Review of Wagga Wagga Floodplain Risk Management Study & Plan

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1 Introduction

1.1 Background

Wagga Wagga is located in south central NSW on the banks of the Murrumbidgee River. The Murrumbidgee River drains a total catchment area of approximately 26,400 km^2 through Wagga Wagga.

The Wagga Wagga township and surrounding villages are subject to mainstream flooding from the Murrumbidgee River. The majority of development within Wagga Wagga is located on the southern bank of the river and is protected by a levee ("Wagga CBD Levee") which has recently been upgraded to provide a level of protection equivalent to the 1% AEP design event[1]. A levee was constructed around North Wagga ("North Wagga Levee") on the northern bank of the river in 1983 and provides flood protection for approximately 203 properties up to the 12% AEP flood. The 2012 flood overtopped the North Wagga Levee causing widespread damage to properties.

A number of flood studies have been completed for the township and its surrounds over the last 20 years. Most recently, the 'Wagga Wagga Murrumbidgee River Floodplain Risk Management Study and Plan' (WMAwater, 2018) (referred to hereafter as "FRMS&P 2018") was prepared to address mainstream flood risk across the Wagga CBD, East Wagga, North Wagga, West Wagga, Gumly Gumly, Oura, Wagga and Eunony floodplain precincts, and adopted by Resolution of Council in early 2018. The FRMS&P 2018 followed the 'Detailed Flood Model Revision' (WMAwater, 2014) which redefined flood characteristics across the Wagga Wagga floodplain based on updated data and improved modelling techniques, and is a revision to the previously completed 'Wagga Wagga Floodplain Risk Management Study' (WMAwater, 2009).

The FRMS&P 2018 recommended the implementation of nineteen (19) floodplain risk management options. These options cover a range of flood modification, property modification and response modification measures. A feasibility study was recommended to be undertaken to further investigate the potential of the following two options:

- Voluntary House Raising (VHR) & Voluntary Purchase (VP) Scheme in Wagga Wagga study area (Option PR1): This option proposed a VHR and VP Scheme for the study area to reduce flood risk. VHR would involve residents raising their property to the recommended Flood Planning Level (1% AEP + 0.5 m), where possible. VP involves residents selling their properties to Council whereby the dwelling will be demolished and rezoned to prevent future development.
- North Wagga Levee upgrade to the 5% Annual Exceedance Probability (AEP) level of protection (Option L4(B)) including Hampden Avenue upgrade and conveyance improvements through Wilks Park: This option assessed the outcomes of raising the levee to a 5% AEP flood level of protection. The works would involve increasing the current levee by up to 0.9 m in some locations as well as increasing the footprint to allow for embankment protection (an additional 5 m width would be required). The results of the FRMS&P 2018 predicted a decrease in the frequency of inundation of North Wagga, protecting the township in smaller events. However, the modelling

[1] It is understood that the Wagga CBD levee upgrade was not in place at the time the FRMS&P 2018 was prepared.

results also predicted impacts on flood behaviour in the upstream floodplain that would adversely affect a number of properties.

Representatives from the North Wagga community have raised concerns regarding the study. These concerns include the adequacy of the range of the flood mitigation options investigated and recommended for North Wagga (including consideration of only the 5% AEP and 1% AEP design levels of protection for the North Wagga Levee upgrade), and the suitability of the 5% AEP level of protection recommended to proceed to feasibility study for the North Wagga Levee. In response to these concerns, BMT was engaged by the City of Wagga Wagga (CoWW) to undertake an independent peer review of the FRMS&P 2018.

1.2 Objectives of Peer Review

This peer review is focussed on the methodology and outcomes of the FRMS&P 2018 and has been undertaken to:

(1) Ensure the study followed industry standard techniques and aligns with best practice.

(2) Verify the study product and outputs.

(3) Ensure the recommended options align with predicted flood behaviour and address whole of community concerns.

(4) Identify potential missed opportunities which might be rectified or addressed in future works.

(5) Determine if there is a cause to reasonably conclude that a flood protection levee greater than a 5% AEP level of protection should be considered in the feasibility study.

(6) Formulate findings of the review and recommended future actions.

1.3 Peer Review Process

BMT has undertaken the peer review across the following key study components:

- Flood risk assessment;
- Flood damages assessment;
- Flood risk management;
- Flood risk management plan; and
- Consultation.

For each component (and sub-component), the FRMS&P 2018 methodology has been reviewed and its alignment with best-practice assessed. In addition, the way in which the methodology was implemented was investigated to ensure it was in accordance with the reported methodology and applied correctly. Based on this assessment, recommendations have been made for corrective or future work to address issues. These recommendations are provided in the relevant sections throughout this report and subsequently compiled in Section 7.2. Categorisation of identified issues and recommendations has also been undertaken to assist in assigning responsibility and prioritisation for recommended actions. These categories are as follows.

1.3.1 Issue Type

Issue type categories are:

- Errors - These are errors that have been noted and require correction. They are typically implementation errors.
- Not best practice - These are methodology issues that are not in alignment with current best practice.
- Gap - This is additional work that can provide further flood intelligence and may improve outcomes for Council, the community and/or other stakeholders (e.g. SES).

1.3.2 Significance of Issue

A traffic light system has been used to indicate the significance of the issue. Significance is defined as the potential impact of the issue on the overall outcomes (e.g. robustness of the FRMS&P 2018 outcome and/or the importance of filling a gap in intelligence). Each issue is allocated a colour (green, yellow or red) in accordance with Table 1-1. In many cases, the significance (impact) of the issue cannot be fully determined until the issue is addressed appropriately and its impact (or otherwise) is known.

Table 1-1 Significance of Issue

Category	Category Description
Low	The issue should be addressed but is not timing critical and does not relate specifically to an issue with the FRMS&P 2018.
Medium	Important issue that should be addressed either now to strengthen the FRMS&P 2018 or in the future to strengthen flood-related outcomes for the Wagga Wagga community.
High	Potentially significant issue which may have an impact on FRMS&P 2018 conclusions and recommendations and/or for the community in the short term. If not addressed, future work that is dependent on this component may not be robust or defendable.

1.3.3 Timing

The recommended timing for addressing identified issues has been divided simply into two categories:

- FRMS&P 2018 (short-term) – These are items that have been found to be incorrect, unclear, missing or misaligned in the FRMS&P 2018 and are recommended for short-term remedy.
- Future – These are items which go beyond the scope of the completed FRMS&P 2018 and should be pursued as additional tasks in the short to medium-term or as part of the feasibility study for recommended options (when/if it proceeds).

Council may elect to move recommendations from one category to another based on their immediate requirements and priorities or their knowledge of the scope of the FRMS&P 2018.

Note that some of the items are dependent on others and need to be undertaken in sequential order.

1.4 Supplied Information

BMT has relied on the following information supplied by CoWW to complete this review:

- 'Wagga Wagga Murrumbidgee River Floodplain Risk Management Study and Plan' (WMAwater, 2018);
- Hydraulic input and results files from the FRMS&P 2018 provided to BMT by Council on a hard drive (supplied 8 February 2021);
- Damage calculation spreadsheets "NON_RESI_FloodDamages_Design_Wagga.xlsx" and "RESI_FloodDamages_Design_Wagga.xlsx" from the FRMS&P 2018;
- Wagga Wagga Levee Detail Design Drawings (Rev B) (Public Works, dated February 2016)
- 'Wagga Wagga Floodplain Risk Management Study' (WMAwater, 2009);
- 'Wagga Wagga Floodplain Risk Management Plan' (WMAwater, 2009);
- 'Wagga Wagga Detailed Flood Model Revision' (WMAwater, 2014);
- Report PSRP-7 submitted to the Policy and Strategy Committee Meeting on Monday 13 July 2015, entitled 'Levee Upgrade Detailed Design and Community Consultation' and attachments (the Public Works Economic Report);
- 'Wagga Wagga and North Wagga Murrumbidgee River Levee Upgrade Review of Environmental Factors' (GHD, 2013);
- 'Wagga Wagga Levee Upgrade Detailed Design Report (Report No. DC15012)' (Public Works, December 2015);
- 'Options for the Upgrade of the Main and North Wagga Levees for Flood Security, Cost Effectiveness Analysis' (Public Works, 2015);
- Correspondence from the North Wagga Residents' Association to Council's Director Commercial Operations, Caroline Angel, dated 21 January 2019 and the Floodplain Risk Management Advisory Committee's response;
- Submissions by community members during the Public Exhibition of the Draft FRMS 2018; and
- Submissions during FRMS&P 2018 community consultation process; and
- Subsequent missing modelling files requested from WMAwater by BMT.

1.5 Industry Standards and Best Practice

1.5.1 Floodplain Development Manual (2005)

Flooding in NSW is managed in accordance with the NSW Government's Flood Prone Land Policy[2]. Under the Policy, the management of flood liable land is the responsibility of the local authority, in this case the City of Wagga Wagga. This responsibility is defined through the 'Floodplain

[2] The FRMS&P 2018 was completed under the Flood Prone Land Policy at the time it was undertaken. However, an update to the Flood Prone Land Package came into effect on 14 July 2021.

Development Manual' (2005) and includes the preparation of a floodplain risk management study and plan. The manual defines a floodplain risk management study as a multi-disciplinary process that balances different factors to formulate, evaluate and recommend a mix of management measures to deal with existing, future and continuing flood risk. Factors that should be considered within a floodplain risk management study include flood characteristics, community costs of flooding, future land use, available flood risk management measures, environmental needs of the floodplain, and environmental and cultural impacts of management measures.

The 'Floodplain Development Manual' (2005) outlines a merit-based framework to assist with floodplain risk management and provides guidance for Councils in the development and implementation of local flood studies, floodplain risk management studies and plans. It is supported by floodplain risk management guidelines that provide additional technical information to Councils and consultants for the preparation of these studies. Relevant to this review is the 'Floodplain Risk Management Guideline – Residential Flood Damages' (issued 25 October 2007) and 'Floodplain Risk Management Guideline – Flood Emergency Response Planning Classification of Communities' (issued 25 October 2007).

1.5.2 Handbook 7: Managing the Floodplain. A Guide to Best Practice in Flood Risk Management in Australia (2017)

Further guidance on best practice principles in flood risk management across Australia is documented within Handbook 7 of the Australian Disaster Resilience Handbook Collection, *'Managing the Floodplain. A Guide to Best Practice in Flood Risk Management in Australia'* (AIDR, 2017) (hereafter referred to as 'Handbook 7'). This handbook aims to provide advice to those with roles in understanding and managing flood risk and its consequences on the community. It outlines best practice principles that need to be considered when managing flood risk and formulating floodplain management plans for effective, equitable and sustainable land use across Australia's floodplains.

1.5.3 Australian Rainfall and Runoff: A guide to flood estimation (2019)

Australian Rainfall and Runoff 2019 (ARR2019) provides detailed guidelines for flood investigations using the design event method at any location in Australia. It *"discusses fundamental issues and basic approaches to flood estimation, data related aspects inclusive of its management and data uncertainty, risk based design and dealing with climate change"* (Ball *et al.*, 2019).

1.6 Limitations

In preparing this report, BMT has relied upon and presumed accurate, information (or absence thereof) provided by CoWW. Except as otherwise stated in this report, BMT has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete, then it is possible that our observations and conclusions as expressed in this report may change.

BMT has undertaken only limited checking and re-running of supplied flood models. It is assumed that the results documented by WMAwater in the FRMS&P 2018 correspond to the model inputs and results supplied by CoWW for this peer review.

Furthermore, the models that form the basis of the assessment of flood risk and proposed management options documented within the FRMS&P 2018 were initially developed by WMAwater as part of the 'Wagga Wagga Murrumbidgee River Model Conversion Project' (WMAwater, 2010) and subsequently extended and updated as part of the 'Wagga Wagga Detailed Flood Model Revision' (WMAwater, 2014). BMT assumes that the modelling and associated work undertaken as part of these studies has undergone sufficient quality assurance and peer review by WMAwater, as well as being subject to review by CoWW and relevant NSW government agencies (i.e. DPIE, former OEH, etc.). BMT also understands that the models were calibrated and validated to ensure their ability to reliably represent historic flood behaviour. Accordingly, BMT assumes that the underlying models are reliable, robust and in accordance with best practice. Our review is therefore limited to the representation of mitigation options for North Wagga.

Whilst related and previous studies (refer list in Section 1.4) were considered as part of this project, the scope of the review of those documents was to provide context, background and supporting information for the peer review of the FRMS&P 2018, rather than to review the adequacy of the work documented in those reports.

Other documents and resources exist which guide and inform floodplain management within the CoWW, including the Wagga Wagga Local Environment Plan 2010 and Development Control Plan 2010. These documents and resources have not been reviewed as part of this project; however it is assumed that they were used to inform the FRMS&P 2018.

2 Flood Risk Assessment

The assessment of flood risk requires the consideration of flood likelihood, flood behaviour and exposure of people, properties and infrastructure in the floodplain. Each of these elements are discussed below in relation to the FRMS&P 2018.

2.1 Flood Likelihood

2.1.1 FRMS&P 2018 Methodology and Implementation

Consideration was given to a wide range of flood magnitudes between frequent and rare floods, including the 0.2 Exceedances per Year (EY), 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP floods and probable maximum flood (PMF).

In addition to examining existing flood risk, the FRMS&P 2018 also considered the impact of climate change. The climate change assessment for the FRMS&P 2018 was based on the comparison of 1% AEP flood levels with 0.5% AEP flood levels.

The largest predicted climate change impacts were reported within the floodplain upstream of North Wagga where a breakout from an oxbow on the main channel results in a higher peak flood level. At the reported location of Hampden Avenue/Mill Street, this manifested as a 0.5 m increase in peak 1% AEP flood level.

2.1.2 BMT Assessment

Guidance on climate change assessment is provided in ARR2019. The climate change factors published in ARR2019 indicate that a 9.1% increase in rainfall is the best estimate of likely rainfall intensity increases by 2090 under Representative Concentration Pathway scenario 4.5 (RCP4.5) (i.e. greenhouse gas emissions are reduced in the future). Under RCP8.5 conditions (i.e. current greenhouse gas emissions increase in the future), rainfall intensities would likely increase by 18.6% by 2090.

The approach used by the FRMS&P 2018 whereby rarer events (such as the 0.5% or 0.2% AEP events) were used as a proxy for the simulation of a 1% AEP plus climate change event is an accepted alternative approach to climate change sensitivity analysis, particularly for studies that define design discharges based on Flood Frequency Analysis (FFA) such as the FRMS&P 2018. As the use of 0.5% AEP flows was reported to result in a greater than 20% increase in flows (compared to 1% AEP flows), this approach is considered to be a conservative assessment based on current RCP8.5 predictions and in line with current guidance. However, it is noted that there is a high degree of uncertainty in future rainfall trends and guidance is continually being revised to reflect best available knowledge and science.

A sufficient range of flood event sizes were assessed and the assessment of climate change impacts are considered to be appropriate.

2.1.3 BMT Recommendations

No recommendations required.

2.2 Flood Behaviour

2.2.1 FRMS&P 2018 Methodology and Implementation

Flood Behaviour

For the FRMS&P 2018, flood behaviour was defined based on the results of the TUFLOW modelling of the Murrumbidgee River and its floodplain. Flood depths and extents were mapped for the full range of modelled design events. In addition, flood characteristics were further analysed to determine and map flood hazard, flood function and flood emergency response precincts.

Flood Hazard

Flood hazard was defined and mapped based on the flood hazard categories provided in 'Handbook 7' (AIDR, 2017), based on combinations of flood velocity, depth and depth x velocity (i.e. velocity-depth product).

