchment which contributes to flow in this area, as in this way the storage requirements can be more accurately determined.

It is recommended that as part of the preparation of the comprehensive floodplain risk management strategy for the Queanbeyan CBD, a study be undertaken to assess the feasibility of providing temporary flood storage in Queanbeyan Park which includes a detailed overland flooding investigation for the catchment which lies to its west.

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3.5 Property Modification Measures

3.5.1 Controls over Future Development

3.5.1.1 Current Government Policy

The circular issued by the Department of Planning on 31 January 2007 contained a package of changes clarifying flood related development controls to be applied on land in low flood risk areas (land above the 1% AEP flood plus freeboard). The package included an amendment to the Environmental Planning and Assessment Regulation 2000 in relation to the questions about flooding to be answered in Section 10.7 planning certificates, a revised ministerial direction (Direction 15 – now Direction 4.3 issued of 1 July 2009) regarding flood prone land (issued under Section 9.1 Directions of the EP&A Act, 1979) and a new Guideline concerning flood-related development controls in low flood risk areas. The Circular advised that councils will need to follow both NSWG, 2005, as well as the Guideline to gain the legal protection given by Section 733 of the Local Government Act.

The Department of Planning Guideline confirmed that unless exceptional circumstances applied, councils should adopt the 1% AEP flood with appropriate freeboard as the FPL for residential development. In proposing a case for exceptional circumstances, a council would need to demonstrate that a different FPL was required for the management of residential development due to local flood behaviour, flood history, associated flood hazards or a particular historic flood. Unless there were exceptional circumstances, a council should not impose flood-related development controls on residential development on land with a low probability of flooding, that is land above the residential FPL.

However, the guideline does advise consideration be given to evacuation routes and vulnerable developments (e.g. nursing homes) in areas above the residential FPL. The safety of people and associated emergency response management needs to be considered in low flood risk areas, which may result in:

- Restrictions on types of development which are particularly vulnerable to emergency response, for example, developments for aged care and schools.
- Restrictions on critical emergency response and recovery facilities and infrastructure. These aim to ensure that these facilities and the infrastructure can fulfil their emergency response and recovery functions during and after a flood event. Examples include evacuation centres and routes, hospitals and major utility facilities. There are currently no critical developments of this nature in the floodplain.

3.5.1.2 Considerations for Setting Flood Planning Level

Selection of the FPL for an area is an important and fundamental decision as the standard is the reference point for the preparation of floodplain risk management plans. It is based on adoption of the peak level reached by a particular flood plus an appropriate allowance for freeboard. It involves balancing social, economic and ecological considerations against the consequences of flooding, with a view to minimising the potential for property damage and the risk to life and limb. If the adopted FPL is too low, new development in areas outside the FPA (particularly where the difference in level is not great) may be inundated relatively frequently and damage to associated public services will be greater. Alternatively, adoption of an excessively high FPL will subject land that is rarely flooded to unwarranted controls.

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Councils are responsible for determining the appropriate FPLs within their local government area. *Queanbeyan LEP 2012* nominates the "*1:100 ARI (average recurrence interval) flood event plus 0.5 m freeboard*" as the FPL.

Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Design variables that are typically incorporated in the derivation of freeboard typically comprise the following:

- increases in peak flood levels due to wind and wave action;
- increases in peak flood levels due to local water surge;
- uncertainties in the design flood level estimates due to the confidence limits associated with the peak flow estimates derived from the flood frequency analysis, inaccuracies in the LiDAR survey data and possible variations in key parameters such as hydraulic roughness; and
- increases in peak flood levels due to future climate change.

Table 3.2 provides a summary of a joint probability analysis which was undertaken to assess the freeboard allowance which should be incorporated in the derivation of the FPL for Queanbeyan, noting that the methodology for deriving the various components of the freeboard allowance is based on the approach set out in NSW Public Works, 2010.

TABLE 3.2
SUMMARY OF FREEBOARD ANALYSIS

Design Variable	Probability of Occurrence	Maximum Allowance (m)	Joint Probability Allowance (m)
Wave Action (Run-up)	20%(1)	0.30	0.06
Wave Action (Set-up)	50%	0.02	0.01
Local Water Surge	50%	0.00	0.00
Inaccuracies in Peak 1% AEP Flood Level Estimate			
- LiDAR survey data	100%	0.15	0.15
- Peak flow estimate	50%	0.40	0.20
- Hydraulic roughness	25%(2)	0.60	0.15
Future Climate Change	50%	1.20	0.60
TOTAL			**1.17**

1. Based on no wave run-up in the case of vertical buildings and that the majority of the Queanbeyan CBD is located in an embayment.
2. A relatively high roughness value which took into account the high debris load in the Queanbeyan and Molonglo Rivers was adopted for deriving the best estimate design flood levels at Queanbeyan, hence why a reduced weighting was applied to this component of the freeboard allowance.

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The maximum allowance for uncertainties in the peak 1% AEP flood level estimate is comprised of the following

- inaccuracies in the LiDAR survey data (0.15 m);
- provision for a 10% increase in the best-estimate peak 1% AEP flow derived by the flood frequency analysis (0.4 m)
- increase in peak flood levels associated with a possible 20% increase in the best-estimate hydraulic roughness values (0.6 m).

In regards future climate change, typically the 0.5% AEP flood event is adopted as a proxy to describe the impact a potential 10% increase in design 1% AEP rainfalls would have on flood behaviour. However, it is noted that the design rainfall intensity for the 48 hour 0.5% AEP storm event at Queanbeyan is about 13% higher than the corresponding 1% AEP design rainfall intensity and that the interim climate change factors set out in Geoscience Australia, 2016 for Representative Concentration Pathway (**RCP**) 4.5 indicates increases of about 6.5% and 9% can be expected by the years 2050 and 2090, respectively

Based on a comparison of the 0.5% and 1% AEP flood events at Queanbeyan, a 13% increase in the design 1% AEP rainfall translates to about a 40% increase in the peak flow estimate at Queanbeyan (refer **Table C3.3** in **Appendix C**), likely due to the reduction in the attenuating effects of Googong Dam for the larger flood event, which in turn translates into a 1.6 m increase in peak 1% AEP flood levels at Queanbeyan. An increase in design 1% AEP rainfall intensities of up to 9% by 2090 (which is likely within the service life of any future residential tower within the Queanbeyan CBD) will have a lesser impact on peak 1% AEP flood levels, which for the purpose of the present assessment has been set at 1.2 m.

Following several meetings of the Floodplain Risk Management Committee it was determined that the FPL for main stream flooding be set equal to the peak 1% AEP flood level plus 500 mm, but that the minimum floor level of future residential development that is located in the Queanbeyan CBD be set at the peak 1% AEP flood level plus 1.2 m as this would allow for potential increases in peak flood levels associated with future climate change over the service life of the multi-storey residential towers.

3.5.1.3 Proposed Planning Controls for Queanbeyan

While *Queanbeyan DCP 2012* contains a set of flood related development controls, these are linked to flood mapping and peak flood levels which have been superseded by the more detailed flood modelling that has been undertaken as part of the present investigation. Proposed planning controls for flood prone areas in Queanbeyan, along with a draft *Flood Policy* for future development in those areas which are based on this more detailed flood modelling, are presented in **Appendix E**. They are based on the proposed subdivision of the floodplain and amendments to the *Queanbeyan LEP 2012* introduced in **Section 2.12** of this report.

It is proposed that properties intersected by the extent of the FPA would be subject to S10.7 flood affectation notification and planning controls graded according to flood hazard and evacuation constraints. NSWG, 2005 suggests wording on S10.7 (2) Planning Certificates along the following lines:

> *"Council considers the land in question to be within the Flood Planning Area and therefore subject to flood related development controls. Information relating to this flood risk may be obtained from Council. Restrictions on development in relation to flooding apply to this land as set out in Council's Flood Policy which is available for inspection at Council offices or website."*

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Annexure 2 in **Appendix E** sets out the graded set of flood related planning controls which have been developed for Queanbeyan. Minimum floor level requirements would be imposed on future development in properties that are identified as lying either partially or wholly within the extent of the FPA shown on **Figure E1.1**.

The Minimum Floor Levels (**MFLs**) for all land use types is the level of the 1% AEP flood event plus 0.5 m freeboard, with the exception of future development located within the Queanbeyan CBD on land zoned *B3-Commerical Core* where the MFL of residential development is the 1% AEP flood event plus 1.2 m freeboard, while the MFL of commercial development is the 5% AEP flood level.

Essential Community Facilities, Critical Utilities and Flood Vulnerable development is not permitted on land which is subject to main stream flooding.

Figure E1.2 in **Appendix E** is the *Flood Hazard Map* for Queanbeyan which shows the subdivision of the floodplain into a number of categories which have been used as the basis for developing the graded set of planning controls.

The floodplain has been divided into the following six categories in areas that are affected by main stream flooding:

- **Inner Floodplain (Hazard Category 1)**, which is shown in solid red colour. This zone comprises areas where factors such as the depth and velocity of flow, time of rise, isolation on Low Flood Islands and evacuation problems mean that the land is unsuitable for some types of development. It includes areas of High and Low Hazard Floodway, Flood Storage and Flood Fringe areas. Erection of buildings and carrying out of work; use of land, subdivision of land and demolition subject to State Environmental Planning Policies and Local Environmental Plan provisions are considered to be unsuitable in this zone.
- **Inner Floodplain (Hazard Category 2A)**, which is shown in solid green colour. This zone comprises the floodway which forms during periods when intense rain falls directly over Queanbeyan. This zone is limited to land zoned *B3-Commercial Core*. Development is not to impede the free discharge of major overland flow in this zone.[6]
- **Inner Floodplain (Hazard Category 2B)**, which is shown in solid orange colour. This zone comprises land zoned *B3 - Commercial Core* that lies below the Flood Planning Level which is not classified as Inner Floodplain (Hazard Category 1 and 2A). Commercial and residential development is permitted in this zone provided it complies with the development controls set out in **Annexure 2** of the draft *Flood Policy* (refer **Appendix E**). The MFL for residential and commercial development located in this zone is the 1% AEP flood levels plus 1.2 m and the 5% AEP flood level, respectively.

  In order to best manage the significant flood risk in this zone, controls have been imposed on any future residential development above the FPL. As a result, it will be necessary for Council to apply to the Secretary for "exception circumstances" exception prior to updating its Development Control Plan to incorporate the recommendations of the *FRMS&P*.

[6] It would be feasible to combine Inner Floodplain (Hazard Category 2A) with Inner Floodplain (Hazard Category 2B) provided that the area identified as needing to be maintained for the conveyance of overland flow is identified elsewhere in the Development Control Plan and that appropriate controls are applied to any development that is proposed within its limits.

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- **Inner Floodplain (Hazard Category 2C)**, which is shown in solid yellow colour. This zone comprises High Hazard Flood Storage areas where residential development that is replacing existing residential development may be permitted subject to it not increasing the density of persons resident on a site and meeting other requirements which are also applicable to residential land in the Intermediate Floodplain. Mixed use development is also permitted in this zone. However, Council will require a *Flood Risk Report* confirming the adequacy of the structure to resist hydrodynamic loadings and that the proposal would have no adverse impacts on local flooding patterns, either individually or cumulatively in conjunction with similar extensions in adjacent properties. The *Flood Risk Report* will also need to set out how the development complies with the controls set out in the draft *Flood Policy* (refer **Appendix E**).
- **Intermediate Floodplain**, which is shown in solid blue colour. This area is the remaining land lying outside the extent of the Inner Floodplain zones, but within the extent of the FPA. Within this zone, there would only be the requirement for MFLs to be set at the 1% AEP flood level plus 0.5 m. Land use permissibility would be as specified by State Environmental Planning Policies or the Local Environmental Plan. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is considered to be unsuitable in this zone.
- **Outer Floodplain**, which is shown in solid cyan colour. This area represents the remainder of the floodplain between the Intermediate Floodplain and the extent of the PMF (that is, the extent of the floodplain). This area is outside the extent of the FPA and hence controls on residential, commercial and industrial development do not apply. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is not to be encouraged in this zone.

3.5.1.4 Revision of Queanbeyan LEP 2012 by Council

To implement the recommended approach set out in the *FRMS&P*, clause 7.2 of *Queanbeyan LEP 2012* would require minor amendments, namely in regards the wording of sub clause (2) and (5). It is recommended that the following clause replaces the existing clause 7.2 of *Queanbeyan LEP 2012*:

"7.2 Flood planning

(1) The objectives of this clause are as follows:

(a) to minimise the flood risk to life and property associated with the use of land,

(b) to allow development on land that is compatible with the land's flood hazard, taking into account projected changes as a result of climate change,

(c) to avoid significant adverse impacts on flood behaviour and the environment.

(2) This clause applies to land at or below the flood planning level.

(3) Development consent must not be granted for development on land to which this clause applies unless the consent authority is satisfied that the development:

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(a) is compatible with the flood hazard of the land, and

(b) will not significantly adversely affect flood behaviour resulting in detrimental increases in the potential flood affectation of other development or properties, and

(c) incorporates appropriate measures to manage risk to life from flood, and

(d) will not significantly adversely affect the environment or cause avoidable erosion, siltation, destruction of riparian vegetation or a reduction in the stability of river banks or watercourses, and

(e) is not likely to result in unsustainable social and economic costs to the community as a consequence of flooding.

(4) A word or expression used in this clause has the same meaning as it has in the Floodplain Development Manual, unless it is otherwise defined in this Plan."

(5) In this clause:

flood planning level *means the level of a 1% AEP (annual exceedance probability) flood event plus 0.5 metre freeboard, or other freeboard as determined by an adopted floodplain risk management plan.*

The steps involved in Council's amending *Queanbeyan LEP 2012* following the finalisation and adoption of the *FRMS&P* are:

1. Council Planning Staff consider the conclusions of the *FRMS&P* and suggested amendments to *Queanbeyan LEP 2012*.
2. Council resolves to amend *Queanbeyan LEP 2012* in accordance with the *FRMS&P*.
3. Council prepares a Planning Proposal in accordance with NSW Planning and Environment Guidelines. Planning Proposal submitted to NSW Planning and Environment in accordance with section 3.33 of the EP&A Act, 1979.
4. Planning Proposal considered by NSW Planning and Environment and determination made in accordance with section 3.34 of the EP&A Act, 1979 as follows:

   (a) whether the matter should proceed (with or without variation),

   (b) whether the matter should be resubmitted for any reason (including for further studies or other information, or for the revision of the planning proposal),

   (c) community consultation required before consideration is given to the making of the proposed instrument (the community consultation requirements),

   (d) any consultation required with State or Commonwealth public authorities that will or may be adversely affected by the proposed instrument,

   (e) whether a public hearing is to be held into the matter by the Planning Assessment Commission or other specified person or body,

   (f) the times within which the various stages of the procedure for the making of the proposed instrument are to be completed.
5. Planning Proposal exhibited for public comment.

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6. Planning Proposal reviewed following public submissions and submissions from relevant State and Commonwealth authorities.
7. Final Local Environmental Plan with proposed amendments drafted.
8. Amending Local Environmental Plan made by the Minister and gazetted.

3.5.2 Voluntary Purchase of Residential Properties

Removal of housing from high hazard floodway areas in the floodplain is generally accepted as a cost effective means of correcting previous decisions to build in such areas. The Voluntary Purchase (**VP**) of residential property in hazardous areas has been part of subsidised floodplain risk management programs in NSW for over 20 years.[7] After purchase, land is subsequently cleared and the site re-developed and re-zoned for public open space or some other flood compatible use. A further criterion applied by State Government agencies in assessing eligibility for funding is that the property must be in a high hazard floodway area, that is, in the path of flowing floodwaters where the depth and velocity at the peak of the flood are such that life could be threatened, damage of property is likely and evacuation difficult.

Under a VP scheme the owner is notified that the body controlling the scheme, Council in the present case, is prepared to purchase the property when the owner is ready to sell. There is no compulsion whatsoever to sell at any time. The price is determined by independent valuers and the Valuer General, and by negotiation between Council and the owners. Valuations are not reduced due to the flood affected nature of the site.

Prior to progressing to the purchase of a property, it would first be necessary to undertake a *Voluntary Purchase Feasibility Study*, especially if Council intends to apply for NSW Government grant funding. The study would include discussions with each eligible and agreeable property owner, as well as a detailed assessment of each property to determine a priority order and costing for each.

There are 15 residential unit blocks comprising 230 individual units that are located in the High Hazard Floodway area where it extends onto Trincullo Place and Macquoid Street on the eastern overbank and Morisset Street and Carinya Street on the western overbank of the Queanbeyan River. While the funds available for voluntary purchase in NSW would not be sufficient to fund the purchase of the affected unit blocks, there would be sufficient funds to purchase the seven individual dwellings which are also located in the high hazard floodway area. While six of the seven properties are located on the western side of the Queanbeyan River in the Queanbeyan local government area, it is noted that the seventh property is located on the northern side of the Goulburn-Queanbeyan Railway Line in the ACT.[8]

While Council estimated that it would cost $6.34 Million to purchase the seven properties, given the hazardous nature of the flooding, their inclusion in the NSW Government's VP Scheme has been included in the *FRMP*.

[7] State government funding is only available for properties where the buildings were approved and constructed prior to 1986 when the original *Floodplain Development Manual* was gazetted. Properties built after this date should have been constructed in accordance with the principles in the manual.

[8] For confidentiality reasons, the address of the seven individual dwellings have been provided separately to Council.

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3.5.3 Raising Floor Levels of Residential Properties

The term “house raising” refers to procedures undertaken, usually on a property by property basis, to protect structures from damage by floodwaters. The most common process is to raise the affected house by a convenient amount so that the floor level is at or above the MFL. For weatherboard and similar buildings this can be achieved by jacking up the house, constructing new supports, stairways and balconies and reconnecting services. Alternatively, where the house contains high ceilings, floor levels can be raised within rooms without actually raising the house. It is usually not practical to raise brick or masonry houses. Most of the costs associated with this measure relate to the disconnection and reconnection of services. Accordingly, houses may be raised a considerable elevation without incurring large incremental costs.

State and Federal Governments have agreed that flood mitigation funds will be available for house raising, subject to the same economic evaluation and subsidy arrangements that apply to other structural and non-structural flood mitigation measures. In accepting schemes for eligibility, the Government has set out the following conditions:

- House raising should be part of the adopted *FRMP*.
- The scheme should be administered by the local authority.

State government funding is only available for properties where the buildings were approved and constructed prior to 1986 when the original *Floodplain Development Manual* was gazetted. Properties built after this date should have been constructed in accordance with the principles in the manual. The Government also requires that councils carry out ongoing monitoring in areas where subsidised voluntary house raising has occurred to ensure that redevelopment does not occur to re-establish habitable areas below the design floor level. In addition, it is expected that councils will provide documentation during the conveyancing process so that subsequent owners are made aware of restrictions on development below the design floor level.

Council’s principal role in subsidised voluntary house raising would be to:

- Define a habitable floor level, which it will have already done in exercising controls over new house building in the area.
- Guarantee a payment to the builder after satisfactory completion of the agreed work.
- Monitor the area of voluntary house raising to ensure that redevelopment does not occur to re-establish habitable areas below the design floor level.

Prior to progressing to the raising of a dwelling, it would first be necessary to undertake a *Voluntary House Raising Feasibility Study*, especially if Council intends to apply for NSW Government grant funding. The study would include discussions with each eligible and agreeable property owner, as well as a detailed assessment of each property to determine a priority order and costing for each.

The current cost to raise a medium sized (150 m^2) house is about $100,000 based on recent experience in other centres.

While there are a number of dwellings located along Woodger Parade on the western side of the Queanbeyan River that would be eligible for inclusion in a house raisings scheme, they are all of brick veneer type construction, which means their floor levels could not be raised. Similarly, there are a number of properties located to the west of the Queanbeyan CBD which would also be eligible for inclusion in a house raisings scheme. However, a large number of these properties

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are also of brick veneer type construction, which means their floor levels could not be raised. While there a limited number of dwellings in this area that are of clad type construction and could therefore be raised, the resulting depth of above-floor inundation is either relatively shallow in a 1% AEP flood event, meaning their raising could not be justified economically, or they would need to be raised by more than 1 m off the ground in order to achieve the required 0.5 m freeboard to the 1% AEP flood level which would cause overshadowing of adjacent development.

There is a single dwelling that is located on the western side of the Queanbeyan River that is of clad type construction and could be raised 0.5 m above the peak 1% AEP flood level. As the dwelling is located on a sloping block, raising it by the required 1.3 m would not result in adverse visual impacts in neighbouring properties. Based on this finding, its inclusion in the voluntary house raising scheme has been included in the *FRMP*.[9]

3.6 Response Modification Measures

3.6.1 Improvements to Flood Warning System

Improvements to the flood warning and response procedures were strongly favoured by the community during the consultation process. An effective flood warning system has three key components, i.e. a flood forecasting system, a flood warning broadcast system and a response/evacuation plan. All systems need to be underpinned by an appropriate public flood awareness program.

As mentioned in **Section 2.13.2**, BoM currently operates a well-established and proven flood warning system which provides predictions of gauge heights at Queanbeyan. BoMs system is based on the conversion of rainfalls recorded at telemetered rain gauges within the catchments to predicted peak flood levels at the stream gauges, which are updated and conveyed to NSW SES Local Units during a flood emergency. The flood warning system includes the automated stream gauge at Wickerslack and the manually read stream gauge at Queens Bridge. In regards the latter, there is merit in replacing the manual stream gauge with a telemetered stream gauge so that water levels can be monitored remotely in real time by NSW SES and others. The installation of a telemetered stream gauge at Queens Bridge is strongly supported by NSW SES and has been incorporated in the *FRMP*.

While flood warnings are disseminated in a number of ways, including by way of door knocking and local and social media, there is currently no automated means to disseminate flood warning and evacuation orders by either public address or telephone based systems. In order to improve the flood warning system at Queanbeyan it is recommended that Council in consultation with NSW SES develop both a public address and telephone based system for disseminating flood warnings. This could be built around a Ready-Set-Go type approach, where the warning level escalates as the anticipated flood threat in Queanbeyan worsens.

The findings of the present investigation could be used to develop relationships between outflows from Googong Dam with water levels at both the Wickerslack and Queens Bridge stream gauges. For example, once a trigger outflow from Googong Dam is reached and later confirmed by a corresponding water level at the Wickerslack stream gauge, then either a manual or automatically compiled message could be sent out via the public address and telephone based flood warning system. The contents of the message being sent via the flood warning system would be dependent on the outflow from Googong Dam and the corresponding predicted flood level at Queens Bridge.

[9] For confidentiality reasons, the address of the single dwelling has been provided separately to Council.

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While strongly favoured by the community, the implementation of a flash flood warning system for the Queanbeyan CBD would be the subject of more detailed flood modelling and assessment, as for example the provision of temporary flood storage in Queanbeyan Park in combination with improved planning controls may militate the need for such a system.

3.6.2 Improved Emergency Planning and Response

As mentioned in **Section 2.13**, the *Local Flood Plan* provides detailed information regarding preparedness measures, conduct of response operations and coordination of immediate recovery measures for all levels of flooding.

NSW SES should ensure information contained in this report on the impacts of flooding on urban development, as well as recommendations regarding flood warning and community education are used to update Annexes A and B in the *Local Flood Plan*. Details of where information that can be used to update Annexes A and B can be found in this report are set out below:

<u>**Annex A – The Flood Threat**</u> includes the following sub-sections:

1.1 Land Forms and River Systems – ref. **Sections 2.1** and **2.2** of the report for information on these topics.

1.4 Characteristics of Flooding – Indicative extents of inundation for the 1% AEP and PMF events are shown on **Figures 2.2** and **2.3**. Water surface profiles along the Queanbeyan and Molonglo Rivers is shown on **Figure 2.4**, while typical times of rise of floodwaters at major crossings of the two rivers are shown on **Figure 2.5**. **Figure 2.6** shows the rate of rise of floodwaters at Queens Bridge for a range of design flood events. **Figure 2.5** shows the nature of local catchment flooding in the Queanbeyan CBD. **Table 2.4** summarises the impact flooding has on vulnerable development and critical infrastructure at Queanbeyan. The location of critical infrastructure relative to the flood extents is shown on **Figure 2.8**.

1.5 Flood History – Recent flood experience at Queanbeyan is discussed in **Section 2.3** of the report.

1.6 Flood Mitigation Systems – Apart from the attenuating effects of Googong Dam on flood flows, there are no other significant flood mitigation systems in Queanbeyan.

1.7 Extreme Flood Events – The Probable Maximum Flood was modelled and the indicative extent and depth of inundation presented on **Figure 2.3**.

<u>**Annex B – Effects on the Community**</u>

Information on the number of properties affected by the 1% AEP design flood are included in this report. As a large number of the floor level data used in this assessment were estimated from the LiDAR survey and "drive by" survey they are indicative only. While fit for use in estimating the economic impacts of design floods, the data should not be used to provide specific details of the degree of flood affectation of individual properties.

Figure 2.5 shows stage hydrographs at major road and rail crossings at Queanbeyan, the locations of which are shown on **Figure 2.8**.

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Figure 2.8 shows the location of vulnerable development and critical infrastructure at Queanbeyan relative to the extents of floods ranging between 20% and 0.2% AEP, as well as the PMF. Refer **Section 2.8** and **Table 2.4** for details of affected vulnerable development and critical infrastructure.

Figures 3.6 and **3.7** show the flood emergency response planning classifications for the 1% AEP and PMF events, respectively, based on the definitions set out in the *Floodplain Risk Management Guideline – Flood Emergency Response Classification of Communities* (DECC, 2007).

Given the linear and relative steep sided nature of the floodplain at Queanbeyan, areas that are affected by flooding are generally classified as either Low or High Hydraulic Hazard Flooding, with a limited number of Low Flood Islands present for a 1% AEP event. While not populated, there are Low and High Trapped Perimeter areas located between the Goulburn-Queanbeyan Railway Line and the Molonglo River east (upstream) of the Queanbeyan River confluence.

3.6.3 Public Awareness Programs

Community awareness and appreciation of the existing flood hazards in the floodplain would promote proper land use and development in flood affected areas. A well informed community would be more receptive to requirements for flood proofing of buildings and general building and development controls imposed by Council. Council should also take advantage of the information on flooding presented in this report, including the flood mapping, to inform occupiers of the floodplains of the flood risk.

One aspect of a community's preparedness for flooding is the "flood awareness" of individuals. This includes awareness of the flood threat in their area and how to protect themselves against it. The overall level of flood awareness within the community tends to reduce with time, as memories fade and as residents move into and out of the floodplain. The improvements to flood warning arrangements described above, as well as the process of disseminating this information to the community, would represent a major opportunity for increasing flood awareness in Queanbeyan.

Means by which community awareness of flood risks can be maintained or may be increased include:

- displays at Council offices using the information contained in the present study and photographs of historic flooding in the area; and
- talks by NSW SES officers with participation by Council and longstanding residents with first-hand experience of flooding in the area.
- preparation of a *Flood Information Brochure* which could be prepared by Council with the assistance of NSW SES containing both general and site specific data and distributed with rate notices.

The community should also be made aware that a flood greater than historic levels or the planning level can, and will, occur at some time in the future.

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4 SELECTION OF FLOODPLAIN RISK MANAGEMENT MEASURES

4.1 Background

NSWG, 2005 requires a Council to develop a *FRMP* based on balancing the merits of social, economic and environmental considerations which are relevant to the community. This chapter sets out a range of factors which need to be taken into consideration when selecting the mix of works and measures that should be included in the *FRMP*.

The community will have different priorities and, therefore, needs to establish its own set of considerations used to assess the merits of different options. The considerations adopted by a community must, however, recognise the State Government's requirements for floodplain risk management as set out in NSWG, 2005 and other relevant policies. A further consideration is that some elements of the *FRMP* may be eligible for subsidy from State and Federal Government sources and the requirements for such funding must, therefore, be taken into account.

Typically, State and Federal Government funding is given on the basis of merit, as judged by a range of criteria:

- The magnitude of damage to property caused by flooding and the effectiveness of the option in mitigating damage and reducing the flood risk to the community.
- Community involvement in the preparation of the *FRMP* and acceptance of the option.
- The technical feasibility of the option (relevant to structural works).
- Conformance of the option with Council's planning objectives.
- Impacts of the option on the environment.
- The economic justification, as measured by the benefit/cost ratio of the option.
- The financial feasibility as gauged by Council's ability to meet its commitment to fund its part of the cost.
- The performance of the option in the event of a flood greater than the design event.
- Conformance of the option with Government Policies (e.g. NSWG, 2005 and Catchment Management objectives).

4.2 Ranking of Options

A suggested approach to assessing the merits of various options is to use a subjective scoring system. The chief merits of such a system are that it allows comparisons to be made between alternatives using a common "currency". In addition, it makes the assessment of alternatives "transparent" (i.e. all important factors are included in the analysis). The system does not, however, provide an absolute "right" answer as to what should be included in the *FRMP* and what should be left out. Rather, it provides a method by which the Council can re-examine its options and if necessary, debate the relative scoring given to aspects of the *FRMP*.

Each option is given a score according to how well the option meets the considerations discussed above. In order to keep the scoring simple the following system is proposed:

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+2 Option rates very highly

+1 Option rates well

0 Option is neutral

- 1 Option rates poorly

- 2 Option rates very poorly

The scores are added to get a total for each option.

Based on considerations outlined in this chapter, **Table 4.1** presents a suggested scoring matrix for the options reviewed in **Chapter 3** at Queanbeyan. This scoring has been used as the basis for prioritising the components of the *FRMP*. ***The proposed scoring and weighting shown in Table 4.1 was carefully reviewed by the Floodplain Risk Management Committee as part of the process of finalising the overall FRMP.***

4.3 Summary

Table 4.1 indicates that there are good reasons to consider including the following elements into the *FRMP*:

- Improved planning controls via the update of *Queanbeyan DCP 2012*.
- An update of the *Queanbeyan LEP 2012* to allow better management of the floodplain
- Incorporation of the catchment specific information on flooding impacts contained in this report in NSW SES Response Planning and Flood Awareness documentation for the study area.
- Improved public awareness of flood risk in the community
- Installation of telemetered stream gauge on the Queanbeyan River at Queen Bridge.
- Improvements to the flood warning system through the development of a public address and telephone based system which utilises the findings of this Study to set key trigger levels for disseminating flood warnings.
- The commissioning of a *Voluntary Purchase and House Raising Feasibility Study* to assess the merits of including one dwelling that is located in a High Hazard Flood Storage area in the NSW Government's Voluntary House Raising Scheme and seven dwellings that are located in a High Hazard Floodway area in the NSW Government's Voluntary Purchase Scheme.
- The development of a comprehensive floodplain risk management strategy for the Queanbeyan CBD which takes into account the current planning provisions which allow up to 30 m high multi-storey commercial and residential unit towers to be built on land zoned *B3 - Commercial Core*.

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TABLE 4.1
ASSESSMENT OF POTENTIAL FLOODPLAIN RISK MANAGEMENT MEASURES

Option	Impact on Flooding/ Reduction in Flood Risk	Community Acceptance	Technical Feasibility	Planning Objectives	Environ. Impacts	Economic Justification	Financial Feasibility	Government Policies and TCM Objectives	Score
Flood Modification									
Vegetation management along the Queanbeyan River	0	+2	0	0	+2	0	0	+1	+5
Levee Schemes to Protect Urban areas in Queanbeyan	+1	0	-2	0	-2	0	-1	+1	-3
Detention storage in Queanbeyan Park to mitigate local catchment flooding in Queanbeyan CBD	+1	+1	+1	+1	+1	+1	-2	0	+4
Raising Bungendore Road level at Big Dipper	+1	+1	+1	+1	-2	-2	-2	0	-2
Raising Morisset Street levels at Queanbeyan River crossing	+1	0	+1	+1	-2	-2	-2	0	-3
Property Modification									
Controls over Future Development (via updated of *Queanbeyan DCP 2012*)	+2	+2	+2	+2	0	0	0	+2	+10
Update of the *Queanbeyan LEP 2012* to allow better management of the floodplain	+2	+2	+2	+2	0	0	0	+2	+10
Voluntary Purchase of Residential Property in High Hazard Floodway Areas	+2	0	+2	+1	0	-2	-2	+1	+2
House Raising in High Hazard Flood Storage Areas	+2	0	+2	+1	0	-1	+2	+1	+7
Development of a comprehensive floodplain risk management strategy for the Queanbeyan CBD	+2	+2	+2	+2	0	0	0	+2	+10
Response Modification									
Improvements to the existing Flood Warning System and the possible inclusion of a flash flood warning system	+2	+2	+2	+1	0	0	+1	+2	+10
Improved Emergency Planning and Response	+1	+2	+2	+1	0	0	+1	+2	+9
Public Awareness Programs	+1	+2	+1	+1	0	0	+1	+2	+9

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5 QUEANBEYAN FLOODPLAIN RISK MANAGEMENT PLAN

5.1 The Floodplain Risk Management Process

The *Floodplain Risk Management Study (**FRMS**)* and *Floodplain Risk Management Plan* (***FRMP***) have been prepared for Queanbeyan as part of a Government program to mitigate the impacts of major floods and reduce the hazards in the floodplain. The *FRMP* which is set out in this Chapter has been prepared as part of the Floodplain Risk Management Process in accordance with NSW Government's Flood Prone Land Policy.

The first steps in the process of preparing the *FRMP* were the collection of flood data and the update of previous flooding investigations that have been relied upon for planning purposes at Queanbeyan (***Updated Flood Study***). The *Updated Flood Study* was the formal starting process of defining management measures for flood liable land and represented a detailed technical investigation of flood behaviour along the Queanbeyan and Molonglo Rivers at Queanbeyan.

5.2 Purpose of the Plan

The overall objectives of the *FRMS* were to assess the impacts of flooding, review policies and options for the management of flood affected land and to develop a *FRMP* which:

i) sets out the recommended program of works and measures aimed at reducing over time, the social, environmental and economic impacts of flooding and establishes a program and funding mechanism for the *FRMP*;

ii) proposes amendments to Queanbeyan-Palerang Regional Council's (**Council's**) existing policies to ensure that the future development of flood affected land along the Queanbeyan and Molonglo Rivers is undertaken so as to be compatible with the flood hazard and risk;

iii) ensures the *FRMP* is consistent with NSW SES's local emergency response planning procedures; and

iv) ensures that the *FRMP* has the support of the community.

5.3 The Study Area

The study area for this *FRMP* comprises land which is subject to flooding along the Queanbeyan and Molonglo Rivers at Queanbeyan (referred to herein as "main stream flooding"). The *FRMP* only applies to areas that are affected by the surcharge of floodwater from these two watercourses and does not include flooding along their minor tributaries or the shallower and slower moving major overland flow that occurs in the urbanised parts of Queanbeyan.

5.4 Community Consultation

The Community Consultation process provided valuable direction over the course of the investigations, bringing together views from key Council staff, other departments and agencies, and importantly, the views of the community gained through:

- the delivery of a *Community Newsletter and Questionnaire* to property occupiers located in the floodplain which allowed the wider community to gain an understanding of the issues being addressed as part of the study;
- meetings of the Floodplain Risk Management Committee to discuss results as they became available; and
- a community information session which was held during the exhibition of the draft *FRMS&P* report.

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A summary of the responses to the questions contained in the *Community Questionnaire* is contained in **Appendix A** of the *FRMS.*

5.5 Economic Impacts of Flooding

Table 5.1 shows the number of properties that would be flooded to above-floor level and the damages experienced for the various classes of property that are subject to flooding when the Queanbeyan and Molonglo Rivers break their banks. Damages in property located along the two rivers at Queanbeyan are evaluated in **Appendix C** of the *FRMS.*

TABLE 5.1
FLOOD DAMAGES AT QUEANBEYAN

Design Flood Event (% AEP)	Residential	Commercial/ Industrial	Public	Total Damage ($ Million)
20	0	0	0	0
10	0	0	0	0
5	0	5	0	0.3
2	93	65	2	17.8
1	260	239	10	69.6
0.5	529	336	28	177
0.2	853	351	39	311
PMF	3,003	388	73	1,111

While the floor levels in 493 flood affected properties were surveyed in 2006, the floor levels of a much larger number of properties were mainly estimated from a “drive by” survey. Consequently, the results should not be used to identify the degree of flood affectation or otherwise of individual properties, for which a site specific survey would be required.

5.6 Indicative Flood Extents

Figures 2.2 and **2.3** show the indicate extent and depths of inundation of both the 1% Annual Exceedance Probability (**AEP**) and Probable Maximum Flood (**PMF**) events, respectively, while **Figure 2.8** shows the indicate extent of flooding at Queanbeyan for floods ranging between 20% AEP and the PMF. Also shown on **Figure 2.8** is the location of vulnerable development and critical infrastructure relative to the extents of flooding.

The 1% AEP design flood has been adopted as the “planning flood” for the purposes of specifying flood related controls over future development. The extent of flooding is indicative only, being based on hydrologic and hydraulic models that were developed as part of the *Updated Flood Study*.

This level of accuracy in the flood mapping is supported by the NSW Department of Planning, Industry and Environment (**DPIE**), as the costs associated with undertaking of detailed ground survey in each flood affected property lies outside the scope of the NSW Government’s floodplain program. Under the program, it is Council’s responsibility to identify the flood risk within the floodplain and prepare maps showing indicative flood extents (i.e. the mapping presented in this *FRMS* report), with the onus being on the property owner to carry out sufficient survey to allow a more accurate picture of flood affection to be described in his/her allotment.

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To allow Council to assess individual development proposals for the purposes of the draft *Flood Policy* (ref. **Section 5.8** below), a detailed site survey would be required to allow the extent of flooding and the flood hazard to be evaluated using the results of the *Updated Flood Study*. For this reason, proponents will be required to submit a detailed survey plan of the site for which development is proposed.