Flood function

Flood function was mapped for the 1% and 5% AEP floods based on the definitions provided in the 'Floodplain Development Manual' (2005). These areas were selected through the following process determined for the 1% AEP flood and then also applied to the 5% AEP flood:

- Floodway - based on four (4) potential floodway parameters using a combination of velocity-depth product and/or velocity values that were tested and determined by encroachment analysis similar to the Thomas *et al.* (2012) methodology.
- Flood storage - areas outside the floodway where depths are greater than 0.5 m.
- Flood fringe - remaining areas in the floodplain after floodway and flood storage has been accounted for (i.e. areas outside the floodway areas with depth less than 0.5 m).

Flood Emergency Response

Flood emergency response classifications were applied using the approach provided in 'Floodplain Risk Management Guideline - Flood Emergency Response Planning Classification of Communities' (NSW Government, 2007) to identify areas which are either Flood Islands, Road Access Areas, Overland Escape Routes, Trapped Perimeter Areas or Indirectly Affected. Numerous precincts were classified using this approach, with discussion of the factors that contribute to the risk and classification. Whilst the current best practice approach is defined in 'Handbook 7' (AIDR, 2017) and includes additional sub-categories relating to submerged or elevated islands and overland escape or rising road access, the approach used within the FRMS&P 2018 aligns with the best practice methodology at the time the study was undertaken.

Flood Characteristics in North Wagga

The FRMS&P 2018 provides a description of the overall flood behaviour within each floodplain precinct, including the following key flood characteristics and risk relevant to North Wagga:

- The North Wagga Levee provides protection to 203 dwellings.
- Flood modelling results indicate that the North Wagga Levee commences to overtop at about the 8 year ARI flood (~12% AEP).

- During the March 2012 flood[3], there were reports that the North Wagga Levee overtopped below 9.6 m on the Wagga Wagga gauge, which is 0.3 m below the current levee design level. In this flood event, the vast majority of houses within the area protected by the levee were flooded to depths of up to 2 metres.
- In the 5% AEP flood, 156 houses in North Wagga are estimated to flood above floor level, to a maximum depth of 1.6 m. Because of the potential for frequent and severe flooding in North Wagga, the area contributes significantly to the overall annual flood damages for the study area.
- North Wagga (behind the levee) is a Low Flood Island from about 9.6 m on the Wagga Wagga gauge when the levees begin to overtop (~12% AEP). People failing to evacuate prior to inundation of the evacuation route will be isolated for at least 2 to 3 days. If floodwaters overtop the levee, they could be forced to retreat to refuge areas (e.g. spectator mounds at the oval) or rooftops, and require rescue.
- Hydraulic hazard maps show that in a 1% AEP flood, substantial areas within North Wagga (within the levee protection area) would be at H5 hazard conditions, which poses a danger to buildings. In a PMF, the entire area would be subject to extremely dangerous H6 conditions.
- During the 1% AEP flood, much of the floodplain within the study area is classified as floodway in and North Wagga (as well as Gumly Gumly and Oura) are also largely classified as floodways.

2.2.2 BMT Assessment

Flood Function

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringe. Descriptions of these terms within the 'Floodplain Development Manual' (2005) are essentially qualitative in nature. The Howells *et al.* (2003) (Howells) method utilises the velocity-depth product (VxD) when assessing hydraulic categories, whilst the Thomas *et al.* (2012) methodology defines the floodway extent as the area of floodplain conveying around 80% of the total flood flow and testing of the resultant afflux when areas of fill encroach on floodways. The FRMS&P 2018 appears to have applied these appropriately.

Flood Hazard and Emergency Response

'Handbook 7' (AIDR, 2017) hazard categories, 'Floodplain Development Manual' (2005) hydraulic categories and emergency response precincts are per national guidance or NSW guidance at the time the study was undertaken. These appear to have been applied appropriately.

Timing aspects of flood behaviour were not presented in any quantitative (e.g. graphs, mapping etc.) or qualitative way (descriptions). This information is highly valuable for identification of flood risk, selection of appropriate mitigation measures, emergency management planning and, in some cases, land use planning. Timing information can also be used to assess the benefits of raising levees by estimating how much additional evacuation time is available in the raised versus existing scenario. It should be noted that timing-related data is less reliable than level or extent mapping, however it can provide a valuable indication of both absolute and relative timing.

[3] The 2012 event reached a height of 10.6 m (equivalent to a level of 180.65 mAHD) at the Hampden Bridge gauge. This indicates the event was in the order of a 1 in 35 year Average Recurrence Interval (ARI) (or 2.85% AEP).

2.2.3 BMT Recommendations

It is recommended that further investigations be undertaken to develop timing-related flood intelligence by interrogating the flood modelling results, historical event data and local knowledge / anecdotal data not captured elsewhere. The scope of these investigations should be developed in conjunction with disaster management officers to identify gaps in current knowledge and critical information required for disaster management planning. The types of investigations that are available and might be considered include:

- Mapping time to first inundation or hazard to understand typical sequencing of inundation and areas which are prone to more rapid onset of flooding (which may require different response strategies).
- Identification of road inundation timing and duration, including to isolated areas. This information can be extracted from hydraulic models, however, should be further refined to include local knowledge.
- Relationship data between stream gauge heights (including classified levels) and critical impacts in the floodplain. Once these critical levels are identified, analysis of design flood data (across all AEPs and temporal patterns), plus historic events, can help to build a database of plausible timing relationships.

ID	Recommendation	Issue Type	Issue Significance	Timing
2-1	Develop timing-related flood intelligence in conjunction with disaster managers	Gap	Low	Future

2.3 Exposure

2.3.1 FRMS&P 2018 Methodology and Implementation

Flood exposure was primarily considered in the FRMS&P 2018 through property risk. Property risk was identified using counts of properties and via flood damages assessment (discussed further in Section 3), both informed by property data including floor level information and predicted flood levels.

Social characteristics were assessed using data from the 2011 Census and reported in Section 2.3 of the FRMS&P 2018 at the scale of the Wagga Wagga Local Government Area (LGA) (i.e. a single region for the entire study area). The social characteristics considered were population growth, age, average people per dwelling, property ownership, vehicle ownership and English language usage. The social characteristics data could not be assessed as a true aspect of exposure, because it was not mapped or considered at a sufficiently small resolution (e.g. floodplain precinct or community level) to be intersected with flood hazard. However, it is noted that there is evidence that some social information was subsequently considered at a finer scale. This comprised the discussion of the age of the population in the North Wagga, Oura and Gumly Gumly communities and the associated risk of limited mobility of elderly citizens with regard to evacuation issues for levee options in these floodplain precincts.

The FRMS&P 2018 considered and assessed the flood impacts on susceptible critical infrastructure (e.g. water treatment plants, sewerage treatment plans, electrical substations, hospitals, emergency

services etc.) and vulnerable infrastructure (e.g. education, child care, aged care etc. facilities). However, no mapping of these was provided.

Mapping of vegetation communities and areas of protected regrowth in the study area are included in the 'Murrumbidgee River Wagga Wagga Riparian Vegetation Management Plan' (Waratah Ecoworks and WMAwater, 2017) contained in Appendix H of the FRMS&P 2018. Whilst threatened flora and fauna species are listed in the vegetation management plan, areas of high ecological significance were not mapped, nor were these areas intersected with flood behaviour or hazard mapping to identify ecological locations at risk from current or future flooding.

2.3.2 BMT Assessment

Property exposure is a key metric of flood exposure. However, it should be recognised that it does not represent the entire spectrum of flood risk. Additional aspects of flood exposure which might have been considered (depending on available data include):

- population at risk (this can be determined from person to dwelling ratios derived from census data and applied to surveyed property data at community scale);
- demographic characteristics of the population relating to vulnerability such as age, mobility, English language skills etc.;
- roads and other linear infrastructure; and
- ecologically significant areas (these were not mapped nor intersected with flood mapping to identify exposure).

2.3.3 BMT Recommendations

Recommendations to be considered in future assessments of exposure are discussed in the following sections.

2.3.3.1 Additional Flood Risk Assessment Items

The following tasks could be undertaken to help quantify and describe flood risk and exposure:

- Calculation of properties within each of the emergency response precincts. This is a simple GIS query and would help disaster management officers understand the magnitude of risk in each precinct.
- Articulation of exposure changes as a result of climate change, with particular focus on locations where risk will substantially change in future.
- Intersection of ecological significance data with flood hazard or extent, using both current and future climate scenarios and summary of at-risk areas.

2.3.3.2 Risk Framework

Establishment of a risk-framework can be used to identify potential measures. A clear approach to identifying acceptable and unacceptable risk will ensure that all areas of unacceptable risk are identified and prioritised, and that measures can be selected which help to reduce the risk to acceptable levels. By understanding the full spectrum of flood risk, risk can be more fully described

and the selection and assessment of mitigation measures can be informed by an understanding of the way in which flooding affects all risk receptors.

A risk framework provides the following benefits:

- All aspects of flood risk are included in the assessment and integrated appropriately.
- Council's risk assessment process is clearly articulated and communicated.
- A clear line of sight is provided from the assessment of existing risk (including identification of areas of unacceptable risk) to identification of risk management measures (in response to areas of unacceptable risk), and assessment of those measures (to determine if unacceptable risk will be managed to acceptable levels).

The risk framework should consider the following elements:

- How various combinations of flood likelihood and hazard (including flood timing) are prioritised in terms of hydraulic risk.
- How community vulnerability and tolerability modifies hydraulic risk.
- What types of land use (exposure) is compatible with the hydraulic risk, including identification of tolerable and intolerable uses.

2.3.3.3 Community Vulnerability Mapping

Community vulnerability data can be mapped at a more detailed scale using Census data. This has the benefit of providing a nuanced and improved understanding of flood risk. Residents with higher vulnerability are at higher risk than the average population, even when exposed to the same degree of hazard. In particular, having an informed understanding of community vulnerability can help to:

- Prioritise flood mitigation measures by recognising community attributes as a contributor to overall flood risk profiles, particularly when integrated in a risk framework (see Section 2.3.3.2).
- Create risk-appropriate evacuation plans.
- Conduct tailored community engagement and resilience building activities.
- Determine resource allocation, including preparation of evacuation centres.
- Identify areas which might require early or pre-emptive flood warning.

Attributes which might be considered in vulnerability mapping include age, socio-economic status, health (particularly mobility) and English language proficiency. Note that mapping of vulnerable institutions (as discussed in Section 2.3.3.4) is also considered vulnerability mapping, but at a point-scale rather than community / neighbourhood scale.

2.3.3.4 Mapping of Critical Infrastructure and Vulnerable Institutions

Identification of 'vulnerable institutions' (e.g. aged care, schools, day care, hospitals) and 'critical infrastructure' (e.g. water treatment plants, power substations etc.) can support risk prioritisation and selection of mitigation measures to prioritise risk reduction at these locations. Whilst these institutions/facilities are discussed in the FRMS&P 2018 report, no mapping was provided to

accompany the reporting and enable a spatial understanding of the locations of these facilities within the Wagga Wagga floodplain, nor were these locations intersected with mapped flood data to understand exposure.

2.3.3.5 *Evacuation Capability Assessment*

A comprehensive evacuation capability assessment will identify areas where there is a risk of insufficient time and / or resources available to complete a full evacuation. These assessments help identify suitable options for reducing that risk and maximising the safety of the community.

The primary output of an evacuation capability assessment is an estimate of whether each area / neighbourhood can be safely evacuated in a range of flood event sizes, based on current disaster management plans and evacuation routes. Assessments also provide information on:

- The geographical extent of evacuation required.
- The number of houses affected and, correspondingly, the number of residents and vehicles requiring evacuation.
- Trouble spots and key areas, including low-islands and high-island isolated areas.
- At-risk communities, such as caravan park residents and older demographics.
- Constraints to the evacuation process, such as early cutting of key routes, or insufficient warning / prediction time.
- Emergency response resource requirements, including evacuation centre capacities and door knocking teams.

The evacuation capability assessment can be informed by data already developed through the FRMS&P 2018 study and additional information recommended in this review, such as timing-related information (Section 2.2.2).

It is recognised that most inputs into evacuation capability assessments (flood behaviour, community response and traffic) are difficult to predict and introduce a high level of uncertainty in the estimation of a community's evacuation capability. Nonetheless, the assessment forms a vital part of the flood risk management process and should not be avoided due to uncertainties and the risk of error.

Further information on evacuation planning can be found in Evacuation Planning 'Handbook 4' (AIDR, 2017).

ID	Recommendation	Issue Type	Issue Significance	Timing
2-2	Map susceptible infrastructure, vulnerable infrastructure and high ecological significance with flood extents and flood impacts	Gap	Medium	Future
2-3	Additional flood risk assessment tasks	Gap	Low	Future
2-4	Develop flood risk framework	Gap	Medium	Future

ID	Recommendation	Issue Type	Issue Significance	Timing
2-5	Undertake community vulnerability mapping	Gap	Low	Future
2-6	Undertake evacuation capability assessment	Gap	Low	Future

3 Flood Damages Assessment

Understanding the ‘cost’ of flooding to a community can help focus and prioritise the selection of floodplain management measures and inform cost-benefit analyses of proposed measures.

The definitions and methodology used in estimating flood damage are summarised in the ‘Floodplain Development Manual’ (2005). Figure 3-1 summarises the types of flood damages considered as part of the floodplain risk management process. The two main categories are 'tangible' and 'intangible' damages. Tangible flood damages are those that can be more readily evaluated in monetary terms, while intangible damages relate to the social cost of flooding impacts to the community, such as fatalities, impact on mental and physical health etc. and therefore are much more difficult to quantify.

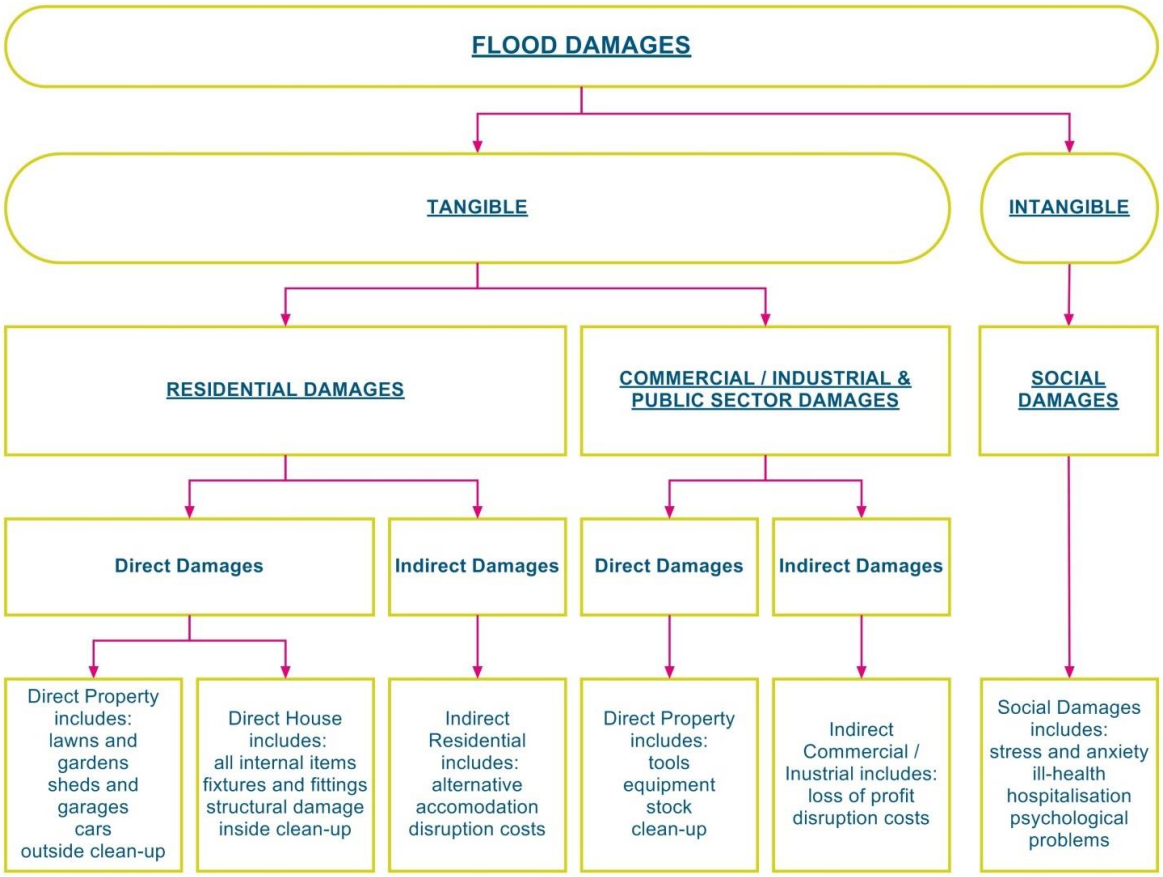

Figure 3-1 Types of Flood Damage
(Source: Floodplain Development Manual (2005))

Tangible damages can be further divided into ‘direct’ and ‘indirect’ costs, where:

- Direct damages can be estimated from an investigation of the number of buildings flooded, the area flooded, the depth of flooding and the type of land use.
- Indirect damages can be estimated based on the degree of social and community disruption from evacuation, clean up and recovery from a flood.

The general accepted process for undertaking a flood damages assessment is:

(1) Creating a property database containing data on property type (e.g. residential, commercial, etc.), number of storeys (e.g. single storey, double storey), type of construction (e.g. weatherboard, brick, etc.) and floor levels of properties.

(2) Identifying properties subject to flooding in design flood events up to the PMF.

(3) Determining depth of inundation above floor level and above ground level for a range of design event magnitudes.

(4) Defining appropriate stage-damage relationships for various property types/uses.

(5) Estimating potential flood damage for each property.

(6) Calculating the total flood damage for a range of design events.

(7) Calculating the Average Annual Damage (AAD).

3.1 Floor Level and Property Database

3.1.1 FRMS&P 2018 Methodology and Implementation

Floor level estimates across the study area are required to complete a flood damage assessment. The FRMS&P 2018 based the assessment of flooding and damages on the following floor level data:

- North Wagga Properties: Floor level survey for 174 properties provided with a level of protection by the North Wagga Levee was undertaken in 2008 as part of the 2009 FRMS&P. The FRMS&P 2018 reports that the 2008 data was examined to identify changes to existing properties or addition of new properties since the survey was completed, and updated to 2016 conditions as required (although the method of assessment of changes to conditions post-2008 and the number of updated properties is not documented).
- Wagga City Properties: More than 3,000 properties situated inside the Wagga CBD Levee that have the potential to become flood affected in events larger than the 1% AEP did not have any available floor level estimates. Due to the large number of properties requiring floor level estimates, a sample population was examined to determine the average floor level height above ground. This information was then combined with LiDAR data (no date of LiDAR reported within the FRMS&P 2018) to estimate floor levels for these properties.
- Properties Outside the Levees: Approximately 500 properties situated outside the North Wagga and Wagga CBD Levees did not have any detailed floor level estimates. The floor levels for these properties were estimated through visual inspection of height above ground in combination with ground surface elevations defined by LiDAR data. The means of visual inspection (e.g. in-person or desktop Google Street View inspection) is not documented.

Typical data collected as part of a floor level survey includes information such as lowest habitable floor level; ground level; and other property-specific information such as type of house construction, number of floors, relative size, etc. Review of the FRMS&P 2018 and the associated flood damage calculation spreadsheet indicates that the only property-specific information collected during the floor level survey is number of storeys; information regarding relative size and house construction was not collected for the damage assessment.

3.1.2 BMT Assessment

There are a number of options available for the floor level survey, each with its own limitations. These are listed below in order of decreasing typical vertical accuracy:

(1) Detailed floor level survey.

(2) Drive-by mobile LiDAR survey.

(3) Desktop-based assessment using for example, Google Street View, to determine height of floor above ground level of each property.

(4) Desktop-based assessment to determine height of floor above ground level of a representative property within each street or area using for example, Google Street View, and then applying this estimate across all properties in that street or area.

Ideally, detailed floor level survey for all flood affected properties within the study area would be undertaken. However, the size of the floodplain and number of flood affected properties means that detailed floor level survey of all flood prone properties may have been cost-prohibitive. It is appropriate to use a combination of techniques to estimate floor level and property data, as long more reliable methods are used for properties at higher risk of frequent flooding. This has occurred in the FRMS&P 2018 with method (1) above applied for the majority of properties within the North Wagga Levee, method (3) applied for properties outside the levees and method (4) applied for properties within the Wagga CBD Levee.

The level of accuracy associated with the adopted floor level estimates is considered adequate for a regional study such as the FRMS&P 2018. Due to the nature of floor level estimates, damages documented in the FRMS&P 2018 are not an indicator of flood risk exposure at individual property level but rather a regional assessment of flood risk exposure and flood damages. This limitation is also explicitly expressed within the FRMS&P 2018 report.

3.1.3 BMT Recommendations

If proposed structural mitigation measures are likely to worsen flood risk at any properties, it is recommended that detailed floor level survey be collected for these properties, to better understand how the flood impacts may change as a result of the measure.

ID	Recommendation	Issue Type	Issue Significance	Timing
3-1	Collect detailed floor level survey if flood impacts are predicted at properties	Gap	Medium	Future

3.2 Identifying Property Impacts

3.2.1 FRMS&P 2018 Methodology and Implementation

Floor level estimates and design flood results were used to identify flood impacts for residential and non-residential (i.e. commercial/industrial) properties for events between the 10% AEP and PMF events. This assessment determined which event first results in property and/or over floor flooding and the resultant flood immunity level of each property. Results from this assessment were reported

in the FRMS&P 2018 as the number of properties affected at ground level and number of properties flooded above floor for each design event and for both residential and non-residential properties.

The FRMS&P 2018 developed and used flood damage calculation spreadsheets "NON_RESI_FloodDamages_Design_Wagga.xlsx" and "RESI_FloodDamages_Design_Wagga.xlsx" (referred to herein as "Non-Residential Damage Spreadsheet" and "Residential Damage Spreadsheet") to undertake damage calculations.

3.2.2 BMT Assessment

A review of the data contained within the FRMS&P 2018 Non-Residential Damage Spreadsheet and Residential Damage Spreadsheet was undertaken to determine how and where within each property the ground and flood levels were sampled. The X and Y coordinates provided in the spreadsheet were plotted in GIS for sample locations. These locations were found to be located at the centroid of the property.

The source and date of collection of ground level data was not documented within the FRMS&P 2018 or stated within the damages spreadsheet (there is only a reference to "LiDAR" in Section 2.5.1 of the report). Thus, it is difficult to accurately cross-check this data as part of this peer review because the method and location of data extraction, as well as the source of the ground level data, is not reported.

However, for the purposes of this peer review, BMT developed a Digital Elevation Model (DEM) of the study area using LiDAR (Light Detection and Ranging) data dated 2009 and available from the ELVIS webpage (https://elevation.fsdf.org.au/) (note: the 5 m resolution was used for the purposes of this peer review, however 1 m resolution data is also available). LiDAR DEM elevations were sampled at the X and Y coordinate points and compared to ground levels contained within the flood damage calculation spreadsheet. This comparison did not result in a match between the FRMS&P 2018 ground levels and 2009 LiDAR DEM (5 m resolution) ground levels, however it is noted that the levels for the FRMS&P 2018 may not have been directly extracted at the X and Y coordinate points, but may have been sampled as, for example, either the minimum, maximum or median elevation within the whole allotment. Nevertheless, for a significant number of residential properties the differences in elevations between the 2009 LiDAR DEM developed by BMT and the elevations quoted in the flood damage calculation spreadsheet exceeded reasonable bounds of tolerance (i.e. greater than 0.5 m) given the uncertainty in the source of the LiDAR used for the FRMS&P 2018, location/method of the sampling of the elevation within each lot and general topographic nature of the floodplain (i.e. relatively flat).

A histogram showing the distribution of differences in elevation between ground levels used within the FRMS&P 2018 Residential Damage Spreadsheet and ground levels extracted from the 2009 LiDAR DEM at the quoted X and Y coordinates is provided in Figure 3-2. This histogram quantifies the spread and magnitude of the variation and helps to understand the potential influence of this issue. For comparison, a similar histogram is also provided in Figure 3-3 for the non-residential properties. Note that the difference refers to the 2009 LiDAR elevation minus the elevation within the damage calculation spreadsheet.

The greater impacts on damage calculations at a property level would occur as a result of the property being newly impacted above ground and/or above floor, or alternatively no longer impacted

above ground and/or above floor. However, the overall impact of this issue across the whole study area may result in a minor net change in total intangible damages or alternatively, may result in a significant net change in total tangible damages.

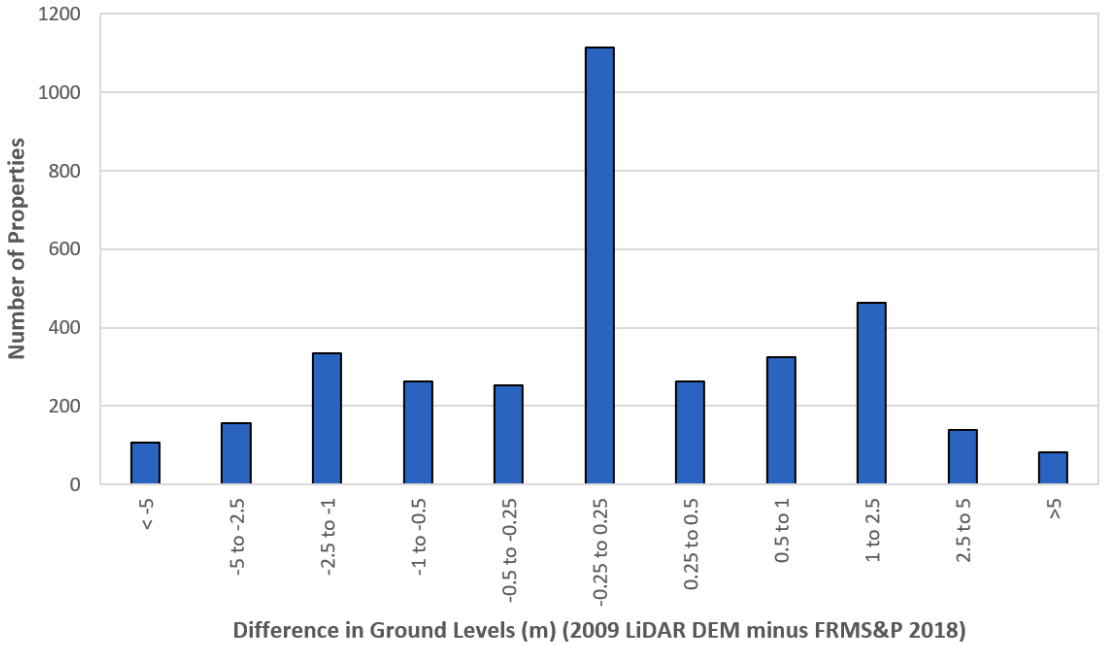

Figure 3-2 Histogram showing the distribution of difference in elevations between the 2009 LiDAR and FRMS&P 2018 values for residential properties

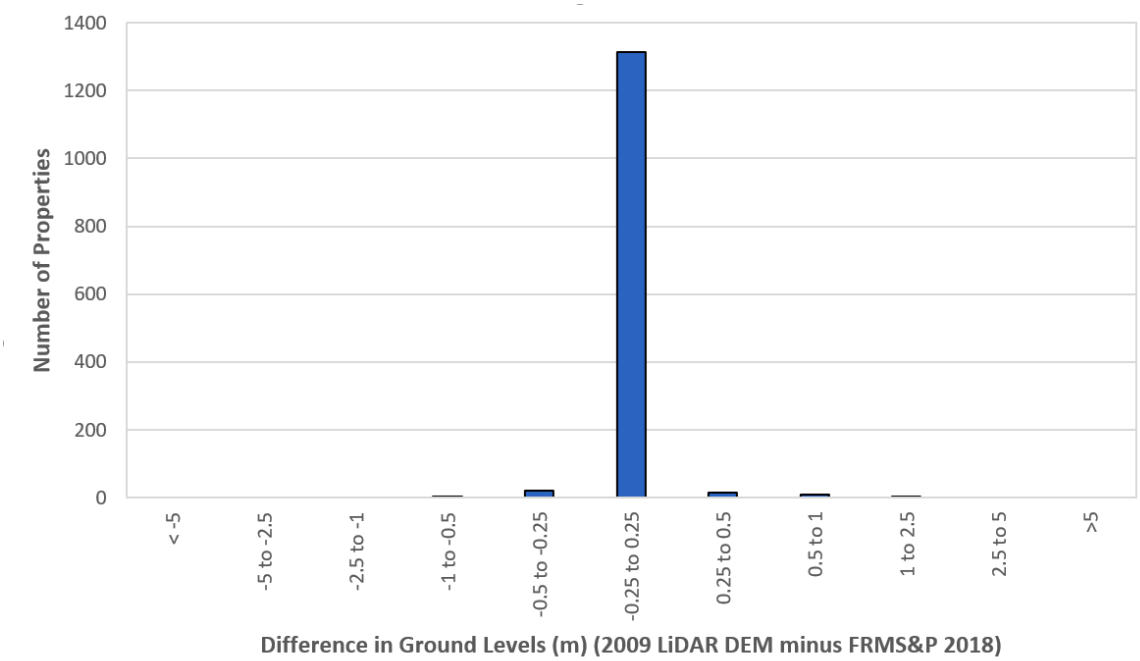

Figure 3-3 Histogram showing the distribution of difference in elevations between the 2009 LiDAR and FRMS&P 2018 values for non-residential properties

The X and Y coordinates and relevant fields within the damage calculation spreadsheet, including “Ground”, “Floor” and “Street” within the “RESIDENTIAL_DAMAGES_Design” tab of the spreadsheets were also plotted in GIS and checked for consistency. This review determined that for Residential Damage Spreadsheet, specifically:

- There is inconsistency between the property “street” field and location of the property. Figure 3-4 presents a GIS output for a sample area within the study extent which shows that a number of properties on Crampton Street are labelled with different street references.
- An example of ground, floor and flood levels at neighbouring properties on Crampton Street (Wagga Wagga) is provided in Table 3-1. As shown in Figure 3-5, these two properties are situated on relatively flat terrain and appear to have similar floor levels, however the data fields in the damage calculation spreadsheet indicate that there is a ground level difference (and therefore a floor level difference) of approximately 3.5 m between these properties. Whilst the PMF flood level applied at these properties is within 0.11 m, 56 Crampton Street is predicted to be affected by above floor flooding of almost 6 m, whilst 58 Crampton Street has above floor flooding of about 2.3 m.
- There may be inconsistency between the locations where the ground level, floor level and flood levels have been extracted within a property (i.e. the ground/floor levels sampled in one property, whilst the flood level data sampled in a different property). However, it is difficult to determine given that the full addresses of properties are not contained within the damage calculation spreadsheet and the location and type of sampling of the ground/floor/flood levels within properties is not reported.
- These inconsistencies require checking and assessment to determine if property data, flood impacts and damages have been correctly calculated or if any component of the assessment is erroneous. For a thorough review to be completed, the correct street name references and lot numbers should be provided.