5.7 Structure of Floodplain Risk Management Study and Plan

The *FRMS* and *FRMP* are supported by Appendices which provide additional details of the investigations. A summary of the *FRMP* proposed for the study area along with broad funding requirements for the recommended measures are shown in **Table S1** at the commencement of the *FRMS* report. These measures comprise the voluntary purchase of seven dwellings that are located in high hazard floodway areas, the raising of one dwelling that is located in a high hazard flood storage area, improvements to existing planning documentation by Council and also the existing flood warning system at Queanbeyan by NSW SES, and the implementation of a community education program by both Council and NSW SES to improve flood awareness and response. The measures will over time achieve the objectives of reducing the flood risk to existing and future development for the full range of floods.

The *FRMP* is based on the following mix of measures which have been given a provisional priority ranking according to a range of economic, social, environmental and other criteria set out in **Table 4.1** of the report:

- **Measure 1** – Improved planning controls via the update of Queanbeyan Development Control Plan 2012 (***Queanbeyan DCP 2012***).
- **Measure 2** – Update of the wording in the Queanbeyan Local Environmental Plan 2012 (***Queanbeyan LEP 2012*)**.
- **Measure 3** – Improvements in flood emergency response planning.
- **Measure 4** – Increase public awareness of the risks of flooding in the community.
- **Measure 5** – Installation of a telemetered stream gauge on the Queanbeyan River at Queens Bridge.
- **Measure 6** – Review of potential improvements to the existing flood warning system at Queanbeyan
- **Measure 7** – Continued management of vegetation along the Queanbeyan River
- **Measure 8** – Commissioning of a *Voluntary Purchase and House Raising Feasibility Study* and subject to the findings of the study and the mutual agreement between Council and the affected property owners, the voluntary purchase of seven dwellings and the raising of one dwelling.
- **Measure 9** – Development of a comprehensive floodplain risk management strategy for the Queanbeyan CBD.

5.8 Planning and Development Controls

The results of the *FRMS* indicate that an important measure for Council to adopt in the floodplain would be strong floodplain risk management planning applied consistently by all of its branches. The results of the *FRMS* also indicate that the commonly adopted freeboard of 500 mm would not provide the necessary factor of safety to peak 1% AEP flood levels for residential development that is associated with the multi-storey tower type developments which are permitted in parts of

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the Queanbeyan CBD. Based on the findings of a joint probability analysis, the study recommended the adoption of a 1.2 m freeboard for setting the Minimum Flood Level (**MFL**) for residential development that is located on land zoned *B3-Commerical Core*.

5.8.1 Draft Flood Policy

Recommended wording in the form of a draft *Flood Policy* (**Appendix E**) uses the concepts of *flood hazard* and *hydraulic categorisation* outlined in **Section 2.11** of the report to develop flood related controls for future development that is subject to flooding from the Queanbeyan and Molonglo Rivers (**Measure 1**).

Figure E1.1 in the draft *Flood Policy* is an extract from the *Flood Planning Map* relating to the urbanised parts of Queanbeyan which are located on the floodplains of the Queanbeyan and Molonglo Rivers. The extent of the Flood Planning Area (**FPA**) (the area that lies below the Flood Planning Level (**FPL**) and is subject to flood related development controls) is shown in a solid red colour and has been defined as land which lies at or below the 1% AEP plus 0.5 m freeboard.

It is proposed that properties intersected by the extent of the FPA would be subject to S10.7 flood affectation notification and planning controls graded according to flood hazard (dependent on depth of inundation and flow velocity). **Annexure 2** in the draft *Flood Policy* sets out the graded set of flood related planning controls which have been developed for areas within Queanbeyan that are subject to flooding from the Queanbeyan and Molonglo Rivers.

MFL requirements would be imposed on future development in properties that are identified as lying either partially or wholly within the extent of the FPA shown on the *Flood Planning Map*. The MFLs for all land use types affected by flooding from the Queanbeyan and Molonglo Rivers is the level of the 1% AEP flood event plus 0.5 m freeboard, with the exception of development located on land zoned *B3-Commerical Core* in the Queanbeyan CBD, where the MFL of residential and commercial development is the 1% AEP flood levels plus 1.2 m and the 5% AEP flood level, respectively.

Figure E1.2 in the draft *Flood Policy* is the *Flood Hazard Map*. The figure shows the subdivision of the floodplain into a number of categories which have been used as the basis for developing the graded set of planning controls. The floodplain has been divided into the following six categories in areas that are affected by main stream flooding:

- **Inner Floodplain (Hazard Category 1)**, which is shown in solid red colour. This zone comprises areas where factors such as the depth and velocity of flow, time of rise, isolation on Low Flood Islands and evacuation problems mean that the land is unsuitable for some types of development. It includes areas of High and Low Hazard Floodway, Flood Storage and Flood Fringe areas. Erection of buildings and carrying out of work; use of land, subdivision of land and demolition subject to State Environmental Planning Policies and Local Environmental Plan provisions are considered to be unsuitable in this zone.
- **Inner Floodplain (Hazard Category 2A)**, which is shown in solid green colour. This zone comprises the floodway which forms during periods when intense rain falls directly over Queanbeyan. This zone is limited to land zoned *B3-Commercial Core*. Development is not to impede the free discharge of major overland flow in this zone.[10]

[10] It would be feasible to combine Inner Floodplain (Hazard Category 2A) with Inner Floodplain (Hazard Category 2B) provided that the area identified as needing to be maintained for the conveyance of overland

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- **Inner Floodplain (Hazard Category 2B)**, which is shown in solid orange colour. This zone comprises land zoned *B3-Commercial Core* that lies below the Flood Planning Level which is not classified as Inner Floodplain (Hazard Category 1 and 2A). Commercial and residential development is permitted in this zone provided it complies with the development controls set out in **Annexure 2** of the draft *Flood Policy* (refer **Appendix E**) The MFL for residential and commercial development located in this zone is the 1% AEP flood levels plus 1.2 m and the 5% AEP flood level, respectively.

  In order to best manage the significant flood risk in this zone, controls have been imposed on any future residential development above the FPL. As a result, it will be necessary for Council to apply to the Secretary for "exception circumstances" exception prior to updating its Development Control Plan to incorporate the recommendations of the *FRMS&P*.

- **Inner Floodplain (Hazard Category 2C)**, which is shown in solid yellow colour. This zone comprises High Hazard Flood Storage areas where residential development that is replacing existing residential development may be permitted subject to it not increasing the density of persons resident on a site and meeting other requirements which are also applicable to residential land in the Intermediate Floodplain. Mixed use development is also permitted in this zone. However, Council will require a *Flood Risk Report* confirming the adequacy of the structure to resist hydrodynamic loadings and that the proposal would have no adverse impacts on local flooding patterns, either individually or cumulatively in conjunction with similar extensions in adjacent properties. The *Flood Risk Report* will also need to set out how the development complies with the controls set out in the draft *Flood Policy* (refer **Appendix E**).

- **Intermediate Floodplain**, which is shown in solid blue colour. This area is the remaining land lying outside the extent of the Inner Floodplain zones, but within the extent of the FPA. Within this zone, there would only be the requirement for MFLs to be set at the 1% AEP flood levels plus 0.5 m. Land use permissibility would be as specified by State Environmental Planning Policies or the Local Environmental Plan. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is considered to be unsuitable in this zone.

- **Outer Floodplain**, which is shown in solid cyan colour. This area represents the remainder of the floodplain between the Intermediate Floodplain and the extent of the Probable Maximum Flood (PMF) (that is, the extent of the floodplain). This area is outside the extent of the FPA and hence controls on residential, commercial and industrial development do not apply. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is not to be encouraged in this zone.

A full list of prescriptive controls that apply to areas subject to main stream flooding are set out in **Annexure 2** of **Appendix E**.

5.8.2 Revision to Queanbeyan LEP 2012

Clause 7.2 of *Queanbeyan LEP 2012* entitled "Flood Planning" outlines Council's objectives in regard to development of flood prone land. The FPL referred to is the 1% AEP flood plus an allowance for freeboard of 0.5 m. The area encompassed by the FPL is known as the FPA and

flow is identified elsewhere in the Development Control Plan and that appropriate controls are applied to any development that is proposed within its limits.

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denotes the area subject to flood related development controls, such as locating development outside high hazard areas and setting minimum floor levels for future residential development.

To improve floodplain management in Queanbeyan in accordance with the recommendations set out in the *FRMP*, clause 7.2 of *Queanbeyan LEP 2012* would require minor amendment (**Measure 2**). Suggested amendments are given in **Section 3.5.1.4**. **Figure E1.1** in **Appendix E** is an extract from the *Flood Planning Map* showing the extent of land to which this clause applies along the Queanbeyan and Molonglo Rivers.

5.9 Improvements in Emergency Planning and Flood Awareness

Four measures are proposed in the *FRMP* to improve flood warning, emergency response planning and community awareness to the threat posed by flooding.

Measure 3 involves the update by NSW SES of the *Queanbeyan City Local Flood Plan, 2013* using information on flooding patterns, times of rise of floodwaters and flood prone areas identified in this report. Figures have been prepared showing indicative extents of flooding, high hazard areas, expected rates of rise of floodwaters in key areas and locations where flooding problems would be expected. **Section 3.6.2** of the *FRMS* report references the locations of key data within this report.

Council should also take advantage of the information on flooding presented in this report, including the flood mapping, to inform occupiers of the floodplains of the flood risk (included as **Measure 4** of the *FRMP*). This information could be included in a *Flood Information Brochure* to be prepared by Council with the assistance of NSW SES containing both general and site specific data and distributed with the rate notices. The community should also be made aware that a flood greater than historic levels or the planning level can, and will, occur at some time in the future. The *FRMP* should be publicised and exhibited at community gathering places to make residents aware of the measures being proposed.

Measure 5 involves the installation of a telemetered stream gauge on the Queanbeyan River at Queens Bridge to supplement the manually read stream gauge at this location. The installation of the telemetered stream gauge would allow NSW SES and others remotely monitor water levels in the river in real time.

Measure 6 involves a review of potential improvements to the existing flood warning system at Queanbeyan. Potential improvements include the establishment of a public address and telephone based flood warning system which is linked to key trigger outflows from Googong Dam and water levels recorded at the telemetered Wickerslack stream gauge which is located about 6 km upstream of Queanbeyan. While strongly favoured by the community, the implementation of a flash flood warning system for the Queanbeyan CBD would be the subject of more detailed flood modelling and assessment as part of **Measure 9**, as for example the provision of temporary flood storage in Queanbeyan Park in combination with improved planning controls may militate the need for such a system.

5.10 Flood Modification Works

The only flood modification measure included in the *FRMP* is the continued management of vegetation along the Queanbeyan River (included as **Measure 7** of the *FRMP*).

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5.11 Voluntary Purchase and House Raising Scheme

The analysis undertaken in the *FRMS* showed that there are 15 residential unit blocks comprising 230 individual units that are located in the High Hazard Floodway area which extends onto the overbank area of the Queanbeyan River. While it would not be possible to fund the acquisition of the 15 unit blocks under the State Government Voluntary Purchase Scheme given the large cost, it would be feasible to include the purchase of seven residential properties that are located in the High Hazard Floodway area.

The analysis undertaken in the *FRMS* also showed that the implementation of a voluntary house raising program which is sometimes adopted as a management measure for reducing risk in high hazard flood storage areas is limited in scope by the fact that most of the dwellings that are located in High Hazard Flood Storage areas are of brick veneer type construction. However, the analysis did find that there is merit in raising the floor level of one clad house that is located on the western bank of the Queanbeyan River upstream of the Queanbeyan CBD. Based on this finding, it is recommended that the dwelling be included in the NSW Government's Voluntary House Raising Scheme.

Prior to progressing to the purchase of the seven residential properties and the raising of the single dwelling, it would first be necessary to undertake a *Voluntary Purchase and House Raising Feasibility Study*, especially if Council intends to apply for NSW Government grant funding. The study would include discussions with each eligible and agreeable property owner, as well as a detailed assessment of each property to determine a priority order and costing for each. The commissioning of the *Voluntary Purchase and House Raising Feasibility Study* forms **Measure 8** of the FRMP. A provisional amount has also been included in **Measure 8** to acquire the seven properties and raise the single dwelling.

5.12 Development of Comprehensive Floodplain Risk Management Strategy for the Queanbeyan CBD

Master planning for future development within the Queanbeyan CBD has to date not addressed the existing, continuing and future flood risk in this area. While the draft *Flood Policy* in **Appendix E** aims to address the flood risk associated with both local catchment and main stream flooding in the Queanbeyan CBD, it is recommended that a comprehensive floodplain risk management strategy be prepared for this area. The preparation of the strategy, which has been included as **Measure 9** in the *FRMP*, will need to address issues such as:

- The suitability of adopting vertical evacuation as a flood risk management strategy (as currently set out in the draft *Flood Policy*) versus the provision of elevated walkways linking the proposed buildings with rising ground to the north of the Queanbeyan CBD.
- The management of major overland flow and how gradual infill development can occur without adversely impacting flood behaviour in adjacent development. This may require Council to commit to the construction of a detention basin in Queanbeyan Park to offset the impact future development in areas subject to local catchment flooding would have on flood behaviour. In order to assess the requirements for the temporary storage of major overland flow upstream of the Queanbeyan CBD it will be necessary to extend the hydraulic model that has been developed as part of the present investigation to include the definition of major overland flow in the urbanised catchment which lies to its west.

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- The suitability of the improvements which have been recommended as part of this Study to the existing flood warning system in regards the safe and timely evacuation of occupiers of the Queanbeyan CBD during a flood on the Queanbeyan River. Based on the findings of the aforementioned major overland flow study, it may also be necessary to develop a flash flood warning system for the Queanbeyan CBD.

It is recommended that a working group be set up to oversee the development of the strategy. The working group should include representatives from Council, DPIE and NSW SES.

5.13 Implementation Program

The steps in progressing the floodplain risk management process from this point onwards are:

1. Floodplain Risk Management Committee to consider and adopt the recommendations of this study. In particular, the Committee should review the basis for ranking floodplain risk management measures (as set out in **Table 4.1** of the *FRMS* and the proposed works and measures to be included in the *FRMP* as set out in **Table S1**); exhibit the *FRMS* and *FRMP* and seek community comment. (**Now Completed**)
2. Consider public comment, modify the document if and as required, and submit to Council. (**Now Completed**)
3. Council adopts the *FRMP* and submits an application for funding assistance.
4. Assistance for funding qualifying projects included in the *FRMP* may be available upon application under the Commonwealth and State funded floodplain risk management programs currently administered by OEH.
5. As funds become available from Government agencies and/or Council's own resources, implement the measures in accordance with the established priorities.

The *FRMP* should be regarded as a dynamic instrument requiring review and modification over time. The catalysts for change could include new flood events and experiences, legislative change, alterations in the availability of funding, reviews of Council's planning strategies and importantly, the outcome of some of the study proposed in this report as part of the *FRMP*. In any event, a thorough review every five years is warranted to ensure the ongoing relevance of the *FRMP.*

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6 GLOSSARY OF TERMS

Note: For expanded list of definitions, refer to Glossary contained within the NSW Government Floodplain Development Manual, 2005.

TERM	DEFINITION
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, for a flood magnitude having five per cent AEP, there is a five per cent probability that there would be floods of greater magnitude each year.
Australian Height Datum (AHD)	A common national surface level datum corresponding approximately to mean sea level.
Floodplain	Area of land which is subject to inundation by floods up to and including the Probable Maximum Flood (**PMF**) event, that is, flood prone land.
Flood Planning Area	The area of land that is shown to be in the Flood Planning Area on the *Flood Planning Map*.
Flood Planning Map	The *Flood Planning Map* shows the extent of land on which flood related development controls apply, an extract of which is shown on **Figure E1.1**.
Flood Planning Level (FPL)	Flood levels selected for planning purposes, as determined in the *Queanbeyan Floodplain Risk Management Study* and incorporated in the associated *Queanbeyan Floodplain Risk Management Plan*. For development in the Queanbeyan River and Molonglo River floodplains, the FPL is equal to the flood level derived from the 1% AEP flood event, plus the addition of a 0.5 m freeboard.
Flood Prone/Flood Liable Land	Land susceptible to flooding by the PMF. Flood Prone land is synonymous with Flood Liable land.
Floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Flood Storage Area	Those parts of the floodplain that may be important for the temporary storage of floodwaters during the passage of a flood. Loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding a particular flood chosen as the basis for the FPL and Minimum Floor Level (MFL) is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the FPL and MFL.

TERM	DEFINITION
Habitable Room	In a residential situation: a living or working area, such as a lounge room, dining room, kitchen, bedroom or workroom. In an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
Inner Floodplain (Hazard Category 1)	This zone comprises areas where factors such as the depth and velocity of flow, time of rise, isolation on Low Flood Islands and evacuation problems mean that the land is unsuitable for some types of development. It includes areas of High and Low Hazard Floodway, Flood Storage and Flood Fringe areas. Erection of buildings and carrying out of work; use of land, subdivision of land and demolition subject to State Environmental Planning Policies and Local Environmental Plan provisions are considered to be unsuitable in this zone.
Inner Floodplain (Hazard Category 2A)	This zone comprises the floodway which forms during periods when intense rain falls directly over Queanbeyan. This zone is limited to land zoned *B3-Commercial Core*. Development is not to impede the free discharge of major overland flow in this zone. The configuration of this zone may be altered subject to approval by Council.
Inner Floodplain (Hazard Category 2B)	This zone comprises land zoned B3-Commercial Core that lies below the peak 1% AEP plus 0.5 m which is not classified as Inner Floodplain (Hazard Category 1 and 2A). Commercial and residential development is permitted in this zone provided it complies with the development controls set out in **Annexure 2** of the draft *Flood Policy* (refer **Appendix E** of this report for details). The MFL for residential and commercial development located in this zone is the 1% AEP flood levels plus 1.2 m and the 5% AEP flood level, respectively.
Inner Floodplain (Hazard Category 2C)	This zone comprises High Hazard Flood Storage areas where residential development that is replacing existing residential development may be permitted subject to it not increasing the density of persons resident on a site and meeting other requirements which are also applicable to residential land in the Intermediate Floodplain. Mixed use development is also permitted in this zone. However, Council will require a *Flood Risk Report* confirming the adequacy of the structure to resist hydrodynamic loadings and that the proposal would have no adverse impacts on local flooding patterns, either individually or cumulatively in conjunction with similar extensions in adjacent properties. The *Flood Risk Report* will also need to set out how the development complies with the controls set out in the draft Flood Policy (refer **Appendix E**).
Intermediate Floodplain	This area is the remaining land lying outside the extent of the Inner Floodplain zones, but within the FPA. Within this zone, there would only be the requirement for MFLs to be set at the 1% AEP flood levels plus 0.5 m. Land use permissibility would be as specified by State Environmental Planning Policies or the Local Environmental Plan. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is considered to be unsuitable in this zone.
Outer Floodplain	This area represents the remainder of the floodplain between the Intermediate Floodplain and the extent of the PMF (that is, the extent of the floodplain). This area is outside the extent of the FPA and hence controls on residential, commercial and industrial development do not apply. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is not to be encouraged in this zone.

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TERM	DEFINITION
Local Drainage	Land on an overland flow path where the depth of inundation during the 1% AEP storm event is less than 100 mm.
Main Stream Flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam. In Queanbeyan, Main Stream Flooding is confined to the Queanbeyan and Molonglo Rivers and its major tributaries.
Minor Tributary Flooding	The inundation of normally dry land occurring when water overflows the natural or artificial banks of a minor stream. The nature of Minor Tributary Flooding at Queanbeyan is not defined in the *Queanbeyan Floodplain Risk Management Study and Plan.*
Major Overland Flow	Where the depth of overland flow during the 1% AEP storm event is greater than 100 mm. The nature of Major Overland Flow outside the Queanbeyan CBD is not defined in the *Queanbeyan Floodplain Risk Management Study and Plan.*
Minimum Floor Level (MFL)	The combinations of flood levels and freeboards selected for setting the MFLs of future development located in properties subject to flood related planning controls.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. For the study area, the extent of the PMF has been trimmed to include depths greater than 100 mm.

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APPENDIX A

COMMUNITY CONSULTATION

TABLE OF CONTENTS

ATTACHMENTS

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A1. INTRODUCTION

At the commencement of the *FRMS,* the Consultants prepared a *Community Newsletter* and a *Community Questionnaire*, both of which were distributed by Council to residents and business owners bordering the Queanbeyan River and its surrounding areas (refer to **Attachment 1**).

The purpose of the *Community Newsletter* was to introduce the objectives of the study and set the scene on flooding conditions so that the community would be better able to respond to the *Community Questionnaire* and contribute to the study process.

The *Community Newsletter* contained the following information:

- A plan showing the extent of flood prone land in Queanbeyan (riverine type flooding only).
- A statement of the objectives of the *FRMS&P*; namely the development of a strategy for reducing the flood risk and minimising the long-term impact of flooding on the community.
- A brief summary of the measures which comprised the *draft FRMP* that was developed by Lyall & Associates, 2008.

The *Community Questionnaire* was structured with the objectives of:

- Determining residents' and business owners' attitudes to controls over future development in flood liable areas.
- Inviting community views on the floodplain management options which comprise the *draft FRMP* that was developed by Lyall & Associates, 2008 which will be reassessed as part of the present investigation.
- Inviting community views on possible flood management options which weren't included in the *draft FRMP* that was developed by Lyall & Associates, 2008 but should be considered for further investigation in the present investigation.
- Obtaining feedback on any other flood related issues and concerns which the residents and business owners cared to raise.

This Appendix to the *FRMS&P* report discusses the responses to the nine questions included in the *Community Questionnaire* and comments made by respondents.

Chapter A2 deals with the residents' and business owners' experience with historic flooding, as well as determining their views on the relative importance of classes of development over which flood-related controls should be imposed by Council.

Chapter A3 identifies residents' and business owners' views on the suitability of the various options which could be considered in more detail in the *FRMS&P.*

Chapter A4 discusses the best methods by which the community could provide feedback to the Consultants over the course of the study.

Chapter A5 summarises the findings of the *Community Questionnaire*.

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A2 RESIDENT PROFILE AND FLOOD AWARENESS

A2.1 General

Residents and business owners were requested to complete the *Community Questionnaire* and return it to the Consultants by 1 December 2017. The deadline was extended to include any submissions that were received after this date. The Consultants received 203 responses in total out of the 1781 that were distributed by Council at the commencement of the study.

The Consultants have collated the responses which are shown in graphical format in **Attachment 2**.

A2.2 Respondent Profile

The first three questions of the *Community Questionnaire* canvassed resident information such as whether the respondent was a resident or business owner, length of time at the property, the type of property (e.g. house, unit/flat).

Of the 203 responses, 161 were residents, 16 were business owners, 24 were property owners but did not live at the address and one was a representative from a local church that is located on Morisset Street (one respondent did not complete this question) (**Question 1**).

The length of time at which respondents had been at the address was found to be varied, with approximately 20% of respondents having lived at the residence for between '1-5 years', 40% for '5 to 20 years', and 40% for 'more than 20 years' (**Question 2**).

The majority of respondents occupied residential type property (**Question 3**), which included single dwellings (122 respondents), units/flats/apartments (42), villas/townhouses (25) and semi-rural farms (2). Three responses received were concerned with property which is vacant land. Sixteen respondents owned non-residential type property, which included shops (6 respondents), warehouses or factories (3), motels (2), historic buildings (2), a hotel, a community building and a church. One response did not specify the type of property. Note that some responses were included in more than one property classification type.

A2.3 Controls over Development in Flood Prone Areas

The respondents were asked to rank from 1 to 4 the classes of development which they consider should receive protection from flooding (**Question 4**). Rank 1 was the most important and rank 4 the least.

The classes in decreasing order of importance to respondents ranged from:

- vulnerable residential (e.g. aged persons accommodation),
- residential property,
- essential community facilities (e.g. schools, evacuation centres); and
- commercial/business type development.

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These results gave a guide to the Consultants as to the appropriate location of future development of the various classes within the floodplain. For example, on the basis of community views, vulnerable residential development would receive the highest level of protection by locating future development of this nature outside the floodplain.

In **Question 5**, respondents were asked what notifications Council should give about the flood affectation of individual properties. The community was strongly in favour of advising existing residents (137) and prospective purchasers (115) of the known potential flood threat, while 30 respondents favoured only advising those who enquire to Council about the known potential flood risk and five respondents who favoured not providing any notification.

Eleven respondents to Question 5 were in favour of Council providing some level of advice to the community on potential flooding in Queanbeyan, but suggested alternative methods which included:

- Advise residents when the flood maps are updated.
- Advertise the flood affectation via SMS, radio and newsletter.
- Maintain an online database of property classifications.
- Advise residents once at the finalisation of the *FRMS&P*.

Respondents were also asked in **Question 6** about the level of control Council should place on new development to minimise flood related risks. The most popular response was to have Council place restrictions on development to reduce the potential for flood damage (77 respondents). Prohibiting all new development in those locations that would be extremely hazardous during floods (56) and providing advice of the potential flood risk, but allowing the individual to choose to develop (52) were also strongly favoured by the community. Prohibiting all development on land with any potential to flood was less favoured (40). There were only two respondents who were in favour of Council providing no advice regarding potential flood risk.

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A3 POTENTIAL FLOOD MANAGEMENT MEASURES

The respondents were asked for their opinion on the potential flood management measures that were included in the *draft FRMP* that was developed as part of Lyall & Associates, 2008 by ticking a “yes” or “no” to the nine potential options identified in **Question 7**.

The options comprised two *structural flood management measures* (i.e. construction of flood detention basins in Queanbeyan Park and Queanbeyan Showground and the raising of Bungendore Road at the Big Dipper); as well as various *non-structural management measures* (update Queanbeyan LEP 2012 and Queanbeyan DCP 2012; consider flood related issues concerning future high density development in the Queanbeyan CBD; implement a Flash Flood Warning System; update QCLFP 2013; a flood education program; voluntary purchase of residential properties in high hazard areas; raising the Flood Planning Level to account for climate change). The options were not mutually exclusive, as the *FRMP* adopted could, in theory, include all of the options set out in the *Community Questionnaire*, or indeed, other measures to be nominated by the respondents or the FRMC.

Most options were generally favoured by the respondents. Of the non-structural measures, consideration of flood related issues concerning future high-density development in the CBD was of the utmost importance, followed by the update of Queanbeyan LEP 2012, Queanbeyan DCP 2012, and Queanbeyan City LFP 2013. Implementing a Flash Flood Warning System at Queanbeyan, as well as a flood education program were also highly favoured among respondents. Of the structural measures, raising the road level of Bungendore Road at the Big Dipper was highly favoured, while investigating the use of Queanbeyan Park and the showground as detention basins was also favoured, but to a lesser degree.

Voluntary purchase of residential property in high hazard areas and raising the FPL to account for climate change received a mixed response from respondents, having approval ratings of approximately 43% and 52%, respectively.

In **Question 8** the respondents were also asked for their opinion on other potential structural and non-structural measures that weren’t included in the draft *FRMP* set out in L&A, 2008, but which could be evaluated as part of the present investigation.

The most popular structural measures were the management of vegetation along the river corridor, removal of floodplain obstructions and improving the stormwater system in the Queanbeyan CBD. The respondents were less supportive of the construction of levee banks along the river to contain floodwaters and the widening of watercourses.

Of the non-structural measures, provision of Planning Certificates to property purchasers was favoured by the respondents. However, providing subsidies for raising the floor levels of existing residential properties located in less hazardous zones of the floodplain was found to be an unpopular option.

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A4 INPUT TO THE STUDY AND FEEDBACK FROM THE COMMUNITY

In **Question 9** residents were asked for their view on the best methods of their providing input to the Study and feedback to the Consultants over the course of the investigation. Articles in the local newspaper and communication via Council's website were the two most popular methods, whilst communication through the FRMC was also a popular method of community engagement. Other common suggestions by respondents included mail outs / newsletters (24), social media (7), email (6), radio (6) and public information sessions (2).

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A5 SUMMARY

A5.1 Response Rate and Respondent Profile

Two hundred and three responses were received to the *Community Questionnaire* which was distributed by Council to residents and business owners in Queanbeyan. The responses amounted to about 11 per cent of the total distributed.

Of those that responded, about 80% were residents, 8% were business owners and 12% were owners of land in the survey area but resided outside of the city. The length of time at which respondents had been at the address was found to be varied, with approximately 20% of respondents having lived at the residence for between '1-5 years', 40% for '5 to 20 years', and 40% for 'more than 20 years'.

A5.2 Issues

The issues identified by the community in their responses to the *Community Questionnaire* support the objectives of the study, as nominated in the attached *Community Newsletter,* and the activities nominated in the Study Brief. Respondents were found to be in favour of providing information on the potential flood threat to residents and prospective purchasers of property in Queanbeyan. The majority of respondents were in favour of Council taking some role to reduce flood risks in the community. However, respondents were split between prohibiting development in some or all of the floodplain, or whether Council should allow development in the floodplain areas provided appropriate measures to minimise flood risk are taken. The respondents generally prioritised flood protection towards residential and vulnerable residential type development rather than essential community facilities or commercial development.

A5.3 Flood Management Measures

Of the structural measures which were included in the *draft FRMP* that was developed as part of Lyall & Associates, 2008, raising Bungendore Road in the vicinity of the Big Dipper and the construction of flood detention basins in Queanbeyan Park and the showground were both supported by the respondents.

Of the non-structural measures, consideration of flood related issues associated with high density development in the CBD was of upmost importance to the community, followed by the updating of Queanbeyan LEP 2012, Queanbeyan DCP 2012 and Queanbeyan City LFP 2013. Implementation of a flash flood warning system at Queanbeyan, as well as a flood education program were also popular, albeit to a slightly lesser degree. A voluntary purchase scheme of residential property in high hazard areas and raising the Flood Planning Level to account for climate change were only moderately supported.

Of the additional measures not included in the *draft FRMP* set out in Lyall & Associates, 2008, the management of vegetation along the river corridor and improvements to the stormwater system in the CBD were the most popular structural measures, while the issuing of planning certificates to purchasers in flood prone areas was the most popular of the non-structural measures (albeit this is already standard practice).

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ATTACHMENT 1

COMMUNITY NEWSLETTER AND QUESTIONNAIRE

Queanbeyan
Floodplain Risk Management Study & Plan

To Residents and Business Owners of Queanbeyan:

Queanbeyan-Palerang Regional Council has engaged consultants to finalise the Floodplain Risk Management Study and Plan for the city of Queanbeyan, a draft of which was prepared in 2008. The draft Floodplain Risk Management Study assessed options which are aimed at reducing the impacts of flooding on existing development and the establishment of a framework to manage flood liable land in accordance with current best floodplain management principles, while the draft Plan sets out a recommended program of works and measures which will over time reduce the social, environmental and economic impacts of flooding at Queanbeyan. A brief summary of the measures which comprise the draft Plan is provided over.

The finalisation of the draft Study and Plan is jointly funded by Council and the NSW Office of Environment & Heritage. Council has re-established the Floodplain Management Committee which is comprised of relevant council members, state government agencies and community representatives.

The attached figure shows the indicative extent of the 1 in 100 annual exceedance probability (AEP) flood along the Queanbeyan and Molonglo Rivers at Queanbeyan, as well as the extent of flood prone land at Queanbeyan (as defined by the extent of the Extreme Flood). The 1 in 100 AEP flood is a flood which has a 1% chance of occurrence in any one year, while the Extreme Flood is the largest flood that could conceivably occur at Queanbeyan. *Note that the scope of the mapping is limited to flooding along the Queanbeyan and Molonglo Rivers.*

Have Your Say on Floodplain Management

An important first step in the finalisation of the draft Floodplain Risk Management Study and Plan is to reassess the flood issues which are important to the community. The attached **questionnaire** has been provided to residents and businesses to assist the consultants in gathering this important information. The questionnaire may also be completed online via Council's website at http://yourvoice.qprc.nsw.gov.au/queanbeyan-floodplain-risk-management-plan. All information provided will remain confidential and for use in this study only. Please return the completed questionnaire in the reply paid envelope provided by **Friday 1 December 2017**.

Contact: Queanbeyan-Palerang Regional Council

Thomas Hogg | Engineer

Phone: (02) 6285 6992

Email: Thomas.Hogg@qprc.nsw.gov.au

Floodplain Management Measures Forming the
draft *Queanbeyan Floodplain Risk Management Plan (2008)*

Option	Estimate Cost	Priority Assigned to Implementation of Measure
Update Local Environmental Plan and Development Control Plan documents to include minimum Flood Planning Levels for different types of development and land zones.	Council Cost	High
Consider flood related issues associated with future high density development in the central business district (CBD) of Queanbeyan.	Council Cost	High
Implement a Flash Flood Warning System for the local catchment draining through the Queanbeyan CBD.	$280,000	Medium
Updates to existing Queanbeyan City Local Flood Plan to include recent flood level information in Flood Warning System.	NSW SES Cost	High
Program of flood education to raise awareness amongst the local community and provide information to allow residents to be 'flood ready'.	NSW SES Cost	High
Voluntary purchase of residential property in high hazard areas.	Council Cost and Cost of Property	Low
Raise the Flood Planning Level for residential properties to account for climate change.	Council Cost	Medium
Investigate the possibility of using Queanbeyan Park and Showground as flood detention basins during large storms to reduce the severity of local catchment flooding in the Queanbeyan CBD.	$50,000 (Feasibility Study Only)	High
Raise the road level at the Big Dipper on Bungendore Road north of Queens Bridge.	$20,000 (Feasibility Study Only)	Medium
Total Cost of Implementing High and Medium Priority Flood Mitigation Measures	**$350,000**	

Queanbeyan Floodplain Risk Management Study & Plan

QPRC

Community Questionnaire

This Questionnaire is part of the *Queanbeyan Floodplain Risk Management Study and Plan*, which is currently being finalised by Queanbeyan-Palerang Regional Council with the financial and technical support of the NSW Office of Environment & Heritage. Your responses to the questionnaire will help us reassess the flood issues that are important to you.

Please return your completed Questionnaire in the reply paid envelope provided by **Friday 1 December 2017**. No postage stamp is required. If you have misplaced the supplied envelope or wish to send an additional submission the address is:

Lyall & Associates Consulting Water Engineers
Reply Paid 85163
NORTH SYDNEY NSW 2060

Alternatively, the questionnaire can be completed online via the following link:

http://yourvoice.qprc.nsw.gov.au/queanbeyan-floodplain-risk-management-plan

Your name (optional):____

Address:____

About your property

1. Please tick as appropriate:

- ☐ I am a resident
- ☐ I am a business owner
- ☐ Other (please specify_______________)

2. How long have you been at this address?

- ☐ 1 year to 5 years
- ☐ 5 years to 20 years
- ☐ More than 20 years (… years)

3. What is your property?

- ☐ House
- ☐ Villa/Townhouse
- ☐ Unit/Flat/Apartment
- ☐ Vacant land
- ☐ Industrial unit in larger complex
- ☐ Stand alone warehouse or factory
- ☐ Shop
- ☐ Community building
- ☐ Other (_________________________)

Your attitudes to Council's development controls

4. Please rank the following development types according to which you think are the most important to protect from floods

(1=highest priority to 4=least priority)

Development Type	Rank
Commercial/Business	
Residential	
Vulnerable residential development (e.g. aged persons accommodation)	
Essential community facilities (e.g. schools, evacuation centres)	

5. What notifications do you consider Council should give about the potential flood affectation of individual properties?

(Tick one or more boxes)

- ☐ Advise every resident and property owner on a regular basis of the known potential flood threat
- ☐ Advise only those who enquire to Council about the known potential flood threat
- ☐ Advise prospective purchasers of property of the known potential flood threat.
- ☐ Provide no notifications
- ☐ Other (______________________)

6. What level of control do you consider Council should place on new development to minimise flood-related risks?

(Tick only one box)

(In addition to being favoured by the Community, these options would also need to comply with legislation)

- ☐ Prohibit all new development on land with any potential to flood
- ☐ Prohibit all new development only in those locations that would be extremely hazardous to persons or property due to the depth and/or velocity of floodwaters, or evacuation difficulties
- ☐ Place restrictions on developments which reduce the potential for flood damage (e.g. minimum floor level controls or the use of flood compatible building materials)
- ☐ Advise of the flood risks, but allow the individual a choice as to whether they develop or not, provided steps are taken to minimise potential flood risks
- ☐ Provide no advice regarding the potential flood risks or measures that could minimise those risks

Your opinions on floodplain risk management measures

7. The draft *Queanbeyan Floodplain Risk Management Study Plan* (2008) included a number of measures which were aimed at minimising the effects of flooding in Queanbeyan. Do you consider that these options should be included in the updated Plan?

For each of the options listed, please indicate "yes" or "no" to indicate if you favour the option. Please leave blank if undecided.

Option	Yes	No
Update Local Environmental Plan and Development Control Plan documents to include minimum Flood Planning Levels for different types of development and land zones.		
Consider flood related issues associated with future high density development in the central business district (CBD) of Queanbeyan.		
Implement a Flash Flood Warning System for the local catchment draining through the Queanbeyan CBD.		
Updates to existing Queanbeyan City Local Flood Plan to include recent flood level information in Flood Warning System.		
Program of flood education to raise awareness amongst the local community and provide information to allow residents to be 'flood ready'.		
Voluntary purchase of residential property in high hazard areas.		
Raise the Flood Planning Level for residential properties to account for climate change.		
Investigate the possibility of using Queanbeyan Park and Showground as flood detention basins during large storms to reduce the severity of local catchment flooding in the Queanbeyan CBD.		
Raise the road level at the Big Dipper on Bungendore Road north of Queens Bridge.		