Figure 3-4 Plot of X and Y co-ordinates from the Residential Damage Spreadsheet showing the data in the "STREET" field in the Crampton Street area

Table 3-1 Property Data for 56 and 58 Crampton Street, Wagga Wagga

Address	56 Crampton Street, Wagga Wagga (ID WC_3365)	58 Crampton Street, Wagga Wagga (ID WC_3026)
Data in "STREET" Field	Crampton St	Donnelly Ave
Ground Level (mAHD)	179.46	182.98
Level extracted from the 2009 LiDAR for this peer review (mAHD)	179.44	179.41
Difference in ground level (m)*	0.01	3.56
Floor Level (mAHD)	179.74	183.26
PMF Level (mAHD)	185.67	185.56
Depth of inundation above ground (m)	6.21	2.58
Depth of inundation above floor (m)	5.93	2.30

Note: *Difference calculated as the FRMS&P 2018 ground level minus the 2009 LiDAR ground level.

Figure 3-5 Google Street View image of 56 Crampton Street (left) and 58 Crampton Street (right)

3.2.3 BMT Recommendations

Errors have been identified in the property data within the Residential Damage Spreadsheet. This should be checked and revised, where necessary. The source of this error is not clear as the methodology for creating the property data set, including source of ground level data and method of data extraction, was not provided in the spreadsheet nor documented in the FRMS&P 2018. Any error in this data or calculations has implications on other aspects of the FRMS&P 2018, including flood damage values, Average Annual Damage (AAD) and number of flood affected properties for both existing conditions and with-options conditions reported as part of the FRMS&P 2018. Subsequently, benefit-cost ratios (BCR) calculated for the options may also be incorrect.

ID	Recommendation	Issue Type	Issue Significance	Timing
3-2	Review and rectify errors in property database, in particular floor levels. Update all subsequent study components that rely upon the property database up to and including options assessment and the FRMP. Update all relevant report sections and add clarification on methodology used and source of data upon which the assessment is based.	Error	High	FRMS&P 2018

3.3 Stage-Damage Curves

Stage-damage curves describe the tangible damages that might be expected when flooding reaches various depths above floor in a building and above ground within a property (for below floor flooding). Separate stage-damage curves were used for:

- Residential dwellings (categorised into single storey/low set, single storey/high set and 2 storey); and
- Non-residential premises (categorised into single storey/low set, single storey/high set and 2 storey) and reported in the FRMS&P 2018 to include non-residential properties but not public buildings such as toilet blocks, schools, fire stations etc.

3.3.1 FRMS&P 2018 Methodology and Implementation

The FRMS&P 2018 reports that the curves include points for the PMF, 0.5%, 1%, 2%, 5%, 10% and 20% AEP floods. However, damages were calculated for the PMF, 0.2%, 0.5%, 1%, 2%, 5%, and 10% AEP floods. Therefore, there is inconsistency between what has been implemented and what has been reported.

It is noted that each component of tangible damages were capped at a certain depth and value (5 m) based on the assumption within the FRMS&P 2018 that any greater depths than the capped value do not incur additional damages. This assumption is considered acceptable because it is assumed that all potential damages should have occurred once a floodwater depth of 5 m is reached.

Residential damage curves were based on stage-damage curves for residential property from the 'Floodplain Risk Management Guideline – Residential Flood Damages' (NSW Government, 2007). The FRMS&P 2018 (main document and/or Appendix C) reported that the residential damage curve was adjusted for use for non-residential properties, assuming that commercial and industrial damages are higher than residential damages as follows:

- Average content damages: This was estimated to be $150,000 for a non-residential property versus $60,000 for residential properties. These reported values are consistent with the values within the damage calculation spreadsheets.
- Typical building size factor: The FRMS&P 2018 assumes that damage to non-residential buildings will scale with size of the building. Appendix C of the FRMS&P 2018 states that a multiplier was applied to the total damage per property for each event by adjusting the typical building size values within the curve development calculations for non-residential properties. However, a comparison of Non-Residential Damage Spreadsheet and Residential Damage Spreadsheet indicated that a 'Total Building Adjustment Factor' of 1.0 and a 'Typical House Size' of 240 m^2 was consistently applied for both residential and non-residential properties.
- Bench height: Appendix C of the FRMS&P 2018 states that the bench height was reduced for commercial properties to assume storage of stock at floor level, whilst residential properties often have more valuable items (such as electrical appliances) stored on benches. However, a comparison of Non-Residential Damage Spreadsheet and Residential Damage Spreadsheet indicated that a 'Typical Table/Bench Height (TTBH)' of 0.9 m was applied for both residential and non-residential calculations.

Consistent values are contained in the curve inputs within the damage calculation spreadsheets for residential and non-residential properties in terms of:

- Clean-up costs - $4,000.

- External damage - $6,700 (although reported in Appendix C of FRMS&P 2018 as being set to $1,250).
- Additional accommodation costs / Loss of rent = $660 (assuming $220/week for a three week period).
- Damage for below floor flooding (linearly interpolated between $0 and $10,050 depending on depth above ground level and height of floor level above ground level). BMT was unable to determine if this results in double counting external damage with $6,700 (above) because the supplied spreadsheets only contain values (no formulas and references).

Estimations for external factors such as the 'Post late 2001 adjustments', 'Contents Damage Repair Limitation Factor' and 'Regional Cost Variation Factor' are also included in the inputs for the calculation of tangible flood damage curves.

The FRMS&P 2018 reports that a post-late 2001 adjustment factor of 1.5 was extracted from the FEB2012 Australian Bureau of Statistics (ABS) report and applied to adjust the stage-damage values within the spreadsheets from 2001 dollars to February 2012 dollars based on the change in Average Weekly Earnings (AWE) figures for Australia at that point in time. However, the adopted factor of 1.5 adjusts the damage values to May 2011 dollars (not February 2012 which would have a value of 1.56 as highlighted in the "AWE Stats" tab of the damage calculation spreadsheets). Whilst it is not stated in the FRMS&P 2018, it is assumed that the damage calculations relate to 2011 dollars only, although the report is dated 2018.

The Regional Cost Variation Factor for buildings is set at 1.0. This factor is included to capture how much more it costs to build in a regional area compared to the State capital city of Sydney. Rawlinsons (2012) indicates that Sydney has a base value of 100 and Wagga Wagga has a value of 105, whilst Rawlinsons (2021) indicates that Sydney has a base value of 100 and Wagga Wagga has a value of 103. Therefore, a slightly higher factor of 1.03 (at least and based on current factors) should be used to appropriately calculate damages for Wagga Wagga.

3.3.2 BMT Assessment

Outcomes from the BMT assessment of methodology and implementation are contained within the above section to ensure context is maintained for each component.

3.3.3 BMT Recommendations

It is recommended that the following be reviewed for stage-damage curve calculations:

- The FRMS&P 2018 states that a multiplier was applied to the total non-residential damage per property for each event by adjusting the typical building size values within the curve development calculations for non-residential properties and that different bench heights were also applied, however this does not appear to have been applied within the calculations. As a minimum, the report should be updated to be consistent with the calculations that have been undertaken. Beyond that, it should be considered whether flood damage estimations for non-residential properties are understated in this study and how that may affect decision making and cost benefit assessment.

- As the report is dated 2018, the damages quoted within the FRMS&P 2018 should relate to 2017 dollars. The Post-late 2001 adjustment factor for November 2017 was calculated by BMT based on Average Weekly Earnings (AWE) sourced from the ABS website (www.abs.gov.au). Therefore, a factor of 1.76 should be applied (rather than the currently applied factor of 1.5) to uplift the values to 2017 dollars.
- The indirect damage calculations for non-residential properties does not consider loss of profit to businesses resulting from flooding.
- The Regional Cost Variation Factor for buildings be adjusted to 1.03.
- Update the report to clarify whether the non-residential external damages of $6,700 were added to the interpolated below floor damages.

ID	Recommendation	Issue Type	Issue Significance	Timing
3-3	Review assumptions and calculations in developing stage-damage curves. Undertake a sensitivity assessment to determine impact of errors and assumptions on stage-damage curves, damage calculations and BCR of options. If sensitivity assessment indicates actionable impact on study outcomes, update stage-damage curves and redo all subsequent tasks. If no actionable impact, as a minimum, update methodology discussion in the report to be consistent with the actual detail of implementation.	Error	High	FRMS&P 2018
3-4	Undertake a sensitivity assessment to determine impact of considering 0.2EY event on damage calculations and BCR of options. If sensitivity assessment indicates actionable impact on study outcomes, update damages and AAD, and redo all subsequent tasks. If no actionable impact, as a minimum, update discussion in the report to be consistent with the actual detail of implementation.	Error	High	FRMS&P 2018

3.4 Treatment of Levees

3.4.1 FRMS&P 2018 Methodology and Implementation

The FRMS&P 2018 reports that, as per "OEH advice" (also referred to as *"OEH guidance"*), the damage assessment adopted a conservative approach whereby it is assumed that a levee only offers protection against floods up to the magnitude of the design level of protection. For flood magnitudes larger than the design flood, levees are deemed to have failed and spillways become active. No reference is provided for the OEH guidance quoted in the report and therefore, a suitable reference

should be documented in the FRMS&P 2018 report to enable the source of the approach to be verified by readers and as part of this review.

For events greater than the 1% AEP flood, failure of the Wagga CBD Levee was reported to be modelled by removing 0.4 m of freeboard from the spillways and lowering the remaining crest height by the same amount, leaving a modelled freeboard of 0.5 m compared to the original 0.9 m freeboard allowance. A similar approach was reported to be used for proposed North Wagga Levee upgrade options.

As the current North Wagga Levee has a 0.3 m freeboard which is considered to be insufficient under current freeboard recommendations of 0.75 m (Public Works, 2010), for existing levee conditions the North Wagga Levee was reported to be modelled in line with the OEH Guidelines for levees that do not have a formal spillway design. The FRMS&P 2018 reports that hydraulic modelling artificially breaches the existing North Wagga Levee in events greater than and including the 5% AEP flood (i.e. modelled events with a magnitude greater than ~ 8 year ARI) and it was not deemed necessary to breach the levee in the 10% AEP flood as the levee is not overtopped in this design event.

3.4.2 BMT Review of Hydraulic Modelling

The breach of the existing North Wagga Levee is modelled by reducing a 100 m section on each side of the levee (upstream and downstream) to a level halfway between natural surface and the existing level of protection to allow controlled failure to occur. The breach is modelled in TUFLOW as a “variable Z shape”. Essentially, TUFLOW 2D model topography is varied over time to represent embankment failure when the water level reaches a specified height (in this case the design level of protection) at a specified trigger location (refer modelled breach locations in in Figure 3-6).

Under North Wagga Levee upgrade scenarios (i.e. Option L3(A-C) and L4(A-C)), the North Wagga Levee was reported within the FRMS&P 2018 to be modelled using the same approach as for the Wagga CBD Levee (i.e. described above) because the upgrades would include formal spillway designs. However, it is noted that the report does not define what portion of freeboard is removed from the spillways and the remaining freeboard that has been modelled. Contrary to what was reported, the North Wagga Levee upgrade Option L4(B) was found to be hydraulically modelled based on a similar approach as the modelling of the existing scenario. That is, a breach was modelled by reducing a 100 m section on each side of the levee (upstream and downstream) to a level halfway between natural surface and the proposed level of protection to allow controlled failure to occur. A levee freeboard of between 0.3 and 0.6 m was found to be modelled (refer Section 4.3.2).

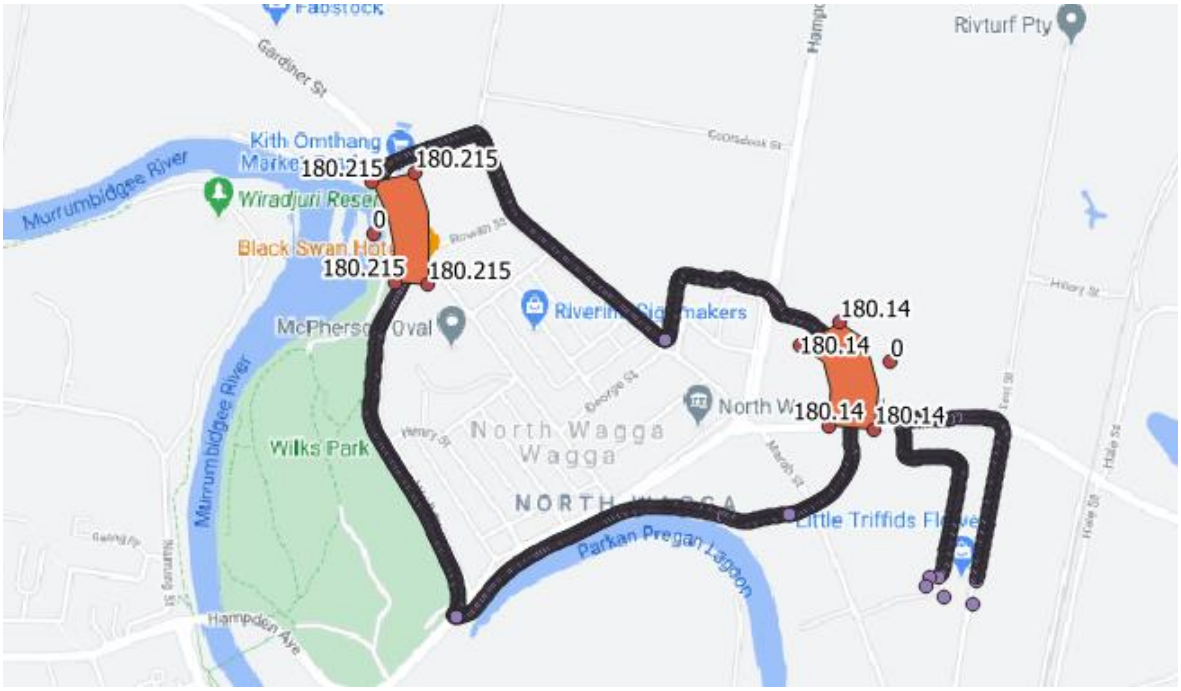

Figure 3-6 North Wagga Levee breach locations (shown as orange polygons)

3.4.3 BMT Assessment

Damage values will be greater in areas protected by levees as a result of the FRMS&P 2018 approach. Therefore, this approach is considered to provide conservative damage estimates within levees, particularly within the Wagga CBD Levee because:

- recent upgrade works have been completed to provide 0.9 m freeboard in line with the 'Wagga Wagga Levee Upgrade – Flood Freeboard Report, NSW' (Public Works, 2010);
- the structural integrity of this levee is known (in terms of, for example, settlement, defects, etc); and
- regular maintenance should be provided to ensure its maintained integrity.

This would also be similar for any upgraded North Wagga Levee option, which should be designed with a 0.75 m freeboard in line with the 'Wagga Wagga Levee Upgrade – Flood Freeboard Report, NSW' (Public Works, 2010) recommendations and would have known structural integrity at the time of upgrade and ongoing maintenance for continued integrity.

However, it is noted that the structural integrity of the existing North Wagga Levee is not known and that a geotechnical assessment of the levee is proposed as part of the future feasibility study for Option L4(B) (as documented in the FRMS&P 2018). Therefore, the approach for modelling the existing North Wagga Levee failure is considered to be based on valid assumptions and a suitably conservative approach. However, it is not understood why levee failure was not modelled for the 10% AEP flood.

The review of the modelling determined that the North Wagga Levee was modelled as reported for proposed levee upgrade options (i.e. breach failure and spillways became active) for both the existing and design scenarios for flood damage calculations. The North Wagga Levee was modelled with a

reduced freeboard of 0.3 to 0.6 m, however as the report did not include the intended freeboard level of this levee failure scenario, the review was unable to determine the reliability of the assessment.

3.4.4 BMT Recommendations

In practice, freeboard will provide additional protection if the levee remains intact during an event. Therefore, it would also be beneficial to test the performance of levees with full freeboard and no failure, and to calculate the damages for these no failure scenarios. A further scenario that could be considered is full freeboard with partial (upstream) levee failure (i.e. no failure downstream), which could also potentially occur and would result in high damages (and hazard) within the levee. This would enable a "sensitivity assessment" of the impact on the calculated damages and BCR of the options.

ID	Recommendation	Issue Type	Issue Significance	Timing
3-5	Correct inconsistency between reported methodology and implementation within the modelling undertaken in relation to freeboard and levee failure for North Wagga. Undertake a sensitivity assessment to re-model reported freeboard and approach and determine impact on results and damages. If sensitivity results are not actionable, as a minimum, update report to be consistent with actual modelling implementation. If actionable, update assessment and all subsequent tasks.	Error	High	FRMS&P 2018
3-6	Undertake a sensitivity assessment of the following scenarios: 1. Full freeboard with no levee failure; 2. Full freeboard with partial (upstream) levee failure.	Gap	Medium	Future

3.5 Damage Calculations

3.5.1 FRMS&P 2018 Methodology and Implementation

As reported in the FRMS&P 2018, a total of 3,501 residential and 1,382 non-residential properties within the PMF extent were included in the damage assessment. Tangible flood damages (both direct and indirect damages) were calculated using the database of potentially flood affected properties and stage-damage curves derived for residential and non-residential properties within the catchment.

The damage calculation spreadsheets do not include formulas, only numerical values. Therefore, it was difficult to cross-check the references, calculations and values within and across the various tabs in the spreadsheets. However, as discussed in Section 3.2, property data within the Residential Damage Spreadsheet, in particular, requires checking and is potentially in error. Thus, the damage calculations should be reviewed and revised, as required.

Average Annual Damage (AAD) was calculated on the basis of area under the damage versus probability curve. In calculating AAD for the FRMS&P 2018, it was assumed that there would be no flood damages in events smaller than the 0.2EY event.

3.5.2 BMT Assessment

In calculating damages and AAD, it is important to consider an appropriate range of design flood magnitudes (i.e. more frequent to rarer and extreme events above the Flood Planning Level (FPL)) that result in flood impacts within the study area. The FRMS&P 2018 reports that there would be no flood damages in events smaller than the 0.2EY event. However, the damages calculations (contained within the damage calculation spreadsheets) do not include the modelled 0.2EY event. Therefore, flood damage and AAD calculations should also consider the 0.2EY event or appropriate justification for the exclusion of this event should be provided in the FRMS&P 2018 report (i.e. does the report mean events smaller than and including the 0.2EY event?).

The FRMS&P 2018 report focusses on tangible damages and notes that intangible damages have not been quantitatively assessed due to difficulties in assigning a monetary value. The aspects of tangible damages considered are:

- Direct urban damage comprising contents, external and structural damage. Direct damages have been assessed through the derivation and application of stage-damage curves informed by peak flood levels for all modelled events with the exception of the 0.2EY event.
- Indirect damages comprising clean-up costs and alternate accommodation costs. This was partially included, however indirect damages for non-residential properties comprising loss of trade, loss of wages and loss of profit was not included.

In relation to the current flood damage estimates, there are potential issues with the property database used for the damage calculations and a number of factors within the stage-damage curve inputs should be reviewed. Therefore, damage calculations need to be revised accordingly.

The types of damages that have not been quantified and included as part of this assessment include:

- Direct and indirect (tangible) public and infrastructure costs including the cost of damage to contents of public buildings (schools, hospitals, etc.), public property, vehicles and machinery, physical damage to infrastructure (electricity, water, gas, roads, etc), clean-up costs associated with public infrastructure and disruption of services. Typical approaches to the estimation of damages include either a percentage of the total direct damages for residential and non-residential properties, or cost per hectare. For example:
  - ‘Lake Illawarra Floodplain Risk Management Study’ (Cardno, 2012) adopted an indirect damages value of 50% of the total direct residential and commercial/industrial damages.
  - ‘Avalon to Palm Beach Floodplain Risk Management Study and Plan’ (MHL, 2017) reports that *“OEH advised that damages to infrastructure (road etc) be estimated as 15% of total direct residential and commercial/industrial damages”.*
  - ‘Gloucester Floodplain Risk Management Study and Plan’ (BMT, 2021) assumed an indirect damages cost of $13,400 per hectare of flood extent.

- Intangible losses include damages related to the social impact of flooding such as:
  - inconvenience;
  - isolation;
  - disruption of family and social activities;
  - anxiety, pain and suffering, trauma;
  - physical ill-health; and
  - psychological ill-health.

Whilst intangible damages have not been quantified, they may be significant. The 'Floodplain Development Manual' (2015) recognises that intangible damages are difficult to quantify in meaningful dollar terms, however, can be considered *"in terms of the likely number of people affected, can be inferred on the basis of flood behaviour, flood severity and the size of the flood prone population".*

Intangible losses may be considered as a percentage of the total tangible damages. For example, 'Lake Illawarra Floodplain Risk Management Study' (Cardno, 2012) adopted 5% of the total tangible damages, whilst the 'Avalon to Palm Beach Floodplain Risk Management Study and Plan' (MHL, 2017) reports that *"in keeping with advice previously received from OEH, social damages have been estimated (as a separate item) as 25% of 'total damages', which are interpreted as the sum of direct residential damages and direct non-residential damages".*

As a further example of the contribution of intangible damages, an economist on the 'Brisbane River Strategic Floodplain Management Plan' (BMT, 2018) team recommended the below uplift for intangible damages, calculated as a multiplier of tangible damages.

Table 3-2 Proposed intangibles uplift factors according to event probability[4]

AEP	Intangibles uplift factor as % of 1% AEP uplift factor	Proposed intangibles uplift factor
5%	0%	0.00
2%	60%	0.72
1%	100%	1.20*
PMF	380%	4.56

Note: *These uplift factors mean that for every $1 spent on tangible damages in a 1% AEP flood (including direct and indirect), an additional $1.20 would be spent on intangible damages.

Estimation of these identified additional damage types and values would ensure that the study considers the 'total flood damage' as a sum of the total tangible and intangible damages, as per the definition within the 'Floodplain Development Manual' (2005). Accordingly, additional sources of flood damages (beyond direct damages and indirect damages for residential, commercial/industrial properties) should be considered for use in future.

[4] From Brisbane River Strategic Floodplain Management Plan Technical Evidence Report (BMT et al., 2018)

It is recognised that these additional sources of damages are not 'needed' to demonstrate the economic viability of the assessed structural measures, however there are two key benefits to introducing additional sources.

- The true "cost" of flooding is captured and helps recognise all sources of flood impacts (e.g. damage to road infrastructure, mental health impacts etc.). This would provide for a more robust estimate of the economic consequence of flooding, hence providing a better understanding of the benefit of potential flood mitigation measures through updated BCR.
- Additional mitigation measures which are assessed in future may be more economically viable as a result of considering all sources of damages.

It is noted that estimation of additional sources of damages is difficult, with little data to support estimations. However, it is generally preferable to include an approximation than to exclude these items altogether. Additionally, additional sources of damages could be reported as both combined and separate AAD calculations if there is concern over the degree of uncertainty.

3.5.3 BMT Recommendations

Recommendations detailed in Section 3.5.2 are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
3-7	Correct error relating to property database (refer to Recommendation 3-2), as well as other damage-related errors associated with inconsistencies between reported methodology and implementation (as required), and update damages assessment	Error	High	FRMS&P 2018
3-8	Include direct and indirect (tangible) public and infrastructure costs, and intangible damages in total damage assessment	Not Best Practice	Medium	FRMS&P 2018

4 Flood Risk Management

Floodplain risk management involves the consideration of various options together with their social, economic and environmental consequences. Options can be grouped into three broad categories:

- Flood Modification Options:
  These options modify existing flood behaviour (i.e. extent, depth and velocity). Examples include retarding basins, on-site detention, channel improvements, levees, floodways and stormwater network upgrades.
- Property Modification Options:
  These options modify individual properties and/or planning controls to reduce the potential for inundation in the first instance and/or improve flood resilience should inundation occur. Examples include flood proofing (house raising or sealing entrances), changes to land use planning and development controls (e.g. zoning, updates to DCP and LEP, etc.) or voluntary purchase.
- Response Modification Options:
  These options modify the response of the emergency services and the community to residual flood risk by providing information, education and awareness about the nature of flooding so that informed decisions can be made before, during and after a flood. Examples include provision of flood warnings, community education and improved information for emergency response.

4.1 Identification of Options

4.1.1 FRMS&P 2018 Methodology and Implementation

Various flood management options were identified and assessed for their effectiveness at managing flood risk. This included a number of options that were previously identified within the 2009 FRMS. The range of flood mitigation options considered in the FRMS&P 2018 included:

- Flood Modification:
  - Structural options - levees; channel modification; bypass floodways; major structural modification; road raising; temporary flood barriers; retarding/detention basins; flood mitigation dams.
- Property Modification:
  - Planning Modifications – land zoning; building; development controls.
  - Individual Property Modifications – Voluntary purchase (VP); Voluntary House Raising (VHR); flood proofing.
- Response Modification:
  - Emergency planning – flood warning; evacuation planning; evacuation access; flood plan / recovery plan.
  - Community awareness and education.

Following initial identification of potential options, a range of flood modification options including temporary flood barriers, retarding/detention basins, flood mitigation dams were discounted due to

factors such as their unsuitability at reducing flood risk and inundation of dwellings, as well as site constraints (e.g. availability of suitable land). A range of levee, road raising, excavation, bridge modification and vegetation management options (refer list in Table 4-1) were pursued for further, more detailed assessment and focussed on the Oura, Gumly Gumly, North Wagga and West Wagga floodplain precincts.

4.1.2 BMT Assessment

The FRMS&P 2018 (and previous 'Wagga Wagga Detailed Flood Model Revision Report' (WMAwater, 2014)) provided an update to design flood modelling and developed numerous risk assessment tools based on that modelling, such as 'Handbook 7' (AIDR, 2017) hazard categories, hydraulic categories and emergency response precincts. Additionally, updated damage and cost-benefit assessments were completed. It is therefore appropriate that measures that were previously identified as feasible in the 2009 FRMS were re-assessed using these updated tools.

A range of measures and options were considered and reported in detail within the FRMS&P 2018. Flood modification measures were focussed on areas identified as having higher flood risk and potential flood damages, including North Wagga, West Wagga and Wagga floodplain in particular, whilst property and response modification options were typically considered applicable to all floodplain precincts.

4.1.3 BMT Recommendations

The process of identifying options could have been improved through the application of a holistic flood risk assessment process which identified the location of vulnerable communities and vulnerable institutions (schools, hospitals, childcare etc).

ID	Recommendation	Issue Type	Issue Significance	Timing
4-1	Locate and map vulnerable communities (using higher resolution Census data) and vulnerable institutions. Refer also to Recommendation 2-2.	Gap	Medium	Future

4.2 Assessment Methodology

4.2.1 FRMS&P 2018 Methodology and Implementation

Structural (flood modification) options were assessed using the following approach:

- Identification of appropriate location and design parameters (e.g. alignment and crest levels for levees, road elevations for flood immunity, etc).
- Simulation of the hydraulic model(s) for design events ranging from 10% AEP flood to the PMF with each option in place.
- Assessment of impacts on flood behaviour – assessed as the change to peak flood level "with option" compared to "base case" (existing or without option).

- Calculation of properties that are either newly flooded and newly flooded above floor, or no longer flooded or no longer flooded above floor, as a result of the proposed option.
- Determination of change in potential frequency of above floor flooding due to option implementation (i.e. property flooded in less frequent event or more frequent event as shown in within Section 9 of the FRMS&P 2018).
- Calculation of residential and non-residential (i.e. commercial/industrial) properties flooded above floor and above ground, and reduction or increase in these counts compared to base case.
- Total damage for each flood event size and AAD.
- High-level cost estimates for the construction of options.
- Economic assessment (i.e. calculation of BCR) informed by reduction in flood damages and construction cost-estimates.
- Recognition and discussion of concerns such as construction practicalities, access and isolation, level of protection, community awareness of residual risk, etc.
- A relative assessment to establish the potential feasibility of each option based on a suite of factors (e.g. flood risk, technical feasibility, economic merits, environmental impacts, etc.) to determine which measures demonstrate merit for further consideration (i.e. the Multi-criteria Assessment).

For the non-structural measures, proposed strategies and considerations for implementation were provided, e.g. adoption of a matrix-style Development Control Plan, setting Flood Planning Levels (FPLs), etc.

4.2.2 BMT Assessment

The overall approach to assessing flood risk management options within the FRMS&P 2018 is typically considered to be sound. However, it should be noted that climate change scenarios were not considered in the assessment of options (especially the North Wagga options), even though the results of the climate change modelling for existing conditions indicated that the North Wagga floodplain is sensitive to climate change impacts.

Although two (2) potential options have been recommended for further investigation, including feasibility studies to investigate VHR and VP schemes in the Wagga Wagga study area (Option PR1) and the North Wagga Levee Upgrade to the 5% AEP level (Option L4(B)), a combined assessment with both Option L4(B) and Option PR1 in place was not undertaken to inform the overall recommendation of these measures. Moreover, all options were individually assessed (i.e. in isolation); no combined options were considered to determine the cumulative impacts of the options and the potential for the use of multiple options to offset the impacts of individual options. This is not in line with best practice guidance in ‘Floodplain Development Manual’ (2005), which advocates the cumulative assessment of decisions relating to mitigation works and measures. Specific reference is made to Section G3 of Appendix G of the manual, which states that “*The impact of management works or proposed development on flooding behaviour elsewhere, should be assessed on a cumulative rather than individual or ad hoc basis within the context of the management plan*”.

Detailed reviews of the hydraulic assessment (i.e. modelling "with options"), impact assessment, economic assessment and multi-criteria analysis are provided in the following sections.

4.2.3 BMT Recommendations

Recommendations detailed in Section 4.2.2 are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
4-2	Assess combined options/scheme to complement and/or mitigate options and ensure potential cumulative impacts are considered.	Not Best Practice	High	FRMS&P 2018
4-3	Consider impact of climate change on option assessment	Not Best Practice	Medium	Future

4.3 Hydraulic Assessment of Flood Modification Options

4.3.1 FRMS&P 2018 Methodology and Implementation

As discussed, a broad range of flood modification measures such as levees, channel modifications, bypass floodways, road raising, and major structure modification were investigated as part of the FRMS&P 2018 (refer Table 4-1). As flood modification measures aim to modify the physical behaviour of the flood such as the depth, velocity, and re-direction of floodwaters, their hydraulic impact on existing flood behaviour was assessed by updating the TUFLOW hydraulic model to include each flood modification option. The updated TUFLOW models were then used to re-simulate each of the design floods with the options in place.