8. **Below is a list of other possible options that may be looked at to try to minimise the effects of flooding in the study area.**

This list is not in any order of importance and there may be other options that you think should be considered. For each of the options listed, please indicate "yes" or "no" to indicate if you favour the option. Please leave blank if undecided.

Option	Yes	No
Management of vegetation along creek corridors to provide flood mitigation, stability, aesthetic and habitat benefits.		
Widening of watercourses.		
Removal of floodplain obstructions.		
Improve the stormwater system within the Queanbeyan CBD.		
Construct permanent levees along the river to contain floodwaters.		
Provide funding or subsidies to raise houses above major flood level in low hazard areas.		
Provide a Planning Certificate to purchasers in flood prone areas, stating that the property is flood affected.		

Other Information

9. **What do you think is the best way for us to get input and feedback from the local community about the results and proposals from this study?** **(Tick one or more boxes)**

- ☐ Council's website
- ☐ Articles in local newspaper
- ☐ Through Council's Floodplain Management Committee
- ☐ Other (please specify) ________________

10. **If you wish us to contact you so you can provide further information, please provide your details below:**

Name: ______________________________

Address: ______________________________

____

Phone: ______________________________

Best time to call is ______________________

Fax No:______________________________

Email:______________________________

Who can I contact for further information?

Queanbeyan-Palerang Regional Council
Thomas Hogg | Engineer
Phone: (02) 6285 6992
Email: Thomas.Hogg@qprc.nsw.gov.au

Copies of this Questionnaire can be obtained from:
http://yourvoice.qprc.nsw.gov.au/queanbeyan-floodplain-risk-management-plan

COMMENTS

Please write any additional comments here:

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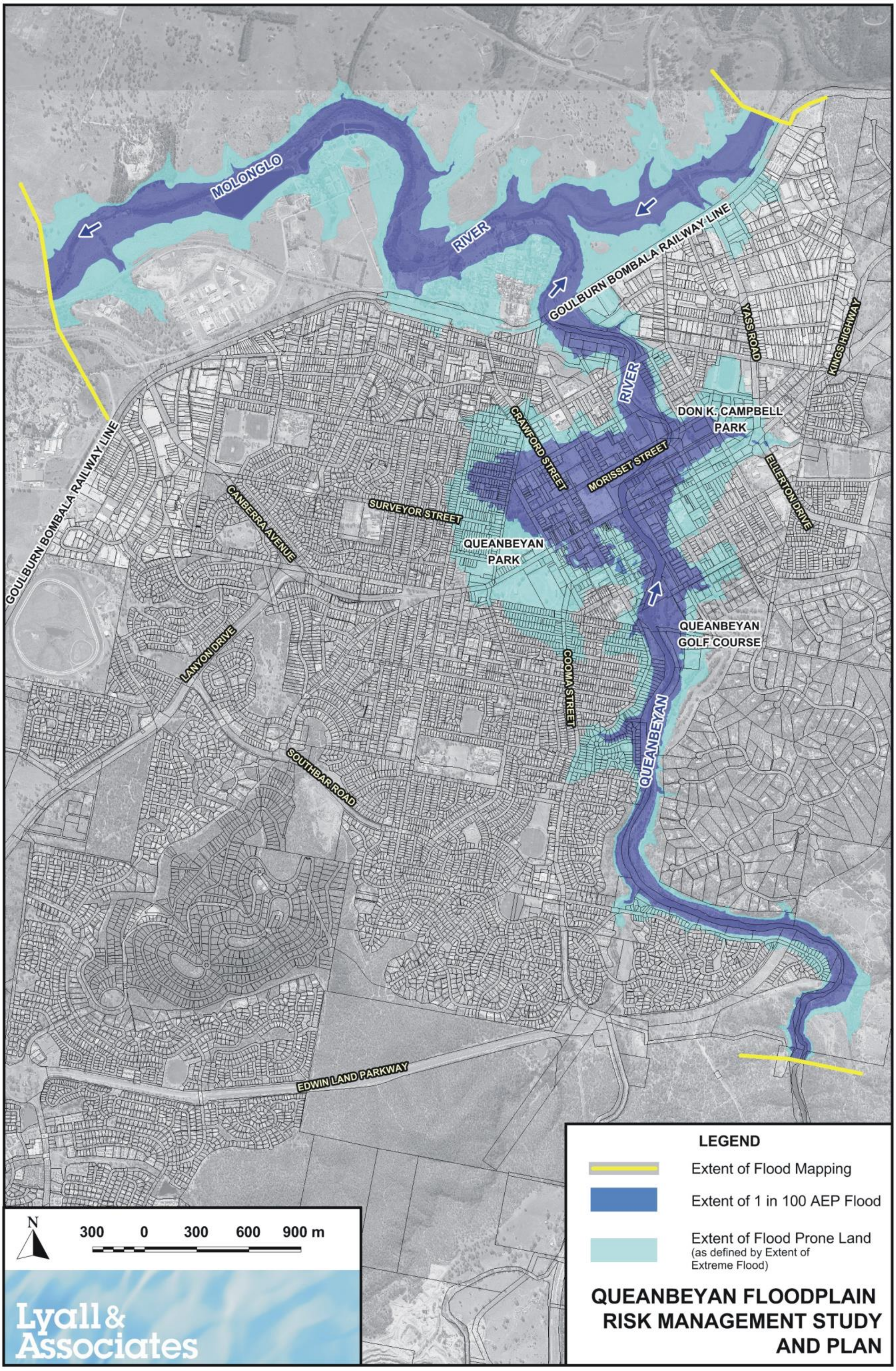
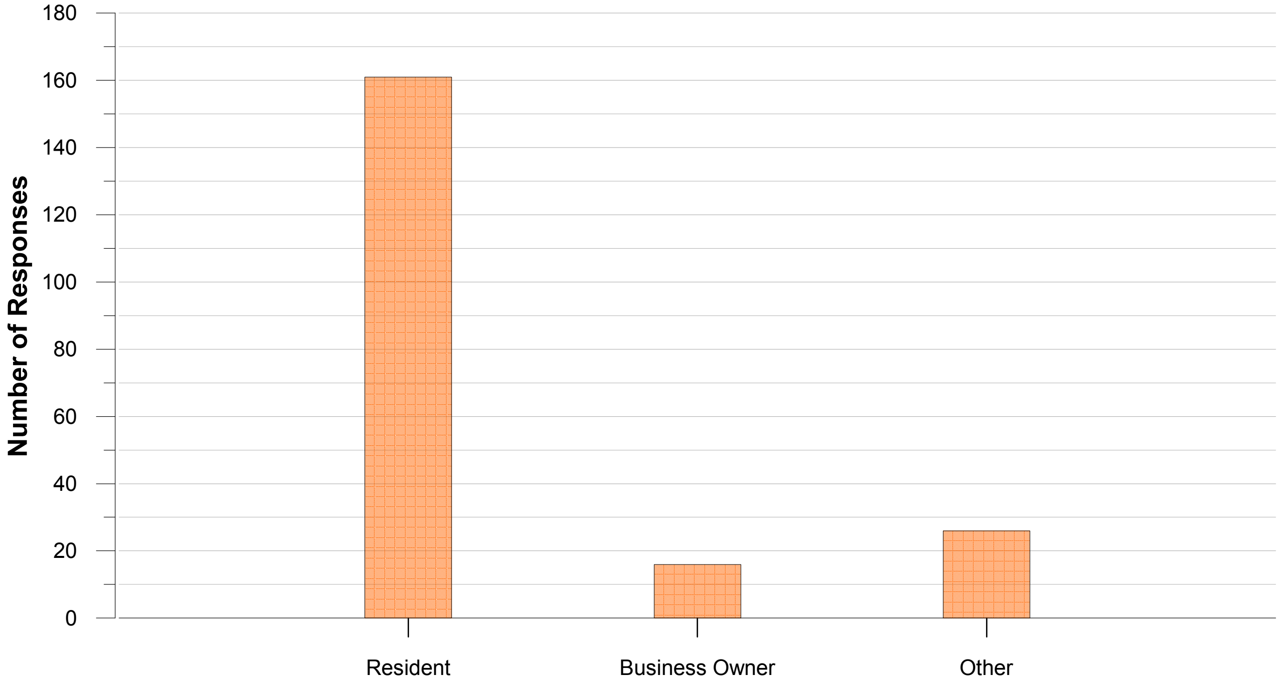


MOLONGLO
RIVER
GOULBURN BOMBALA RAILWAY LINE
YASS ROAD
KINGS HIGHWAY
RIVER
DON K. CAMPBELL
PARK
CRAWFORD STREET
MORISSET STREET
ELLERTON DRIVE
GOULBURN BOMBALA RAILWAY LINE
CANBERRA AVENUE
SURVEYOR STREET
QUEANBEYAN
PARK
QUEANBEYAN
GOLF COURSE
LANYON DRIVE
COOMA STREET
QUEANBEYAN
SOUTHBAR ROAD
EDWIN LAND PARKWAY
LEGEND
Extent of Flood Mapping
Extent of 1 in 100 AEP Flood
Extent of Flood Prone Land
(as defined by Extent of
Extreme Flood)
QUEANBEYAN FLOODPLAIN
RISK MANAGEMENT STUDY
AND PLAN
N
300 0 300 600 900 m
Lyall &
Associates

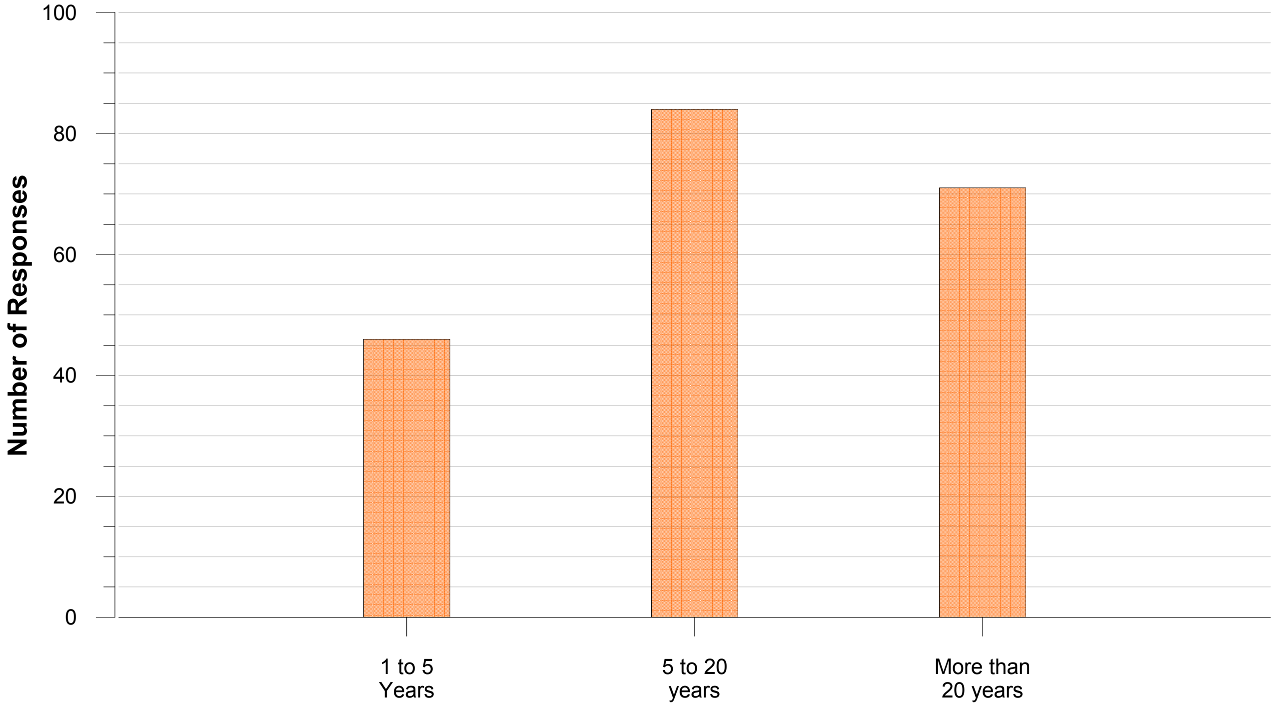
ATTACHMENT 2

RESPONSES TO COMMUNITY QUESTIONNAIRE

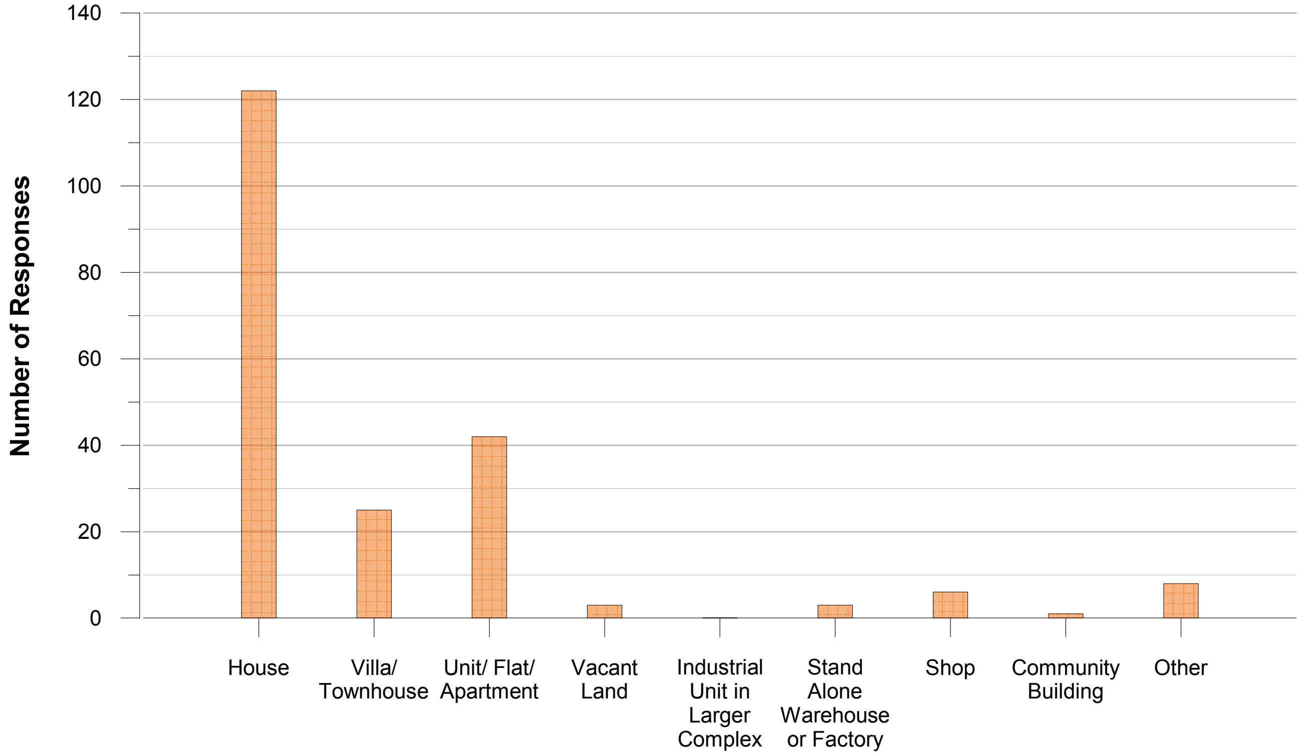
Q1. Residential Status

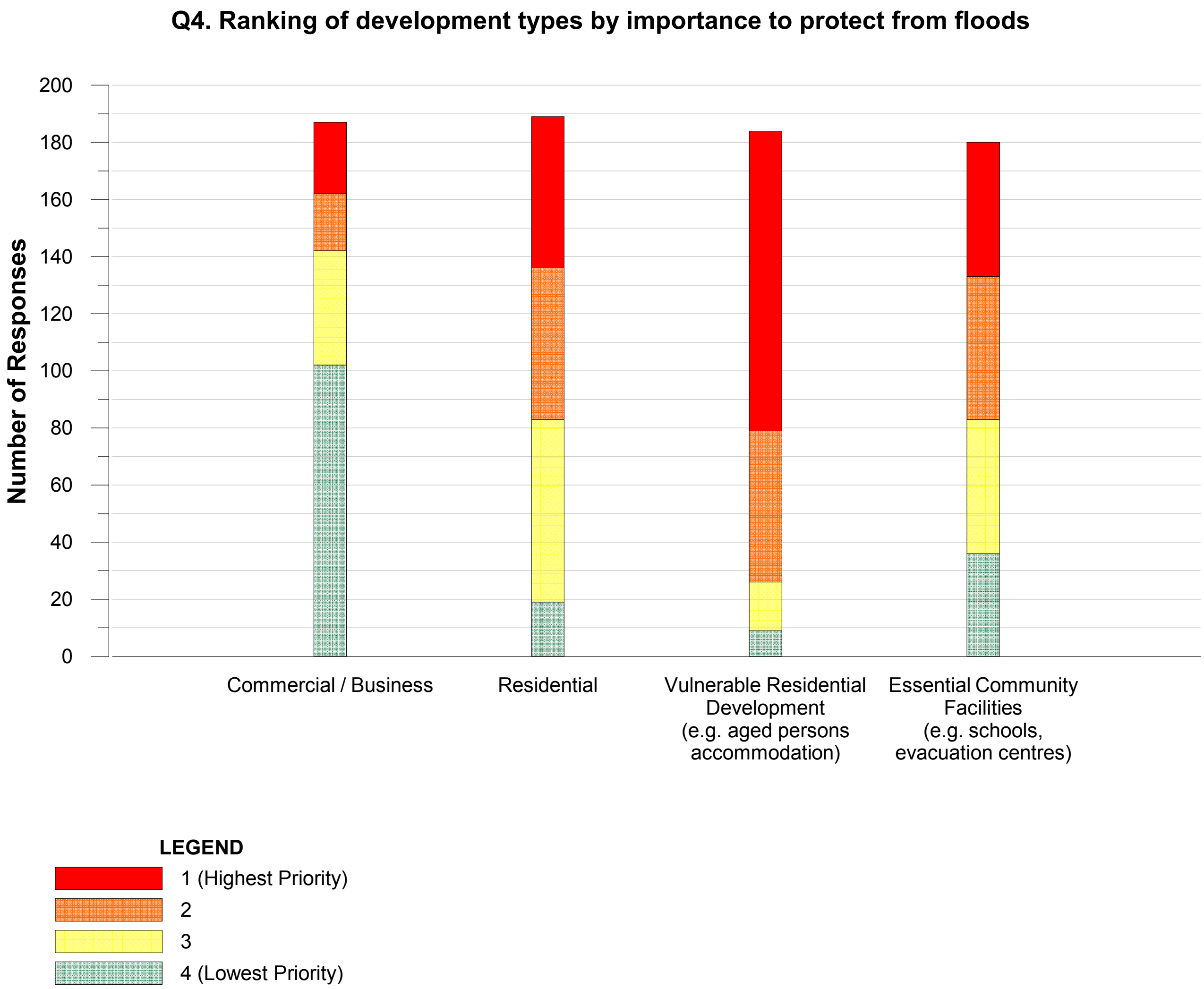


Q2. How long have you owned or lived at this address?



Q3. Type of Property?





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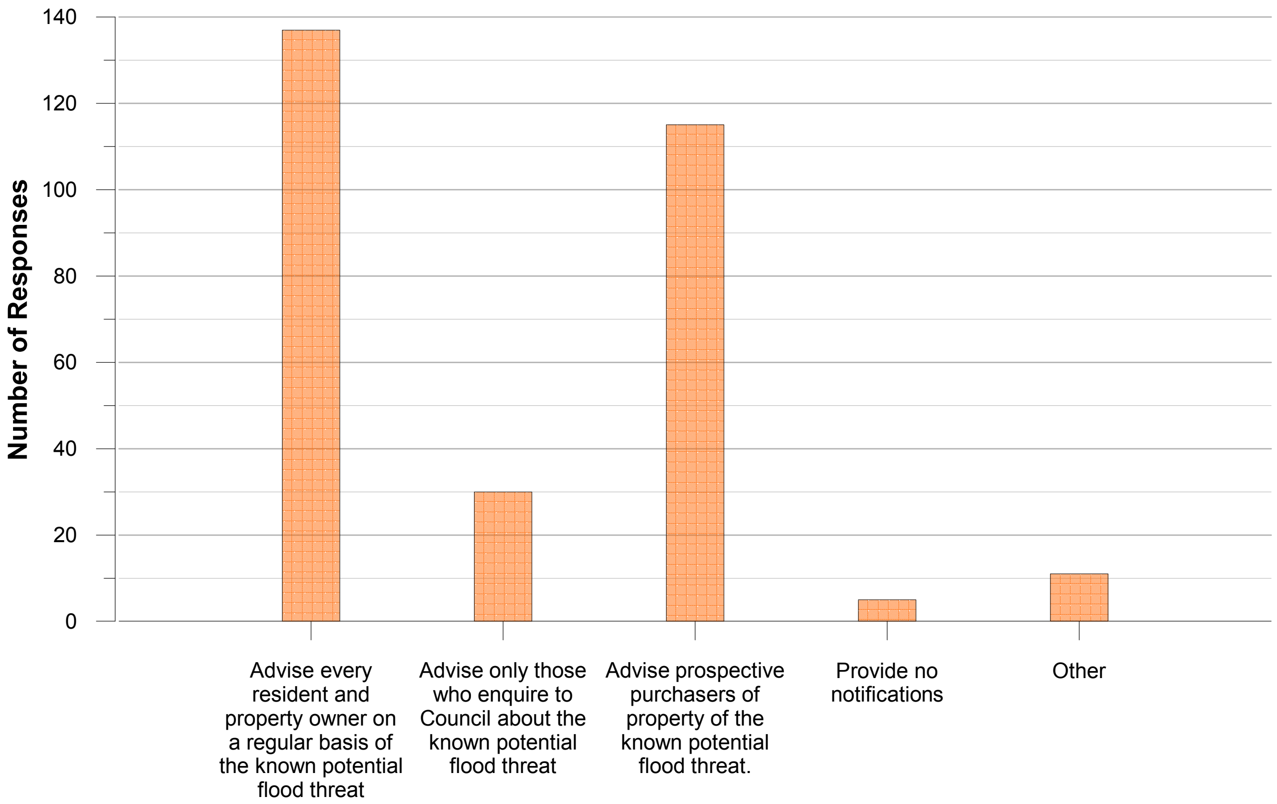
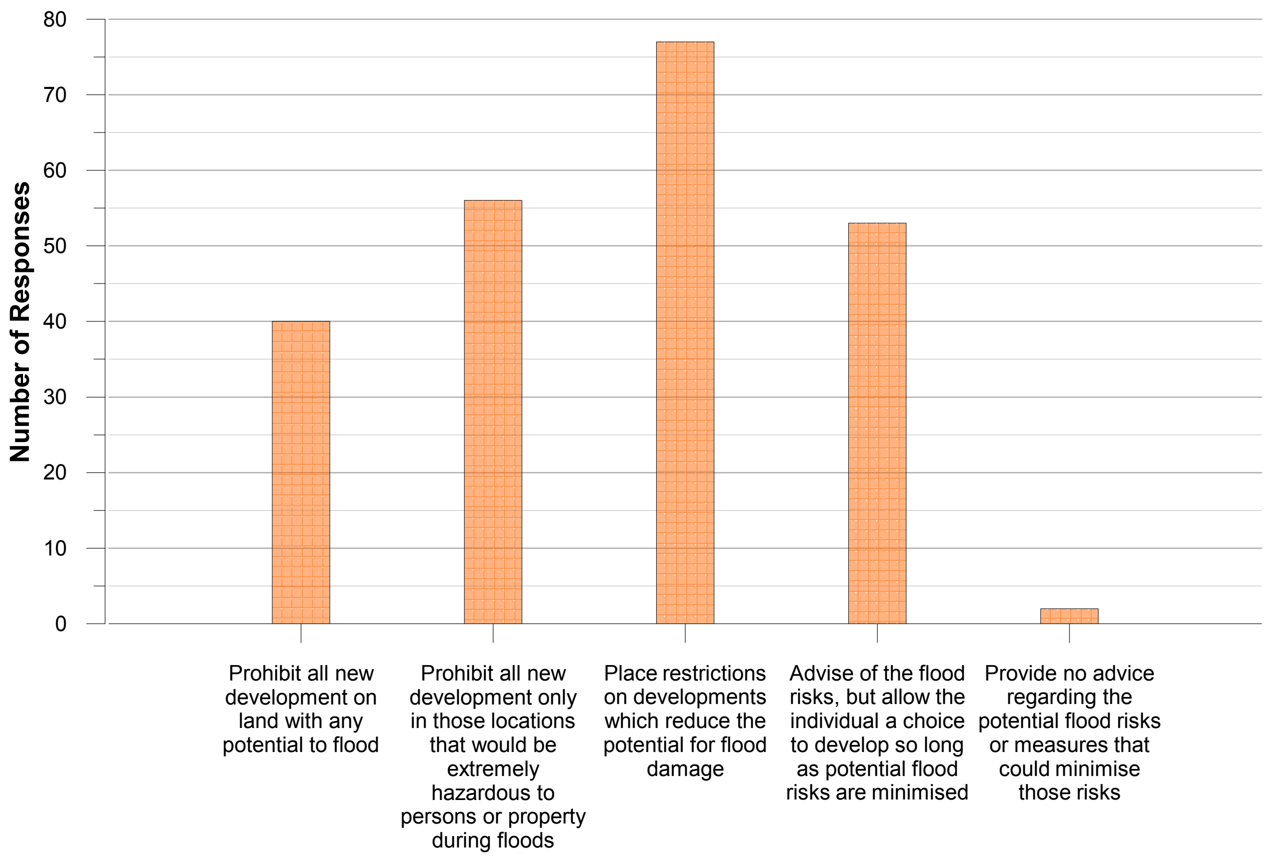
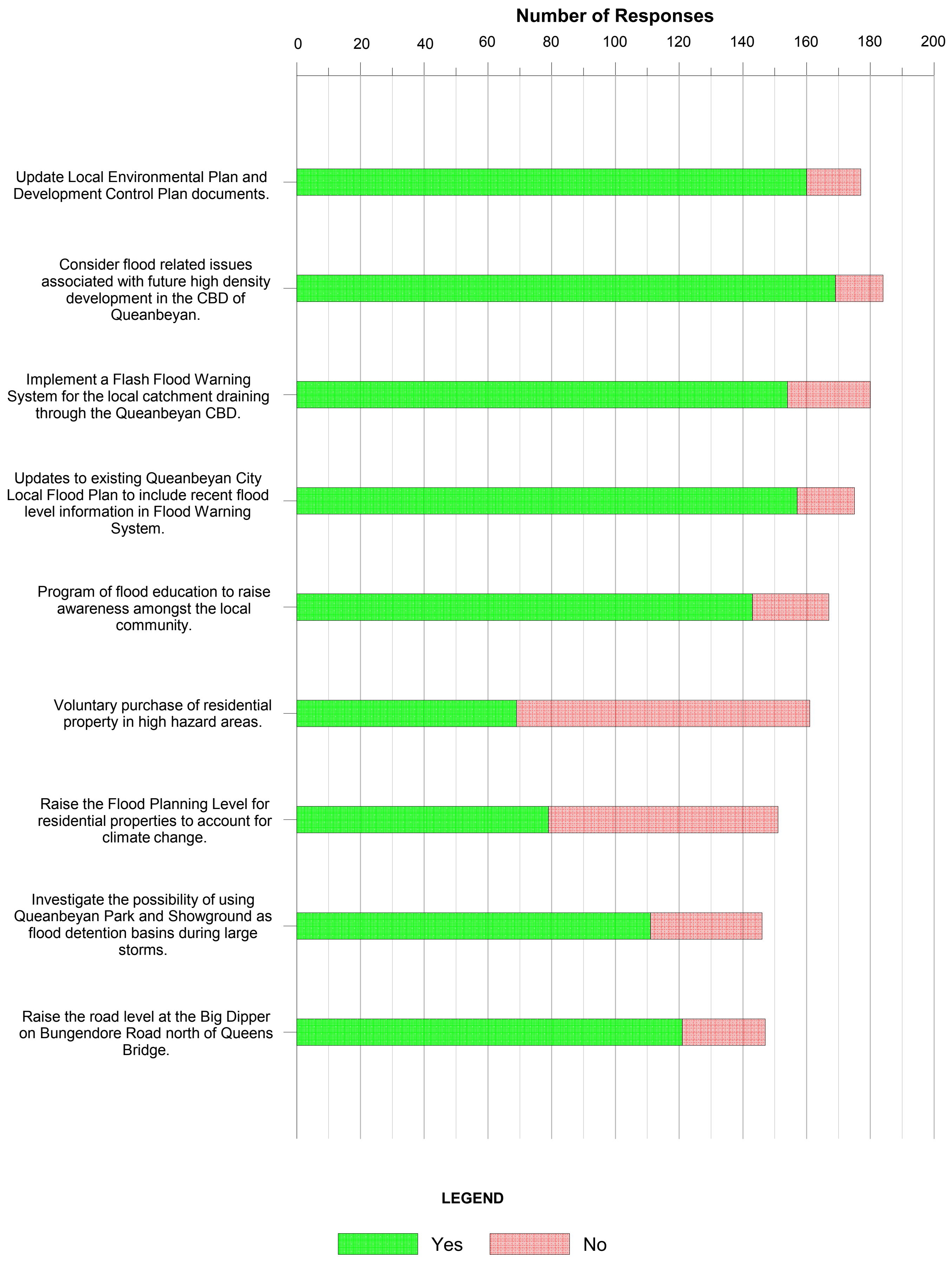
Q5. What notifications should Council give about the potential flood affectation of properties?



Q6. What level of control should Council place on new development to minimise flood-related risks?



Q7. Possible Flood Management Options identified in the draft *FRMS&P* (2008)



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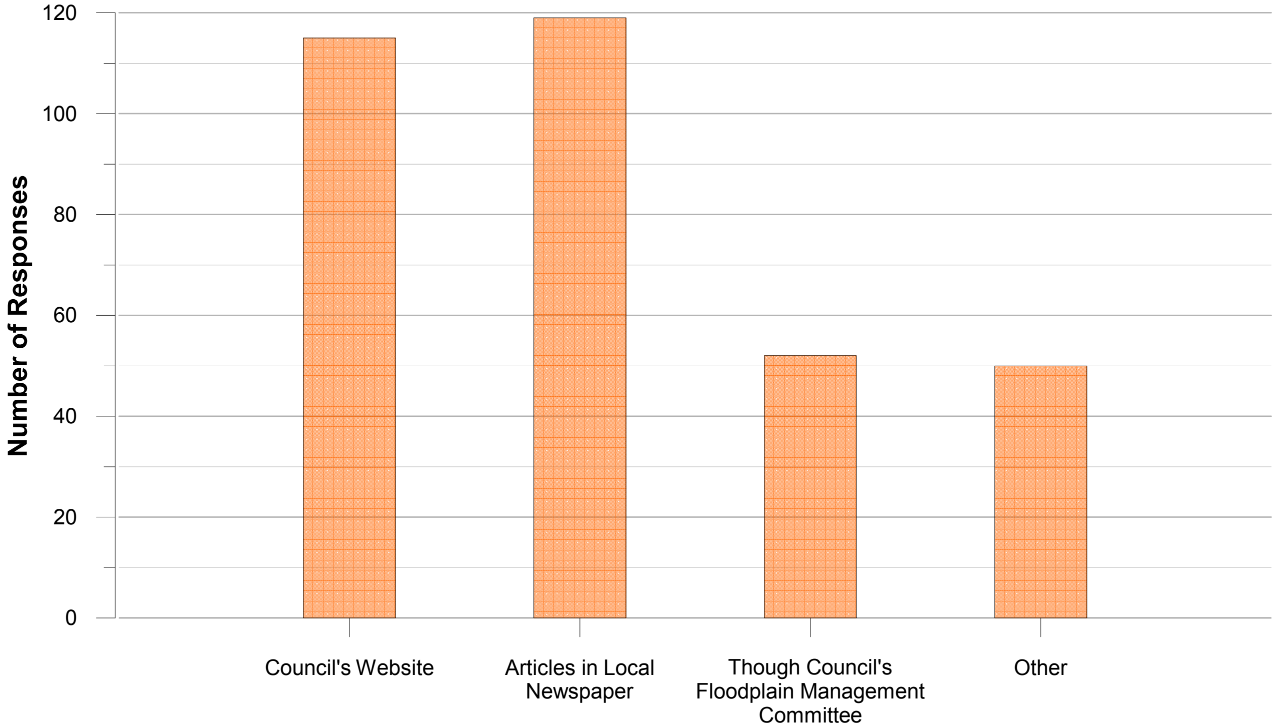
Q8. Other Possible Methods to Minimise Effects of Flooding

Q9. Best methods to get input and feedback from the local community



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APPENDIX B

HISTORIC FLOOD DATA

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Page No.

ANNEXURES

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FIGURES
(BOUND IN VOLUME 2)

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B1. SUMMARY OF AVAILABLE DATA

Data collected for the purpose of the present investigation included:

- Photographs obtained from NSW SES as part of Lyall & Associates, 2018, as well as those provided by respondents to the *Community Questionnaire* for floods that occurred in July 1922, August 1974, October 1976 and December 2010 (copies of which are contained in **Annexure A** of this Appendix).
- An article written in *The Queanbeyan Age* on Friday 29 May 1925 which describes how floodwater rose quickly on the evening of Tuesday 26 May 1925 and isolated a number of residents but did not cause any loss of life. A partial copy and full transcript of the newspaper article is contained in **Annexure B** of this Appendix.
- Rainfall recorded by the network of pluviographic rainfall stations that are operated by the ACT Environment, Planning and Sustainable Development Directorate (**EPSDD**) and BoM, as well as daily-read gauges operated by BoM. The location of the network of rain gauges relative to the study catchments are shown on **Figure 1.1** of the Main Report, while **Table B1.1** gives the commencement date of each pluviographic type rain gauge.
- Stream flow data recorded at nine telemetered stream gauges that are operated by either Icon Water (formerly ACT Electricity and Water (**ACTEW**)), EPSDD and WaterNSW. The location of the nine stream gauges are shown on **Figure 1.1** of the Main Report, while their commencement dates are set out in **Table B1.1**. **Figure 1.1** also shows the location of the manually read stream gauge which is located on the upstream side of the Queens Bridge at Queanbeyan. **Annexures C**, **D** and **E** of this Appendix contain annual maximum peak flows for the Googong, Wickerslack and Burbong stream gauges, respectively.
- Historic flood data taken from DWR, 1992 comprising peak flood levels on the Queanbeyan River floodplain for floods that occurred in 1925, 1974 and 1976.
- Historic flood mark data that were surveyed by Council following the December 2010 flood event. **Figure B1.1** shows the location of a select number of the 171 flood marks that were surveyed by Council.
- LiDAR survey data and aerial photography captured in May 2015 and October 2016, respectively. The LiDAR survey data were captured to the International Committee on Surveying and Mapping Level 3 standard with a 95% confidence interval on horizontal accuracy of ±800 mm and a 95% confidence interval on vertical accuracy of ±300 mm.
- GIS based data sets including cadastral information and stormwater pit and pipe data, as compiled by Council. **Figure 2.1** (2 sheets) of the Main Report shows the layout of the drainage system in the study area.
- Detailed ground and inbank survey of a 90 m reach of the Queanbeyan River immediately upstream of the Morisset Street Bridge provided by Council (refer **Figure B1.1** for extent of detailed survey).
- A number of previous studies which contain flood related information at Queanbeyan (refer **Chapter B2** of this Appendix for further details).

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TABLE B1.1
DETAILS OF AVAILABLE PLUVIOGRAPHIC RAINFALL AND STREAM FLOW GAUGES

Gauge Type	Gauge Number	Gauge Name	Gauge Operator	Commencement Date
Pluviographic Rainfall	570931	Jerangle (Slap-up)	EPSDD / BoM	December 1961
	570916	Jingera (Hillside)		March 1956
	570965	Tinderry (Queanbeyan River)		January 1966
	570951	Burra Creek at Burra Road		March 1989
	570816	Queanbeyan River U/S Googong Dam		July 1990
	570818	Googong Climate Station		September 1990
	570983	Wickerslack (Queanbeyan River)		January 1973
	570960	Parker's Gap		June 1962
	570923	Rossi (Sawmill)		October 1979
	570943	Molonglo River at Oaks Estate		January 1963
Stream Flow	410734	Queanbeyan River at Tinderry	IconWater	August 1966
	410774	Burra Creek at Burra Road		March 1985
	410781	Queanbeyan River U/S Googong Dam		February 1990
	410748	Queanbeyan River at Googong		1912(1)
	410760	Queanbeyan River at Wickerslack		August 1973(2)
	410770	Queanbeyan River at A.C.T. Border	EPSDD	September 1977
	410705	Molonglo River at Burbong		March 1929
	410729	Molonglo River at Oaks Estate		June 1963
	41000208	Molonglo River at Kobada	WaterNSW	June 2004
	-	Queanbeyan River at Queens Bridge(3)	-	-

1. Exact commencement date unknown. Gauge ceased operation in 1975.
2. Annual maximum peak discharges dating back to 1913 are available in DWR, 1992.
3. Manually read stream gauge.

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B2. PREVIOUS STUDIES

B2.1. Flood Inundation Map – Queanbeyan River at Queanbeyan (WRC, 1977)

In January 1977, the Water Resources Commission (**WRC**) (now OEH) produced a flood inundation map of Queanbeyan as part of an overall state-wide programme of preparing flood maps in flood affected towns. The flood map showed the extent of flooding likely to be experienced in floods having AEPs of 5, 2 and 1 per cent as defined by the height at the Queens Bridge stream gauge based on post-Googong dam flow estimates in the Queanbeyan River.

Maps showing the extent of flooding likely to be experienced in floods having AEPs of 5, 2, 1 and 0.5 per cent, as well at the PMF were published in The Queanbeyan Age on 5 November 1976.[1]

B2.2. Flood Study Report – Queanbeyan (DWR, 1992)

The *Flood Study Report – Queanbeyan* prepared by the Department of Water Resources (**DWR**) (now OEH) in 1992 used a rainfall-runoff model of the Queanbeyan and Molonglo River catchments that had previously been developed by ACTEW as the basis for the investigation. ACTEWs hydrologic model was based on the RAFTS software and was calibrated to flood events that occurred in 1974, 1976, 1978 (March and September), 1984, 1988 and 1989. The model was updated and re-calibrated to flood events that occurred in 1988 and 1991 as part of DWR, 1992.

Table B2.1 over shows the design peak flow estimates that were derived from a flood frequency analysis that was undertaken as part of DWR, 1992 for the Queanbeyan River at the decommissioned Googong (GS 410701) stream gauge using the 79 years of annual peak flows for the period 1913 to 1991[2,3]. **Table B2.1** also shows the design peak flow estimates that were derived for the Molonglo River at Burbong (GS 410705) stream gauges using the 61 years of annual peak flows for the period 1930 to 1991.

Table B2.2 shows the hydrologic parameters that were applied to the RAFTS model in order to match the pre-Googong Dam peak flow estimates derived as part of the flood frequency analysis (refer Column D of **Table B2.1**). The RAFTS model was then updated to incorporate the Googong Dam storage details in order to derive a set of post-Googong Dam peak flow estimates (refer Column E of **Table B2.1**).

The pre- and post-dam relationship derived as part of DWR, 1992 (refer Columns D and E of **Table B2.1**) has been relied upon to convert pre-dam flows at the Googong stream gauge to post-dam flows at the Wickerslack stream gauge as part of the present investigation.

[1] Whilst it was not possible to determine the source of the flood maps as part of the present investigation, it has been assumed that the maps were developed as part of the design of Googong Dam and represent flooding patterns at Queanbeyan based on pre-Googong dam flow estimates in the Queanbeyan River.

[2] The Queanbeyan River at Googong (GS 410701) stream gauge was decommissioned in 1975 at the commencement of construction of Googong Dam.

[3] Pre-Googong Dam peak flow estimates for the period 1976 to 1991 (i.e. during and after construction of the dam) were derived as part of DWR, 1992 using the recorded stage hydrograph at the dam, as well as the storage capacity rating table and the spillway rating table.

TABLE B2.1
PREVIOUSLY DERIVED DESIGN PEAK FLOW ESTIMATES AT QUEANBEYAN[1] (m^3/s)

AEP (%)	Log-Pearson Type III Distribution		RAFTS	
	Queanbeyan River at Googong (GS 410701)[2]	Molonglo River at Burbong (GS 410705)	Queanbeyan River at Queanbeyan	
			Pre-Googong Dam	Post-Googong Dam
[A]	[B]	[C]	[D]	[E]
50	230	150	200	130
20	400	270	400	270
10	570	370	570	400
5	820	520	830	590
2	1,280	740	1,210	910
1	1,620	1,010	1,590	1,450
0.5	2,170	1,300	2,050	1,900
0.2	2,900	1,600	2,700	2,490

1. Design peak flow estimates derived from flood frequency analysis and hydrologic modelling undertaken as part of DWR, 1992.
2. Peak flow estimates based on pre-Googong Dam peak flows.

TABLE B2.2
RAFTS MODEL PARAMETERS[1]

AEP (%)	Initial Loss (mm)	
	Queanbeyan River	Molonglo River
50	25	20
20	25	20
10	25	20
5	25	20
2	21	17
1	18	13
0.5	15	10
0.2	10	6

1. A constant Continuing Loss of 2.5 mm/hr and BX routing parameter of 1.0 were adopted for all design flood events.

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Googong Dam was found to have a progressively smaller effect on flooding at Queanbeyan with increasing flood severity. For example, for the 20% AEP flood, the peak discharge would be reduced from 400 m^3/s to 270 m^3/s, corresponding with a reduction of 0.8 m in peak flood levels in the CBD area, while for the 1% AEP flood the corresponding peak discharge would be reduced from 1,590 m^3/s to 1,450 m^3/s, equivalent to a reduction in peak flood levels of about 0.4 m.

Hydraulic modelling was undertaken using a steady-state HEC-2 model that covers a 7.5 km long reach of the Queanbeyan River. The HEC-2 model comprised about 25 cross sections and extended from the upstream limits of the City in the vicinity of the confluence of the Queanbeyan River and Valley Creek to its confluence with the Molonglo River. The HEC-2 model was calibrated against levels observed in the 1974 and 1976 flood events.

B2.3. Queanbeyan City Local Flood Plan (NSW SES, 2013)

The *Queanbeyan City Local Flood Plan, 2013*, published by NSW SES covers preparedness measures, the conduct of response operations and the coordination of immediate recovery measures for all levels of flooding within the Queanbeyan area. The *Local Flood Plan* is administered by the Queanbeyan NSW SES Local Controller who controls flood operations within the Queanbeyan-Palerang Regional Council area, which is itself located within the Southern Highlands NSW SES Division.

Section 2.13.1 of the Main Report contains a detailed summary of *Queanbeyan City Local Flood Plan, 2013*.

B2.4. Dam Safety Emergency Plan – Googong Dam (2008) (ActewAGL, 2008)

ActewAGL (now Icon Water) undertook hydraulic studies for the preparation of its *Dam Safety Emergency Plan - Googong Dam* in 2008. These studies showed that the spillway is capable of passing the PMF without overtopping the embankment. A dam-break analysis showed that a Sunny Day failure of the dam will result in floodwater rising to about 13 m above the 1% AEP flood level at the Queens Bridge, or about 6 m above the PMF level at this location. Should the dam fail during a PMF event, peak flood levels at Queanbeyan would be about 18 m higher than the 1% AEP flood level.

The report gives the following peak design flow rates at the dam spillway:

- 1:5 AEP – 315 m^3/s
- 1:20 AEP – 784 m^3/s
- 1:100 AEP – 1,394 m^3/s
- 1:500 AEP – 2,020 m^3/s
- PMF - 9,300 m^3/s.

Reference to ActewAGL, 2008 has been included in this Appendix as the document was current at the time the *FRMS* was commenced, noting that it was subsequently updated in April 2020 (refer **Section B2.7** over for details).

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B2.5. Initial Assessment of Potential Flood Mitigation for Communities Downstream of Googong Dam (Jacobs, 2015)

In 2015, Icon Water (previously ActewAGL) and Council commissioned Jacobs to undertake an initial assessment of the following three potential flood mitigation measures which were aimed at reducing the impact of flooding on communities that lie downstream of Googong Dam:

i. targeting of air space in Googong Dam;

ii. a reduction in the operating level of Lake Burley Griffin; and

iii. the clearing of vegetation along the channel and floodplain of the Queanbeyan and Molonglo Rivers between the Googong Dam and Lake Burley Griffin.

Jacobs, 2015 assessed the flood mitigation benefits which could be achieved by implementing the above measures by reference to the December 2010 flood, which as shown in **Table 2.1** of the Main Report is equivalent to about a 5% AEP flood event at Queanbeyan.

Given the limited terms of reference, Jacobs, 2015 recommended that further liaison be conducted with relevant stakeholders to identify a broader range of structural and non-structural flood mitigation measures that may be considered for Queanbeyan.

B2.6. Flood Intelligence Report – Upper Wollondilly and Molonglo Valleys – December 2010 Flood (Lyall & Associates, 2018)

In 2010, NSW SES commissioned Lyall & Associates to collect and analyse flood data for flooding that occurred in the Wollondilly and Molonglo Valleys in December 2010. The study analysed both recorded rainfall and stream flow data, and provided a description of flooding behaviour that was experienced at Queanbeyan and Captains Flat during the December 2010 flood.

B2.7. Googong Dam Dam Safety Emergency Plan (Icon Water, 2020)

Actew, 2008 was updated by Icon Water in April, 2020 (Icon Water, 2020) based on flooding information contained in the report entitled "*Googong Dam Risk Assessment*" (Sinclair Knight Merz, 2015). The report gives the following peak design flow rates at the dam spillway:

- 1:100 AEP – 1,200 m^3/s
- 1:10,000 AEP – 2,900 m^3/s
- 1:1,000,000 AEP – 9,500 m^3/s
- PMF - 10,100 m^3/s.

The report contains a series of flood extent maps for two sunny day dam failure scenarios, as well as for the 1:100,000 AEP and PMF events under "no breach" and "main embankment piping breach" conditions.

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B3. ANALYSIS OF HISTORIC RAINFALL DATA

Following a review of the available flood data, rainfall depths recorded at the network of pluviographic rain gauges were obtained for the storm that occurred in December 2010, noting that historic rainfall data were not obtained as part of the present investigation for storms that occurred prior to this event.

Figure B3.1 shows the cumulative depths of rain that were recorded by the network of pluviographic rain gauges during the December 2010 storm. **Figure B3.1** shows that 90-180 mm of rainfall fell over the rain days of 29 November to 6 December which saturated the catchment and resulted in surface runoff that almost filled Googong Dam. **Figure B3.1** also shows a shorter and more intense burst of rain fell on the rain days of 9 and 10 December which was the cause of the flooding in Queanbeyan.

Figures B3.2 shows contours of equal rainfall depth over the study catchments for the rain days of 9 and 10 December 2010, while **Figure B3.3** (5 sheets) shows design versus historic intensity-frequency-duration (**IFD**) curves for each pluviographic rain gauge for the two aforementioned bursts of rainfall. **Table B3.1** over gives the approximate AEP of the recorded rainfall for durations ranging between 1 and 48 hours.

By inspection of **Figure B3.3** and the values given in **Table B3.1**, the storm burst that occurred between 29 November and 6 December 2010 was generally equivalent to an event with an AEP of 1 Exceedances per Year (**EY**), except in the reach of the Queanbeyan River immediately upstream of Googong Dam where the rainfall recorded had a minimum AEP of between 5-10% for a 1 hour period. While the rainfall was not intense enough to generate significant flood peaks in the Queanbeyan River, it served to fill the Googong Dam storage and saturate the catchment which increased the runoff potential in the subsequent storm burst.

The storm burst that occurred on 9 and 10 December 2010 was generally more intense than that which occurred earlier in the month. In the headwaters of the Queanbeyan River catchment upstream of Googong Dam the AEP of the recorded rainfalls generally ranged between 50-10%, with the exception of that recorded immediately upstream of Googong Dam which had an AEP of about 1% for periods of between 6 and 18 hours.

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TABLE B3.1
APPROXIMATE AEPs OF RECORDED RAINFALL FOR DECEMBER 2010 STORM
(% AEP)

Rain Gauge	28 November – 6 December 2010						9-10 December 2010					
	Duration (hours)											
	1	3	6	12	24	48	1	3	6	12	24	48
Jerangle (Slap-up) (GS 570931)	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>50	20-50	>50	>50	>1EY	>1EY
Jingera (Hillside) (GS 570916)	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	5-10	10	10	10	20	>50
Tinderry (Queanbeyan River) (GS 570965)	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>50	>50	20-50	50	20-50	>50
Burra Creek at Burra Road (GS 570951)	1EY	1EY	1EY	50	1EY	1EY	20-50	20-50	10	10-20	20	50
Queanbeyan River U/S Googong Dam (GS 570816)	5-10	10-20	20-50	50	1EY	50	2-5	1	<1	1	1-2	5
Googong Climate Station (GS 570818)	>1EY	>1EY	>1EY	>1EY	1EY	>1EY	>1EY	>1EY	1EY	1EY	>1EY	>1EY
Wickerslack (Queanbeyan River) (GS 570983)	1EY	>1EY	>1EY	1EY	>1EY	>1EY	>1EY	>1EY	>50	1EY	>1EY	>1EY
Parker's Gap (GS 570960)	>1EY	>1EY	>1EY	>1EY	>1EY	1EY	>1EY	>50	50	50	>50	>1EY
Rossi (Sawmill) (GS 570923)	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY
Molonglo River at Oaks Estate (GS 570943)	20	10	20	10	20	20-50	>1EY	>1EY	>1EY	>1EY	>1EY	>1EY

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B4. ANALYSIS OF AVAILABLE STREAM GAUGE DATA

B4.1. General

Table B4.1 over the page lists the ten largest floods that have been experienced on both the Queanbeyan and Molonglo Rivers at Queanbeyan. **Table B4.1** shows that five of the six largest floods at Queanbeyan occurred prior to or during the early stages of construction of Googong Dam.[4]

Table B4.1 shows that the attenuating effects of Googong Dam reduced the flow in the Queanbeyan River by about 30% during the December 2010 flood. As mentioned in **Section 2.4.8** of the Main Report, absent the storage effects of Googong Dam, flooding patterns at Queanbeyan during the December 2010 flood event would have been similar to those experienced during the larger October 1976 flood.

Table B4.1 also shows that while the December 2010 flood is the sixth largest recorded flood in the Queanbeyan River at Queanbeyan, it is not one of the ten largest flood events to have been experienced in the Molonglo River at Queanbeyan.[5] While the rainfall data shows that very intense rainfall was experienced in the vicinity of Googong Dam during the December 2010 storm, its spatial and temporal distribution was such that it did not generate significant flows in the Molonglo River.

The historic rating tables for Icon Water's Queanbeyan River at Wickerslack stream gauge were extracted from BoMs web-based service *Water Data Online*. The left hand side of **Figure B4.1** shows the difference between the historic rating curves that have been developed by Icon Water for the gauge, as well as all gaugings that have been taken at the site between 1973 and 2017. **Figure B4.1** also shows that the historic rating curve has remained unchanged since 1988, and that the largest gauged flow at the site is 101 m^3/s which corresponds to a gauge height of RL 2.37 m.

Following development of the hydrologic and hydraulic models as part of the *Updated Flood Study*, it was found that it was not possible to reproduce observed flood behaviour at Queanbeyan based on the peak flow estimates derived using the Icon Water rating curves that were current at the time of the historic floods. In response to this finding, the TUFLOW model that was developed as part of the *Updated Flood Study* (refer **Chapter C2** in **Appendix C** for further details) was used to derive a revised rating curve above a gauge height of RL 5.75 m. The revised rating curve, which for the purpose of the present investigation has been denoted the "*L&A Derived Rating Curve*" is shown on **Figure B4.1**.[6][7]

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[4] While the October 1976 flood occurred during construction of the dam, it has been considered a pre-dam flood as part of the present investigation as the dam wall was only partially completed at the time of the flood. As a result, the attenuating effects of the dam would have been much less than would have occurred had construction of the dam been completed at the time of the flood.

[5] **Table D1** in **Annexure D** of this Appendix shows that the December 2010 flood is the 30th largest flood to occur in the Molonglo River at Queanbeyan in the 88 year period since the establishment of the Burbong stream gauge.

[6] The *L&A Derived Rating Curve* is based on Icon Water's Rating Curve (No. 2) for gauge heights less than RL 5.75 m.

[7] The operator has not levelled the Wickerslack stream gauge to Australian Height Datum (**AHD**). In order to derive a rating curve using the results of the TUFLOW model, the gauge zero was assumed to be equal to RL 574.45 m AHD.

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TABLE B4.1
LARGEST FLOODS RECORDED AT QUEANBEYAN STREAM GAUGES[1]

Rank	Queanbeyan River at Googong[1] (GS 410701)		Queanbeyan River at Wickerslack[2] (GS 410760)			Molonglo River at Burbong[3] (GS 410705)		
	Date	Discharge (m^3/s)	Date	Gauge Height[5] (m)	Discharge (m^3/s)	Date	Gauge Height (m)	Discharge (m^3/s)
1	May 1925	2,120	May 1925	-	-	August 1974	4.28	594
2	July 1922	1,020	July 1922	-	-	October 1976	4.22	581
3	August 1974	-	August 1974	8.63[5]	1,008[5]	October 1959	3.96	518
4	October 1976	-	October 1976	8.07[6]	893[6]	June 1956	3.89	501
5	April 1945	716	April 1945	-	-	April 1988	4.01	482
6	December 2010	-	December 2010	6.86	658	March 1978	3.43	407
7	April 1950	631	April 1950	-	-	April 1950	3.35	392
8	July 1988	-	July 1988	5.72	457	September 1952	3.35	392
9	July 1991	-	July 1991	5.57	435	June 1975	2.94	312
10	April 1989	-	April 1989	5.07	368	April 1945	2.93	309

1. Refer **Table B1.2** for commencement dates for each gauge.
2. Refer **Table C1** in **Annexure C** of this Appendix for full record of annual maximums.
3. Refer **Table D1** in **Annexure D** of this Appendix for full record of annual maximums.
4. Refer **Table E1** in **Annexure E** of this Appendix for full record of annual maximums.
5. Recorded gauge height and discharge relate to pre-dam conditions.
6. Recorded gauge heights and discharges are considered to represent pre-dam conditions as Googong Dam was only partially constructed at the time of the flood.

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Figures B4.2, **B4.3** and **B4.4** show the discharge hydrographs that were recorded during the floods that occurred in August 1974, October 1976 and December 2010, respectively. The three figures also show the peak discharge at the Wickerslack stream gauge based on the *L&A Derived Rating Curve* is significantly higher when compared to the peak flow which is derived using the rating curve that was current at the time of the flood. **Figures B4.3** and **B4.4** show the change that occurred in water level of Googong Dam relative to its spillway level during the October 1976 and December 2010 floods, respectively.

B4.2. Annual Flood Frequency Analysis

B4.2.1. General

The flood frequency analysis undertaken as part of DWR, 1992 was updated as part of the present investigation to assess the impact that incorporating the additional 26 years of data that has been recorded at the stream gauges in the vicinity of Queanbeyan since the adoption of the DWR, 1992 (i.e. 1992-2017) has on design peak flow estimates.

Flood frequency analyses were undertaken at the following stream gauges:

- Queanbeyan River at Googong (GS 410701) (Decommissioned in 1975 prior to construction of Googong Dam) in order to determine pre-dam design peak flow estimates in the Queanbeyan River.
- Queanbeyan River at Wickerslack (GS 410760) (established in 1973) in order to determine post-dam peak flow estimates in the Queanbeyan River.
- Molonglo River at Burbong (GS 410705) in order to determine design peak flow estimates in the Molonglo River.

The TUFLOW Flike software was used as part of the present investigation to fit a log-Pearson Type III (**LP3**) probability distribution to the annual series of instantaneous flood peaks at the three stream gauges using the Bayesian Maximum Likelihood approach. **Tables C1**, **D1** and **E1** in **Annexures C**, **D** and **E** of this Appendix set out the annual series of flood peaks for the three stream gauges, as well as the source of the annual maxim data, respectively.

Values at the low end of the observed range of flood peaks can distort the fitted probability distribution and affect the estimates of large floods. Deletion of these low values may improve the fitting of the remaining data. As the recorded flood peaks are only a small sample of peaks actually occurring over a longer duration, an expected probability adjustment was also made using the procedure set out in Geoscience Australia, 2016.

Geoscience Australia, 2016 also recommends implementing the expected probability adjustment in situations where the probability of exceedance is of primary importance, such as in floodplain management, in order to reduce the risk of under estimating design peak flows.

B4.2.2. Queanbeyan River (Pre-dam)

The flood frequency analysis undertaken as part of DWR, 1992 fitted curves to the partial and annual series of pre-Googong Dam flood peaks at the decommissioned Queanbeyan River at Googong stream gauge for the period 1913 to 1991 using the LP3 distribution technique.[8] As Googong Dam was constructed between 1975 and 1978, pre-dam flood peaks for the period 1977

[8] The partial series was used to estimate the design peak flows for flood events up with an AEP of 10% or higher, while the annual series was used to estimate the design peak flow for for rarer floods.

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to 1991 were synthesized as part of DWR, 1992 using stage hydrographs, a stage-storage relationship and the spillway rating curve for the dam. Column B of **Table B4.2** sets out the peak design flows which were derived based on this process.

For comparative purposes, the TUFLOW Flike software was used to fit an LP3 probability distribution to the same data. By comparison of the peak flows given in Columns B and C of **Table B4.2**, the Bayesian Maximum Likelihood approach to fitting the LP3 distribution utilised in the Flike software generates slightly higher estimates than the method of moments approach adopted in DWR, 1992.

The series of pre-Googong Dam flood peaks was extended to incorporate the additional 26 years of data. Pre-dam annual maxims for the period of record since construction of the dam (i.e. 1977-2017) were synthesized by converting flows recorded at the Wickerslack stream gauge to pre-dam flows based on the relationship of pre- versus post-dam flows presented in DWR, 1992 (refer Columns D and E of **Table B2.1**).

The left hand side of **Figure B4.5** shows a comparison of the flood frequency curves and 5% and 95% confidence limits derived from the LP3 distribution that was fitted to the annual series of flood peaks for the 79 year period of record that was adopted in DWR, 1992 (i.e. 1913-1991) (refer green lines) and the full 105 year period of record (i.e. 1913-2017) (refer red lines). The analysis shows that inclusion of the additional data reduces the estimated peak flow for the 1% AEP flood event from 1,820 m^3/s to 1,600 m^3/s (refer Columns C and D of **Table B4.2**).

The right hand side of **Figure B4.5** shows the results of omitting twenty-three annual flows less than 30 m^3/s from the analysis and applying the expected probability adjustment to the remaining data. The removal of the low flows increases the peak flow estimate for the 1% AEP event under pre-dam conditions to 1,680 m^3/s (refer Column E in **Table B4.2**). It is noted that the peak flow estimate for the 1% AEP is less than the highest flow that has been recorded in the Queanbeyan River in the past 105 years (i.e. 1,680 m^3/s for the 1% AEP flood versus 2,120 m^3/s for the 1925 flood).

The analysis shows that incorporating the additional 26 years of pre-dam annual maxim data and omitting twenty-three annual flows less than 30 m^3/s from the analysis generates similar design peak flow estimates to those derived as part of DWR, 1992 (refer Columns B and E of **Table B4.2**).

B4.2.3. Queanbeyan River (Post-dam)

The left hand side of **Figure B4.6** shows flood frequency curves and 5% and 95% confidence limits derived from the LP3 distribution that was fitted to the annual series of flood peaks for the 41 year period of record since the construction of Googong Dam (i.e. 1977-2017) at the Wickerslack stream gauge.[9] Column F of **Table B4.2** sets out the peak design flows which were derived based on this process, while Column G of **Table B4.2** and the right hand side of **Figure B4.6** show that omitting the nineteen annual flows less than 30 m^3/s significantly reduces the peak flow estimates.

As shown in **Table B4.1**, five of the largest floods to have been experienced at Queanbeyan either occurred prior to or during construction of Googong Dam. By comparison of the pre-and post-dam peak flows set out in Columns B to G in **Table B4.2**, the omission of these floods from the flood

[9] Note that the annual peak flows at the Wickerslack stream gauge were generated using the *L&A Derived Rating Curve*.

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frequency analysis results in a significantly lower estimate of design peak flows in the Queanbeyan River at Queanbeyan under post-dam conditions. This finding indicates that excluding the pre-dam flow recorded heavily skews the results of the flood frequency analysis, which if adopted would result in peak flows estimates that are much lower than have been adopted in previous studies.

In order to take account of the larger flood events, the series of post-dam flood peaks was extended to incorporate the 64 years of data prior to construction of the dam (i.e. 1913-1976). Post-dam annual maxims for the period of record between 1913-1976 were synthesized by converting pre-dam flows at the decommissioned Googong stream gauge presented in DWR, 1992 to post-dam flows based on the relationship of pre- versus post-dam flows also presented in DWR, 1992 (refer Columns D and E of **Table B2.1**).

The left hand side of **Figure B4.7** shows flood frequency curves and 5% and 95% confidence limits derived from the LP3 distribution that was fitted to the annual series of post-dam flood peaks for the 105 year period of record (i.e. 1913-2017) at the Wickerslack stream gauge. The right hand side of **Figure B4.7** shows the results of omitting the thirty annual flows less than 30 m^3/s. The analysis shows that inclusion of the additional 64 years of data increases the estimated post-dam peak flow for the 1% AEP flood event from 730 m^3/s to 1,430 m^3/s (refer Columns G and I of **Table B4.2**).

Based on the findings of the present investigation, the construction of Googong Dam has resulted in a reduction in the peak flow for the 1% AEP flood event by about 250 m^3/s (i.e. from 1,680 m^3/s to 1,430 m^3/s) (refer Columns E and I of **Table B4.2**).[10] This finding is generally consistent with that of DWR, 1992 which relied upon a shorter period of post-dam record, noting that the earlier study found that the construction of Googong Dam resulted in a reduction in the peak flow for the 1% AEP flood event by about 140 m^3/s (i.e. from 1,590 m^3/s to 1,450 m^3/s). The two post-dam peak flows estimates derived by the two studies are also basically the same (i.e. 1,430 m^3/s versus 1,450 m^3/s). .

B4.2.4. Molonglo River

The flood frequency analysis undertaken as part of DWR, 1992 fitted curves to the annual series of flood peaks at the Molonglo River at Burbong stream gauge for the period 1930 to 1991 using an LP3 type probability distribution. Column J of **Table B4.2** sets out the peak design flows which were derived based on this process.

For comparative purposes, the TUFLOW Flike software was used to fit an LP3 probability distribution to the same data. By comparison of the peak flows given in Columns J and K of **Table B4.2**, the Bayesian Maximum Likelihood approach to fitting the LP3 distribution utilised in the Flike software generates slightly lower estimates than the method of moments approach adopted in DWR, 1992.

The left hand side of **Figure B4.8** shows flood frequency curves and 5% and 95% confidence limits derived from the LP3 distribution that was fitted to the annual series of flood peaks for the 62 year period of record that was adopted in DWR, 1992 (i.e. 1930-1991) at the Burbong stream gauge (refer green lines). The left hand side of **Figure B4.8** also shows the results when using the full 88 year period of record (i.e. 1930-2017) (refer red lines). The analysis shows that the inclusion of

[10] In comparison, the RAFTS model developed as part of DWR, 1992 found that the construction of Googong Dam resulted in a reduction in the peak flow in the Queanbeyan River for the 1% AEP flood event by about 140 m^3/s (i.e. from 1,590 m^3/s to 1,450 m^3/s) (refer Columns D and E of **Table B2.1**).

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the additional data reduces the estimated peak flow for the 1% AEP flood event from 970 m^3/s to 700 m^3/s (refer Columns K and L of **Table B4.2**).

The right hand side of **Figure B4.8** shows that omitting the twenty-one annual flows less than 20 m^3/s further reduces the estimated peak flow on the Molonglo River to 685 m^3/s for the 1% AEP flood event (refer Columns M of **Table B4.2**).

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TABLE B4.2
PEAK FLOW ESTIMATES AT QUEANBEYAN
(m^3/s)

Annual Exceedance Probability %	Queanbeyan River at Googong (Representative of Pre-dam Conditions) (GS 410701)(1,2)				Queanbeyan River at Wickerslack (Representative of Post-dam Conditions) (GS 410760)(7,8)				Molonglo River at Burbong (GS 410705)(9)			
	1913-1991 (DWR, 1992)	1913-1991 (Present Investigation)(3)	1913-2017 Full Period of Record(4)	1913-2017 Low Flows Omitted(5,6)	1977-2017 Full Period of Record	1977-2017 Low Flows Omitted(5)	1913-2017 Full Period of Record	1913-2017 Low Flows Omitted(5)	1930-1991 (DWR, 1992)	1930-1991 (Present Investigation)(10)	1930-2017 Full Period of Record(11)	1930-2017 Low Flows Omitted(12,13)
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	[L]	[M]
20	400	365	330	315	165	170	220	**205**	270	240	210	**215**
10	570	600	575	535	320	325	400	**370**	370	385	330	**340**
5	820	885	855	815	530	475	610	**585**	520	535	450	**460**
2	1,280	1,370	1,250	1,260	900	635	960	**990**	740	750	590	**590**
1	1,620	1,820	1,600	1,680	1,380	730	1,270	**1,430**	1,010	970	700	**685**
0.5	2,170	2,400	1,960	2,200	2,200	800	1,650	**2,030**	1,300	1,240	820	**780**
0.2	2,900	3,400	2,550	3,160	4,200	870	2,250	**3,220**	1,600	1,710	1,020	**930**

1. Refer **Table C1** in **Annexure C** of this Appendix for full period of pre-dam annual maximums.
2. Flood frequency analysis based on pre-dam flows only. Period of record between 1977-2017 generated by converting post-dam flows recorded at the Wickerslack stream gauge to pre-dam flows based on the relationship of pre- versus post-dam flows presented in DWR, 1992 (refer Columns D and E of **Table B2.1**).
3. Refer relationship shown as solid green line on left hand side of **Figure B4.5**.
4. Refer relationship shown as solid red line on left hand side of **Figure B4.5**.
5. Peak flows less than 30 m^3/s omitted.
6. Refer relationship shown as solid red line on right hand side of **Figure B4.5**.
7. Refer **Table D1** in **Annexure D** of this Appendix for full period of post-dam annual maximums and **Figure B4.6** and **B4.7** for flood frequency curves.
8. Flood frequency analysis based on post-dam flows only. Period of record between 1913-1977 generated by converting pre-dam flows at the Googong stream gauge presented in DWR, 1992 to post-dam flows based on the relationship of pre- versus post-dam flows also presented in DWR, 1992 (refer Columns D and E of **Table B2.1**).
9. Refer **Table E1** in **Annexure E** of this Appendix for full period of annual maximums.
10. Refer relationship shown as solid green line on left hand side of **Figure B4.8**.
11. Refer relationship shown as solid red line on left hand side of **Figure B4.8**.
12. Peak flows less than 20 m^3/s omitted.
13. Refer relationship shown as solid red line on right hand side of **Figure B4.8**.

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B5. REFERENCES

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ANNEXURE A

PLATES SHOWING HISTORIC FLOODING IN QUEANBEYAN

JULY 1922 FLOOD

Plate B1.1 – Queanbeyan River downstream of old Kings Highway bridge.

Source: 1922, Queanbeyan Bridge and River in flood, July 1922 , viewed 6 April 2018 http://nla.gov.au/nla.obj-141276031

Plate B1.2 – The old Elmsall Inn at Queanbeyan during the 1922 flood.

Source: The Canberra Times

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AUGUST 1974 FLOOD

Plate B2.1 – Looking east across Queanbeyan River in vicinity of Morisset Street (*Source: Council*)

Plate B2.2 – Looking west across Queanbeyan River in vicinity of Morisset Street (*Source: Council*)

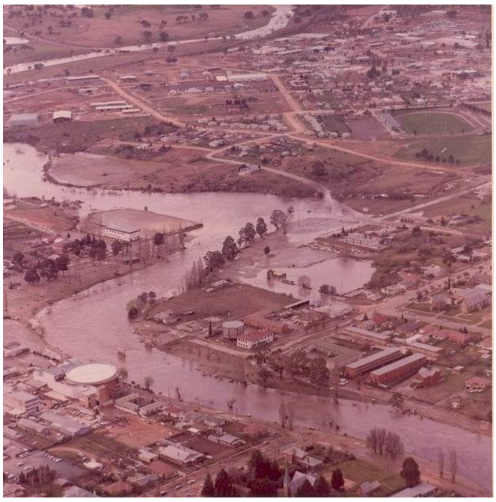

Plate B2.3 – Looking north along Queanbeyan River (*Source: Council*)

Plate B2.4 – Looking west along Queens Bridge (under construction) (*Source: Council*)

Plate B2.5 – Looking south along Queanbeyan River in vicinity of Queens Bridge (*Source: Council*)

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OCTOBER 1976 FLOOD

Plate B3.1 – Floodwater spilling over the partially constructed Googong Dam wall (*Source: The Queanbeyan Age*)

Plate B3. 2 – Floodwater spilling over the partially constructed Googong Dam wall (*Source: The Queanbeyan Age*)

Plate B3.3 – Floodwater spilling over the partially constructed Googong Dam wall (*Source: ArchivesACT*)

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OCTOBER 1976 FLOOD

Plate B3.4 – Floodwater spilling over the partially constructed Googong Dam wall (*Source: FEMA P-1015,2014*)

Plate B3.5 – Floodwater spilling over the partially constructed Googong Dam wall (*Source: ArchivesACT*)

Plate B3.6 – Engineers inspecting the dam wall for damage between flood peaks (*Source: ArchivesACT*)

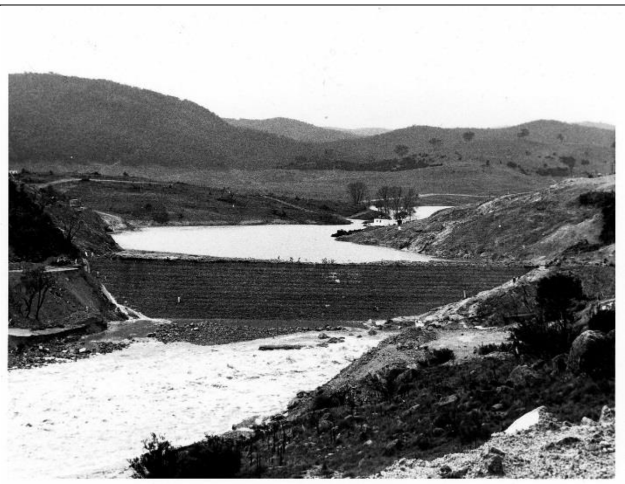

Plate B3.7 – Engineers inspecting the dam wall for damage between flood peaks (*Source: ArchivesACT*)

Plate B3.8 – Looking east across the Queanbeyan River from the Queanbeyan Leagues Club (*Source: The Queanbeyan Age*)

Plate B3.9 – Queanbeyan Leagues Club (*Source: The Queanbeyan Age*)

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OCTOBER 1976 FLOOD

Plate B3.10 – Queanbeyan River downstream of the Queanbeyan Leagues Club (*Source: The Queanbeyan Age*)

Plate B3.11 – Flooding in the vicinity of Macquoid Street at around 14:00 hours on 18 October 1976 (*Source: The Queanbeyan Age*)

Plate B3.12 – Flooding in the vicinity of Macquoid Street at around 14:00 hours on 18 October 1976 (*Source: The Queanbeyan Age*)

Plate B3.13 – Flooding in the vicinity of Macquoid Street at around 14:00 hours on 18 October 1976 (*Source: The Queanbeyan Age*)

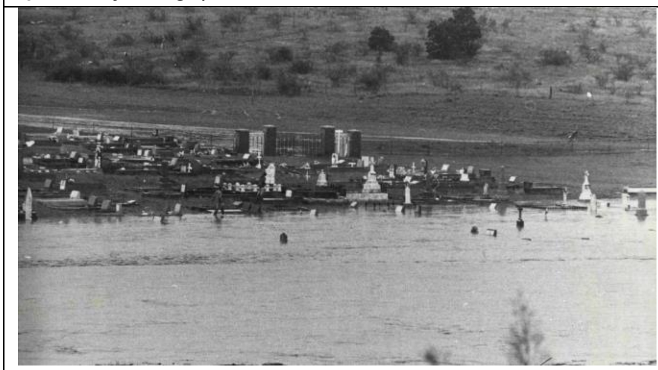

Plate B3.14 – Flooding in the vicinity of Riverside Cemetery (*Source: The Queanbeyan Age*)

Plate B3.15 – Debris left behind in Queanbeyan Golf Course by receding floodwater (*Source: The Queanbeyan Age*)

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DECEMBER 2010 FLOOD

(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.1 – 9/12/10 10:04 hours - Molonglo River in vicinity of Queanbeyan Sewage Treatment Plant (*Source: NSW SES*)

Plate B4.2 – 9/12/10 10:05 hours – Oaks Estate Road crossing of Molonglo River (road is submerged) (*Source: NSW SES*)

Plate B4.3 – 9/12/10 10:17 hours – Looking north along Queanbeyan River at the Goulburn – Bombala Railway (*Source: NSW SES*)

Plate B4.4 – 9/12/10 10:18 hours – Riverside Sporting Facility submerged by floodwater (*Source: NSW SES*)

Plate B4.5 – 9/12/10 10:19 hours – Queanbeyan River immediately downstream of Queens Bridge (*Source: NSW SES*)

Plate B4.6 – 9/12/10 10:19 hours – Looking east along Morisset Street (*Source: NSW SES*)

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DECEMBER 2010 FLOOD
(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.7 – 9/12/10 10:19 hours – Build-up of debris at intersection of Morisset Street and Ford Street (*Source: NSW SES*)

Plate B4.8 – 9/12/10 10:20 hours – Bungendore Road at the Big Dipper (*Source: NSW SES*)

Plate B4.9 – 9/12/10 10:21 hours – Looking south along Queanbeyan River in vicinity of Queanbeyan Golf Course (*Source: NSW SES*)

Plate B4.10 – 9/12/10 10:21 hours – Queanbeyan River in vicinity of Woodger Parade (*Source: NSW SES*)

Plate B4.11 – 9/12/10 10:29 hours – Flooding at southern end of Trinculo Place (*Source: NSW SES*)

Plate B4.12 – 9/12/10 10:40 hours – Googong Dam Spillway (*Source: NSW SES*)

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DECEMBER 2010 FLOOD
(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.13 – 9/12/10 10:40 hours – Floating debris in Googong Dam (*Source: NSW SES*)

Plate B4.14 – 9/12/10 11.25 hours – Trinculo Place (*Source: NSW SES*)

Plate B4.15 – 9/12/10 11:25 hours – Trinculo Place (*Source: NSW SES*)

Plate B4.16 – 9/12/10 11:25 hours – Trinculo Place (*Source: NSW SES*)

Plate B4.17 – 9/12/10 11:25 hours – Trinculo Place (*Source: NSW SES*)

Plate B4.18 – 9/12/10 11:25 hours – Trinculo Place (*Source: NSW SES*)

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DECEMBER 2010 FLOOD

(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.19 – 9/12/10 11:27 hours – Build-up of debris against Goulburn – Bombala Railway (*Source: NSW SES*)