Table 4-1 summarises flood modification options assessed for each floodplain community and the outcomes of the review of the hydraulic assessment. The suitability of the adopted modelling techniques has been reviewed in more detail in the following sections, with focus on the options proposed for North Wagga.

It is important to note that at the time the FRMS&P 2018 was prepared, the Wagga CBD upgrade to a 1% AEP level of protection was not complete. However, hydraulic assessment of structural options within the FRMS&P 2018 assumed that this upgrade had occurred, and therefore included the Wagga CBD upgrade in the base case when testing all other options.

A TUFLOW Classic model is typically examined with respect to mass balance and occurrences of negative depths which is a pre-cursor to model instability. For the purpose of determining the overall model health, the TUFLOW model for one mitigation option (L4(A)) was simulated until the end of the simulation. The TUFLOW log file for this simulation indicates a final cumulative mass balance error of –0.1% with zero 1D negative depths and three 2D negative depths. As such, these parameters indicate a healthy and a stable model (note: limited to the model checked but assumed that all model simulations were checked as part of the QA process undertaken by WMAwater for the FRMS&P 2018). A full model review of the base case was not undertaken; this review was limited to verifying the overall health of the model and the appropriateness of modelling approach for flood modification options.

Table 4-1 Outcomes of Hydraulic Model Review for Flood Modification Options

Floodplain Precinct	Option	Mitigation Options Considered	Outcome of Review
Oura	L1	Oura Levee	Modelled correctly but with lower than reported freeboard.
	R1	Oura Road raising to 1% AEP level	Not reviewed as complete model input data was not provided with the hydraulic model.
Gumly Gumly	L2	Gumly Gumly Levee	Modelled correctly but with lower than reported freeboard.
	R2	Raising Sturt Highway to 1% AEP level	Not reviewed as complete model input data was not provided with the hydraulic model.
North Wagga	L3(A-C)	North Wagga Levee upgrade (1% AEP level of protection ("LOP")) with and without the Hampden Avenue upgrades	Modelled correctly but with lower than reported and recommended freeboard.
	L4(A-C)	North Wagga Levee upgrade (5% AEP LOP) with and without the Hampden Avenue upgrades	Modelled correctly but with lower than reported and recommended freeboard.
	L5	Removing North Wagga Levee	Modelled correctly
	L6	Opening North Wagga Levee	Modelled correctly
Wagga Floodplain	A1	Increase conveyance beneath Wiradjuri Bridge	Modelled correctly
	BF1	North Wagga Floodplain Bypass Floodway	Modelled correctly
West Wagga	CM1	Excavation of Malebo Gap	Modelled correctly
	CM2	Excavation of Gobbagombalin Bridge	Modelled correctly
Study Area	VMP (A-D)	Vegetation Management Plan	Modelled correctly

4.3.2 North Wagga Options

The existing levee provides protection for North Wagga equivalent to a 12% AEP flood. Following the recent floods in 2010 and 2012 and the Wagga CBD Levee upgrade, the North Wagga Levee is of particular concern to many residents and was one of the key considerations with regard to options for the Wagga Wagga floodplain. Thus, a number of North Wagga Levee options were assessed as part of the FRMS&P 2018, including both 5% AEP and 1% AEP levels of protection, levee options combined with access upgrades to Hampden Avenue, and opening or complete removal of the levee.

Table 4-2 summarises flood modification mitigation options assessed for the North Wagga floodplain community. The following sections outline the findings of BMT's review of the hydraulic assessment of these options in further detail.

Table 4-2 North Wagga Flood Modification Options

Option ID	Level of Protection of Levee	Option Description
L3(A)	1% AEP	Levee Upgrade (1% AEP LOP) only
L3(B)	1% AEP	Levee Upgrade (1% AEP LOP) with Hampden Avenue upgraded (as embankment)
L3(C)	1% AEP	Levee Upgrade (1% AEP LOP) with Hampden Avenue upgraded (as overland bridge)
L4(A)	5% AEP	Levee Upgrade (5% AEP LOP) only
L4(B)	5% AEP	Levee Upgrade (5% AEP LOP) with Hampden Avenue upgraded (as embankment)
L4(C)	5% AEP	Levee Upgraded (5% AEP LOP) with Hampden Avenue upgraded (as overland bridge)
L5	N/A	Removal of North Wagga Levee
L6	20% AEP	Opening of North Wagga Levee (lowering spillways to 20% AEP LOP)

4.3.2.1 North Wagga Levee Upgrade

Options L3(A) and L4(A) assess upgrading the existing North Wagga levee to protect against a 1% AEP and 5% AEP flood event, respectively, without any modifications to Hampden Avenue. The North Wagga ring levee is modelled in TUFLOW as a Z shape line with a width value of 2. As the shape width is greater than zero and less than or equal to 1.5 times the model 2D cell size of 20 m, the North Wagga Levee is modelled as a thick line (i.e. a 20 m width).

Elevations are assigned to the levee at locations where Z points are snapped. Separate Z point layers are read in for the levee for the 1% or 5% AEP levels of protection. The dZ attribute of the Z shape is used to raise the Z points by a further 0.3 m. The final elevations along the levee are determined by linear interpolation between the revised Z points.

The FRMS&P 2018 report states that a freeboard of 0.75 m was recommended for the North Wagga Levee (Public Works, 2010), however Section 9.3.3.1 of the FRMS&P 2018 states that the proposed North Wagga Levee options include a freeboard of 0.7 m. Within the modelling, the crest of the levee is above the designed AEP flood level, with the freeboard generally varying between 0.3 m and 0.6 m based on a comparison of modelled levee elevations against modelled design flood levels. This is shown in Figure 4-1.

Therefore, neither the recommended nor reported levee freeboard is reflected in the modelling. Furthermore, the modelled freeboard for the no failure scenario was found to be the same as the modelled freeboard for the failure scenario for North Wagga Levee options (albeit without the spillway lowering). This finding is valid for modelling of all North Wagga Levee options but is in conflict with the approach reported in the FRMS&P 2018.

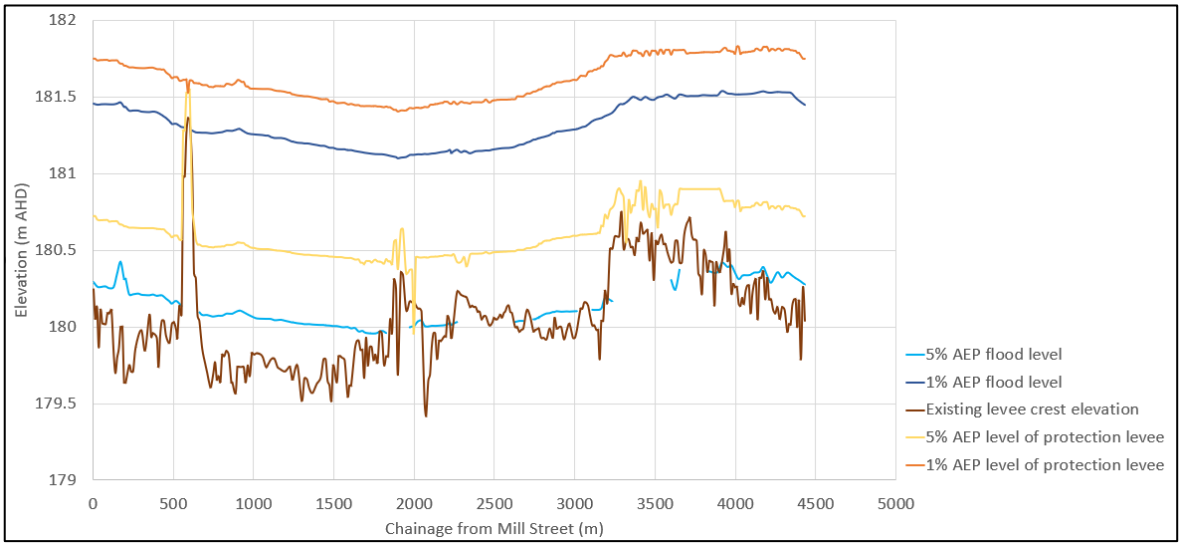

Figure 4-1 Modelled Levee Crest Elevation vs Design Flood Levels

4.3.2.2 North Wagga Levee Upgrade with Hampden Avenue Upgraded as Embankment

Options L3(B) and L4(B) assess the same levee options as L3(A) and L4(A) with the addition of an upgrade to Hampden Avenue. In this scenario, Hampden Avenue is modelled as an embankment style construction from Wiradjuri Bridge through to Parken Pregan Bridge. This is modelled in TUFLOW as a thick Z shape line. Similar to the North Wagga Levee, elevations of the Hampden Avenue Upgrade are assigned where Z points (i.e. "Z" ground elevation points) are snapped. Separate Z point layers are read in for the 1% and 5% AEP level of protection.

In addition to the Hampden Avenue Upgrade, Parken Pregan Bridge is extended and excavated to allow increased conveyance to offset flood level impacts that are caused by the levee. This is modelled in TUFLOW as a Z shape polygon with Z points snapped to assign elevations. The excavated area is modelled as approximately 3 m to 5 m lower than the existing ground elevation.

In the excavated regions, Hampden Avenue at Parken Pregan Bridge is modelled as a layered flow constriction (FC). Layered FCs function by adjusting the flow width of the 2D cell so as to represent the combination of blockages of the four layers. When the flow is only within Layer 1, only the attributes of Layer 1 are applied. As the water level rises into Layer 2, the influence of the Layer 2 attributes increase and similarly for Layer 3 and Layer 4. Consequently, two separate layered flow constriction layers are read in for 1% and 5% AEP level of protection designs. The modelling of the North Wagga Levee with Hampden Avenue upgrade as an embankment is considered acceptable for this study.

4.3.2.3 North Wagga Levee Upgrade with Hampden Avenue Upgraded as Overland Bridge

The North Wagga Levee modelled in Option L3(A) and L4(A) is paired with an upgrade to Hampden Avenue as an overland bridge to form Options L3(C) and L4(C). The upgrade to Hampden Avenue has been assessed using an overland bridge style construction from Hampden Bridge through to Parken Pregan Bridge that involves removing the existing road embankment and excavating the flow path beneath the existing Parken Pregan Bridge to increase flow conveyance. This means that the

overland bridge is modelled as a single spanned bridge with no allowance for flow constriction caused by piers.

The excavation is modelled in TUFLOW as a Z shape polygon with Z points snapped to assign elevations. The excavated region is up to approximately 4 m lower than the existing ground elevation. It is difficult to assess the suitability of this modelling approach as no concept design is provided for this option.

4.3.2.4 Removing North Wagga Levee

This option assesses the removal of the existing North Wagga Levee. A 2D Z shape polygon was used to triangulate Z point values based on the Z point elevations of the polygon perimeter, simulating the lowering of the levee to match adjacent ground levels. The modelling of the removal of North Wagga Levee is considered acceptable for this study.

4.3.2.5 Opening North Wagga Levee

This option assesses the opening of the currently enclosed North Wagga ring levee by excavating an upstream and downstream spillway to the level of the 0.2EY flood event. The spillway is modelled in TUFLOW as a Z shape polygon. The 'NO MERGE' option is used to assign a single elevation to all Z points falling within the Z shape polygon. The opening is at an elevation of 179.45 mAHD, while the downstream opening is at an elevation of 179 mAHD. The modelling of the North Wagga Levee opening is considered acceptable for this study.

4.3.3 BMT Assessment

As discussed, the freeboard modelled (i.e. 0.3 to 0.6 m) for the North Wagga Levee options did not meet the reported value of 0.7 m nor the recommended value of 0.75 m (Public Works, 2010). It is considered that the impact of this inconsistency between modelled and reported/design freeboard would be as follows:

- For flood events with a smaller magnitude than the design level of protection:
  A lower modelled freeboard will not change the resultant flood behaviour and impacts because water levels should remain below the crest of the levee.
- For flood events with a larger magnitude than the design level of protection but with flood levels lower than the modelled levee crest (i.e. design level of protection plus modelled freeboard):
  A lower modelled freeboard will not change the resultant flood behaviour and impacts because water levels should remain below the crest of the levee.
- For flood events with a larger magnitude than the design level of protection and where predicted flood levels are higher than the modelled crest but below the reported crest elevation based on the reported/recommended freeboard:
  There will be the largest impact on resultant flood behaviour and impacts.
- For flood events with a larger magnitude than the design level of protection and where predicted flood levels are higher than the correct (either recommended or reported) crest elevation based on the reported/recommended freeboard:

There will be an impact on resultant flood behaviour and impacts due to a reduced impediment to flow (between the modelled and reported crest elevation).

The correct (either recommended or reported) freeboard should be applied to the modelling of levee options and a sensitivity assessment should be completed for all design events to determine the impact of adjusting the levee crest elevations to be consistent with what is reported in the FRMS&P 2018.

4.3.4 BMT Recommendations

Recommendations detailed in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
4-4	Review and correct inconsistency between reported methodology on freeboard and modelled freeboard. This is likely to require updates to the modelling and damage assessment.	Error	High	FRMS&P 2018

4.4 Impact Assessment of Options

4.4.1 FRMS&P 2018 Methodology and Implementation

The flood level and extent results from the options assessment simulations were compared against the flood level and inundation extent results from the existing conditions to prepare “difference mapping” for the 5% AEP and 1% AEP flood events. The difference mapping provided in the FRMS&P 2018 shows the magnitude and location of changes in flood levels and inundation extents associated with implementation of the option.

‘Change in Property Flood Affectation’ (i.e. property flood impacts) is also reported for each option within Section 9 of the FRMS&P 2018, with tables listing the net reduction and net increase in number of properties flooded externally and above floor. Diagrams of how properties flooded over floor are affected by implementation of the options across the full range of design events are also provided.

4.4.2 BMT Assessment

It is recognised that in order to update the AAD associated with the options, all design events between the 10% AEP and PMF were simulated with the options in place as part of the FRMS&P 2018. However, a focus was placed on mapping the flood level differences predicted during the 5% AEP and 1% AEP floods. This aligns with the design levels of protection considered for the North Wagga Levee upgrade, as well as providing an indication of how the option would perform during more frequent (i.e. 5% AEP) and rarer (i.e. 1% AEP) floods. Therefore, the presentation of results only for these events is considered to be suitable.

It is also noted that impact assessments for levee options are based on ‘no failure’ of levees (i.e. full freeboard), whilst the damages assessments for the levee options are based on ‘failure’ of levees. This makes it difficult to reconcile the predicted flood impacts of the levee options reported in the FRMS&P 2018 with the economic impacts for each option as they are based on different modelled levee scenarios.

4.4.3 BMT Recommendations

Similar to the discussion in Section 3.4.3, it would be beneficial to compare the flood behaviour and impacts of the options for failure and no failure scenarios. This would enable the study to test the performance of the levee with correct (i.e. either recommended or reported) freeboard and no failure, as well as the performance of the levee with reduced freeboard and failure.

In terms of levee impacts, additional consideration might be given to how the proposed levee works will impact disaster management. In particular:

- How much additional time is available for evacuation as a result of the levee works. This would involve modelling the overtopping event, i.e. something just slightly larger than the design plus freeboard event, and comparing this to the overtopping event for the existing levee. This would provide an indication of the benefits of additional time to evacuate that would result from a higher levee and/or greater flood immunity of egress routes.
- Changes to the emergency response planning classification categories resulting from the levee works, such as reduced areas of isolation. This would be most relevant to the 1% AEP emergency response planning classification with levee upgrades to a 1% AEP LOP (i.e. Options L3(A), L3(B) and L3(C)).