Plate B4.20 – 9/12/10 11:27 hours – Build-up of debris in vegetation adjacent to Molonglo River (*Source: NSW SES*)

Plate B4.21 – 9/12/10 07:00 hours – Queens Bridge stream gauge (Gauge height 6.4 m) (*Source: NSW SES*)

Plate B4.22 – 9/12/10 07:15 hours – Queens Bridge stream gauge (Gauge height 6.7 m) (*Source: NSW SES*)

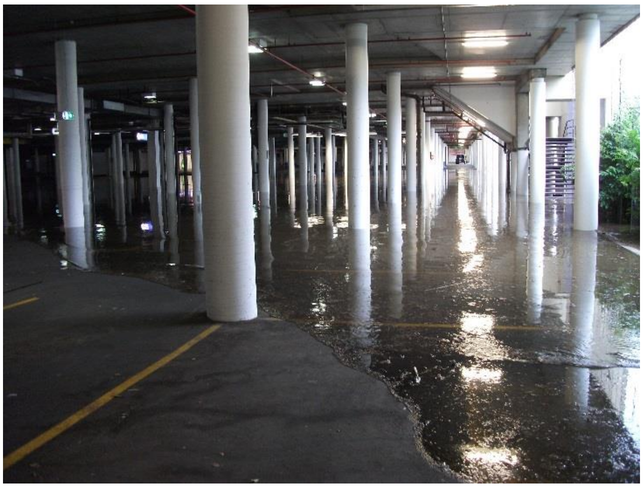

Plate B4.23 – 9/12/10 07:33 hours – Riverside Plaza carpark (*Source: NSW SES*)

Plate B4.24 – 9/12/10 08:33 hours – Intersection of Monaro Street and Collett Street (*Source: NSW SES*)

DECEMBER 2010 FLOOD

(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.25 – Time unknown – No. 1 Mowatt Street (*Source: NSW SES*)

Plate B4.26 – 9/12/10 09:16 hours – Looking east along Bungendore Road towards The Big Dipper from Queens Bridge (*Source: NSW SES*)

Plate B4.27 – 9/12/10 09:17 hours – Queanbeyan River upstream of Queens Bridge (*Source: NSW SES*)

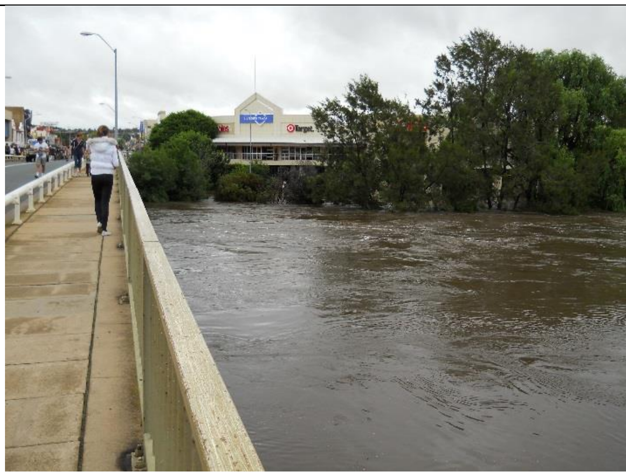

Plate B4.28 – 9/12/10 09:17 hours – Queanbeyan River downstream of Queens Bridge (*Source: NSW SES*)

Plate B4.29 – 9/12/10 09:18 hours – Looking south along Trinculo Place from Queens Bridge (*Source: NSW SES*)

Plate B4.30 – 9/12/10 09:24 hours – Looking east across the Queanbeyan River from the western side of the Queanbeyan Suspension Bridge (*Source: NSW SES*)

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DECEMBER 2010 FLOOD

(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.31 – 9/12/10 09:25 hours – Intersection of Collett Street and Isabella Street (*Source: NSW SES*)

Plate B4.32 – 9/12/10 15:37 hours – Build-up of debris in vegetation on western bank of river in vicinity of Collett Street and Isabella Street intersection (*Source: NSW SES*)

Plate B4.33 – 9/12/10 15:58 hours – Collett Street in vicinity of Riverside Plaza (*Source: NSW SES*)

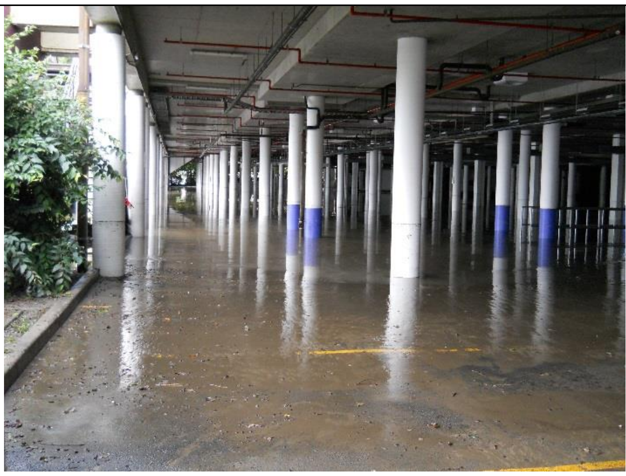

Plate B4.34 - 9/12/10 15:58 hours – Riverside Plaza carpark (*Source: NSW SES*)

Plate B4.35 – 10/12/2010 – Build-up of debris on western bank of Queanbeyan River in vicinity of Thorpe Street (*Source: NSW SES*)

Plate B4.36 – 10/12/2010 – Build-up of debris on western bank of Queanbeyan River at eastern end of Hayes Street (*Source: NSW SES*)

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DECEMBER 2010 FLOOD
(Peak at Queanbeyan Occurred at approximately 09:50 hours on 9/12/10)

Plate B4.37 – Build-up of debris in vicinity of intersection of Morisset Street and Ford Street (*Source: NSW SES*)

Plate B4.38 – Build-up of debris in vicinity of intersection of Morisset Street and Ford Street (*Source: NSW SES*)

Plate B4.39 – Build-up of debris in vicinity of intersection of Morisset Street and Ford Street (*Source: NSW SES*)

Plate B4.40 – Build-up of debris against Morisset Street bridge (*Source: NSW SES*)

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ANNEXURE B

PARTIAL COPY AND FULL TRANSCRIPT OF *THE QUEANBEYAN AGE* NEWSPAPER ARTICLE FROM FRIDAY 29 MAY 1925

Source of Newspaper Article:

1925 'Raging Floodwaters', Queanbeyan Age and Queanbeyan Observer (NSW : 1915 - 1927), 29 May, p. 2. , viewed 04 Apr 2018, http://nla.gov.au/nla.news-article31686402

Excerpt of Newspaper Article:

Raging Flood Waters

INUNDATE PART OF QUEANBEYAN

NIGHT OF PERIL

RESCUERS HAVE THRILLING TIME

NO LIVES LOST

The greatest, and at the same time the most disastrous flood in the history of Queanbeyan (extending over more than a century), was that which occurred on Tuesday night.

Previous to this, it was in 1891 that this district suffered its most serious inundation owing to flood rains, and the level of the water on that occasion was a couple of feet higher than the flood of 1922, but the majority of those who saw both floods are willing to concede that the deepened channel of the river carried a greater volume of water three years ago than the 1891 flood. The flood of this week was six feet higher than in 1891.

As the result of heavy rainfall in the mountainous country at the head of the Queanbeyan River, extending over the last week end, the river rose rapidly on Tuesday afternoon and continued to do so till it overflowed its banks soon after dark. Still rising it reached its maximum height

Mr. George Morton lost about £800 worth of property from a shed close by, and his new concrete house had over four feet of water in it and a layer of mud several inches deep.

Across the street the residences of Messrs. Leslie, S. O. Taylor, Jas. Penney, and the Misses Hunt also suffered considerable damage. Portion of the walls of a stone building at the rear of Mr. Leslie's, used for storage purposes, was swept away, as well as part of the brick walls of the dwelling, while the garden was laid waste. This was also the case with several other gardens.

Portion of the walls of the cottage adjoining Mr. Sacagio's, were also demolished by the weight of the water which flowed through this area with considerable force.

An eight-roomed brick house, owned by Messrs. McInnes Bros., on the flat below the main bridge, was swept away, though an iron tower, on which was a large tank, held its own, having but a slight list down stream.

On this flat several other residences suffered considerable damage not from the flood waters alone, but from the mud and debris that was piled up against them.

The flooding of many of the houses in Morrisett Street was due entirely to backwater occasioned by the Molonglo River being also in high flood and junctioning with the Queanbeyan River only a mile below the town.

Though eight inches of rain had fallen in Queanbeyan in little more than 48 hours, it had been steady, so the big drain which flows under Monaro Street, even when unable to discharge properly by reason of the river covering its mouth, did not

Transcript of Newspaper Article:

RAGING FLOODWATERS INUNDATE PART OF QUEANBEYAN

NIGHT OF PERIL RESCUERS HAVE THRILLING TIME NO LIVES L OST

The greatest, and at the same time the most disastrous flood in the history of Queanbeyan (extending over more than a century), was that which occurred on Tuesday night.

Previous to this, it was in 1891 that this district suffered its most serious inundation owing to flood rains, and the level of the water on that occasion was a couple of feet higher than the flood of 1922, but the majority of those who saw both floods are willing to concede that the deepened channel of the river carried a greater volume of water three years ago than the 1891 flood. The flood of this week was six feet higher than in 1891.

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As the result of heavy rainfall in the mountainous country at the head of the Queanbeyan River, extending over the last week end, the river rose rapidly on Tuesday afternoon and continued to do so till it overflowed its banks soon after dark. Still rising it reached its maximum height about midnight when the debris floated level with the decking of the main bridge.

At daylight on Wednesday morning there was little, if any, diminution in the volume of rushing water, but as the forenoon wore away, to the relief of the whole community, it commenced to considerably abate.

Early in the evening the fire engine shed above the mouth of the big drain was swept away. The work shop of Messrs. Price and McGuffie, builders, which was a little higher up, was inundated with several feet of water and a great quantity of building material damaged. Later on, the water rose still higher, and the residence of Mr. and Mrs. Vic. Williams, and the electrical shop of Messrs. Stacey & Co. were flooded.

So suddenly did the water over flow the river's banks that some householders were taken quite unawares. Mr. G. Sutcliffe, who lived in lower Irishtown, was awakened by the rattling of petrol tins at the back of the house and on opening the door met a rush of water, and with his family escaped by the front door with only a couple of blankets. Later the house, all but one room, to which the roof remained fast, was swept away.

The inmates of nearly all the houses along Morrissett Street between Balcombe-St. and the Park had to be rescued by the police and other men who waded waist deep in the water.

In Crawford Street the water surged into the premises of Mr. J. H. Hincksman and Mrs. Savage, and even reached to the steps of the Triumph Theatre at which place Mr. W. B. Freebody was sheltering many of the sufferers.

The Aylife, Bainbridge, Tait, Price, and Lee households were res cued with difficulty, and in the course of this one of Mr. T. R. O'Neill's motor cars was stalled in the flood, while a car driven by Mr. Shindler skidded and overturned, the driver being slightly injured.

The water in the Misses Lees' house was up to five feet deep, and in the confusion it was not known if all the inmates were rescued, so that one lady, Mrs. Tom Reid, spent the night standing on a table in one of the rooms, being rescued at an early hour on Wednesday morning.

Mr. and Mrs. S. E. Gibbs and their two daughters, with Mr. and Mrs. S. Hart and an infant child, finding themselves unable to get away made themselves comfortable in a loft, but their position was the cause of much uneasiness to all who were aware of their plight. A small raft was constructed, but owing to the darkness rescuers desisted in attempts to get them out. They were rescued at daylight.

Mr. Sacagio's two-storey brick building next the main bridge, used as a boarding house and store, was early surrounded with floodwater and about two score people were thus marooned. Here the water was over seven feet deep in the ground floor rooms, but on the whole the in mates were fairly safe.

No boat being available, a punt was hastily constructed and in the fore noon efforts were made to take off those willing to make the venture. Three trips were made between the building and the approach to the bridge, and half-a-dozen ferried over by which time it was possible to wade across, the water being then less than a foot deep, so rapidly did it subside, falling three feet in less than half an hour.

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Prior to this, when it was feared that the river might rise still higher, efforts were made to get a rope across to the balcony of the house, on which the inmates were assembled anxiously watching the surging waters. It was found impossible to do so from the approach to the bridge, though a couple of men stood waist deep in the water. Subsequently a couple of the marooned men climbed on to the roof of an adjoining house, and managed to throw a fishing line across, and to this the rope was fastened and ultimately was transferred to the balcony. It was by means of this rope the rescuers pulled themselves over to the balcony in the punt, and took off several of the men.

The occupants of the other residences in Trinculo Place adjoining got away before night, except Mr. R. W. Abrahams and another man who remained in the attic rooms and on Wednesday morning got on to the bridge by means of a rope, which was thrown over to them by men on the approach.

Mr. R. F. Land's cordial factory suffered immense damage estimated at close on £1000. The engine shed and factory were silted up with mud and water to the depth of several feet, and when the water subsided there was about six feet of mud and sand in the yard.

Mr. George Morton lost about £800 worth of property from a shed close by, and his new concrete house had over four feet of water in it and a layer of mud several inches deep.

Across the street the residences of Messrs. Leslie, S. O. Taylor, Jas. Penney, and the Misses Hunt also suffered considerable damage. Portion of the walls of a stone building at the rear of Mr. Leslie's, used for storage purposes, was swept away, as well as part of the brick walls of the dwelling, while the garden was laid waste. This was also the case with several other gardens.

Portion of the walls of the cottage adjoining Mr. Sacagio's, were also demolished by the weight of the water which flowed through this area with considerable force.

An eight-roomed brick house, owned by Messrs. McInnes Bros., on the flat below the main bridge, was swept away, though an iron tower, on which was a large tank, held its own, having but a slight list downstream.

On this flat several other residences suffered considerable damage not from the floodwaters alone, but from the mud and debris that was piled up against them.

The flooding of many of the houses in Morrissett Street was due entirely to backwater occasioned by the Molonglo River being also in high flood and junctioning with the Queanbeyan River only a mile below the town.

Though eight inches of rain had fallen in Queanbeyan in little more than 48 hours, it had been steady, so the big drain which flows under Monaro Street, even when unable to discharge properly by reason of the river covering its mouth, did not overflow to any great extent, and the overflow down the street, as well as the water breaking through some of the old man-holes, caused but little inconvenience.

The receding water left behind shoals of sand in Macquoid Street; and in the yards of Trinculo Place several feet of sand and mud remained, while in Morrissett and Crawford Street, the silt is from four to six inches deep on the crown of the roadway.

The water invaded the back rooms of The Manse and the Presbyterian School Hall, but did not enter the church, while nearer the river the residences of Rev. W. Evans (Methodist) and Mr. W. Hill, being on slightly higher elevations were also above the water level. The house of Mr. Johns, on the river bank at the Hayes Subdivision, and also the old Dodsworth homestead on the upper part of the town were also in the path of the water.

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The scene at present is an appalling one. The desolation and havoc wrought by the floodwaters cannot be remedied for many months, and it will be weeks at least before most of the houses that had to be left can be restored to anything approaching the comfort and convenience they afforded prior to the flood.

Gardens have been ruined and out houses demolished, while furniture and household goods and chattels were broken or swept away. Chests of drawers and similar furniture were filled with silt after being cap sized by the invading waters, and much of their contents absolutely ruined.

Quite a large number of fowls were drowned in the backed-up waters.

Damage to the streets, and road way has been very extensive. The approach to the main bridge from Monaro Street has subsided about nine inches. The railing of the foot walk on the opposite side has also been smashed about.

Tons of debris clung to the bridge decking and the tearing off of the bridge decking seemed imminent on several occasions. Fears in this direction were finally allayed when a big 30 feet log which had caught lengthwise and held a huge quantity of debris became entangled in the remains of a large, battered willow tree, which had been denuded of all but the stumps of its main branches, and the greater pull enabled the current to suck the whole mass under the bridge. Shortly after this the waters began to subside.

One outstanding feature so far as the township is concerned was that there was no loss of life, though the position in which many people were placed was one of great peril. This was due to the unquestionable bra very of the police and other citizens some of whose names were not readily obtainable, for which reason we refrain from special mention of any.

In their hour of need all the sufferers found ready offers of accommodation. Besides the Triumph Theatre, people were sheltered at St. Gregory's Hall, and over the river at St. Gregory's Church.

The school room at St. Benedict's Convent has also been offered should it be needed.

In order to attend a maternity case on the east side of the river on Wednesday morning, Nurse Darmody had to be driven in a car as far as the railway, and walk across the railway Bridge to the roadway, where she was met by a vehicle and eventually arrived safely at her destination.

Another case which commands great sympathy was that of a mother with a two-days'-old baby, who was cut off by the floodwaters, and had to be carried on a stretcher to a place of safety.

A motor car in Sacagio's yard was almost buried by sand and mud in yesterday's flood.

A wallet, the property of Mr. Geo. McInnes, and containing a couple of sovereigns and his war medals, was recovered at Acton yesterday.

From the top of the hill at the side of the Hospital the sight was a most spectacular one, the water spreading out in a great triangular lake with a base a mile wide.

About 10 o'clock on Tuesday night the town was plunged into 'total darkness through the dislocation of the electric cable and added to the danger and discomfort of the residents. The remainder of the street lights were not 25 per cent efficient.

Nearly 100 homes on the lower levels of the town were abandoned, fortunately for the most part as a matter of prudence than because of imminent peril.

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ANNEXURE C

QUEANBEYAN RIVER AT GOOGONG STREAM GAUGE DATA (GS 410701)

TABLE C1
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT GOOGONG STREAM GAUGE

Year	Peak Height (m)	Peak Discharge[1] (m^3/s)	Source of Discharge Data
1913	Not Available	101	DWR,1992
1914		101	
1915		160	
1916		160	
1917		119	
1918		84	
1919		32	
1920		84	
1921		84	
1922		1020	
1923		101	
1924		21	
1925		2120	
1926		10	
1927		19	
1928		17	
1929		205	
1930		4	
1931		247	
1932		42	
1933		64	
1934		458	
1935		225	
1936		160	
1937		29	
1938		108	
1939		140	
1940		56	

Refer over for footnotes to table.

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TABLE C1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT GOOGONG STREAM GAUGE

Year	Peak Height (m)	Peak Discharge(1) (m^3/s)	Source of Discharge Data
1941	Not Available	151	DWR,1992
1942		66	
1943		120	
1944		45	
1945		716	
1946		36	
1947		239	
1948		375	
1949		65	
1950		631	
1951		198	
1952		286	
1953		216	
1954		118	
1955		76	
1956		436	
1957		28	
1958		92	
1959		523	
1960		227	
1961		518	
1962		217	
1963		91	
1964		152	
1965		27	
1966		370	
1967		81	
1968		117	

Refer over for footnotes to table.

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TABLE C1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT GOOGONG STREAM GAUGE

Year	Peak Height (m)	Peak Discharge[1] (m^3/s)	Source of Discharge Data
1969	Not Available	140	DWR,1992
1970		95	
1971		255	
1972		165	
1973		61	
1974	8.63[2]	1008 [913]	L&A Revised Rating Curve
1975	5.38[2]	408 [408]	
1976	8.07	893 [818]	
1977	1.24	47	Pre- vs Post-Googong Dam relationship derived as part of DWR, 1992[3]
1978	4.01	357	
1979	0.78	7	
1980	0.68	3	
1981	0.81	9	
1982	0.48	0	
1983	1.21	44	
1984	4.44	425	
1985	1.88	106	
1986	2.8	202	
1987	0.62	2	
1988	5.72	648	
1989	5.07	528	
1990	2.26	144	
1991	5.57	618	
1992	2	117	
1993	1.47	71	
1994	1.38	62	

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TABLE C1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT GOOGONG STREAM GAUGE

Year	Peak Height (m)	Peak Discharge(1) (m^3/s)	Source of Discharge Data
1995	3.85	334	Pre- vs Post-Googong Dam relationship derived as part of DWR, 1992(3)
1996	1.16	37	
1997	1.45	69	
1998	2.44	164	
1999	1.44	68	
2000	1.2	42	
2001	0.72	5	
2002	0.7	4	
2003	0.63	2	
2004	0.84	10	
2005	0.6	2	
2006	0.63	2	
2007	0.86	12	
2008	0.59	2	
2009	0.64	2	
2010	6.86	910	
2011	1.33	56	
2012	4.31	405	
2013	3.08	234	
2014	1.21	43	
2015	1.58	81	
2016	3.58	297	
2017	0.67	3	

1. Numbers in [ ] represent peak discharge derived using IconWater Rating Curve current at time of flood.
2. Peak gauge height recorded prior to construction of Googong Dam.
3. Refer **Columns D** and **E** of **Table B2.1** for Pre- vs Post-Googong Dam relationship extracted from DWR, 1992.

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ANNEXURE D

QUEANBEYAN RIVER AT WICKERSLACK STREAM GAUGE DATA (GS 410760)

TABLE D1
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT WICKERSLACK STREAM GAUGE

Year	Peak Height (m)	Peak Discharge(1) (m^3/s)	Source of Discharge Data
1913	Not Available	66	Pre- vs Post-Googong Dam relationship derived as part of DWR, 1992(3)
1914		66	
1915		104	
1916		104	
1917		78	
1918		55	
1919		22	
1920		55	
1921		55	
1922		750	
1923		66	
1924		15	
1925		1964	
1926		8	
1927		13	
1928		12	
1929		134	
1930		3	
1931		163	
1932		28	
1933		42	
1934		314	
1935		148	
1936		104	
1937		20	
1938		71	
1939		91	
1940		37	

Refer over for footnotes to table.

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TABLE D1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT WICKERSLACK STREAM GAUGE

Year	Peak Height (m)	Peak Discharge[1] (m^3/s)	Source of Discharge Data
1941	Not Available	98	Pre- vs Post-Googong Dam relationship derived as part of DWR, 1992[3]
1942		44	
1943		79	
1944		30	
1945		507	
1946		24	
1947		157	
1948		253	
1949		43	
1950		445	
1951		129	
1952		190	
1953		141	
1954		77	
1955		50	
1956		298	
1957		19	
1958		60	
1959		364	
1960		149	
1961		360	
1962		142	
1963		60	
1964		99	
1965		19	
1966		249	
1967		53	
1968		77	

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TABLE D1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT WICKERSLACK STREAM GAUGE

Year	Peak Height (m)	Peak Discharge[1] (m^3/s)	Source of Discharge Data
1969	Not Available	91	Pre- vs Post-Googong Dam relationship derived as part of DWR, 1992[3]
1970		62	
1971		169	
1972		107	
1973		40	
1974	8.63[2]	740	
1975	5.38[2]	276	
1976	8.07	643	
1977	1.24	31 [31]	L&A Revised Rating Curve
1978	4.01	240 [240]	
1979	0.78	6 [6]	
1980	0.68	3 [3]	
1981	0.81	7 [7]	
1982	0.48	0 [0]	
1983	1.21	29 [29]	
1984	4.44	289 [289]	
1985	1.88	70 [70]	
1986	2.8	132 [132]	
1987	0.62	2 [2]	
1988	5.72	457 [457]	
1989	5.07	368 [341]	
1990	2.26	94 [94]	
1991	5.57	435 [391]	
1992	2	77 [78]	
1993	1.47	47 [47]	
1994	1.38	41 [41]	

Refer over for footnotes to table.

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TABLE D1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
QUEANBEYAN RIVER AT WICKERSLACK STREAM GAUGE

Year	Peak Height (m)	Peak Discharge[(1)] (m^3/s)	Source of Discharge Data
1995	3.85	224 [223]	L&A Revised Rating Curve
1996	1.16	25 [24]	
1997	1.45	45 [46]	
1998	2.44	107 [106]	
1999	1.44	45 [45]	
2000	1.2	28 [27]	
2001	0.72	4 [3]	
2002	0.7	3 [3]	
2003	0.63	2 [2]	
2004	0.84	8 [7]	
2005	0.6	1 [1]	
2006	0.63	2 [2]	
2007	0.86	9 [8]	
2008	0.59	1 [1]	
2009	0.64	2 [2]	
2010	6.86	658 [519]	
2011	1.33	37 [37]	
2012	4.31	274 [268]	
2013	3.08	154 [154]	
2014	1.21	29 [28]	
2015	1.58	53 [53]	
2016	3.58	198 [197]	
2017	0.67	3 [2]	

1. Numbers in [ ] represent peak discharge derived using IconWater Rating Curve current at time of flood.
2. Peak gauge height recorded prior to construction of Googong Dam.
3. Refer **Columns D** and **E** of **Table B2.1** for Pre- vs Post-Googong Dam relationship extracted from DWR, 1992.

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ANNEXURE E

MOLONGLO RIVER AT BURBONG STREAM GAUGE DATA (GS 410705)

TABLE E1
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
MOLONGLO RIVER AT BURBONG STREAM GAUGE

Year	Peak Height (m)	Discharge (m^3/s)	Rank
1930	0.91	13	71
1931	2.90	304	11
1932	1.78	112	31
1933	0.79	7	76
1934	2.07	161	28
1935	1.14	28	56
1936	1.52	73	39
1937	0.63	4	81
1938	1.52	73	39
1939	1.17	31	53
1940	1.17	31	53
1941	1.37	53	46
1942	1.07	22	62
1943	0.91	13	71
1944	1.07	22	62
1945	2.93	309	10
1946	1.14	28	56
1947	2.41	218	17
1948	2.68	265	14
1949	1.07	22	62
1950	3.35	392	7
1951	1.52	73	39
1952	3.35	392	7
1953	1.45	62	44
1954	0.61	4	81
1955	1.07	22	62
1956	3.89	501	4
1957	1.12	28	56
1958	0.84	11	73
1959	3.96	518	3

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TABLE E1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
MOLONGLO RIVER AT BURBONG STREAM GAUGE

Year	Peak Height (m)	Discharge (m^3/s)	Rank
1960	2.32	195	21
1961	2.28	189	24
1962	1.82	112	31
1963	1.62	82	37
1964	1.40	61	45
1965	0.91	15	69
1966	2.56	245	15
1967	2.02	151	29
1968	1.55	79	38
1969	2.13	169	27
1970	1.65	94	34
1971	2.24	187	25
1972	1.02	22	62
1973	1.02	22	62
1974	4.28	594	1
1975	2.94	312	9
1976	4.22	581	2
1977	1.28	46	50
1978	3.43	407	6
1979	0.99	20	68
1980	0.36	2	85
1981	1.32	50	48
1982	0.13	0	88
1983	1.12	29	55
1984	1.63	91	36
1985	1.69	92	35
1986	1.50	64	43
1987	0.75	7	76
1988	4.01	482	5
1989	3.02	269	13

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TABLE E1 (Cont'd)
RECORDED PEAK HEIGHT AND DISCHARGE DATA IN DATE ORDER
MOLONGLO RIVER AT BURBONG STREAM GAUGE

Year	Peak Height (m)	Discharge (m^3/s)	Rank
1990	2.68	215	18
1991	3.14	292	12
1992	1.92	101	33
1993	1.48	52	47
1994	1.66	69	42
1995	2.64	210	19
1996	1.10	23	61
1997	2.51	191	23
1998	2.42	176	26
1999	0.95	14	70
2000	0.84	9	75
2001	0.62	4	81
2002	0.66	5	80
2003	0.77	7	76
2004	0.79	7	76
2005	1.29	37	52
2006	0.26	1	86
2007	1.44	49	49
2008	0.48	3	84
2009	0.19	1	86
2010	2.24	147	30
2011	1.18	28	56
2012	2.84	240	16
2013	2.56	198	20
2014	1.31	38	51
2015	1.17	28	56
2016	2.54	194	22
2017	0.86	10	74

APPENDIX C

HYDROLOGIC AND HYDRAULIC MODELLING UPDATE

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(BOUND IN VOLUME 2)

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C1. HYDROLOGIC MODEL DEVELOPMENT AND CALIBRATION

C1.1. Hydrologic Modelling Approach

The present investigation required the use of a hydrologic model which is capable of representing the rainfall-runoff processes that occur within the Queanbeyan and Molonglo River catchments, as well as those in the urbanised parts of the city. It also had to be capable of applying the new ensemble approach to design flood estimation that is set out in ARR, 2016.

The hydrologic response of the Queanbeyan and Molonglo River catchments were simulated using the RAFTS rainfall-runoff modelling approach as the catchment is principally rural in nature, while the hydrologic response of the urban parts of Queanbeyan which drain directly to the Queanbeyan and Molonglo Rivers was simulated using the ILSAX rainfall-runoff modelling approach which has been developed primarily for this purpose.

The DRAINS software was used to develop the hydrologic models of the study catchment as it incorporates both the RAFTS and ILSAX sub-models. It is also ARR, 2016 compatible. Discharge hydrographs generated by the RAFTS and ILSAX sub-models were applied to the TUFLOW hydraulic model as either point or distributed inflow sources (refer **Section C2.4** for further details).

C1.2. Hydrologic Model Layout

Figure C1.1 (2 sheets) shows the layout of the sub-catchments which comprise the hydrologic model for the Queanbeyan and Molonglo River catchments (**Queanbeyan Hydrologic Model**). The hydrologic modelling which was originally undertaken as part of DWR, 1992 was used as the basis for the present investigation. Upstream of the City the sub-catchment delineation and slopes derived as part of the previous study were reviewed using LiDAR survey data (where available) and Shuttle Radar Topography Mission (**SRTM**) data. The water storage at Googong Dam was incorporated into the Queanbeyan Hydrologic Model based on details provided by the dam operators.

Additional definition of the sub-catchments in the vicinity of the CBD was incorporated in the Queanbeyan Hydrologic Model to ensure flows generated by the local catchment would be properly routed through the Queanbeyan TUFLOW Model. In addition to using the LiDAR based contour data, the location of inlet pits and headwalls were also taken into consideration when deriving the boundaries of the various sub-catchments.

Percentages of impervious area were assessed using the available aerial photography and cadastre boundary data. Sub-catchment slopes used for input to the RAFTS component of the hydrologic model were derived using the vectored average slope approach, whilst the average sub-catchment slope computed by the Vertical Mapper software was used for input to the ILSAX sub-model. The available contour data, which comprised both LiDAR survey and SRTM contour sets, were used as the basis for computing the slope for both methods.

The RAFTS model developed as part of DWR, 1992 adopted the Muskingum-Cunge algorithm to route the flood wave to the outlet of the catchment. As the Muskingum-Cunge method is not available in the DRAINS software, it was necessary to develop an alternative method for routing the flood wave through the catchment as part of the present investigation.

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Figure C1.2 shows that in the December 2010 flood the peak took about 1 hour to travel along the 18.4 km reach of the Queanbeyan River between the Tinderry and U/S Googong Dam stream gauges, and about 14 hours to travel along the 48.4 km reach of the Molonglo River between the Kobada and Burbong stream gauges. Based on the above, the travel times along the Queanbeyan and Molonglo Rivers were derived using average flow velocities of 4 and 1 m/s, respectively.

C1.3. Hydrologic Model Calibration

C1.3.1. General

The RAFTS model that was developed as part of DWR, 1992 was calibrated to historic floods that occurred in 1974, 1976, 1978 (March and September), 1984, 1988, 1989 and 1991. DWR, 1990 found that a routing parameter (BX) of 1.0 resulted in a good match between the modelled and recorded flows for the historic flood events. DWR, 1992 does not indicate what initial and continuing losses were adopted in the hydrologic model calibration. The water storage at Googong Dam, which was constructed between 1975 and 1978, was only incorporated in the January 1984, 1988, 1989 and 1991 RAFTS models.

The Queanbeyan Hydrologic Model was calibrated to the more recent historic flood event that occurred in December 2010, noting that it was not calibrated to the earlier flood events due to the limited availability of historic rainfall data.

Note that for model calibration purposes, the following constant values for PERN were adopted:[1]

- wooded slopes = 0.08
- cleared pastoral land = 0.045

C1.3.2. Discussion of Results

Table C1.1 shows the RAFTS hydrologic parameters which gave a good match with the recorded data for the December 2010 flood, while **Figure C1.2** shows a comparison of recorded versus modelled discharge hydrographs at the telemetered stream gauges in the Queanbeyan and Molonglo River catchments.

TABLE C1.1
RAFTS HYDROLOGIC MODEL PARAMETERS

Hydrologic Parameter	Value
Initial Loss (mm)	15
Continuing Loss (mm/hr)	2.5
BX	0.8

[1]A PERN value of 0.06 was applied to those sub-catchments which comprised a mixture of both wooded and cleared pastoral land.

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In general, the Queanbeyan Hydrologic Model was able to reproduce the shape and timing of the discharge hydrographs that were recorded by the various stream gauges with a few exceptions. For example, while the shape of the hydrograph and peak discharge at the Burra Creek stream gauge were not able to be reproduced, the volume of runoff is comparable between the modelled and recorded data. Whilst not undertaken as part of the present investigation, a better match could likely be achieved by splitting the single RAFTS sub-catchment upstream of the gauge site into multiple sub-catchments.

The peak discharge at the Molonglo River at Oaks Estate stream gauge was also not able to be reproduced. The reason for this may lie in the sensitivity of flood levels at the gauge site to the build-up of woody debris on the banks of the river (refer **Section C2.5** for further discussion).

C1.4. Recommended Set of Parameters for Design Flood Estimation

Based on the findings set out in **Section C1.3**, it was concluded that a flow velocity of 4 and 1 m/s for determining lag times in the Queanbeyan and Molonglo Rivers, respectively and a BX factor of 0.8 should be used for design flood estimation purposes. The PERN values set out in **Section C1.3.2** should also be used for deriving design discharge hydrographs for input to the hydraulic models.

Whilst historic flood data is not available to allow a formal calibration of the overland flow generator (i.e. ILSAX) in the Queanbeyan Hydrologic Model to be undertaken, the following parameters were adopted for design flood estimation based on the findings of previous studies:

- Soil Type = 3.0
- AMC = 3.0
- Paved flow path roughness = 0.02
- Grassed flow path roughness = 0.07

Details in relation to the values of initial and continuing loss adopted for design flood estimation are set out in **Chapter C3**.

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C2. HYDRAULIC MODEL DEVELOPMENT AND CALIBRATION

C2.1. General

The present investigation required the use of a hydraulic model which is capable of analysing the time varying effects of flow in the Queanbeyan and Molonglo Rivers and the local stormwater drainage system and the two-dimensional nature of flow on both the floodplain and in the steeper parts of the study area that are subject to overland flow. The TUFLOW modelling software was adopted as it is one of only a few commercially available hydraulic models which contain all of the required features.

This chapter deals with the development and calibration of a TUFLOW model that was used to define both main stream flooding along the Queanbeyan and Molonglo Rivers and overland flow behaviour in the CBD (**Queanbeyan TUFLOW Model**). It also deals with the calibration of the Queanbeyan TUFLOW Model using the available flood data from the May 1925, August 1974, October 1976 and December 2010 floods.

C2.2. Brief Review of TUFLOW Modelling Approach

TUFLOW is a true two-dimensional hydraulic model which does not rely on a prior knowledge of the pattern of flood flows in order to set up the various fluvial and weir type linkages which describe the passage of a flood wave through the system.

The basic equations of TUFLOW involve all of the terms of the St Venant equations of unsteady flow. Consequently the model is "fully dynamic" and once tuned will provide an accurate representation of the passage of the flood wave through the drainage system (both surface and piped) in terms of extent, depth, velocity and distribution of flow.

TUFLOW solves the equations of flow at each point of a rectangular grid system which represent overland flow on the floodplain and along streets. The choice of grid point spacing depends on the need to accurately represent features on the floodplain which influence hydraulic behaviour and flow patterns (e.g. buildings, streets, changes in channel and floodplain dimensions, hydraulic structures which influence flow patterns, etc.).

Pipe drainage and channel systems can be modelled as one-dimensional elements embedded in the larger two-dimensional domain which typically represents the wider floodplain. Flows are able to move between the one and two-dimensional elements of the model depending on the capacity characteristics of the drainage system being modelled.

The Queanbeyan TUFLOW Model also allows for the assessment of potential flood management measures, such as detention storage, increased channel and floodway dimensions, augmentation of culverts and bridge crossing dimensions, diversion banks and levee systems.

C2.3. TUFLOW Model Setup

C2.3.1. General

The layout of the Queanbeyan TUFLOW Model is shown on **Figure C2.1** (2 sheets). The model comprises the pit and pipe drainage system in the vicinity of the CBD, a 9 km reach of the Queanbeyan River, as well as the overland flow paths which are present in the CBD within the two-dimensional (in plan) model domain using a grid based approach.

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The 12 km reach of the Molonglo River between the Burbong stream gauge and its confluence with Reedy Creek and the 8 km reach between the Queanbeyan STP and Lake Burley Griffin have been modelled as a one-dimensional element using a series of cross sections which were orientated normal to the direction of flow, while the inbank area on the 8 km reach of the Molonglo River between its confluence with Reedy Creek and the Queanbeyan STP has been modelled as a one-dimensional element, with its overbank area modelled in the two-dimensional model domain.

The following sections provide further details of the development of the Queanbeyan TUFLOW Model.

C2.3.2. Two-dimensional Model Domains

An important consideration of two-dimensional modelling is how best to represent the roads, fences, buildings and other features which influence the passage of flow over the natural surface. Two-dimensional modelling is very computationally intensive and it is not practicable to use a mesh of very fine elements without excessive times to complete the simulation, particularly for long duration flood events. The requirement for a reasonable simulation time influences the way in which these features are represented in the model.

A grid spacing of 4 m was found to provide an appropriate balance between the need to define features on the floodplain versus model run times, and was adopted for the investigation. Ground surface elevations for model grid points were initially assigned using a Digital Terrain Model (**DTM**) derived from the LiDAR survey data, and updated using ground survey data where such data were available.

Ridge and gully lines were added to the Queanbeyan TUFLOW Model where the grid spacing was considered too coarse to accurately represent important topographic features which influence the passage of overland flow. The elevations for these ridge and gully lines were determined from survey data where available, or otherwise from inspection of LiDAR survey or site-based measurements. Gully lines were also used to represent various watercourses where it was not necessary to precisely represent the conveyance capacity of these watercourses. The use of gully lines ensured that positive drainage was achieved along the full length of these watercourses, and thus avoided creation of artificial ponding areas as artefacts of the 'bumpy' nature of the underlying LiDAR survey data.

The footprints of a large number of individual buildings located in the two-dimensional model domain were digitised and assigned a high hydraulic roughness value relative to the more hydraulically efficient roads and flow paths through allotments. This accounted for their blocking effect on flow while maintaining a correct estimate of floodplain storage in the model.

It was not practicable to model the individual fences surrounding the many allotments in the study area. They comprised many varieties (brick, paling, colorbond, etc.) of various degrees of permeability and resistance to flow. It was assumed that there would be sufficient openings in the fences to allow water to enter the properties, whether as flow under or through fences and via openings at driveways. Individual allotments where development is present were digitised and assigned a high hydraulic roughness value (although not as high as for individual buildings) to account for the reduction in conveyance capacity which will result from fences and other obstructions stored on these properties.

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C2.3.3. One-dimensional Model Elements

Figure C2.1 shows the piped elements contained in Council's asset database which were included in the Queanbeyan TUFLOW Model (192 pipes and 11 box culverts), with the smallest conduit size measuring 150 mm in diameter. Selected pipe and culvert details were available from survey undertaken for Council and this information was used to supplement the asset database as appropriate.

Limited information was available on pipe invert levels, therefore an assumed cover of 600 mm was adopted for those drainage elements where invert levels or depth measurements were not available. Adjustments were made to the assumed invert levels where this approach resulted in a negatively graded reach of pipe or culvert.

Several types of pits are identified on **Figure C4.1**, including junction pits which have a closed lid and inlet pits which are capable of accepting overland flow. Council's asset database contained only limited information in regard to inlet pit types and dimensions. Therefore, inlet capacity relationships for incorporation in the Queanbeyan TUFLOW Model were derived based on visual inspection of the pit.

Pit losses in the various piped drainage networks were modelled using the approach whereby energy loss coefficients at pipe junctions are re-calculated at each time step of the simulation. The losses are based on a range of variables including the inlet/outlet flow distribution, the depth of water within the pit, expansion and contraction of flow through the pit, the horizontal deflection angle between inlet and outlet pipes, and the vertical drop across the pit.

Fourteen cross sections derived from LiDAR survey data were used to define the full waterway area (i.e. both the inbank and overbank area) of the 12 km reach of the Molonglo River between the Burbong stream gauge and its confluence with Reedy Creek. The inbank waterway area of the 8 km reach of the Molonglo River between its confluence with Reedy Creek and the Queanbeyan STP has been defined by fourteen cross sections that were surveyed as part of the Lyall & Associates, 2008 and supplemented by eight cross sections that were derived from the LiDAR survey data. An additional twelve cross sections derived from LiDAR survey data were used to define the full waterway area of the 8 km reach of the Molonglo River between the Queanbeyan STP and Lake Burley Griffin.

The location of the cross sections are also shown on **Figure C4.1**, sheet 1.

C2.4. Model Boundary Conditions

The locations where discharge hydrographs derived by the Queanbeyan Hydrologic Model were applied to the Queanbeyan TUFLOW Model are shown on **Figure C2.1**. These comprise both point-source inflows at selected locations along the existing piped drainage systems, and distributed inflows via "Rain Boundaries".

The location of point source inflows coincide with the location of inlet pits where runoff can presently enter the piped drainage system, and generally correspond with the downstream limit of each sub-catchment modelled in DRAINS.

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The Rain Boundaries act to "inject" flow into the two-dimensional domain of the Queanbeyan TUFLOW Model, firstly at a point which has the lowest elevation, and then progressively over the extent of the Rain Boundary as the grid in the two-dimensional model domain becomes wet as a result of overland flow.

The downstream boundary of the Queanbeyan TUFLOW Model comprised a broad crested weir arrangement, the elevation of which was set equal to the crest level of Scrivener Dam which controls water levels in Lake Burley Griffin.

C2.5. Model Parameters

The main physical parameter for TUFLOW is the hydraulic roughness. Hydraulic roughness is required for each of the various types of surfaces comprising the overland flow paths, as well as for the cross sections representing the geometric characteristics of the various river and creek channels. In addition to the energy lost by bed friction, obstructions to flow also dissipate energy by forcing water to change direction and velocity and by forming eddies. Hydraulic modelling traditionally represents all of these effects via the surface roughness parameter known as "Manning's n". Flow in the piped system also requires an estimate of hydraulic roughness.

Table C2.1 sets out the Mannings n values which were found to give a reasonable correspondence between recorded and modelled flood levels for the four historic flood events used to calibrate the Queanbeyan TUFLOW Model.

TABLE C2.1
"BEST ESTIMATE" OF HYDRAULIC ROUGHNESS VALUES
ADOPTED FOR TUFLOW MODEL CALIBRATION

Surface Treatment	Historic Flood Event			
	1925	1974	1976	2010
Concrete piped elements	0.015			
Asphalt or concrete road surface	0.02			
Well maintained grass (e.g. Golf Course, Sporting Field)	0.03			
River bed (Queanbeyan River),	0.035			
Overbank area, including grass and lawns	0.045			
Creek bed (Molonglo River, Buttles Creek)	0.035	0.06	0.08	0.12
Vegetated areas	0.08			
Allotments (between buildings)	0.10			
Densely vegetated areas	0.10(1)			
River bank (Molonglo River)	0.08	0.14	0.14	0.16
Buildings	10			

1. A Mannings n value of 0.10 was applied to the banks of the Queanbeyan River downstream of the Goulburn-Queanbeyan Railway Line and a 4,800 m^2 area at the intersection of the Ford and Morisset Street intersection to represent the build-up of woody debris that was experienced during the December 2010 flood.

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Photographic records of historic flooding (Refer **Plates B3.11** (1976), **B4.7**, **B4.13**, **B4.19**, **B4.20** and **B4.35** to **B4.40** (all December 2010) in **Annexure A** of **Appendix B**) and anecdotal evidence from newspaper articles and previous engineering reports indicate that major floods on the Queanbeyan River typically carry a large amount of woody debris. Floodplain obstructions and dense vegetation along the banks of the Queanbeyan and Molonglo Rivers act to capture the woody debris which can exacerbate flooding conditions in Queanbeyan.

In order to match the historic flood marks for the August 1974, October 1976 and December 2010 flood events, the Mannings n values assigned to the river bed and banks of the Molonglo River downstream of its confluence with the Queanbeyan River were increased to represent the blocking effect that the debris would have on flow conveyance. It is believed that debris settles in this reach of the river due to the reduction in flow velocity attributable to a flattening of the river bed, as well as the eddying that occurs due to the mixing of flows from the two watercourses.

The adoption of a value of 0.02 for the surfaces of roads, along with an adequate description of their widths and centreline/kerb elevations, allowed an accurate assessment of their conveyance capacity to be made. Similarly, the high value of roughness adopted for buildings recognised that these structures will completely block the flow but are capable of storing water when flooded.

Figure C2.2 is a typical example of flow patterns derived from the above roughness values. This example applies for the October 1976 flood event and shows flows through existing development in the vicinity of Carinya Street and Morisset Street.

The left hand side of the figure shows the roads and inter-allotment areas, as well as the outlines of buildings, which have been individually digitised in the model. The right hand side shows the resulting flow paths in the form of scaled velocity vectors and the depths of inundation. The buildings with their high values of hydraulic roughness block the passage of flow, although the model recognises that they store floodwater when inundated and therefore correctly accounts for flood storage. The flow is conveyed via the road reserves and through the open parts of the allotments. Similar information to that shown on **Figure C2.2** may be presented at any location within the model domain (which is shown on **Figure C2.1**) and will be of assistance to Council in assessing individual flooding problems in the floodplain.

C2.6. Model Calibration

C2.6.1. General

Following a review of the available data, the floods that occurred in May 1925, August 1974, October 1976 and December 2010 were selected for model calibration purposes.

The Queanbeyan TUFLOW Model was calibrated to historic flood level data contained in DWR, 1992 for the May 1925, August 1974, and October 1976 flood events, as well as a series of flood marks from the December 2010 flood event that were surveyed by Council. The Queanbeyan TUFLOW Model was also calibrated to the recorded peak water levels at the stream gauges within the two-dimensional model domain.

Note that the discharge hydrographs that were used as input to the Queanbeyan TUFLOW Model at the location of the Wickerslack stream gauge on the Queanbeyan River for the August 1974 and October 1976 floods were generated by using the *L&A Derived Rating Curve*.

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C2.6.2. May 1925

The May 1925 flood occurred prior to the establishment of the telemetered stream gauges on the Queanbeyan and Molonglo Rivers. Inflow hydrographs comprising a constant peak flow were therefore input to the Queanbeyan TUFLOW Model at the location of the Wickerslack gauge on the Queanbeyan River (2,120 m^3/s based on the findings of DWR, 1992) and the Burbong gauge on the Molonglo River (assumed to be 200 m^3/s).

It was not possible to obtain a good fit between the recorded and modelled data by adopting the peak flow estimate contained in DWR, 1992 (denoted herein as the "Upper Estimate") as the Queanbeyan TUFLOW Model generated peak flood levels which were significantly higher than recorded values. As the topography of the area has not changed significantly since the time of the flood it is highly likely that the Upper Estimate of the peak flow is too high.

The peak flow in the Queanbeyan River was therefore incrementally reduced until a good match was achieved between the modelled and recorded data. Based on the results of the modelling, the peak flow in the Queanbeyan River during the May 1925 flood may have been closer to 1,600 m^3/s (denoted herein as the "Lower Estimate"). It is noted this finding assumes that there was no coincident flow in the Molonglo River, which had it been present would have resulted in a backwater effect, further reducing the peak flow which would have been required to achieve a match with the recorded data.

Table C2.2 provides a comparison of modelled versus recorded peak flood levels for both the Upper and Lower Estimate of the May 1925 flood.

Figure C2.3 shows the TUFLOW model results for the May 1925 flood using the Lower Estimate of the peak flow in the Queanbeyan River, while the modelled water surface profiles for both peak flow estimates are shown on **Figure C2.7**. The plan location and elevation of the single flood mark which is set out in DWR, 1992 is also shown on **Figures C2.3** and **C2.7**, respectively.

TABLE C2.2
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS(1)
MAY 1925 FLOOD

Point No.(2)	Location	Watercourse	Recorded Peak Flood Level (m AHD)	Upper Estimate (Q = 2,120 m^3/s)		Lower Estimate (Q = 1,600 m^3/s)	
				Modelled (m AHD)	Difference(3) (m)	Modelled (m AHD)	Difference(3) (m)
-	Queens Bridge stream gauge	Queanbeyan River	574.80	576.13	1.33	574.93	0.13
1925.1	Morisset Street		574.50	575.77	1.27	574.53	0.03

1. Source of recorded peak flood levels and descriptors: DWR, 1992.
2. Refer **Figure C2.3** for location of available flood mark.
3. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the modelled flood level is lower than the observed flood level.

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C2.6.3. August 1974

The discharge hydrographs recorded by the Wickerslack and Burbong stream gauges for the August 1974 flood were input to the Queanbeyan TUFLOW Model at its upstream boundaries.

Figure C2.4 shows the TUFLOW model results for the August 1974 flood, as well as the plan location of five flood marks which are set out in DWR, 1992. **Table C2.3** shows the Queanbeyan TUFLOW Model generally achieves a good match with the recorded peak flood levels for the August 1974 flood, while **Figure C2.7** shows that the modelled water surface profile generally matches the flood slope indicated by the surveyed flood marks along the Queanbeyan River.

TABLE C2.3
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS(1)
AUGUST 1974 FLOOD

Point No.(2)	Location	Watercourse	Peak Flood Level (m AHD)		Difference(3) (m)
			Recorded	Modelled	
-	Wickerslack stream gauge	Queanbeyan River	583.08	583.21	0.13
1974.1	Adjacent to Woodger Parade		575.20	575.64	0.44
1974.2	Adjacent to Hayes Street		574.90	575.08	0.18
1974.3	Adjacent to Booth Street		574.10	574.36	0.26
-	Queens Bridge stream gauge		573.60	573.57	-0.03
1974.4	Upstream Morisset Street		573.40	573.22	-0.18
1974.5	Adjacent to Erin Street		573.10	572.85	-0.25
-	Oaks Estate stream gauge	Molonglo River	571.10	571.10	0

1. Source of recorded peak flood levels and descriptors: DWR, 1992.
2. Refer **Figure C2.4** for location of available flood marks.
3. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the modelled flood level is lower than the observed flood level.

C2.6.4. October 1976

The discharge hydrographs recorded by the Wickerslack and Burbong stream gauges for the October 1976 flood were input to the Queanbeyan TUFLOW Model at its upstream boundaries.

Figure C2.5 shows the TUFLOW model results for the October 1976 flood event and the plan location of the six observed flood levels that are set out in DWR, 1992. Modelled water surface profiles along the Queanbeyan River, as well as the six flood marks are shown on **Figure C2.7**. **Table C2.4** over shows the TUFLOW model results were generally within 200 mm of the recorded peak flood levels for the October 1976 flood.

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TABLE C2.4
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS[1]
OCTOBER 1976 FLOOD

Point No.[2]	Location	Watercourse	Peak Flood Level (m AHD)		Difference[3] (m)
			Recorded	Modelled	
-	Wickerslack stream gauge	Queanbeyan River	582.52	582.70	0.18
1976.1	Adjacent to Dane Street		575.00	575.22	0.22
1976.2	Adjacent to Hayes Street		574.40	574.65	0.25
1976.3	Queanbeyan Leagues Club		573.20	573.15	-0.05
1976.4	46 Trinculo Place		573.50	573.52	0.02
-	Queens Bridge stream gauge		573.30	573.15	-0.15
1976.5	Morisset Street bridge		573.00	572.88	-0.12
1976.6	Adjacent to Erin Street		572.80	572.59	-0.21
-	Oaks Estate stream gauge	Molonglo River	570.60	570.74	0.14

1. Source of recorded peak flood levels and descriptors: DWR, 1992.
2. Refer **Figure C2.5** for location of available flood marks.
3. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the modelled flood level is lower than the observed flood level.

C2.6.5. December 2010 Flood

Discharge hydrographs generated by the Queanbeyan Hydrologic Model for the December 2010 flood were used as input to the Queanbeyan TUFLOW Model. This included runoff that contributes to flow in the stormwater drainage system that controls local catchment flooding in the CBD.

As discussed in **Section 2.4.8** of the Main Report, the December 2010 flood wave conveyed large amounts of woody debris which were caught in the stands of trees that are located on the banks of the two rivers and which also deposited on the outside bend of the Queanbeyan River adjacent to the Morisset Street Bridge. For model calibration purposes the Mannings n values applied to the river banks downstream of the Goulburn-Queanbeyan Railway Line and in the vicinity of the Morisset Street Bridge were increased to represent the blocking effect caused by the build-up of debris in these areas.

Figure C2.6 shows the TUFLOW model results for the December 2010 flood event, as well as the plan location of 64 flood marks which were surveyed by Council.[2] **Figure C2.7** shows the modelled water surface profiles along the Queanbeyan River. The elevation of the surveyed flood marks are not shown on **Figure C2.7** as they were measured on the edges of the flood affected area and are not representative of water levels within the inbank area of the river.

[2] Note that for ease of comparison between modelled and recorded flood levels, a representative selection of 64 out of the 171 flood marks that were surveyed by Council have been shown on **Figures C2.6**.

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Table C2.5 over provides a comparison of modelled versus recorded peak flood levels for the December 2010 flood. The Queanbeyan TUFLOW Model generated peak flood levels that are generally within 250 mm of the recorded flood marks, with the exception of two flood marks that are located in the Riverside Cemetery (refer Flood Marks 2010.63 and 2010.64) where modelled flood levels are more than 300 mm lower that the recorded data. The difference may be a result of the localised build-up of debris in the river adjacent to the cemetery, which in turn may have caused a localised increase in flood levels, a feature which the Queanbeyan TUFLOW Model was not able to reproduce.

Figure C1.2 shows a comparison between the recorded and TUFLOW derived discharge hydrographs on the Queanbeyan River immediately upstream of its confluence with the Molonglo River (refer Queanbeyan River at A.C.T. Border (GS 410770)) and on the Molonglo River immediately downstream of its confluence with the Queanbeyan River (refer Molonglo River at Oaks Estate (GS 410729)). While the stream gauge on the Queanbeyan River failed during the flood, the gauge on the Molonglo River remained operable. While the flow in the Queanbeyan TUFLOW Model peaked about 2 hours after the recorded peak at 09:50 hours on 9 December 2010, the modelled peak flow is about 190 m^3/s less than the recorded value (i.e. 935 m^3/s recorded versus 745 m^3/s modelled). As there was limited rainfall recorded in the vicinity of Queanbeyan during the flood, it is unlikely that the peak flow in the river would have increased from 660 m^3/s on the Queanbeyan River at Wickerslack to the recorded value of 935 m^3/s on the Molonglo River at Oaks Estate, noting the coincident peak flow on the Molonglo River would have been less than 100 m^3/s. Based on this finding, it is believed that the current rating curve attached to the Oaks Estate stream gauge overestimates the flow in the Molonglo River, possibly above a value of about 400 m^3/s (as this is the point at which the recorded and modelled flows start to diverge on the rising limb of the flood). Elevated water levels in the Molonglo River due to the build-up of woody debris may also have resulted in an over-estimate of the flow at the gauge site (i.e. because the build-up of debris would have increased water levels in the river, which in turn would have resulted in a higher flow rate being derived by application of the rating curve to the recorded values).

C2.6.6. Recommended Values of Manning n for Design Flood Modelling

Based on the findings of the model testing process, both the Queanbeyan Hydrologic Model and the Queanbeyan TUFLOW Model are considered to provide a reasonable match with the available historic flood data. As such, the hydrologic and hydraulic model parameters set out in **Sections C1.3** and **C2.5**, respectively and in particular the hydraulic roughness values set out in **Table C2.1**, were considered appropriate for use in defining flood behaviour along the Queanbeyan and Molonglo Rivers at Queanbeyan for the full range of design flood events. Note that due to the relative sensitivity of modelled peak water surface levels to the adopted hydraulic roughness value for the bed and banks of the Molonglo River, sensitivity analyses to assess the impact of this parameter on flooding behaviour were also undertaken, the results of which are presented in **Section C4.4.2**. Further discussion and presentation of additional hydrologic model parameters that were adopted for design flood estimation purposes is provided in **Chapter C3**.

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TABLE C2.5
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS(1)
DECEMBER 2010 FLOOD

Point No.(2)	Location	Watercourse	Peak Flood Level (m AHD)		Difference(3) (m)
			Recorded	Modelled	
-	Wickerslack stream gauge	Queanbeyan River	581.61	581.56	-0.05
2010.01	Upstream Isabella Street		572.83	572.98	0.15
2010.02	Isabella Street		572.67	572.66	-0.01
2010.03			572.64	572.53	-0.11
2010.04	Collett Street		572.64	572.53	-0.11
2010.05			572.64	572.54	-0.1
2010.06			572.59	572.43	-0.16
2010.07			572.51	572.38	-0.13
2010.08	Trinculo Place		572.71	572.73	0.02
2010.09			572.71	572.73	0.02
2010.10			572.68	572.73	0.05
2010.11			572.70	572.73	0.03
2010.12			572.73	572.73	0
2010.13			572.65	572.73	0.08
2010.14			572.64	572.73	0.09
2010.15			572.68	572.73	0.05
2010.16			572.64	572.73	0.09
2010.17			572.64	572.74	0.1
2010.18			572.60	572.59	-0.01
2010.19			572.43	572.47	0.04
2010.20			572.38	572.39	0.01
2010.21			572.42	572.38	-0.04
2010.22			572.25	572.25	0
2010.23			572.42	572.29	-0.13
2010.24	Collett Street		572.21	572.30	0.09
2010.25			572.18	572.31	0.13
2010.26	Queanbeyan Leagues Club		572.43	572.29	-0.14

Refer over for footnotes to table.

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TABLE C2.5 (Cont'd)
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS[1]
DECEMBER 2010 FLOOD

Point No.[2]	Location	Watercourse	Peak Flood Level (m AHD)		Difference[3] (m)
			Recorded	Modelled	
-	Queens Bridge stream gauge	Queanbeyan River	572.52	572.29	-0.23
2010.27	Riverside Plaza		572.48	572.29	-0.19
2010.28			572.38	572.26	-0.12
2010.29	Collett Street		572.49	572.27	-0.22
2010.30	Queen Elizabeth Park		572.46	572.27	-0.19
2010.31			572.30	572.22	-0.08
2010.32	Morisset Street		572.18	572.15	-0.03
2010.33			572.11	572.07	-0.04
2010.34	Ray Morton Park		572.15	572.05	-0.1
2010.35			572.08	572.06	-0.02
2010.36			572.02	572.07	0.05
2010.37	Upstream Monaro Street		572.12	571.99	-0.13
2010.38			572.25	571.99	-0.26
2010.39			572.21	571.99	-0.22
2010.40	Monaro Street (The Big Dipper)		572.15	571.99	-0.16
2010.41			572.18	571.99	-0.19
2010.42	Waniassa Park		572.02	571.99	-0.03
2010.43	Waniassa Street		572.01	571.99	-0.02
2010.44			571.99	571.92	-0.07
2010.45			572.21	571.92	-0.29
2010.46			571.88	571.92	0.04
2010.47			572.09	571.92	-0.17
2010.48			571.72	571.92	-0.22
2010.49	High Street Playing Field		571.76	571.92	0.16
2010.50	Ford Street		571.61	571.92	0.18
2010.51	Carinya Street		572.07	571.91	-0.16
2010.52			571.99	571.82	-0.17

Refer over for footnotes to table.

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TABLE C2.5 (Cont'd)
COMPARISON OF MODELLED VERSUS RECORDED PEAK FLOOD LEVELS[1]
DECEMBER 2010 FLOOD

Point No.[2]	Location	Watercourse	Peak Flood Level (m AHD)		Difference[3] (m)
			Recorded	Modelled	
2010.53	Riverside Sporting Complex	Queanbeyan River	571.94	571.80	-0.14
2010.54	Riverside Sporting Complex	Queanbeyan River	571.95	571.80	-0.15
2010.55	Downstream Riverside Sporting Complex	Queanbeyan River	571.55	571.75	0.2
2010.56	Blundell Park	Queanbeyan River	571.66	571.80	0.14
2010.57	Blundell Park	Queanbeyan River	571.64	571.69	0.05
2010.58	Blundell Park	Queanbeyan River	571.57	571.58	0.01
2010.59	Blundell Street	Queanbeyan River	571.59	571.56	-0.03
2010.60	Erin Street	Queanbeyan River	571.79	571.50	-0.29
2010.61	Riverside Cemetery	Queanbeyan River	571.50	571.42	-0.08
2010.62	Riverside Cemetery	Queanbeyan River	571.51	571.35	-0.16
2010.63	Riverside Cemetery	Queanbeyan River	571.54	571.21	-0.33
2010.64	Riverside Cemetery	Queanbeyan River	571.47	571.09	-0.38
-	Oaks Estate stream gauge	Molonglo River	569.53	569.61	0.08

1. Source of recorded peak flood levels and descriptors: Council.
2. Refer **Figure C4.6** for location of available flood marks.
3. Note that a positive value indicates that the modelled flood level is higher, and conversely a negative value indicates that the modelled flood level is lower than the observed flood level.

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C3. DERIVATION OF DESIGN DISCHARGE HYDROGRAPHS

C3.1. Design Storms

C3.1.1. Rainfall Intensity

The procedures used to obtain temporally and spatially accurate and consistent Intensity-Frequency-Duration (**IFD**) design rainfall curves for the assessment of flooding at Queanbeyan are presented in GA, 2016. Design storms for frequencies of 20, 10, 5, 2 and 1% AEP were derived for storm durations ranging between 30 minutes and seven days. The IFD dataset was downloaded from the BoMs *2016 Rainfall IFD Data System*.

C3.1.2. Areal Reduction Factors

The rainfalls derived using the processes outlined in GA, 2016 are applicable strictly to a point. In the case of a catchment of over tens of square kilometres area, it is not realistic to assume that the same rainfall intensity can be maintained. An Areal Reduction Factor (**ARF**) is typically applied to obtain an intensity that is applicable over the entire catchment.

ARFs derived for the Queanbeyan and Molonglo River catchments at the upstream extent of the study area for storms ranging between 12 and 72 hours based on the methodology presented in GA, 2016 are shown in **Table C3.1** over

As the local catchment draining to the Queanbeyan CBD is relatively small (400 ha), the reduction in rainfall intensity would be quite small. Accordingly, no reduction in design point rainfalls was made for modelling local catchment storms as part of the present study (i.e. an ARF of 1.0 was adopted).

C3.1.3. Temporal Patterns

GA, 2016 prescribes the analysis of 10 temporal patterns per storm duration for various zones in Australia. These patterns are used in the conversion of a design rainfall depth with a specific AEP into a design flood of the same frequency. The patterns may be used for AEPs down to 0.2 per cent where the design rainfall data is extrapolated for storm events with an AEP less than 1 per cent.

The temporal pattern ensembles that are applicable to catchments with for Frequent (more frequent than 14.4% AEP), Intermediate (between 3.2 and 14.4% AEP) and Rare (rarer than 3.2% AEP) storm events were obtained from the ARR Data Hub[3], while those for the very rare events were taken from the BoMs update of *Bulletin 53* (BoM, 2003).

Point temporal pattern ensembles were applied for storm durations less than 12 hours, while the areal temporal pattern set for catchment areas between 300 to 700 km^2 were applied for storm durations of 12 hours or longer.[4]

[3] It is noted that the temporal pattern data set for the *Murray Basin* region is suitable for use at Queanbeyan.

[4] Although the total catchment area at the Wickerslack stream gauge is greater than 700 km^2, the adoption of the areal temporal pattern set for catchment areas between 700 to 1600 km^2 had a negligible impact of the derived design flows at the gauge. Therefore the areal temporal pattern set for the smaller catchments was adopted.

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TABLE C3.1
ADOPTED AREAL REDUCTION FACTORS(1)

AEP (%)	Queanbeyan River at Wickerslack (GS410760)(2)							Molonglo River at Burbong (GS 410705)(2)						
	12	**18**	**24**	**30**	**36**	**48**	**72**	**12**	**18**	**24**	**30**	**36**	**48**	**72**
20	0.86	0.90	0.93	0.94	0.94	0.94	0.95	0.89	0.92	0.94	0.95	0.95	0.95	0.96
10	0.85	0.89	0.93	0.93	0.93	0.94	0.95	0.88	0.91	0.94	0.95	0.95	0.95	0.96
5	0.85	0.89	0.92	0.93	0.93	0.94	0.94	0.87	0.91	0.94	0.95	0.95	0.95	0.96
2	0.84	0.88	0.92	0.93	0.93	0.93	0.94	0.87	0.91	0.94	0.94	0.94	0.95	0.95
1	0.83	0.88	0.92	0.93	0.93	0.93	0.94	0.86	0.9	0.94	0.94	0.94	0.95	0.95
0.5	0.82	0.87	0.92	0.92	0.92	0.93	0.94	0.85	0.89	0.93	0.94	0.94	0.95	0.95
0.2	0.81	0.86	0.91	0.92	0.92	0.93	0.93	0.84	0.89	0.93	0.94	0.94	0.94	0.95

1. ARFs derived based on the methodology which applies to catchments that are affected by the South East Coast region as defined in GA, 2016.
2. Based on a total catchment area of 909 km^2 at the Wickerslack stream gauge.
3. Based on a total catchment area of 498 km^2 at the Burbong stream gauge.

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C3.1.4. Probable Maximum Precipitation

Estimates of PMP were made using the Generalised Short Duration Method (**GSDM**) as described in BoM, 2003. This method is appropriate for estimating extreme rainfall depths for catchments up to 1,000 km^2 in area and storm durations up to six hours.[5]

The steps involved in assessing PMP for each study catchment are briefly as follows:

- Calculate PMP for a given duration and catchment area using depth-duration-area envelope curves derived from the highest recorded US and Australian rainfalls.
- Adjust the PMP estimate according to the percentages of the catchment which are meteorologically rough and smooth, and also according to elevation adjustment and moisture adjustment factors.
- Assess the design spatial distribution of rainfall using the distribution for convective storms based on US and world data, but modified in the light of Australian experience.
- Derive storm hyetographs using the temporal distribution contained in BoM, 2003, which is based on pluviographic traces recorded in major Australian storms.

Figures C1.1, sheet 1 shows the location and orientation of the PMP ellipses which were used to derive the rainfall estimates for the Queanbeyan and Molonglo Rivers.

C3.2. Design Rainfall Losses

The ARR Data Hub is generally used to derive the initial and continuing loss values to be applied in flood hydrograph estimation. **Table C3.2** sets out the ARR Data Hub recommend Storm and Continuing Loss values derived using the predicted loss equations that have been developed as part of GA, 2016.

TABLE C3.2
DESIGN STORM AND CONITUINING LOSS VALUES

Source	Catchment	Distance from Queanbeyan	Storm Loss (mm)	Continuing Losses (mm/hr)
ARR Data Hub	-	-	19	7.2
GA, 2016(1)	Jerrabomberra Creek	8.6	22	2.1
	Ginninderra Creek	20.8	38	6.5
	Butmaroo Creek	31.2	40	2.6
	Orroral River	40.6	18	7.1
	Tidbinilla Creek	60.6	10	8.8

1. Taken from Table 5.3.14 in Chapter 3 of Book 5 of GA, 2016.

[5] Estimates of PMP were also made using the Generalised Southeast Australia Method (Inland) (**GSDM**) as described in BoM, 2006, but it was found that those derived using the GSDM method were critical for maximum the peak flows in the Queanbeyan and Molonglo Rivers.

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Table 5.3.14 in Chapter 3 of Book 5 of GA, 2016 contains a list of the median loss values at 35 gauged catchments across Australia that were used to derive prediction equations used to estimate the Storm Continuing Loss values for rural catchments in GA, 2016. **Table C3.2** sets out the median Storm Loss of and Continuing Loss values at five of the abovementioned gauged catchments that are in close proximity to Queanbeyan.

As the loss values recommended for use at Queanbeyan for vary so significantly, the approach adopted as part of the present investigation was to adjust the Storm and Continuing Loss values until a good match was achieved between the Queanbeyan Hydrologic Model and the design peak flow estimates derived from the flood frequency analysis that undertaken as part of the present study and the Wickerslack an Burbong stream gauges (refer **Table C3.3** for adopted loss values).

As DRAINS uses the Hortonian loss modelling approach which does not require the user to input a continuing loss rate, the following set of parameters were adopted for generating flows in the local catchment draining to the Queanbeyan CBD:

- Paved area depression storage = 2 mm
- Grassed area depression storage = 10 mm
- Soil Type = 3.0
- AMC = 3.0

C3.3. Derivation of Design Discharges

The Queanbeyan Hydrologic Model was run with the adopted parameters to obtain discharge hydrographs for design storms of 20, 10, 5, 2, 1, 0.5 and 0.2% AEP, as well as the PMF. **Figure C3.1** shows design discharge hydrographs generated by the hydrologic model at the upstream boundary of the Queanbeyan TUFLOW Model for design floods of between 20 and 0.2% AEP.

Table C3.3 at the end of this chapter shows a comparison between peak flows generated by the calibrated RAFTS model with estimates derived from the results of the flood frequency analysis that was undertaken at the Wickerslack and Burbong stream gauges (refer **Section B4.2** of **Appendix B**). The 48 hour storm was found to be the critical duration event for defining flooding behaviour on the Queanbeyan River floodplain at Queanbeyan.

While the peak 1% AEP flow of 1,430 m^3/s derived as part of the present study at the Wickerslack stream gauge is similar to the peak 1% AEP flow of 1,394 m^3/s given in ActewAGL, 2008 at the spillway of Googong Dam, it is about 20% higher than the revised value of 1,200 m^3/s presented in Icon Water, 2020.

The peak PMF flows in the Queanbeyan and Molongo Rivers derived as part of the present study are 7.5 and 8.2 times higher, respectively than the peak 1% AEP flows. While the peak PMF flow at the Wickerslack stream gauge that was derived as part of the present study is 10,754 m^3/s is about 15% higher than the PMF flow adopted in ActewAGL, 2008 (i.e. 9,300 m^3/s), it is similar to the revised value of 10,100 m^3/s presented in Icon Water, 2020.

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TABLE C3.3
ADOPTED HYDROLOGIC MODEL PARAMETERS

AEP (%)	Flood Frequency		Hydrologic Model Parameters[3]			Queanbeyan Hydrologic Model		Adopted Temporal Pattern[4]
	Discharge (m^3/s)		Storm Loss (mm)	Continuing Loss (mm)		Discharge (m^3/s)		
	Queanbeyan River at Wickerslack[1]	Molonglo River at Burbong[2]		Queanbeyan River at Wickerslack	Molonglo River at Burbong	Queanbeyan River at Wickerslack	Molonglo River at Burbong	
20	205	215	15	4.0	2.3	217	221	Frequent Storm 5 (ID = 4206)
10	370	340	15	4.0	2.5	365	321	Intermediate Storm 5 (ID = 4188)
5	585	460	15	3.9	2.5	589	474	Intermediate Storm 4 (ID = 4152)
2	990	590	15	3.3	3.0	995	584	Rare Storm 4 (ID = 2523)
1	1,430	685	15	2.7	3.3	1,436	682	Rare Storm 4 (ID = 2523)
0.5	2,030	780	15	1.3	3.4	2,027	784	Rare Storm 4 (ID = 2523)
0.2	3,220	930	0	0	4	2,854	938	Rare Storm 4 (ID = 2523)
PMF	-	-	0	1	1	10,754	5,562	Refer BoM, 2003

1. Peak flows taken from **Column I** of **Table B4.2** and **Figure B4.7** (RHS).
2. Peak flows taken from **Column M** of **Table B4.2** and **Figure B4.8** (RHS).
3. A BX of 0.8 was applied to all storms.
4. Taken from designated areal temporal pattern set for catchments with a target catchment area of 500 km^2.

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C4. HYDRAULIC MODELLING OF DESIGN STORMS

C4.1. Accuracy of Hydraulic Modelling

The accuracy of results depends on the precision of the numerical finite difference procedure used to solve the partial differential equations of flow, which is also influenced by the time step used for routing the floodwave through the system and the grid spacing adopted for describing the natural surface levels in the floodplain. The results are also heavily dependent on the size of the two-dimensional grid, as well as the accuracy of the LiDAR survey data, which as noted in **Section B1** have a design vertical accuracy of +/- 150 mm.

Given the uncertainties in the LiDAR survey data and the definition of features affecting the passage of flow, maintenance of a depth of flow of at least 100 mm is required for the definition of a "continuous" flow path in the areas subject to shallow overland flow. Lesser modelled depths of inundation may be influenced by the above factors and therefore may be spurious, especially where that inundation occurs at isolated locations and is not part of a continuous flow path. In areas where the depth of inundation is greater than the 100 mm threshold and the flow path is continuous, the likely accuracy of the hydraulic modelling in deriving peak flood levels is considered to be between 100 and 150 mm.

Use of the TUFLOW Model results when applying flood related controls to development proposals should be undertaken with the above limitations in mind. Proposals should be assessed with the benefit of a site survey to be supplied by applicants in order to allow any inconsistencies in results to be identified and given consideration. This comment is especially appropriate in the areas subject to shallow flow, where the errors in the LiDAR survey data or obstructions to flow would have a proportionally greater influence on the computed water surface levels than in the deeper flooded main stream areas.

Minimum floor levels for residential, commercial and industrial developments should be based on the 1% AEP flood level plus appropriate freeboard (i.e. the *FPL*), to cater for uncertainties such as wave action, effects of flood debris conveyed in the flow stream and precision of modelling. Note that a freeboard of 500 mm has been adopted for defining the *FPLs*.

The sensitivity studies and discussion presented in **Section C4.3** provide guidance on the suitability of the recommended allowance for freeboard under present day climatic conditions.

C4.2. Presentation of Results

Figures 2.2 and **2.3** of the Main Report show the nature of main stream flooding at Queanbeyan for the 1% AEP and PMF events, respectively, while **Figures C4.1** to **C4.6** show similar information for the 20, 10, 5, 2, 0.5 and 0.2% AEP flood events. These diagrams show the indicative extents and depths of inundation, as well as peak water surface elevation contours in the vicinity of Queanbeyan.

Figure 2.4 of the Main Report shows water surface profiles along the Queanbeyan and Molonglo Rivers for the full range of design flood events, while **Table 2.2** of the Main Report sets out the design flood levels at the Wickerslack, Queens Bridge and A.C.T. Border stream gauges on the Queanbeyan River, as well as the Oaks Estate stream gauge on the Molonglo River.

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The key features main stream flooding at Queanbeyan for the various design flood events are described in **Section 2.5.2** of the Main Report.

Figure 2.5 of the Main Report shows the nature of local catchment flooding in the vicinity of the Queanbeyan CBD for a storm event with an AEP of 1 per cent. A brief description of this type of flooding is contained in **Section 2.5.3** of the Main Report.

C4.3. Comparison with Previous Studies

DWR, 1992 defined flooding patterns at Queanbeyan for the 50, 20, 10, 5, 2, 1, 0.5 and 0.2% AEP flood events. A cross sectional based steady-state HEC-2 hydraulic model was developed as part of DWR, 1992 which extended from the upstream limits of the City in the vicinity of the confluence of the Queanbeyan River and Valley Creek to its confluence with the Molonglo River.