ID	Recommendation	Issue Type	Issue Significance	Timing
4-5	As per Recommendation 3-6, undertake a sensitivity assessment of the following scenarios: 1. Full freeboard with levee failure; 2. Full freeboard with partial (upstream) levee failure.	Gap	Medium	Future
4-6	Provide details of how the proposed levee works will impact disaster management	Gap	Medium	Future

4.5 Economic Assessment of Options

4.5.1 FRMS&P 2018 Methodology and Implementation

4.5.1.1 Cost Estimates for Options

The costing of the structural options includes capital works only (no maintenance or operating costs). Costs included are:

- detailed design study;
- planning and approvals / easement requirements;
- detailed survey;
- contractor establishment;
- WHS compliance;
- project management; and

- construction costs.

Costing of these items is described as being based on similar industry project values when compared on a per metre basis. No further information is supplied as to what these values were based on. A 20% contingency value is also added. No ongoing maintenance costs were included in the costings.

The 'Levee Upgrade Detailed Design and Community Consultation' (2015) also includes costing of the levee options. These costs were compared to the costings from the FRMS&P 2018 and found to include an estimated capital cost which is comparable to those in the FRMS&P 2018 (without contingency and no contingency has been reported). It also, however, includes present value of total costs at discount rates that include operation and maintenance costs, which have not been considered in the FRMS&P 2018.

4.5.1.2 Cost-Benefit Analysis

Economic appraisal is a way of analysing all the costs and benefits associated with various options and enables a comparison of their relative costs and benefits. Economic 'benefits' were quantified in the FRMS&P 2018 as the reduction in flood damage costs if the option is implemented. The report notes that benefits of each option were estimated by preparing damage estimates for each design flood event with the option in place and using this information to prepare a revised average annual damage (AAD) estimate. This was then compared with the AAD for existing (i.e. no option) conditions to develop the BCR. As the damage calculation spreadsheets with the options in place were not provided as part of the data package, it was not possible to determine the appropriateness of these calculations.

In order for a BCR to be estimated, it is necessary to modify the 'base' AAD estimates (which reflect the average damage that is likely to be incurred in a single year) to a total damage that could be expected to occur over the design life of each flood risk management option. AAD per annum in today's terms are assumed to apply for each year of the Net Present Value (NPV) of damages. NPV calculations are based on a reasonable project lifespan of say, 50 years for mitigation works, with discount factors of 4%, 7% and 11% applied based upon Treasury guidance. However, it is not known whether this has been undertaken. If such calculations were undertaken, the estimated design life and adopted discount value have not been documented within the FRMS&P 2018.

4.5.2 BMT Assessment

A shortcoming of the FRMS&P 2018 is the visual presentation of proposed measures to supplement the reporting (and costing). In particular, the concept designs for levee design options are limited to typical levee cross-sections that accompany the proposed levee alignments shown on the impact mapping in Appendix E, and very limited details of the levee options including Hampden Avenue embankment raising or overland bridge. The addition of specific concept designs for these options would enable a better understanding of what is proposed and how it aligns with the cost estimates.

The FRMS&P 2018 also makes no reference to the calculation of NPV for either the cost estimates for options or the NPV of AAD 'with option' in place. Therefore, it is difficult to determine whether or how the present values of future flood reduction benefits and costs have been calculated. The estimated design life, discount value and NPV figures should be documented in the FRMS&P 2018.

The range of NPV should also be provided to indicate its sensitivity to the standard discount rates (i.e. 4%, 7% and 11%).

Responses to issues raised during Public Exhibition documented in Appendix M of the FRMS&P 2018 note awareness that increasing the levee height is likely to lead to extended periods of inundation as drainage of North Wagga is slowed by the levee system. The capital cost estimate for the levee options includes an allowance for purchase and installation of drainage pipes, presumedly to address local flooding behind the levee. However, no discussion or consideration of appropriate measures to remove floodwaters from behind the levee have been included in the costings. This could include pumps or flapped gates on pipes to prevent backflow from elevated river levels on the outside of the levee,

In addition to capital expenditure associated with each option, the costing should also include maintenance costs over the design life. This is particularly important for measures such as a levees to ensure they maintain the design level of protection and freeboard across their design life. For example, the 'Options for the Upgrade of the Main and North Wagga Levees for Flood Security, Cost Effectiveness Analysis' (2015) included a cost of $11,000/year (in 2015 dollars) for the North Wagga Levee to cover yearly inspections, 5 yearly audits and 5 yearly crest level surveys associated with the levee, as well as regular yearly maintenance activities (e.g. tree/shrub removal, erosion repair, pest eradication/repair e.g. rabbit holes, grass mowing, weed eradication etc.). This value could have been uplifted to 2017 dollars and used as the basis for ongoing maintenance costs within the FRMS&P 2018.

It is also recommended that the calculations undertaken to estimate the BCR for each assessed option are provided for peer review.

4.5.3 BMT Recommendations

Recommendations described in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
4-7	Develop concept designs for options to provide a better understanding of what is proposed and how it aligns with the cost estimates	Gap	Low	FRMS&P 2018
4-8	Update report to include estimated design life, discount value and NPV. This should align with best practice.	Gap	Medium	FRMS&P 2018
4-9	Include consideration of pumps or flap gates on pipes to prevent backflow through levee, including in the costings	Gap	Medium	Future
4-10	Include maintenance costs for options in calculation of costs and recalculate BCR for each option	Not Best Practice	Medium	Future
4-11	Update damages assessment for options in line with Recommendation 3-7	Error	High	FRMS&P 2018

ID	Recommendation	Issue Type	Issue Significance	Timing
4-12	Provide damage and BCR calculations for the options to enable peer review	Gap	Medium	FRMS&P 2018

4.6 Multi-criteria Assessment

Both 'Handbook 7' (AIDR, 2017) and the 'Floodplain Development Manual' (2015) recommend an approach to assessing risk that involves a combination of the likelihood of occurrence and the consequences of that event when it occurs. Three types of risk are also considered: existing; future; and residual. This assessment should be followed by an assessment of the consequences and decision regarding acceptability and investigation into treating the risk.

The 'Floodplain Development Manual' (2005) uses a broad risk management hierarchy of avoidance, minimisation and mitigation to reduce the social and financial costs from flood risk, increase the sustainable benefits of using floodplain areas and improving (or maintaining) floodplain ecosystems. At the strategic level, this requires consideration of social, economic, cultural, ecological and flooding issues to determine strategies for the management of flood risk. Weighting may then be applied based upon the relative importance of issues to the community.

'Handbook 7' identifies the following broad categories which might be used to assess measures, including safety of people, social, economic, environmental, flood behaviour / impacts, feasibility, attitude, compatibility and key infrastructure. It is recognised that these categories are just starting points and Council might choose to modify assessment criteria to align with existing strategies or internal goals, or with issues identified by the community.

4.6.1 FRMS&P 2018 Methodology and Implementation

The FRMS&P 2018 used multi-criteria assessment (MCA) to score each mitigation option against a range of criteria. The report references the 'Floodplain Development Manual' (2015) in using this approach. Risk to life is given a higher weight than other criteria by expanding the range of scores. The remaining criteria are scored equally.

The following sections discuss the choice of criteria, scoring and the sensitivity of the MCA in determining the most desirable options.

4.6.2 Choice of Criteria and Scoring

Nine criteria are used in the MCA but detailed descriptions of each criteria are not provided. MCA criteria should all be measuring separate impacts and should avoid double counting between criteria. Scoring should be quantitative where possible and well documented, particularly in this instance where there are strong opinions and potential for bias.

A comment that is relevant to most criteria is that impacts are compared back to a 'base' case that includes the Wagga Wagga CBD Levee upgrade. This means that the aim is to maintain the benefits created by this levee at the detriment of any possible improvement elsewhere. In contrast, the 'Wagga Wagga Detailed Flood Model Revision' (2014) considered both the Wagga CBD and North Wagga Levees in combination and compared the results to a pre-levee upgrade option and found that the inclusion of both levee upgrades had little cumulative impact on surrounding areas. As noted

in Section 4.3, the Wagga CBD Levee upgrade has now been completed (in mid-2021). Thus, although the inclusion of the Wagga CBD Levee upgrade in the base case may have been premature at the time of preparing the FRMS&P 2018 and may have caused misunderstandings in interpretation of the options assessment, it is now a somewhat moot point.

It is difficult to determine exactly how each criterion has been scored. However, from interpretation of the name of each criterion and any available description within the FRMS&P 2018, some critiques, questions and ambiguity in the criteria are described in the following sections. The criteria and scoring are represented in Table 4-3 and Table 4-4.

Table 4-3 MCA Criteria and Matrix Scoring System (Source: FRMS&P 2018)

	-3	-2	-1	0	1	2	3
Impact on Flood Behaviour	>100mm increase	50 to 100mm increase	<50mm increase	no change	<50mm decrease	50 to 100mm decrease	>100mm decrease
Number of Properties Benefitted	>5 adversely affected	2-5 adversely affected	<2 adversely affected	none	<2	2 to 5	>5
Technical Feasibility	major issues	moderate issues	minor issues	neutral	moderately straight-forward	Straight-forward	no issues
Community Acceptance[1]	majority against	most against	some against	Neutral	minor	Most for, some against	majority
Economic Merits[2]	major disbenefit BC < 0.4	moderate disbenefit BC: 0.4 – 0.7	minor disbenefit BC 0.7 – 1.0	Neutral BC = 1.0	Low BC:1.0-1.3	Medium BC: 1.3 – 1.6	High BC > 1.6
Financial Feasibility	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Environmental and Ecological Benefits	major disbenefit	moderate disbenefit	minor disbenefit	neutral	low	medium	high
Impacts on SES[3]	major disbenefit	moderate disbenefit	minor disbenefit	neutral	minor benefit	moderate benefit	major benefit
Risk to Life[4]	major increase	moderate increase	minor increase	neutral	minor benefit	moderate benefit	major benefit

Table 4-4 MCA Assessment Matrix (Source: FRMS&P 2018)

Ref	Option	Impact on Flood Behaviour	Impact on Property Damage	Technical Feasibility	Community Acceptance	Economic Merits	Environmental/ Ecological Benefits	Impact on SES	Risk to Life*	Total Score
L1	Oura 1% AEP Levee	-1	0	0	1	-2	-1	-1	-2	-6
L2	Gumly Gumly 1% AEP Levee	-2	-2	-2	-1	-3	-1	-2	-4	-17
L3A	1% AEP North Wagga Levee Upgrade	-3	-3	-2	2	3	-1	-3	-6	-13
L3B	1% AEP North Wagga Levee Upgrade with Hampden Ave Embankment	-2	-2	-3	2	1	-2	-2	-3	-11
L3C	1% AEP North Wagga Levee Upgrade with Hampden Ave Overland Bridge	-1	-2	-3	2	-2	-2	-2	-3	-13
L4A	5% AEP North Wagga Levee Upgrade	-1	-2	-2	-1	3	-1	-3	-3	-10
L4B	5% AEP North Wagga Levee Upgrade with Hampden Ave Upgrade and Conveyance Improvements through Wilks Park	1	-1	-3	-1	2	-2	-1	-2	-7
L4C	5% AEP North Wagga Levee Upgrade with Hampden Ave Overland Bridge	2	0	-3	-1	-2	-2	-1	-2	-9
L5	Removal of North Wagga Levee	-3	-3	-2	-2	-3	-2	-2	-2	-19
L6	Opening of North Wagga Levee	-3	-3	-1	-1	-3	-1	-2	-2	-16
A1	Future Option: Increase Conveyance beneath Wiradjuri Bridge	3	1	-3	2	-3	-3	3	1	1
CM1	Malebo Gap Excavation	1	1	-3	1	-3	-3	0	0	-6
CM2	Gobbagombalin Bridge Excavation	1	1	-3	0	-3	-3	0	0	-7
BF1	North Wagga Bypass Floodway	1	1	-3	0	-3	-3	-2	-2	-11
R1	Oura Road Raising	-1	-1	-1	3	0	1	3	2	6
R2	Sturt Hwy Raised (RMS)	2	0	1	3	0	2	3	2	13
VMP	Vegetation Management Plan	1	0	3	1	0	3	0	0	8
PR1 - VHR	Voluntary House Raising Scheme	2	3	-2	1	1	1	-2	-3	1
PR1- VP	Voluntary House Purchase Scheme	3	3	-1	2	-1	2	3	6	17
PR1	Combined Voluntary House Raising and Voluntary Purchase Scheme	3	3	-2	2	0	2	1	2	11

4.6.2.1 *Impact on Flood Behaviour*

Quantitative scoring criteria is provided for impact on flood behaviour but it is unclear how this is applied. If the score is related to the worst area of flood impact, option L4(B) should not be scored 1 as there are negative impacts. If it is only based on impacts on property and above floor flooding, it is double counting with other criteria.

4.6.2.2 *Number of Properties Benefitted*

This criterion is referred to as ‘Number of Properties Benefitted’ in the matrix scoring system (Table 4-3) but called ‘Impact on Property Damage’ in the scoring matrix (Table 4-4). Property damage is expressly included as part of the cost-benefit analysis, so it appears to be double counted here unless the definition is different. The scoring suggests that this criterion is scored negatively if there is any negative impact to property, regardless of if there are also vast improvements overall (i.e. a nett benefit). This may be a reasonable way of quantifying this criterion but the contrast between this criterion being called ‘number of properties benefitted’ then ‘impact on property damage’ and then scored based on the worst impact caused means that the purpose and suitability of scoring is unclear. It is also not clear whether “properties” relates to residential or commercial/industrial, or property structure or land parcel.

4.6.2.3 *Technical Feasibility*

It is clear that there are significant potential technical issues associated with some options. It might be useful to try to quantify these and then consider if they can be mitigated before adjusting the option to include this mitigation and rescoring. Technical feasibility has large negative impacts on many options and therefore, scores should be clearly justified.

4.6.2.4 Community Acceptance

Due to the strong and sometimes conflicting feelings from the community about various options, it would again be helpful to quantify these scores in order to justify them. For example, an average score could be given for each option for each community and then weighted.

The 'Floodplain Development Manual' (2005) recognises that the adopted management plan may disadvantage certain individuals and advantage others, but the community as a whole will be better off. This process may require compromise and trade-offs. Therefore, it may not be possible to gain the acceptance of all community groups and/or consideration of combined options may be necessary to mitigate impacts in other areas of the floodplain.

4.6.2.5 Economic Merits

The cost-benefit analysis is discussed in Section 4.5.1.2.

4.6.2.6 Financial Feasibility

Financial feasibility is described as a criterion but not included in the scores. It is not clear what impact this criterion was intended to measure, why it was removed or whether this had any impact on outcomes. Perhaps it was considered to overlap with economic merits.

4.6.2.7 Environmental and Ecological Benefits

There appears to be significant and obvious environmental impacts for some options. It is not clear however why some options have scored very well for this criterion. For example:

- The VP scheme scores 2 for this criterion, however it is not clear in what way this scheme will create environmental benefits. Any house that is removed may be rebuilt elsewhere and the newly developed area will have impacts on the environment, depending on green/brownfield status of the new site.
- VHR scores 1. It is not clear what environmental benefit there will be from raising a property.
- Some road raising options also scored positively for environmental benefits. It is not clear why. A higher road generally results in a wider roadway embankment with consequential environmental impact.

It also does not appear that this assessment has been informed by the findings of the 'Wagga Wagga and North Wagga Murrumbidgee River Levee Upgrade Review of Environmental Factors' (GHD, 2013). The Review of Environmental Factors (REF) concludes that any adverse environmental effects associated with the upgrade of the Wagga CBD (1% AEP level of protection) and North Wagga (5% AEP level of protection) Levees would be minimised through the implementation of safeguards and mitigation measures (these are also outlined in the REF). Therefore, it is unlikely that the levee upgrades would have a significant impact on any species, population or ecological community listed under the Threatened Species Conservation Act 1995 nor a significant overall environmental impact. However, the North Wagga Levee upgrade options all score negative values for this criterion (rather than the expected neutral).