Figure 2.4 of the Main Report shows a comparison of the design peak flood levels along the Queanbeyan River derived by DWR, 1992 and those derived as part of the present study for the full range of design flood events, while **Table C4.1** over sets out the difference in peak flood floods derived by the two studies.

While the peak design flood levels at the Queens Bridge generally achieve a good match between the two studies (refer C.S. 3189 if **Table C4.1**) for flood events derived up to 1% AEP in magnitude, the peak flood levels for the 0.5 and 0.2% AEP floods, respectively are 0.5 and 0.9 m higher in the present study as the design peak flows for these events are 7% and 14% higher those adopted in DWR, 1992.

Figure 2.4, sheet 1 shows that peak flood levels on the Queanbeyan River are up to 1.0 m higher than those derived as part of DWR, 1992 upstream of the Queanbeyan Suspension Bridge between River Chainages 3.0 and 5.6 km. The Queanbeyan TUFLOW Model more accurately represents the reduction in floodplain width in the vicinity of Dane Street (Chainage 4.5 km) and Hayes Street (Chainage 5.4 km) than the cross sectional based HEC-2 Model derived as part of DWR, 1992.

Table C4.1 and **Figure 2.4**, sheet 1 also show that the design peak flood levels in the Queanbeyan River downstream of the Morisset Street Bridge are up to 1.8 m higher in the present study due to the high Mannings n roughness values that were required to match recorded flood data for the December 2010 flood and were subsequently adopted for design flood modelling.

C4.4. Sensitivity Studies

C4.4.1. General

The sensitivity of the hydraulic model was tested to variations in model parameters such as hydraulic roughness and the partial blockage of major hydraulic structures across the Queanbeyan River. The main purpose of these studies was to give some guidance on the freeboard to be adopted when setting floor levels of development in flood prone areas, pending the completion of the future *FRMS*. The results are summarised in the following sections.

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TABLE C4.1
COMPARISON OF DESIGN PEAK FLOOD LEVELS

Cross Section ID[1]	20% AEP			10% AEP			5% AEP			2% AEP			1% AEP			0.5% AEP			0.2% AEP		
	Peak Flood Level (m AHD)		Difference[2] (m)	Peak Flood Level (m AHD)		Difference[2] (m)	Peak Flood Level (m AHD)		Difference[2] (m)	Peak Flood Level (m AHD)		Difference[2] (m)	Peak Flood Level (m AHD)		Difference[2] (m)	Peak Flood Level (m AHD)		Difference[2] (m)	Peak Flood Level (m AHD)		Difference[2] (m)
	DWR,1992	Present Study		DWR,1992	Present Study		DWR,1992	Present Study		DWR,1992	Present Study		DWR,1992	Present Study		DWR,1992	Present Study		DWR,1992	Present Study	
C.S. 36	574.9	574.9	0.0	575.9	576.1	0.2	577.1	577.5	0.4	578.6	579.3	0.7	580.2	580.9	0.7	581.4	582.6	1.2	582.7	584.5	1.8
C.S.35	574.1	573.6	-0.5	575.1	574.8	-0.3	576.3	576.3	0.0	577.8	578.1	0.3	579.4	579.7	0.3	580.6	581.4	0.8	582.0	583.2	1.2
C.S 34	573.5	573.2	-0.3	574.5	574.4	-0.1	575.7	575.8	0.1	577.1	577.6	0.5	578.7	579.1	0.4	579.8	580.7	0.9	581.1	582.5	1.4
C.S. 33	572.6	572.7	0.1	573.6	573.8	0.2	574.7	575.2	0.5	576.0	576.9	0.9	577.5	578.3	0.8	578.7	579.9	1.2	580.1	581.7	1.6
C.S. 32	572.4	572.4	0.0	573.4	573.6	0.2	574.6	575.0	0.4	575.8	576.8	1.0	577.4	578.3	0.9	578.6	579.9	1.3	580.0	581.6	1.6
C.S. 3230	572.0	571.9	-0.1	573.0	573.1	0.1	574.1	574.5	0.4	575.2	576.2	1.0	576.6	577.6	1.0	577.7	579.1	1.4	579.0	580.8	1.8
C.S. 3220	571.7	571.5	-0.2	572.7	572.7	0.0	573.8	574.1	0.3	574.8	575.7	0.9	576.2	577.1	0.9	577.3	578.6	1.3	578.6	580.2	1.6
C.S. 3210	571.0	570.4	-0.6	572.0	571.5	-0.5	573.2	573.0	-0.2	574.3	574.6	0.3	575.8	576.1	0.3	577.0	577.7	0.7	578.4	579.5	1.1
C.S. 3205	570.5	569.8	-0.7	571.4	571.0	-0.4	572.7	572.5	-0.2	574.0	574.1	0.1	575.5	575.5	0.0	576.8	577.1	0.3	578.2	578.8	0.6
C.S. 3200	570.4	569.7	-0.7	571.3	570.9	-0.4	572.6	572.4	-0.2	573.9	574.0	0.1	575.5	575.5	0.0	576.7	577.1	0.4	578.1	578.8	0.7
C.S. 3190	570.2	569.7	-0.5	571.1	570.9	-0.2	572.6	572.4	-0.2	573.7	574.0	0.3	575.4	575.5	0.1	576.6	577.1	0.5	578.1	578.9	0.8
C.S. 3189	570.1	569.7	-0.4	571.0	570.9	-0.1	572.2	572.4	0.2	573.7	574.1	0.4	575.4	575.5	0.1	576.6	577.1	0.5	578.0	578.9	0.9
C.S. 3181	570.0	569.6	-0.4	571.0	570.8	-0.2	572.2	572.3	0.1	573.7	574.0	0.3	575.4	575.4	0.0	576.6	577.0	0.4	578.0	578.7	0.7
C.S. 3180	570.0	569.5	-0.5	571.0	570.7	-0.3	572.2	572.3	0.1	573.7	573.9	0.2	575.4	575.4	0.0	576.6	577.0	0.4	578.0	578.7	0.7
C.S. 3140	569.6	569.1	-0.5	570.7	570.6	-0.1	572.1	572.2	0.1	573.5	573.9	0.4	575.3	575.3	0.0	576.5	576.9	0.4	578.0	578.7	0.7
C.S. 3120	569.5	569.0	-0.5	570.6	570.4	-0.2	572.1	572.1	0.0	573.5	573.8	0.3	575.2	575.3	0.1	576.5	576.9	0.4	577.9	578.7	0.8
C.S. 3090	569.3	568.9	-0.4	570.5	570.4	-0.1	572.0	572.1	0.1	573.4	573.8	0.4	575.2	575.3	0.1	576.4	576.9	0.5	577.9	578.6	0.7
C.S. 3070	568.7	568.7	0.0	570.0	570.2	0.2	571.5	571.9	0.4	573.0	573.6	0.6	574.9	575.0	0.1	576.2	576.6	0.4	577.7	578.3	0.6
C.S. 3060	567.9	568.5	0.6	569.2	569.9	0.7	570.7	571.6	0.9	572.2	573.2	1.0	574.2	574.6	0.4	575.6	576.1	0.5	577.1	577.8	0.7
C.S. 3040	567.7	568.4	0.7	568.9	569.8	0.9	570.4	571.5	1.1	571.9	573.2	1.3	573.8	574.6	0.8	575.2	576.1	0.9	576.8	577.8	1.0
C.S. 3030	567.6	568.4	0.8	568.9	569.8	0.9	570.4	571.5	1.1	571.9	573.1	1.2	573.8	574.5	0.7	575.0	576.0	1.0	576.5	577.6	1.1
C.S. 3010	567.0	568.0	1.0	568.2	569.3	1.1	569.5	571.0	1.5	571.1	572.5	1.4	573.0	573.7	0.7	574.3	575.0	0.7	575.7	576.4	0.7
C.S. 3000	566.8	567.9	1.1	568.0	569.2	1.2	569.3	570.9	1.6	570.9	572.4	1.5	572.9	573.5	0.6	574.3	574.8	0.5	575.7	576.2	0.5
C.S. 1845	566.7	567.9	1.2	567.9	569.2	1.3	569.2	570.9	1.7	570.8	572.4	1.6	572.7	573.5	0.8	574.0	574.8	0.8	575.6	576.2	0.6
C.S. 1840	566.6	567.9	1.3	567.8	569.2	1.4	569.1	570.9	1.8	570.6	572.3	1.7	572.5	573.5	1.0	573.8	574.8	1.0	575.5	576.2	0.7

1. Refer **Figure B1.2** (Sheets 1 and 2) for location of DWR, 1992 cross sections.
2. A positive value indicates that the peak flood level derived as part of the present study is higher, and conversely a negative value indicates that the peak flood level derived as part of the present study is lower than those derived as part of DWR, 1992.

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C4.4.2. Sensitivity to Hydraulic Roughness

Figure C4.7 shows the difference in peak flood levels (i.e. the "afflux") for the 1% AEP flood event resulting from an assumed 20% increase in hydraulic roughness compared to values adopted for design flood estimation (refer values set out in **Table C2.1** for the 2010 historic flood event). The typical increase in peak flood level along the Queanbeyan River was found to be in the range 0.5 m to 0.7 m.

Figure C4.8 shows the difference in peak flood levels for the 1% AEP flood event based on the adoption of the hydraulic roughness values that were required to achieve a good match with recorded flood data for the 1925 historic flood event, noting that these values are lower than those adopted for design flood estimation purposes.

Figure C4.8 shows that adopting the lower hydraulic roughness values reduces peak 1% AEP flood levels in the Queanbeyan River as far upstream as the Wickerslack stream gauge. Reductions in peak 1% AEP flood levels of up to 0.9 m in the Queanbeyan CBD and 2.5 m in the Molonglo River were found to occur as a result of the smoother floodplain.

C4.4.3. Sensitivity to Partial Blockage of Hydraulic Structures

The mechanism and geometrical characteristics of blockages in hydraulic structures and piped drainage systems are difficult to quantify due to a lack of recorded data and would no doubt be different for each system and also vary with flood events. Realistic scenarios would be limited to waterway openings becoming partially blocked during a flood event (no quantitative data are available on instances of blockage of the drainage systems which may have occurred during historic flood events).

EA, 2013 includes guidance on modes of blockage which are likely to be experienced for different hydraulic structures. In regards bridge structures, those with clear opening heights less than 3 m are said to be susceptible to blockage in streams where large floating debris is conveyed by floodwater, presumably due to large woody debris becoming lodged in the clear opening of the bridge. For bridges of all heights, EA, 2013 considers that debris is likely to also wrap around the bridge piers. **Table C4.2** sets out the bridges at Queanbeyan that would be susceptible to blockage during major flood events.

TABLE C4.2
STRUCTURES SUSCEPTABLE TO BLOCKAGE DURING MAJOR FLOOD EVENTS

Structure ID(1)	Watercourse	Structure
BLK1	Queanbeyan River	Queanbeyan Suspension Bridge
BLK2		Queens Bridge
BLK3		Morisset Street Bridge
BLK4		Goulburn-Queanbeyan Railway Line
BLK5	Molonglo River	Yass Road Bridge
BLK6		Oaks Estate Road Bridge

1. Refer **Figure C4.9** for location of structure.

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The impact an accumulation of debris on the bridges listed in **Table C4.2** on flood behaviour was assessed as part of the investigation assuming the following three modes of blockage:

- **Blockage Mode 1**: Assumes a 1 m thick raft of debris lodges beneath the underside of the bridge deck.
- **Blockage Mode 2**: Assumes a 4 m wide raft of debris lodges on the upstream side of each bridge pier over the full height of the clear opening.
- **Blockage Mode 3**: Combination of Blockage Modes 1 and 2, plus blockage of any handrails.

Figure C4.9 shows the afflux for the 1% AEP flood event resulting from a partial blockage of hydraulic structures listed in **Table C4.2**. The effects of blockage are generally less than 100 mm on the Queanbeyan River floodplain.

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APPENDIX D

FLOOD DAMAGES

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D1. INTRODUCTION AND SCOPE

D1.1. Introduction

Damages from flooding belong to two categories:

- **Tangible Damages**
- **Intangible Damages**

Tangible damages are defined as those to which monetary values may be assigned, and may be subdivided into direct and indirect damages. Direct damages are those caused by physical contact of floodwater with damageable property. They include damages to commercial and industrial and residential building structures and contents, as well as damages to infrastructure services such as electricity and water supply. Indirect damages result from the interruption of community activities, including traffic flows, trade, industrial production, costs to relief agencies, evacuation of people and contents and clean up after the flood.

Generally, tangible damages are estimated in dollar values using survey procedures, interpretation of data from actual floods and research of government files.

The various factors included in the **intangible damage** category may be significant. However, these effects are difficult to quantify due to lack of data and the absence of an accepted method. Such factors may include:

- inconvenience
- isolation
- disruption of family and social activities
- anxiety, pain and suffering, trauma
- physical ill-health
- psychological ill-health.

D1.2. Scope of Investigation

In the following sections, tangible damages to residential, commercial / industrial and public properties have been estimated resulting from flooding in Queanbeyan. Intangible damages have not been quantified. The threshold floods at which damages may commence to infrastructure and community assets have also been estimated, mainly from site inspection and interpretation of flood level data. However, there is no data available to allow a quantitative assessment of damages to be made to this category.

D1.3. Terminology

Definitions of the terms used in this Appendix are presented in **Chapter D8** which also summarises the value of Tangible Flood Damages.

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D2. DESCRIPTION OF APPROACH

The damage caused by a flood to a particular property is a function of the depth of inundation above floor level and the value of the property and its contents. The warning time available for residents to take action to lift property above floor level also influences damages actually experienced. A spreadsheet model which has been developed by OEH for estimating residential damages and an in-house spreadsheet model which has been developed for previous investigations of this nature for estimating commercial, industrial and public building damages were used to estimate damages on a property by property basis according to the type of development, the location of the property and the depth of inundation.

Using the results of the updated flood modelling, a peak flood elevation for each event was interpolated at each property. The interpolated property flood levels were input to the spreadsheet models which also contained property characteristics and depth-damage relationships. The depth of above-floor inundation was computed as the difference between the interpolated flood level and the floor elevation at each property. The elevations of 493 building floors were surveyed as part of the preparation of Lyall & Associates, 2008, while the remainder of the flood affected properties in Queanbeyan were assessed by adding the height of floor above a representative natural surface within the allotment (as estimated by visual inspection) to the natural surface elevation determined from LiDAR survey. The type of structure and potential for property damage were also assessed during the visual inspection.

The depth-damage curves for residential damages were determined using procedures described in *Guideline No. 4*. Damage curves for other categories of development (commercial and industrial, public buildings) were derived from previous floodplain management investigations.

Damages to the non-residential sector depend on the nature of the enterprise, the depth of inundation over the floor area and the time available for owners to take action to mitigate losses to contents. A spreadsheet model was used which was similar to the residential model in terms of estimation of depths of inundation, but used typical unit damage data which had been adopted in similar studies in NSW in recent years.

It should be understood that this approach is not intended to identify individual properties liable to flood damages and the value of damages in individual properties, even though it appears to be capable of doing so. The reason for this caveat lies in the various assumptions used in the procedure, the main ones being:

- the assumption that computed water levels and topographic data used to define flood extents are exact and without any error;
- the assumption that the water levels as computed by the hydraulic model are not subject to localised influences;
- the estimation of property floor levels by visual inspection rather than by formal field survey;
- the use of "average" stage-damage relationships, rather than a unique relationship for each property;
- the uncertainties associated with assessing appropriate factors to convert *potential damages* to *actual flood damages* experienced for each property after residents have taken action to mitigate damages to contents.

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The consequence of these assumptions is that some individual properties may be inappropriately classified as flood liable, while others may be excluded. Nevertheless, when applied over a broad area these effects would tend to cancel, and the resulting estimates of overall damages, would be expected to be reasonably accurate.

For the above reasons, the information contained in the spreadsheets used to prepare the estimates of flood damages for the catchments should not be used to provide information on the depths of above-floor inundation of individual properties.

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D3. SOURCES OF DATA

D3.1. General

To estimate A*verage Annual Flood Damages* for a specific area it is necessary to estimate the damages for several floods of different magnitudes, i.e. of different frequencies, and then to integrate the area beneath the damage – frequency curve computed over the whole range of frequencies up to the PMF. To do this it is necessary to have data on the damages sustained by all types of property over the likely range of inundation. There are several ways of doing this:

- The ideal way would be to conduct specific damage surveys in the aftermath of a range of floods, preferably immediately after each. An example approaching this ideal is the case of Nyngan where surveys were conducted in May 1990 following the disastrous flood of a month earlier (DWR, 1990). This approach would not be practicable at Queanbeyan given the limited data that are available on historic flood damages.
- The second best way is for experienced loss adjusters to conduct a survey to estimate likely losses that would arise due to various depths of inundation. This approach is used from time to time, but it can add significantly to the cost of a floodplain management study (LMJ, 1985). It was not used for the present investigation.
- The third way is to use generalised data such as that published by CRES (Centre for Resource & Economic Studies, Canberra) and used in the Floodplain Management Study for Forbes (SKM, 1994). These kinds of data are considered to be suitable for generalised studies, such as broad regional studies. They are not considered to be suitable for use in specific areas, unless none of the other approaches can be satisfactorily applied.
- The fourth way is to adapt or transpose data from other flood liable areas. This was the approach used for the present study. As mentioned, the *Guideline No 4* procedure was adopted for the assessment of residential damages. The approach was based on data collected following major flooding in Katherine in 1998, with adjustments to account for changes in values due to inflation, and after taking into account the nature of development and flooding patterns in the study area. The data collected during site inspection in the flood liable areas assisted in providing the necessary adjustments. Commercial and industrial damages were assessed via reference to recent floodplain management investigations of a similar nature to the present study.

D3.2. Property Data

The properties were divided into three categories: residential, commercial / industrial, and public buildings.

For residential properties, the data used in the damages estimation included:

- the location/address of each property
- an assessment of the type of structure
- natural surface level
- floor level

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For commercial / industrial and public properties, the required data included:

- the location of each property
- the nature of each enterprise
- an estimation of the floor area
- natural surface level
- floor level

The property descriptions were used to classify the commercial and public developments into categories (i.e. high, medium or low value properties) which relate to the magnitude of likely flood damages.

The total number of residential properties, commercial / industrial and public buildings is shown in **Table D3.1**.

TABLE D3.1
NUMBER OF PROPERTIES INCLUDED IN DAMAGES DATABASE

Development Type	Number of Properties
Residential(1)	3,189
Commercial / Industrial	395
Public	89
Total	**3,673**

1. Includes individual residential units

D3.3. Flood Levels Used in the Analysis

Damages were computed for the design flood levels determined from the hydraulic model that was developed as part of the present investigation. The design levels assume that the drainage system is operating at optimum capacity. They do not allow for any increase in levels resulting from wave action, debris build-ups in the channels which may cause a partial blockage of bridges and which may result in conversions of flow from the supercritical to the subcritical flow regime, as well as other local hydraulic effects. These factors are usually taken into account by adding a factor of safety (freeboard) to the “nominal” flood level when assessing the “level of protection” against flooding of a particular property. Freeboard could also include an allowance for the future effects of climate change.

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D4. RESIDENTIAL DAMAGES

D4.1. Damage Functions

The procedures identified in *Guideline No 4* allow for the preparation of a depth versus damage relationship which incorporates structural damage to the building, damage to internals and contents, external damages and clean-up costs. In addition, there is the facility for including allowance for accommodation costs and loss of rent. Separate curves are computed for three residential categories:

- Single storey slab on ground construction
- Single storey elevated floor
- Two storey residence

The level of flood awareness and available warning time are taken into account by factors which are used to reduce "potential" damages to contents to "actual" damages. "Potential" damages represent losses likely to be experienced if no action were taken by residents to mitigate impacts. A reduction in the potential damages to "actual" damages is usually made to allow for property evacuation and raising valuables above floor level, which would reduce the damages actually experienced. The ability of residents to take action to reduce flood losses is mainly limited to reductions in damages to contents, as damages to the structure and clean-up costs are not usually capable of significant mitigation.

The reduction in damages to contents is site specific, being dependent on a number of factors related to the time of rise of floodwaters, the recent flood history and flood awareness of residents and emergency planning by the various Government Agencies (BoM and NSW SES).

Flooding in Queanbeyan is "flash flooding" in nature, with surcharge of the Queanbeyan River occurring within three hours after water levels commence to rise. Consequently, there would be very limited time in advance of a flood event in which to warn residents and business owners, and for them to take action to mitigate flood losses.

Provided adequate warning were available, house contents may be raised above floor level to about 0.9 m, which corresponds with the height of a typical table/bench height. The spreadsheet provides two factors for assessing damages to contents, one for above and one for below the typical bench height. The reduction in damages is also dependent on the likely duration of inundation of contents, which would be limited to no more than an hour for most flooded properties.

Table D4.1 over shows total flood damages estimated for the three classes of residential property using the procedures identified in *Guideline No. 4*, for typical depths of above-floor inundation of 0.3 m and 1.0 m (The maximum depth of above-floor inundation in Queanbeyan is about 3.1 m at the 1% AEP level of flooding). A typical ground floor area of 240 m^2 was adopted for the assessment. The values in **Table D4.1** allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

D4.2. Total Residential Damages

Table D4.2 over summarises residential damages for the range of floods in Queanbeyan. The damage estimates were carried out for floods between the 20% AEP and the PMF, which were modelled hydraulically as part of the present study.

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TABLE D4.1
DAMAGES TO RESIDENTIAL PROPERTIES

Type of Residential Construction	0.3 m Depth of Inundation Above Floor Level	1.0 m Depth of Inundation Above Floor Level
Single Storey Slab on Ground	$97,541	$132,959
Single Storey High Set	$82,314	$117,719
Double Storey	$57,620	$82,403

Note: These values allow for damages to buildings and contents, as well as external damages and provision for alternative accommodation.

TABLE D4.2
RESIDENTIAL FLOOD DAMAGES IN QUEANBEYAN

Design Flood Event (% AEP)	Number of Properties		Damages ($ Million)
	Flood Affected	Flood Above Floor Level	
20%	0	0	0
10%	0	0	0
5%	0	0	0
2%	116	93	10.2
1%	313	260	34.9
0.5%	563	529	79.8
0.2%	907	853	142
PMF	3,032	3,003	589

The threshold of flooding for residential type development in Queanbeyan is the 5% AEP flood, above which a large number of properties commence to be flood affected and above-floor inundated. At the 2% AEP level of flooding, floodwater overtops Morrisset Street on the eastern bank of the Queanbeyan River where it inundates parts of the Queanbeyan CBD where several residential properties are located. Several dwellings located along Woodger Street upstream of the Queanbeyan CBD also experience above-floor inundation at the 2% AEP level of flooding.

On the opposing bank of the Queanbeyan River, above-floor inundation is experienced in a number of residential properties that are located along Macquoid Street, Mowatt Street, Waniassa Street at the 2% AEP level of flooding.

The majority of properties that experience above-floor inundation at the 2% AEP level of flooding comprise permanent residential or temporary motel unit type development that is located on both sides of the Queanbeyan River. Two second storey residential units would be above-floor inundated during a 1% AEP event, increasing to 82 and 166 for floods with AEPs of 0.5 and 0.2 per cent, respectively. No third storey units are above-floor inundated at the 0.2% AEP level of flooding. During a PMF event, over 270 second, 150 third, five fourth and five fifth storey residential units would experience above-floor inundation.

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D5. COMMERCIAL / INDUSTRIAL DAMAGES

D5.1. Direct Commercial / Industrial Damages

The method used to calculate damages requires each property to be categorised in terms of the following:

- damage category
- floor area
- floor elevation

The damage category assigned to each enterprise may vary between "low", "medium" or "high", depending on the nature of the enterprise and the likely effects of flooding. Damages also depend on the floor area.

It has recently been recognised following the 1998 flood in Katherine that previous investigations using stage-damage curves contained in proprietary software tends to seriously underestimate true damage costs. OEH are currently researching appropriate damage functions which could be adopted in the estimation of commercial and industrial categories as they have already done with residential damages. However, these data were not available for the present study.

On the basis of previous investigations the following typical damage rates are considered appropriate for potential external and internal damages and clean-up costs for both commercial and industrial properties. They are indexed to a depth of inundation of 2 metres. At floor level and 1.2 m inundation, zero and 70% of these values respectively were assumed to occur:

Low value enterprise	$280/m^2	(e.g. Commercial: small shops, cafes, joinery, public halls. Industrial: auto workshop with concrete floor and minimal goods at floor level, Council or Government Depots, storage areas.)
Medium value enterprise	$420/m^2	(e.g. Commercial: food shops, hardware, banks, professional offices, retail enterprises, with furniture/fixtures at floor level which would suffer damage if inundated. Industrial: warehouses, equipment hire.)
High value enterprise	$650/m^2	(e.g. Commercial : electrical shops, clothing stores, bookshops, newsagents, restaurants, schools, showrooms and retailers with goods and furniture, or other high value items at ground or lower floor level. Industrial: service stations, vehicle showrooms, smash repairs.)

The factor for converting potential to actual damages depends on a range of variables such as the available warning time, flood awareness and the depth of inundation. Given sufficient warning time, a well prepared business will be able to temporarily lift property above floor level. However, unless property is actually moved to flood free areas, floods which result in a large depth of inundation, will cause considerable damage to stock and contents.

For the present study, the potential damages described above were converted to actual damages using a multiplier which ranged from between 0.5 and 0.8 depending on the depth of above-floor inundation.

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D5.2. Indirect Commercial and Industrial Damages

Indirect commercial and industrial damages comprise costs of removal of goods and storage, loss of trading profit and loss of business confidence.

Disruption to trade takes the following forms:

- The loss through isolation at the time of the flood when water is in the business premises or separating clients and customers. The total loss of trade is influenced by the opportunity for trade to divert to an alternative source. There may be significant local loss but due to the trade transfer this may be considerably reduced at the regional or state level.
- In the case of major flooding, a downturn in business can occur within the flood affected region due to the cancellation of contracts and loss of business confidence. This is in addition to the actual loss of trading caused by closure of the business by flooding.

Loss of trading profit is a difficult value to assess and the magnitude of damages can vary depending on whether the assessment is made at the local, regional or national level. Differences between regional and national economic effects arise because of transfers between the sectors, such as taxes, and subsidies such as flood relief returned to the region.

Some investigations have lumped this loss with indirect damages and have adopted total damage as a percentage of the direct damage. In other cases, loss of profit has been related to the gross margin of the business, i.e. turnover less average wages. The former approach has been adopted in this present study. Indirect damages have been taken as 50% of direct actual damages. A clean-up cost of $15/m^2 of floor area of each flooded property was also included.

D5.3. Total Commercial and Industrial Damages

Table D5.1 over summarises estimated commercial and industrial damages in Queanbeyan.

The threshold of flooding for commercial and industrial type development in Queanbeyan is a flood with an AEP that is slightly greater 5 per cent. At the 5% AEP level of flooding, commercial development located in Carinya Street and Morisset Street on the western bank, and in Macquoid Street on the eastern bank of the Queanbeyan River would experience above-floor inundation. The number of commercial properties that experience above-floor flooding increases significantly at the 2% AEP level of flooding, due principally to floodwater entering the Queanbeyan CBD.

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TABLE D5.1
COMMERCIAL AND INDUSTRIAL FLOOD DAMAGES IN QUEANBEYAN

Design Flood Event (% AEP)	Number of Properties		Damages ($ Million)
	Flood Affected	Flood Above Floor Level	
20%	0	0	0
10%	0	0	0
5%	5	5	0.3
2%	72	65	7.5
1%	271	239	32.9
0.5%	340	336	83.3
0.2%	351	351	141
PMF	391	388	409

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D6. DAMAGES TO PUBLIC BUILDINGS

D6.1. Direct Damages – Public Buildings

Included under this heading are government buildings, churches, swimming pools and parks. Damages were estimated individually on an area basis according to the perceived value of the property. Potential internal damages were indexed to a depth of above-floor inundation of 2 m as shown below. At floor level and 1.2 m depth of inundation, zero and 70% of these values respectively were assumed to occur.

Low value	$280/m^2	
Medium value	$420/m^2	(e.g. council buildings, NSW SES HQ, fire station)
High value	$650/m^2	(e.g. schools)

These values were obtained from the Nyngan Study (DWR, 1990), as well as commercial data presented in the Forbes Water Studies report (WS, 1992) and adjusted for inflation. External and structural damages were taken as 4 and 10% of internal damages respectively.

D6.2. Indirect Damages – Public Buildings

A value of $15/m^2 was adopted for the clean-up of each property. This value is based on results presented in the Nyngan Study and adjusted for inflation. Total "welfare and disaster" relief costs were assessed as 50% of the actual direct costs.

D6.3. Total Damages – Public Buildings

Table D6.1 summarises estimated damages to public buildings in Queanbeyan.

The threshold of flooding for public buildings in Queanbeyan is the 5% AEP flood. At the 2% AEP level of flooding, above-floor flooding would be experienced in two public buildings that are located in Morisset Street and Carinya Street. Ten public buildings would be above-floor inundated at the 1% AEP level of flooding, all but one of which are located on the western side of the Queanbeyan River.

TABLE D6.1
PUBLIC FLOOD DAMAGES IN QUEANBEYAN

Design Flood Event (% AEP)	Number of Properties		Damages ($ Million)
	Flood Affected	Flood Above Floor Level	
20%	0	0	0
10%	0	0	0
5%	0	0	0
2%	2	2	0.2
1%	20	10	1.9
0.5%	30	28	14.1
0.2%	41	39	27.7
PMF	73	73	113

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D7. DAMAGES TO INFRASTUCTURE AND COMMUNITY ASSETS

No data are available on damages experienced to infrastructure and community assets during historic flood events. However, a qualitative matrix of the effects of flooding on critical assets in Queanbeyan is presented in **Table 2.4** of the Main Report.

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D8. SUMMARY OF TANGIBLE DAMAGES

D8.1. Tangible Damages

Floods have been computed for a range of flood frequencies from 20% AEP up to the PMF. From **Table D8.1**, the threshold for flood damages is a flood slightly smaller than a 5% AEP flood event, with considerable flood damages expected to occur in Queanbeyan commencing at the 2% AEP level of flooding, principally as a result of floodwater entering the Queanbeyan CBD.

Figure D8.1 shows the damage-frequency curves and cumulative distribution of above-floor depths of inundation at the 1% AEP flood level for residential, commercial and industrial and public buildings in Queanbeyan.

TABLE D8.1
TOTAL FLOOD DAMAGES IN QUEANBEYAN
$ MILLION

Design Flood Event (% AEP)	Residential	Commercial/ Industrial	Public	Total
20%	0	0	0	0
10%	0	0	0	0
5%	0	0.3	0	0.3
2%	10.2	7.5	0.2	17.8
1%	34.9	32.9	1.9	69.6
0.5%	79.8	83.3	14.1	177
0.2%	142	141	27.7	311
PMF	589	409	113	1,111

D8.2. Definition of Terms

Average Annual Damages (also termed “expected damages”) are determined by integrating the area under the damage-frequency curve. They represent the time stream of annual damages, which would be expected to occur on a year by year basis over a long duration.

Using an appropriate discount rate, average annual damages may be expressed as an equivalent “*Present Worth Value”* of damages and used in the economic analysis of potential flood management measures.

A flood management scheme which has a design 1% AEP level of protection, by definition, will eliminate damages up to this level of flooding. If the scheme has no mitigating effect on larger floods then these damages represent the benefits of the scheme expressed on an average annual basis and converted to the *Present Worth Value* via the discount rate.

Using the procedures outlined in *Guideline No. 4*, as well as current NSW Treasury guidelines, economic analyses were carried out assuming a 50 year economic life for projects and discount rates of 7% pa. (best estimate) and 11% and 4% pa. (sensitivity analyses).

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D8.3. Average Annual Damages

The average annual damages for all flood events up to the PMF are shown below in **Table D8.2**. Note that values have been quoted to two decimal places to highlight the relatively small recurring damages.

TABLE D8.2
AVERAGE ANNUAL DAMAGES IN QUEANBEYAN
$ MILLION

Design Flood Event (% AEP)	Residential	Commercial/ Industrial	Public	Total
20%	0	0	0	0
10%	0	0	0	0
5%	0	0.01	0	0.01
2%	0.15	0.12	0	0.27
1%	0.38	0.32	0.01	0.71
0.5%	0.66	0.61	0.05	1.32
0.2%	1.21	1.16	0.16	2.53
PMF	1.21	1.16	0.16	2.53

D8.4. Present Worth of Damages at Queanbeyan

The *Present Worth Value* of damages likely to be experienced for all flood events up to the 1% AEP and PMF, for a 50 year economic life and discount rates of 4, 7 and 11 per cent are shown in **Table D8.3** over.

For a discount rate of 7% pa, the *Present Worth Value* of damages for all flood events up to the 1% AEP flood is about $9.8 Million, for a 50 year economic life. Therefore one or more schemes costing up to this amount could be economically justified if they eliminated damages in Queanbeyan for all flood events up to this level. While schemes costing more than this value would have a benefit/cost ratio less than 1, they may still be justified according to a multi-objective approach which considers other criteria in addition to economic feasibility. Flood management measures are considered on a multi-objective basis in **Chapter 4** of the Main Report.

TABLE D8.3
PRESENT WORTH VALUE OF DAMAGES IN QUEANBEYAN
$ MILLION

Discount Rate (%)	All Floods up to 1% AEP	All Floods up to PMF
4	15.3	54.4
7	9.8	34.9
11	6.4	22.8

D9. REFERENCES

DECC (Department of Environment and Climate Change, NSW) (2007) ***"Floodplain Management Guideline No 4. Residential Flood Damages"***.

DWR (Department of Water Resources, NSW) (1990) ***"Nyngan April 1990 Flood Investigation"***.

LMJ (Lyall, Macoun and Joy, Willing and Partners Pty Ltd) (1985) ***"Camden Floodplain Management Study"***.

SKM (Sinclair Knight Merz) (1994) ***"Forbes Floodplain Management Report and Draft Floodplain Management Plan, Volume 1"***.

WS (Water Studies) (1986) ***"The Sydney Floods of August 1986"***, Volume I Residential Flood Damage Survey, Report prepared for CRCE Water Studies Pty Ltd for the NSW PWD.

WS (Water Studies) (1992) ***"Forbes Flood Damage Survey, August 1990 Flood"***.

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APPENDIX E

DRAFT FLOOD POLICY

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ANNEXURES

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FIGURES
(BOUND IN VOLUME 2)

ABBREVIATIONS

AHD	Australian Height Datum
AEP	Annual Exceedance Probability (%)
Council	Queanbeyan-Palerang Regional Council
FPL	Flood Planning Level (1% AEP flood level + 0.5 m freeboard)
FPA	Flood Planning Area (area inundated at the FPL)
FRMS&P	Floodplain Risk Management Study and Plan
LEP	Local Environmental Plan
MFL	Minimum Floor Level
NSW SES	New South Wales State Emergency Service
PMF	Probable Maximum Flood

Refer **Section E5** of this Appendix for glossary of terms.

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E1. INTRODUCTION

E1.1 Overview

This draft *Flood Policy* has been prepared to provide specific controls to guide development of land that is located on the floodplains of the Queanbeyan and Molonglo Rivers at Queanbeyan. The approach to managing future development that is subject to flooding from the Queanbeyan and Molonglo Rivers as set out in this draft *Flood Policy* supports the findings and recommendations of the *Queanbeyan Floodplain Risk Management Study and Plan*, which has been prepared as part of the NSW Government's program to mitigate the impact of major floods and reduce the associated hazards in the floodplain.

Note that the wording in this draft *Flood Policy* deals specifically with the management of future development that is subject to flooding from the Queanbeyan and Molonglo Rivers. A more general form of wording could be incorporated in the update of *Queanbeyan DCP 2012*, with location and flood behaviour specific related controls set out in a separate set of development control matrices.

E1.2 Objectives

The purpose of this draft *Flood Policy* is to responsibly exercise Council's duty of care, in order that the development of properties located in flood prone areas in Queanbeyan is undertaken in a responsible manner to reduce the impact of flooding and flood liability on individual owners and occupiers of flood prone property, and to reduce private and public losses resulting from floods.

The policy applies to all flood prone land adjacent to the Queanbeyan and Molonglo Rivers, as identified in the *Queanbeyan Floodplain Risk Management Study and Plan* and shown on **Figure E1.1** as the **Outer Floodplain**.

The objectives of this policy are to implement development controls that over time raise the floor levels of all development on flood affected properties to the **Flood Planning Level** appropriate for the particular land use, as a minimum floor elevation, and ensure that all new development is located in areas compatible with the flood risk, with minimum impact on adjacent development and flooding patterns. The policy aims to ensure that development in flood prone areas is undertaken so that:

- The proposed development does not result in any significant increase in risk of loss of life.
- Increases in economic and social costs resulting from new development are minimised.
- There is no significant increase in flood affectation on adjacent development or properties, either individually or in combination with cumulative development likely to occur on the floodplain.
- Reliable access is available for the evacuation from the area and evacuation is consistent with any flood evacuation strategies set out in the *Queanbeyan Local Flood Plan, 2005* published by the State Emergency Service.

Definitions of flood related terms used herein are provided in the **Glossary** in **Section E3** of this document.

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E2. APPLICATION OF THE POLICY

E2.1 Overview

Development controls on flood prone land are set out in **Chapter E3** of this draft *Flood Policy*. The controls recognise that different controls are applicable to different land use, location within the floodplain, depths of potential flood inundation and **Flood Hazard**.

The controls applicable to proposed development depend upon:

- The type of development proposed.
- The location of the development within the floodplain and the **Flood Hazard Zone** in which it is located.

E2.2 Nature of Flooding in Queanbeyan

Parts of Queanbeyan are subject to flooding from the Queanbeyan River which has a catchment area of 850 km^2. River flooding inundates areas on both sides of the river, extending as a backwater into the low lying natural embayment on the western bank downstream of Queens Bridge, where the commercial part of the city is located. The deepest flooded area is bounded by Antill Street and Morisset Street and extends westwards to Lowe Street.

Residential development in low lying areas in the vicinity of Campbell Street and Lowe Street also lie within the backwater influence of the river during major flood events.

At the 1% AEP flood level of 11.4 m on the flood gauge at Queens Bridge, most of the commercial centre of the City is affected. There are around six hours minimum warning time of predicted flood levels.

High flows generated by the local catchment to the west of the Campbell-Lowe Street area can also cause flooding problems when surcharges of the piped stormwater system occur and overland flows are conveyed along the street system and along local depressions through the CBD area towards the river. This type of “flash flooding” although producing lower levels than major river flooding can occur due to local storms in the absence of river flooding and with little warning for residents to take action.

Flooding from the Molonglo River also inundates parts of the City, either as a result of backwater flooding up the Queanbeyan River or due to surcharge of its southern bank during very rare and extreme flood events.

E2.3 Procedure for Applying the Development Control Policy

The procedure Council will apply for determining the specific controls applying to proposed development in flood prone areas in Queanbeyan is set out below. Upon enquiry by a prospective applicant, Council will make an initial assessment of the flood affectation and flood levels at the site using the following procedure and the results of the *Queanbeyan Floodplain Risk Management Study and Plan.*

- Assess whether the development is located in Flood Prone land, that is, land within the extent of the **Outer Floodplain** from **Figure E1.1**.
- Determine which part of the floodplain the development is located in from the **Flood Hazard Map** (**Figure E1.2**).
- Identify the category of the development from **Schedule1: Land Use Categories.**

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- Determine the appropriate **Flood Planning Level** for the category of development from **Schedule 2: Prescriptive Controls** and the flood level at the site from the results of the *Queanbeyan Floodplain Risk Management Study and Plan*.
- Confirm that the development conforms with the controls set out in **Schedule 2**.

With the benefit of this initial information from Council, the applicant will:

- Prepare the Documentation to support the Development Application according to the requirements of **Section 4** of this policy.

A survey plan showing natural surface levels over the site will be required as part of the DA Documentation. Provision of this plan by the applicant at the initial enquiry stage will assist Council in providing flood related information.

E2.4 Land Use Category and Prescriptive Controls

The policy recognises eight different types of land use for which the provisions of this policy applies. They are included in **Schedule 1: Land Use Categories.**

The policy imposes controls over these land uses according to their location within the floodplain. The floodplain of the Queanbeyan and Molonglo Rivers within the City of Queanbeyan have been divided into the following Flood Hazard Zones, the extents of which are shown on **Figure E1.2**:

- **Inner Floodplain (Hazard Category 1)**, which is shown in solid red colour. This zone comprises areas where factors such as the depth and velocity of flow, time of rise, isolation on Low Flood Islands and evacuation problems mean that the land is unsuitable for some types of development. It includes areas of High and Low Hazard Floodway, Flood Storage and Flood Fringe areas. Erection of buildings and carrying out of work; use of land, subdivision of land and demolition subject to State Environmental Planning Policies and Local Environmental Plan provisions are considered to be unsuitable in this zone.
- **Inner Floodplain (Hazard Category 2A)**, which is shown in solid green colour. This zone comprises the floodway which forms during periods when intense rain falls directly over Queanbeyan. This zone is limited to land zoned *B3-Commercial Core*. Development is not to impede the free discharge of major overland flow in this zone. The configuration of this zone may be altered subject to approval by Council.
- **Inner Floodplain (Hazard Category 2B)**, which is shown in solid orange colour. This zone comprises land zoned *B3-Commercial Core* that lies below the Flood Planning Level which is not classified as Inner Floodplain (Hazard Category 1 and 2A). Commercial and residential development is permitted in this zone provided it complies with the development controls set out in **Annexure 2**. The Minimum Floor Level (**MFL**) for residential and commercial development located in this zone is the 1% AEP flood levels plus 1.2 m and the 5% AEP flood level, respectively.
- **Inner Floodplain (Hazard Category 2C)**, which is shown in solid yellow colour. This zone comprises High Hazard Flood Storage areas where residential development that is replacing existing residential development may be permitted subject to it not increasing the density of persons resident on a site and meeting other requirements which are also applicable to residential land in the Intermediate Floodplain. Mixed use development is also permitted in this zone. However, Council will require a *Flood Risk Report* confirming the adequacy of the structure to resist hydrodynamic loadings and that the proposal would have no adverse impacts on local flooding patterns, either individually or

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cumulatively in conjunction with similar extensions in adjacent properties. The Flood Risk Report will also need to set out how the development complies with the controls set out in this Appendix.

- **Intermediate Floodplain**, which is shown in solid blue colour. This area is the remaining land lying outside the extent of the Inner Floodplain zones, but within the FPA. Within this zone, there would only be the requirement for MFLs to be set at the 1% AEP flood levels plus 0.5 m. Land use permissibility would be as specified by State Environmental Planning Policies or the Local Environmental Plan. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is considered to be unsuitable in this zone.
- **Outer Floodplain**, which is shown in solid cyan colour. This area represents the remainder of the floodplain between the Intermediate Floodplain and the extent of the Probable Maximum Flood (PMF) (that is, the extent of the floodplain). This area is outside the extent of the FPA and hence controls on residential, commercial and industrial development do not apply. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is not to be encouraged in this zone.

E2.5 The Need to Consider Cumulative Development in Assessing Developments

The draft Development Control Policy is based on the recognition that individual developments should not be evaluated in isolation, but rather, should be considered in a strategic sense as if it were one of several developments in the area. Whilst individual developments in isolation may not have a measurable impact on flooding, the cumulative impacts of ongoing development could be significant.

In the **Inner Floodplain (Hazard Category 2A)** zone developments should not block the major overland flow routes resulting from flash flooding on the local catchments. Overland flow paths and local catchment flood levels in the street system were identified in the *Queanbeyan Floodplain Risk Management Study and Plan.* Hydraulic modelling of the CBD and adjacent areas influenced by local catchment flows was carried out to provide this information to Council.

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E3. DEVELOPMENT CONTROLS

E3.1 Residential Development

E3.1.1 New Residential Development

No new dwellings or residential developments, including residential flat buildings, dual occupancy buildings or other similar developments will be permitted in the **Inner Floodplain (Hazard Category 1 and 2A)** zones.

Proposals for new dwellings in flood prone areas which are outside the **Inner Floodplain (Hazard Category 1 and 2A)** zones shall be considered following receipt of a suitable development application and the information set out in **Section 4**.

The **Flood Planning Level** defining the minimum floor level for all habitable rooms is the 1% AEP ARI flood plus 0.5 m freeboard.

Council will require any approvals granted for a new dwelling to have all electrical circuit connections to be automatically isolated in the event of floodwaters having the potential to gain access to exposed electrical circuits, either internal or external of the building.

E3.1.2 Replacement of Existing Dwellings

In the event of the destruction of or proposals to replace an existing dwelling or structure, the requirements specified in this plan for the erection of a new dwelling shall be applied to the replacement dwelling or structure.

Redevelopment of existing dwellings in the **Inner Floodplain (Hazard Category 2C)** zone will only be permitted if it is not increasing the density of persons resident on the property. In this situation Council would permit the floor level of the new dwelling to be set equal to that of the existing dwelling.

E3.1.3 Additions to Existing Single Dwellings

<u>**Additions in Inner Floodplain (Hazard Category 1) Zone**</u>

This Policy **does not favour** additions to existing dwellings in this zone because of the potential increase in risk to life and limb resulting from developments in floodway areas where velocities are significant and because of potential increases in the economic impacts of flooding. Council may at its discretion and based on the merits of the case allow a "once only" minor addition, (30 m^2 maximum floor area) provided that:

a) There is a safe evacuation route via continuously rising ground from the subject property to flood free ground.

b) The underside of the floor structure (lowest elevation of floor beams) is to be above the 1% AEP flood level plus 0.5 m.

c) No filling is permissible and obstruction to flow by piers and other supporting structures are to be minimised.

d) A *Flood Risk Report* is required confirming the adequacy of structure to resist hydrodynamic loadings and that the proposal would have no adverse impacts on local flooding patterns, either individually or cumulatively in conjunction with similar extensions in adjacent properties.

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Minor Additions with Floor Level below the Flood Planning Level

Where existing floor levels are below the **Flood Planning Level** and it is not practicable to raise the floor level of the addition to the **Flood Planning Level,** Council may, based on the merits of the proposal, allow a Minor Addition to a single residential dwelling, provided that the following controls are complied with:

a) The area is **not** located in the **Inner Floodplain (Hazard Category 1)** zone**.**

b) The maximum floor area of the ground floor is restricted to 30 m^2 if any part of the existing dwelling is below the **Flood Planning Level.**

c) Other than for the floor level, the controls for new residential development will apply to the Minor Addition.

E3.2 Commercial/Industrial Development

E3.2.1 New Buildings in the Inner Floodplain (Hazard Category 2B) Zone

This area is outside the path of floodwaters and becomes a backwater area during periods of river flooding, although depths of inundation could reach 3 metres in the event of a 1% AEP flood.

Council would prefer the minimum floor level for commercial/industrial development be set at the 1% AEP flood level plus 1.2 m freeboard in order to minimise future flood damages. However, this may not be practicable in the deepest flooded areas. Accordingly, in the **Inner Floodplain (Hazard Category 2B)** zone, Council will give consideration to allowing a floor level to be set at or above the 5% AEP flood level, provided detailed drawings and documentation are provided to Council's satisfaction covering the following items:

a) all piers and all other parts of the structure which are subject to the force of flowing waters or debris have been designed to resist the stresses thereby induced;

b) all forces transmitted by supports to the ground can be adequately withstood by the foundations and ground conditions existing on the site;

c) the structure will be able to withstand stream flow pressure, force exerted by debris, and buoyancy and sliding forces caused by the full range of flooding up to the PMF;

d) Council will require all electrical circuit connections to be automatically isolated in the event of flood waters having the potential to gain access to exposed electrical circuits, either internal or external of the building;

e) all materials used in the construction to be flood compatible to a minimum level equivalent to a 1% AEP flood level plus 1.2 m; and

f) the structure as designed will ensure that the cumulative impact of this and other similar potential developments will have no effect on the flood levels at or upstream from the site and will have no increase in stream velocity downstream of any part of the structure which will cause erosion to the ground surface or instability to any other structure.

g) the floor level is set a minimum 0.5 m above the peak flood level resulting from a 1% AEP storm directly over the catchment which contributes to overland flow through the Queanbeyan CBD.

E3.2.2 Extensions to Existing Buildings

Extensions shall be in accordance with the requirements identified above for new buildings in the respective **Flood Hazard Zones**.

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E3.3 Above and Below Ground Car Parking Facilities

E3.3.1 Specific Objectives

The specific objectives of the Policy as far as car parking is concerned are:

a) Minimise damages to motor vehicles from flooding

b) To ensure that motor vehicles do not become moving debris during floods, threatening the integrity of structures or the safety of people or damage other property.

c) Minimise damage to car parking facilities and their contents from flooding.

d) Minimise risk to human life from the inundation of basement and other car park and driveway areas.

E3.3.2 Prescriptive Controls for Above Ground Car Parking

Garages and open car parks as part of new development and re-development:

a) Minimum finished ground levels to be no lower than the 5% AEP river flood. Consideration may be given to a lower finished ground level where it can be demonstrated that providing the finished ground level below that level is not practical and objectives a) to d) of **Section E3.3.1** above are satisfied.

Garage addition or open car parking to an existing house:

a) The minimum floor level of garage additions or open space parking in areas which lie below the residential FPL should be as high as practicable and designed with respect to meeting objectives a) to d) of **Section E3.3.1** above.

E3.3.3 Prescriptive Controls for Below Ground Car Parking

Below ground or enclosed car parking facilities:

a) Not permitted within the **Inner Floodplain (Hazard Category 1)** zone**.**

b) Permissible for *new commercial and industrial development* elsewhere on the floodplain, subject to the controls over water ingress of Clause c) below.

c) Must have all access, ventilation and any other potential water entry point above the 1% AEP flood level plus freeboard[1] and a clearly signposted flood free pedestrian evacuation route from the basement area separate to the vehicular access ramps. Freeboard

d) Council will not accept flood protection measures which rely on mechanical or hydraulic means of protecting below ground car parking areas to the level of the 1% AEP plus freeboard[1].

[1] Freeboard is set equal to 0.5 m with the exception of development located in the **Inner Floodplain (Hazard Category 2B)** zone where the freeboard is set equal to 1.2 m.

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E3.4 Land Uses Requiring Special Flood Protection

The draft Development Control Policy has regard to several special types of development and the need for a higher level of flood protection than would normally be warranted in order to achieve its objective of minimising risk to human life and maintaining the operation of essential services during a flood emergency. These uses are categorised in **Schedule 1** under the headings *"Essential Community Facilities"* and *"Critical Infrastructure and Vulnerable Residential Uses".*

E3.5 Subdivision on Flood Affected Land

Subdivision on flood affected land will not be permitted on land located within the **Inner Floodplain (Hazard Category 1)** zone, or where additional flood affected residential allotments will be created below the **Flood Planning Level**.

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E4. INFORMATION TO BE SUBMITTED WITH THE DEVELOPMENT APPLICATION

E4.1 Outline of Council's Requirements

The procedure for determining the specific controls applying to proposed development in flood prone areas in Queanbeyan requires the applicant to undertake the following procedure:

- Make initial enquiries of Council regarding flood levels applicable to the site; its location within the **Flood Hazard Zones**; Land Use category and Prescriptive Controls (see **Section E2.3**).
- Prepare the documentation to support the development application according to **Sections E4.2** and **E4.3** below.

Further information is available by discussion with and upon written application to Council.

E4.2 Survey Details

A Survey Plan prepared by a Registered Surveyor is required to be lodged with the Development Application. For property lying within the floodplain i.e. within the extent of the **Outer Floodplain**, additional details relating to flood affectation are required. The Survey Plan must indicate the following:

- The location of existing building or structures;
- The floor levels and ceiling heights of all existing buildings or structures to be retained;
- Existing and/or proposed drainage easements and watercourses or other means of conveying flood flows that are relevant to the flood characteristics of the site;
- **1% AEP and Probable Maximum Flood Levels** over the site; and flood extents;
- 0.2 metre natural surface contour intervals across the entire property (existing and proposed). Note: All levels must be relative to Australian Height Datum (AHD)

E4.3 Flood Risk Report

For Residential Development, a Flood Risk Report is <u>NOT</u> required to be submitted with the development application where the applicant can demonstrate, using Council supplied flood information, that:

1. **All floor levels, including those of existing components of the development, are at or above the residential Flood Planning Level or raised to the residential Flood Planning Level; and**
2. **The property is located in a Low Flood Risk Precinct. In that case, Council would make its evaluation and confirm requirements regarding the proposed site development, based on the Survey Plan and accompanying data.**

E4.3.1 Flood Risk Report - Scope of Work

However, a **Flood Risk Report** is to be submitted for all development on land which lies below the residential Flood Planning Level (i.e. below the peak 1% AEP plus 1.2 m freeboard). This report is to be prepared by a suitably qualified Consulting Engineer and must address the following:

a) Confirm the **Flood Hazard Zone** and the relevant **Flood Planning Level** through enquiries of Council.

b) Specify proposed floor levels (and existing floor levels where they are to be retained) of habitable and non-habitable structures, and where basement or enclosed car parking is proposed, include levels of access, ventilation and any other potential water entry points.

c) Identify the constraints due to flood impacts on the land, including an assessment of the degree of inundation, hazard level, impacts of waterborne debris, buoyancy, evacuation and emergency issues during the 1% AEP and where applicable, the Probable Maximum Flood event.

d) For development in **Inner Floodplain** zones, include a site specific flood assessment that may require flood modelling to demonstrate that there will be no adverse impact on surrounding properties as a result of the development, up to the 1% AEP flood (both as a result of local catchment and riverine type flooding).

e) Provide flood related factors which are to be considered in the structural design and construction of the total development and appropriate modifications to any existing structures to be retained.

f) Propose measures to minimise risk to personal safety of occupants and the risk of property damage, addressing the flood impacts on the site for the 1% AEP event. These measures shall include but are not limited to the following:

   - Types of materials to be used, up to the **Flood Planning Level** to ensure the structural integrity for immersion and impact of velocity and debris.
   - Waterproofing methods, including but not limited to electrical equipment, wiring, fuel lines or any other service pipes and connections.

g) For commercial and industrial developments, include:

   - Flood warning signs/depth indicators for areas that may be inundated, such as open car parking areas.
   - A flood evacuation strategy which identifies a suitable temporary assembly point in a nearby **Outer Floodplain** area. The strategy should also identify one of NSW SES's three Flood Evacuation Centres which may need to be used should people be unable to return home during a flood.
   - Provision of a detailed on-site response plan to minimise flood damage, demonstrating that adequate storage areas are available for hazardous materials and valuable goods at or above the **Flood Planning Level**.
   - Where the development is located in the **Inner Floodplain (Hazard Category 2B and 2C)**, demonstrate that project design conforms with the requirements of **Section E3.2.1**.

h) For subdivisions, demonstrate that adequate building platforms or developable area, including car parking facilities, can be provided on each of the proposed new lots with levels at or above the residential **Flood Planning Level** in accordance with **Section E3.5.1**.

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E4.3.2 Floor Level below Flood Planning Level (Minor Addition to a Single Dwelling only)

Where it is proposed to construct the addition to an existing dwelling below the **Flood Planning Level**, the following issues must be addressed in the **Flood Risk Report**, in addition to the issues listed above:

a) Confirm with council that the property is not located within the **Inner Floodplain (Hazard Category 1)** zone.

b) Confirm the gross floor area of the addition does not exceed 30 m^2.

c) Provide sound reasoning as to why it is not practicable to raise the floor level of the proposed addition to the level of the **Flood Planning Level.**

d) Demonstrate that there are no potential adverse impacts created by this development on the future development of surrounding properties

E4.3.3 Floor Level Variations (Commercial and Industrial Development only)

Where it is proposed to retain the floor levels of any existing part of the development below the **Flood Planning Level**, the following issues must be addressed in the architectural drawings and the **Flood Risk Report**, in addition to the issues listed above in **Section E4.3.1** for consideration in the report.

a) Provide sound reasoning as to why the exemption is being sought including identification of the constraints that make it impracticable to raise the floor levels to the **Flood Planning Level**.

b) Demonstrate that there are no potential adverse impacts created by this development on the future development of surrounding properties.

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E5. GLOSSARY OF TERMS

Note: For expanded list of definitions, refer to Glossary contained within the NSW Government Floodplain Development Manual, 2005.

TERM	DEFINITION
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, for a flood magnitude having five per cent AEP, there is a five per cent probability that there would be floods of greater magnitude each year.
Australian Height Datum (AHD)	A common national surface level datum corresponding approximately to mean sea level.
Floodplain	Area of land which is subject to inundation by floods up to and including the Probable Maximum Flood (**PMF**) event, that is, flood prone land.
Flood Planning Area	The area of land that is shown to be in the Flood Planning Area on the *Flood Planning Map*.
Flood Planning Map	The *Flood Planning Map* shows the extent of land on which flood related development controls apply, an extract of which is shown on **Figure E1.1**.
Flood Planning Level (FPL)	Flood levels selected for planning purposes, as determined in the *Queanbeyan Floodplain Risk Management Study* and incorporated in the associated *Queanbeyan Floodplain Risk Management Plan*. For development in the Queanbeyan River and Molonglo River floodplains, the FPL is equal to the flood level derived from the 1% AEP flood event, plus the addition of a 0.5 m freeboard.
Flood Prone/Flood Liable Land	Land susceptible to flooding by the PMF. Flood Prone land is synonymous with Flood Liable land.
Floodway	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood levels.
Flood Storage Area	Those parts of the floodplain that may be important for the temporary storage of floodwaters during the passage of a flood. Loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation.
Freeboard	Provides reasonable certainty that the risk exposure selected in deciding a particular flood chosen as the basis for the FPL and Minimum Floor Level (MFL) is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the FPL and MFL.

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TERM	DEFINITION
Habitable Room	In a residential situation: a living or working area, such as a lounge room, dining room, kitchen, bedroom or workroom. In an industrial or commercial situation: an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
Inner Floodplain (Hazard Category 1)	This zone comprises areas where factors such as the depth and velocity of flow, time of rise, isolation on Low Flood Islands and evacuation problems mean that the land is unsuitable for some types of development. It includes areas of High and Low Hazard Floodway, Flood Storage and Flood Fringe areas. Erection of buildings and carrying out of work; use of land, subdivision of land and demolition subject to State Environmental Planning Policies and Local Environmental Plan provisions are considered to be unsuitable in this zone.
Inner Floodplain (Hazard Category 2A)	This zone comprises the floodway which forms during periods when intense rain falls directly over Queanbeyan. This zone is limited to land zoned *B3-Commercial Core*. Development is not to impede the free discharge of major overland flow in this zone. The configuration of this zone may be altered subject to approval by Council.
Inner Floodplain (Hazard Category 2B)	This zone comprises land zoned *B3-Commercial Core* that lies below the peak 1% AEP plus 0.5 m which is not classified as Inner Floodplain (Hazard Category 1 and 2A). Commercial and residential development is permitted in this zone provided it complies with the development controls set out in Annexure 2 of the draft *Flood Policy*. While the floor level of commercial development in this zone may be set at the 5% AEP flood level, additional building and flood evacuation related controls apply to development in this zone. The MFL for residential development located in this zone has been set at the 1% AEP flood levels plus 1.2 m.
Inner Floodplain (Hazard Category 2C)	This zone comprises High Hazard Flood Storage areas where residential development that is replacing existing residential development may be permitted subject to it not increasing the density of persons resident on a site and meeting other requirements which are also applicable to residential land in the Intermediate Floodplain. Mixed use development is also permitted in this zone. However, Council will require a *Flood Risk Report* confirming the adequacy of the structure to resist hydrodynamic loadings and that the proposal would have no adverse impacts on local flooding patterns, either individually or cumulatively in conjunction with similar extensions in adjacent properties. The *Flood Risk Report* will also need to set out how the development complies with the controls set out in this Appendix.
Intermediate Floodplain	This area is the remaining land lying outside the extent of the Inner Floodplain zones, but within the FPA. Within this zone, there would only be the requirement for MFLs to be set at the 1% AEP flood levels plus 0.5 m. Land use permissibility would be as specified by State Environmental Planning Policies or the Local Environmental Plan. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is considered to be unsuitable in this zone.
Outer Floodplain	This area represents the remainder of the floodplain between the Intermediate Floodplain and the extent of the PMF (that is, the extent of the floodplain). This area is outside the extent of the FPA and hence controls on residential, commercial and industrial development do not apply. However, Essential Community Facilities, Critical Utilities and Flood Vulnerable development is not to be encouraged in this zone.

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TERM	DEFINITION
Local Drainage	Land on an overland flow path where the depth of inundation during the 1% AEP storm event is less than 100 mm.
Main Stream Flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam. In Queanbeyan, Main Stream Flooding is confined to the Queanbeyan and Molonglo Rivers and its major tributaries.
Minor Tributary Flooding	The inundation of normally dry land occurring when water overflows the natural or artificial banks of a minor stream. The nature of Minor Tributary Flooding at Queanbeyan is not defined in the *Queanbeyan Floodplain Risk Management Study and Plan.*
Major Overland Flow	Where the depth of overland flow during the 1% AEP storm event is greater than 100 mm. The nature of Major Overland Flow outside the Queanbeyan CBD is not defined in the *Queanbeyan Floodplain Risk Management Study and Plan.*
Minimum Floor Level (MFL)	The combinations of flood levels and freeboards selected for setting the Minimum Floor Levels (MFLs) of future development located in properties subject to flood related planning controls.
Probable Maximum Flood (PMF)	The largest flood that could conceivably occur at a particular location. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. For the study area, the extent of the PMF has been trimmed to include depths greater than 100 mm.

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E6. REFERENCES

Lyall and Associates (2020) "***Queanbeyan Floodplain Risk Management Study and Plan***".

New South Wales Government (2005) ***"Floodplain Development Manual – The Management of Flood Liable Land".***

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ANNEXURE 1
LAND USE CATEGORIES

Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business, Commercial/Industrial & Rural Industry	Non-Urban and Outbuildings	Residential Subdivision	Minor Additions (Residential)
Development that may provide an important contribution to the notification and evacuation of the community during flood events; Hospitals; Institutions; Child care centres; Educational establishments.	Telecommunication facilities; Public Utility Installation that may cause pollution of waterways during flooding, or if affected during flood events would significantly affect the ability of the community to return to normal activities after the flood events. Hazardous industry; Hazardous storage establishments.	Group home; Housing for aged or disabled persons; and Units for aged persons.	Dwelling; Residential flat building; Home industry; Boarding house; Professional consulting rooms;	Bulk Store; Bus depot; Bus station; Car repair stations; Club; Commercial premises (other than where referred to elsewhere); General store; Health care professional; Hotel; Intensive livestock keeping; Junkyard; Liquid fuel depot; Motel; Motor showroom; Place of Assembly (other than essential community facilities; Place of public worship; Public building (other than essential community facilities); Recreation facility; Refreshment room; Road transport terminal; Rural industry; Service station; Shop; Tourist facilities; Warehouse.	Retail nursery; Recreation area; Roadside stall; Outbuildings (Sheds, Garages) up to 40 m^2 area.	Subdivision of land involving the creation of new allotments for residential purposes; Earthworks or filling operations covering 100 m^2 or more than 0.3 m deep.	An addition to an existing dwelling of not more than 30 m^2 (habitable floor area)

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ANNEXURE 2
DEVELOPMENT CONTROLS MATRIX
QUEANBEYAN RIVER AND MOLONGLO RIVER FLOODING ONLY

Outer Floodplain

	Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business & Commercial/Industrial	Non-Urban and Outbuildings	Residential Sub-Division	Minor Additions (Residential)
Floor Level								
Building Components								
Structural Soundness								
Flood Affectation								
Below Ground Car Parking								
Evacuation / Access								
Management and Design								

Intermediate Floodplain

	Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business & Commercial/Industrial	Non-Urban and Outbuildings	Residential Sub-Division	Minor Additions (Residential)
Floor Level				A1	A1		A1	A1
Building Components				B1	B1		B1	B1
Structural Soundness				C1	C1		C1	C1
Flood Affectation								
Below Ground Car Parking				E1 E3	E1 E3	E1 E3	E1 E3	E1 E3
Evacuation / Access								
Management and Design					G3		G1	G4

Inner Floodplain (Hazard Category 2C)

	Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business & Commercial/Industrial	Non-Urban and Outbuildings	Residential Sub-Division	Minor Additions (Residential)
Floor Level				A4				A1
Building Components				B1				B1
Structural Soundness				C1				C1
Flood Affectation						D1		
Below Ground Car Parking				E1 E3				E1 E3
Evacuation / Access								
Management and Design						G2 G5		G4

Inner Floodplain (Hazard Category 2B)

	Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business & Commercial/Industrial	Non-Urban and Outbuildings	Residential Sub-Division	Minor Additions (Residential)
Floor Level				A2	A3			A2
Building Components				B2	B2			B2
Structural Soundness				C2	C2			C2
Flood Affectation				D1	D1			
Below Ground Car Parking				E2 E4	E2 E4			
Evacuation / Access				F1 F2 F3	F2 F3			
Management and Design				G5	G5			G4

Inner Floodplain (Hazard Category 2A)

	Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business & Commercial/Industrial	Non-Urban and Outbuildings	Residential Sub-Division	Minor Additions (Residential)
Floor Level								
Building Components								
Structural Soundness								
Flood Affectation								
Below Ground Car Parking								
Evacuation / Access								
Management and Design								

Inner Floodplain (Hazard Category 1)

	Essential Community Facilities	Critical Utilities and Uses	Flood Vulnerable Residential	Residential	Business & Commercial/Industrial	Non-Urban and Outbuildings	Residential Sub-Division	Minor Additions (Residential)
Floor Level								
Building Components								
Structural Soundness								
Flood Affectation						D1		
Below Ground Car Parking								
Evacuation / Access								
Management and Design						G2 G5		

Not to be Encouraged   Not Relevant   Unsuitable Land Use

The Intermediate Floodplain is defined by the area between the four Inner Floodplain zones and the Flood Planning Area (FPA). The Outer Floodplain is the area between the FPA and the Probable Maximum Flood (PMF).

See Notes over page:

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ANNEXURE 2 (CONT'D)
DEVELOPMENT CONTROLS MATRIX
QUEANBEYAN RIVER AND MOLONGLO RIVER FLOODING ONLY

Floor Level

A1. Floor levels to be equal to or greater than the 1% AEP flood level plus 0.5 m freeboard.

A2. Floor levels to be equal to or greater than the 1% AEP flood level plus 1.2 m freeboard.

A3. Floor levels to be equal to or greater than the 5% AEP flood level on the Queanbeyan River, or 1% AEP flood level plus 0.5 m freeboard due to local catchment flooding, whichever is the greater.

A4. Floor level may be set equal to that of the existing dwelling provided the proposed redevelopment does not increase the density of persons resident on the property.

Building Components

B1. All structures to have flood compatible building components below the 1% AEP flood level plus 0.5 m freeboard.

B2. All structures to have flood compatible building components below the 1% AEP flood level plus 1.2 m freeboard.

Structural Soundness

C1. Structure to be designed to withstand the forces of floodwater, debris and buoyancy up to the 1% AEP flood level plus 0.5 m freeboard.

C2. Structure to be designed to withstand the forces of floodwater, debris and buoyancy up to the 1% AEP flood level plus 1.2 m freeboard.

Flood Affection in Adjacent Areas

D1. A Flood Risk Report may be required to demonstrate that the development will not increase flood hazard (see Item 7 Management and Design below).

Note: When assessing Flood Affectation the following must be considered:

i. Loss of conveyance capacity in the floodway or areas where there is significant flow velocity.
ii. Changes in flood levels and flow velocities caused by the alteration of conveyance of floodwaters.

Below Ground Car Parking

E1. Must have all access, ventilation and any other potential water entry point above the 1% AEP flood level plus 0.5 m freeboard and a clearly signposted flood free pedestrian evacuation route from the basement area separate to the vehicular access ramps.

E2. Must have all access, ventilation and any other potential water entry point above the 1% AEP flood level plus 1.2 m freeboard and a clearly signposted flood free pedestrian evacuation route from the basement area separate to the vehicular access ramps.

E3. Flood proofing to the 1% AEP flood level plus 0.5 m freeboard by mechanical or hydraulic means is not permitted.

E4. Flood proofing to the 1% AEP flood level plus 1.2 m freeboard by mechanical or hydraulic means is not permitted.

Evacuation/ Access

F1. A large window opening is to be provided on each residential floor level onto an area of external wall away from electricity connection to the building and free of projections which may prevent a rescue boat from approaching the escape window. The window is to be clearly marked as a potential escape route during times of flood.

F2. Reliable internal access to the roof area of both the commercial and residential components of the building.

F3. Safe areas are to be provided on the roof of both the commercial and residential components of the building, the latter which must be set above the PMF. The areas must be sized so as to comfortably house all occupiers of the building under cover.

Management and Design

G1. Applicant to demonstrate that potential developments as a consequence of a subdivision proposal can be undertaken in accordance with this Policy and the Plan.

G2. No external storage of materials which may cause pollution or be potentially hazardous during PMF.

G3. Where it is not practicable to provide floor levels to the 1% AEP flood level plus 0.5 m freeboard, applicant is to provide an area equivalent to 25% of the whole floor area of the building to store goods at that level.

G4. Where it is not practicable to provide floor levels to the 1% AEP flood level plus 0.5 m freeboard, Council may allow a reduction for minor additions to habitable areas - see **Section E3.1.3**.

G5. Flood Risk Report may be required prior to development of this area – see **Sections E4.3**.

NOTE: THESE NOTES ARE TO BE READ IN CONJUNCTION WITH REMAINDER OF THE DEVELOPMENT CONTROL POLICY, IN PARTICULAR CHAPTER E2.

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ANNEXURE 3A

GENERAL BUILDING MATTERS

Electrical and Mechanical Equipment For dwellings constructed on land to which this policy applies, the electrical and mechanical materials, equipment and installation should conform to the following requirements.
Main Power Supply Subject to the approval of the relevant authority the incoming main commercial power service equipment, including all metering equipment, shall be located above the MFL. Means shall be available to easily isolate the dwelling from the main power supply.
Wiring All wiring, power outlets, switches, etc, should be, to the maximum extent possible, located above the MFL. All electrical wiring installed below this level should be suitable for continuous underwater immersion and should contain no fibrous components. Earth leakage circuit breakers (core balance relays) must be installed. Only submersible type splices should be used below the MFL. All conduits located below the relevant designated flood level should be so installed that they will be self-draining if subjected to flooding.
Equipment All equipment installed below or partially below the MFL should be capable of disconnection by a single plug and socket assembly.
Reconnection Should any electrical device and/or part of the wiring be flooded it should be thoroughly cleaned or replaced and checked by an approved electrical contractor before reconnection.
Heating and Air Conditioning Systems Where viable, heating and air conditioning systems should be installed in areas and spaces of the house above the MFL. When this is not feasible, every precaution should be taken to minimise the damage caused by submersion according to the following guidelines: **i) Fuel** Heating systems using gas or oil as a fuel should have a manually operated valve located in the fuel supply line to enable fuel cut-off. **ii) Installation** The heating equipment and fuel storage tanks should be mounted on and securely anchored to a foundation pad of sufficient mass to overcome buoyancy and prevent movement that could damage the fuel supply line. All storage tanks should be vented to the MFL. **iii) Ducting** All ductwork located below the MFL should be provided with openings for drainage and cleaning. Self-draining may be achieved by constructing the ductwork on a suitable grade. Where ductwork must pass through a watertight wall or floor below the relevant flood level, a closure assembly operated from above the MFL should protect the ductwork. **Sewer** All sewer connections to properties in flood prone areas are to be fitted with reflux valves.

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ANNEXURE 3B

FLOOD COMPATIBLE MATERIALS

Building Component	Flood Compatible Material	Building Component	Flood Compatible Material
Flooring and Sub Floor Structure	• Concrete slab-on-ground monolith construction. Note: clay filling is not permitted beneath slab-on-ground construction which could be inundated. • Pier and beam construction or • Suspended reinforced concrete slab	**Doors**	• Solid panel with waterproof adhesives • Flush door with marine ply filled with closed cell foam • Painted material construction • Aluminium or galvanised steel frame
Floor Covering	• Clay tiles • Concrete, precast or in situ • Concrete tiles • Epoxy formed-in-place • Mastic flooring, formed-in-place • Rubber sheets or tiles with chemical set adhesive • Silicone floors formed-in-place • Vinyl sheets or tiles with chemical-set adhesive • Ceramic tiles, fixed with mortar or chemical set adhesive • Asphalt tiles, fixed with water resistant adhesive • Removable rubber-backed carpet	**Wall and Ceiling Linings**	• Brick, face or glazed • Clay tile glazed in waterproof mortar • Concrete • Concrete block • Steel with waterproof applications • Stone natural solid or veneer, waterproof grout • Glass blocks • Glass • Plastic sheeting or wall with waterproof adhesive
Wall Structure	Solid brickwork, blockwork, reinforced, concrete or mass concrete	**Insulation**	• Foam or closed cell types
Windows	Aluminium frame with stainless steel or brass rollers	**Nails, Bolts, Hinges and Fittings**	• Galvanised • Removable pin hinges

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ANNEXURE 4
DEVELOPMENT APPLICATION REQUIREMENTS

Step 1

Check with Council staff to see whether or not the proposal:

- Is located on *Flood Prone Land* (Based on initial assessment of the extent of flood affectation and flood levels (refer from **Section E1.4** for details)).
- Is permissible in the Flood Hazard zone and determine the MFL for the particular category of land use.
- Note: an existing site survey (see **Section E2.16.1** of the Policy) is to accompany development proposals to confirm the flood affectation of the allotment and its location within the flood risk zoning system.

Step 2

Plans – A Development Application should include the following plans showing the nature of the proposed development and its extent within the allotment:

- A locality plan identifying the location of the property.
- Plan of the existing site layout including the site dimensions (in metric), site area, contours (0.20 m intervals), existing trees, other natural features, existing structures, north point, location of building on adjoining properties (if development involves a building), floor plans located on a site plan, roof plan, elevations and sections of the proposed building, finished levels of floors, paving and landscaped areas, vehicular access and parking.
- Plans should indicate:
  a) The existing ground levels to Australian Height Datum around the perimeter of the proposed building; and
  b) The existing or proposed floor levels to Australian Height Datum.
- Minor additions to an existing dwelling must be accompanied by documentation from a registered surveyor confirming existing floor levels.
- In the case of subdivision, four (4) copies of the proposed site layout showing the number of lots to be created (numbered as proposed lot 1, 2, 3 etc), the proposed areas of each lot in square metres, a north point, nearest roads and the like.

Council require plans presented on A3 sheets as a minimum

A scale of 1:200 is recommended for site plans

Extent of Cut and Fill – All areas subject to cut and fill require the depths of both to be shown as well as the measures proposed to retain both. Applications shall be accompanied by a survey plan (with existing and finished contours at 0.20 m intervals) showing relative levels to Australian height datum.

Vegetation Clearing – Landscaping details including a description of trees to be removed existing and proposed planting, retaining walls, detention basins, fences and paving.

Stormwater Drainage – Any existing and all proposed stormwater drainage to be indicated on the site plan.

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