4.6.2.8 Impact on SES

The following observations are made in regard to the 'Impact on SES' criteria and scoring:

- 'Impact on SES' and 'Risk to Life' appear to be linked as impact on SES seems to largely consider the likelihood of residents to evacuate.
- 'Impact on SES' has been considered greater for higher levees but this does not appear to have been evaluated in any quantitative manner and is instead assumed based on attitude. Although there are concerns about maintaining community compliance during events if a higher levee is in place, there will still be a much lower likelihood of inundation impacting the community. Consequently, emergency evacuation will be much less likely and more time will be available when required (at least for options which also have an evacuation route at the same level of immunity as the levee), which would offset some of the risk that people may not comply as readily. This criterion also seems to be double counted within the 'Risk to Life' criteria which considers isolation risk and community compliance which appear to be the two main factors considered in 'Impact on SES' as well.

4.6.2.9 Risk to Life

The 'Risk to Life' assessment does not appear to consider both probability and consequence (i.e. risk of inundation) as one of the criteria. As shown in Table 4-5, the criteria used to score Risk to Life include:

- proximity to highly hazardous flooding (great depths or significant velocity);
- warning time;
- evacuation time and constraints;
- flood hazard;
- community behaviour and consequences;
- population; and
- period of isolation (and associated health and social risks).

The proximity of highly hazardous flooding criteria should be revised or considered further. The scoring suggests that it is assumed that if a higher levee is built, residents will not evacuate and be isolated close to deep floodwaters protected only by the levee. Lower levee options seem to be scored based on the assumption that residents will evacuate, meaning the scoring is not a 'like for like' comparison of the actual probability of the potential consequences.

Risk due to inundation should instead be included to consider the probability of a range of events and the corresponding hazard at each property. If hydraulic risk is calculated in this way, each option is assessed in the same quantifiable manner. Any evacuation then reduces the risk to life and should be considered as a separate criterion. Probability of evacuation has already been considered and applied as 'community behaviour and consequences' and ability to evacuate is included as 'evacuation time and constraints'. 'Flood hazard' has been included but as it is scored lower than 0

for each levee option, it is not clear what this score is based on but it does not appear to be hydraulic risk due to inundation.

Warning time is included as a criterion but is scored 0 for each event, making it unclear how this is scored. Some options create longer available evacuation times and it would be expected to see higher scores for these options. However, this criterion could be combined with the evacuation time and constraints criteria to reduce double counting as they are interlinked.

The population criterion should be considered as part of the consideration of evacuation constraints, as there is overlap between these criteria.

The period of isolation criterion again appears to assume that no one will evacuate if the levee is raised. Normally isolation risk should consider both likelihood and consequence of isolation rather than apply a worse-case scenario to community response (which is scored separately and therefore assumptions should not also be made in the scoring of this criteria). Isolation risk is given a negative score even for options with evacuation routes raised to the same level of immunity as the design level of protection of the levee. In these cases, there is no possibility of being isolated without being inundated. While the village remains dry, so does the evacuation route, meaning access remains and the residents would either be evacuated or inundated, but not isolated. The existing case that this is compared to has a levee at a higher level than the access route meaning isolation is more likely to occur under current conditions.

The scoring of community behaviour and consequence for the North Wagga options (i.e. values of -2 and -3) appears to be in direct conflict with other messages within the FRMS&P 2018 report and earlier 'Floodplain Risk Management Study' (2009). That is:

- Section 9.3.3.5 reports that *"North Wagga's evacuation compliance has been exemplary in the past, with 97% of residents evacuating when (or before) instructed to do so by the SES, indicating that the current community has a strong understanding of their flood risk and high level of trust in the authority of the local SES controller. Ongoing community engagement will help ensure these attitudes continue in the future."*
- Section 3.2 of the 'Floodplain Risk Management Study' (2009) reports that for North Wagga *"The community is reasonably flood aware and understands that North Wagga will need to be completely evacuated in large flood events."*
- Section 4.4 of the 'Floodplain Risk Management Study' (2009) reports that *"In Wagga Wagga, the community outside the main city area is historically aware of the risk and dangers associated with flooding, particularly in areas such as North Wagga and Gumly Gumly."*

The FRMS&P 2018 could also combine levee options with community education and awareness programs to increase awareness, improve evacuation responsiveness of communities and mitigate against negative behaviours, and/or disaster management options to improve available warning times.

Table 4-5 Risk to Life Scoring

Ref	Option	FERC	Warning Time	Time to Evacuate	Flood Hazard	Community Behaviour and consequences	Population Numbers	Period of Isolation/Inundation	Total Score
L1	Oura 1% AEP Levee	-1	0	1	-1	-2	-1	-1	-5
L2	Gumly Gumly 1% AEP Levee	-3	0	-2	-1	-3	-1	-3	-13
L3A	1% AEP North Wagga Levee Upgrade	-3	0	-2	-3	-3	-2	-3	-16
L3B	1% AEP North Wagga Levee Upgrade with Hampden Ave Embankment	-1	0	1	-3	-2	-2	-3	-10
L3C	1% AEP North Wagga Levee Upgrade with Hampden Ave Overland Bridge	-1	0	1	-3	-2	-2	-3	-10
L4A	5% AEP North Wagga Levee Upgrade	-3	0	-1	-2	-2	-2	-2	-12
L4B	5% AEP North Wagga Levee Upgrade with Hampden Ave Upgrade and Conveyance Improvements through Wilks Park	-2	0	1	-2	-1	-2	-2	-8
L4C	5% AEP North Wagga Levee Upgrade with Hampden Ave Overland Bridge	-2	0	1	-2	-1	-2	-2	-8
L5	Removal of North Wagga Levee	-3	0	-2	-3	1	-2	0	-9
L6	Opening of North Wagga Levee	-3	0	-1	-3	1	-2	-1	-9
A1	Future Option: Increase Conveyance beneath Wiradjuri Bridge	1	0	1	1	0	0	0	3
CM1	Malebo Gap Excavation	0	0	0	0	0	0	0	0
CM2	Gobbagombalin Bridge Excavation	0	0	0	0	0	0	0	0
BF1	North Wagga Bypass Floodway	-1	0	-2	-2	0	0	0	-5
R1	Oura Road Raising	2	0	2	0	0	0	2	6
R2	Sturt Hwy Raised (RMS)	2	0	2	0	0	0	2	6
VMP	Vegetation Management Plan	0	0	0	0	0	0	0	0
PR1 - VHR	Voluntary House Raising	-3	0	0	0	-3	-2	-2	-10
PR1 - VP	Voluntary House Purchase Scheme	3	0	3	3	3	2	3	17
PR1	Combined Voluntary House Raising and Voluntary Purchase Scheme	0	0	3	3	0	0	1	7

4.6.2.10 Other Impacts

It is recommended that social impacts are considered as an additional criterion. This could be informed by the calculation of intangible damages (if calculated separate to the total flood damages) or alternatively if the social costs of flooding are included in the damages assessment they would be included in the BCR.

4.6.3 Interpretation of Scores

The report states:

"This report uses a multi-criteria matrix to assess each option, assigning scores to each of the listed criteria. An option that has a negative score would not be considered viable, while positive scores indicate that there are more pros than cons, and that the option could be considered further."

However, options were recommended that had negative scores in the MCA. The way that the MCA has been designed would suggest that a negative score indicates that has major disbenefits, limitations and/or adverse impacts and so it stands to reason that negatively scored options should not be recommended for further investigation.

4.6.4 Sensitivity Assessment of MCA

All criteria have been weighted equally apart from 'Risk to Life' which has been given a weighting twice that of the other criteria. There are numerous valid approaches to the selection of weightings and the decision to apply weightings such as:

- rank sum;
- rank reciprocal;

- rank order centroid; and
- pairwise.

It is recommended that one of these approaches is adopted in order to properly consider the relative importance of each criteria.

Similarly, sensitivity testing should be undertaken on weightings to determine how much the weightings influence the final score. Various methods of sensitivity testing can be applied to an MCA to detect bias towards particular options and to enable a balanced comparison of options. Methods for sensitivity testing include (but are not limited to):

- stepwise testing method – determines how much the criteria weighting must change to alter the highest scoring option;
- thresholding – changes the proportional weightings of each criteria by increasing and reducing weighting by 50% and 25%, whilst the weighting of other criteria remains proportionally unchanged; and
- balanced assessment - applies equal weighting among all criteria.

In order to demonstrate the sensitivity of the MCA scoring, a sensitivity test has been carried out as part of this review where the pairwise method has been used to rank the criteria (based on arbitrary comparisons of importance between criteria, each criteria should be compared based on local knowledge and importance). Criteria and scores remained unchanged. A simplified thresholding method has then been used to carry out sensitivity testing on the scoring. Furthermore, a sensitivity test of the scoring and the effect of eliminating criteria has been undertaken. The process and results of these tests are outlined below.

4.6.4.1 Pairwise Comparison

This initially involves comparison of each criterion to the other criteria and deciding which is more important. This is usually done in a matrix as per the example rankings for the currently adopted MCA criteria in Table 4-6. Note that the rankings in the Table 4-6 are arbitrary and not based on local knowledge or priorities for this floodplain and are for example purposes only. In this example, criterion ‘A’ (impact on flood behaviour) is compared against criterion ‘B’ (number of properties benefitted) and found that ‘A’ is the more important criterion. Thus, it can be seen that ‘A’ is considered to be more important than ‘B’, but no other criteria. However, criterion ‘H’ (risk to life) is ranked in this example as more important than all other criteria.

Once relative importance has been determined, ranking is based on the occurrence of each criterion in Table 4-6, plus one, converted to a percentage. The weightings must total 100%. From this process, the example ranking results in the strongest (largest) weighting being applied to criterion ‘H’ and the lowest to ‘G’ (impact on SES).

Table 4-6 Example Weightings of Criteria

Criteria										
		A	B	C	D	E	F	G	H	Weighting
Impact on Flood Behaviour	A	**a**	a	c	d	e	f	a	h	8%
Number of Properties Benefitted	B		**b**	c	c	e	f	b	h	6%
Technical Feasibility	C			**c**	d	e	f	c	h	14%
Community Acceptance	D				**d**	e	f	d	h	11%
Economic Merits	E					**e**	f	e	h	17%
Environmental and Ecological Benefits	F						**f**	f	h	19%
Impact on SES	G							**g**	h	3%
Risk to Life	H								**h**	22%

Table 4-6 shows that if the relative importance of each criterion is considered against other criteria, the outcome can be a much larger range of weightings (compared to the equal weighting approach). The scores as per the FRMS&P 2018 report (not adjusted) for the weightings assumed in the report and the example pairwise ratings have been compared in the table below, including the rank of each criteria.

Table 4-7 shows that scores for some options are relatively unchanged but others have changed significantly based only on changed weightings. Overall rankings have changed but not significantly, for example, ranking 1 to 6 of the options remain the same but the order has changed slightly.

Table 4-7 Ranking of Options based on Example Pairwise Scoring

Option	Scoring as per FRMS&P 2018	Rank	Scoring with Pairwise	Rank	Change from FRMS&P 2018 Rank
L1	-6	8	-7.50	8	-
L2	-17	19	-18.61	19	-
L3(A)	-13	16	-9.17	11	+6
L3(B)	-11	14	-10.83	12	+2
L3(C)	-13	16	-15.00	16	-
L4(A)	-10	13	-6.94	7	+6
L4(B)	-7	10	-8.06	10	-
L4(C)	-9	12	-13.33	14	-2
L5	-19	20	-20.83	20	-
L6	-16	18	-16.39	17	+1
A1	1	6	-7.78	9	-3
CM1	-6	8	-12.50	13	-5
CM2	-7	10	-13.61	15	-5
BF1	-11	14	-16.39	17	-3

Option	Scoring as per FRMS&P 2018	Rank	Scoring with Pairwise	Rank	Change from FRMS&P 2018 Rank
R1	6	5	5.56	5	-
R2	13	2	13.33	2	-
VMP	8	4	11.94	3	+1
PR1-VHR	1	6	1.39	6	-
PR1-VP	17	1	14.72	1	-
PR1	11	3	10.00	4	-1

4.6.4.2 Threshold Sensitivity Testing

A simplified threshold sensitivity test was undertaken using the original weightings and scores from the FRMS&P 2018. The test included changing the proportional weightings of each criteria by increasing and reducing weighting by 50%, whilst the weighting of other criteria remains proportionally unchanged.

The sensitivity test showed that both final scores and ranks changed when the 50% increase and decrease were applied to each criteria. However, the rank of the top 5 options remained unchanged.

4.6.5 BMT Assessment

The sensitivity testing carried out on the weightings found that although the compiled scores can change significantly, there was not a large sensitivity to the rank of the options. Whether the options scored positively or negatively could change where the score was close to zero. The choice of criteria and scoring in this case will have the largest impact in the results of the MCA and efforts should therefore focus on ensuring the MCA criteria and scoring are quantifiable, defendable and avoid double counting impacts. Possible mitigation of impacts should also be considered and added to the options before rescoring to eliminate any skew of compiled scoring based on environmental or technical challenges that can be overcome.

Overall, this review does not have strong confidence in the design and hence outcomes of the MCA for the following reasons:

- Poorly designed MCA criteria including double counting.
- Poorly designed MCA weighting process which does not consider community or stakeholder values.
- No consideration of overcoming potential environmental or technical challenges to refine options before re-assessing.
- Inappropriate application of some criteria, such as assigning a 1% levee upgrade option a lower (worse) risk to life criteria than removal of a levee.
- Options with negative scores (e.g. Option L4(B) North Wagga Levee upgrade to the 5% Annual Exceedance Probability (AEP) level of protection including Hampden Avenue upgrade and conveyance improvements through Wilks Park) were recommended for further investigation,

suggesting that either the scoring was not appropriate or that this option should not have been recommended. If negatively scored options have been selected based on other justification (e.g. political decision, etc), this should be stated in the report.

The 'Floodplain Development Manual' (2005) recognises that the matrix approach cannot make the decision, this responsibility initially rests with the committee and ultimately rests with Council. Nevertheless, an MCA *"does provide a simple framework for organising the data and identifying issues in conflict and 'trade-offs"* (NSW Government, 2005). In order for acceptance of the outcomes, the MCA should be robust and defendable.

4.6.6 BMT Recommendations

Recommendations detailed in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
4-13	Review and refine MCA criteria to remove any cases of double-counting	Not Best Practice	High	FRMS&P 2018
4-14	Review MCA weightings to ensure the weightings are appropriately designed.	Not Best Practice	High	FRMS&P 2018
4-15	Consider potential options to overcome environmental or technical issues and impact on scoring/outcome of MCA	Not Best Practice	High	FRMS&P 2018
4-16	Review application of criteria within MCA to ensure that a criterion is not applied inappropriately (e.g. 'risk to life').	Not Best Practice or Error	High	FRMS&P 2018
4-17	Review outcomes of corrected MCA (i.e. upon completion of Recommendations 4-13 to 4-16). It is not known why options with negative scores (e.g. Option L4(B)) were recommended. Either the scoring was not appropriate, an error was made in recommending this option or further justification of selection is required.	Not Best Practice or Error	High	FRMS&P 2018

4.7 Recommended Options for North Wagga

4.7.1 FRMS&P 2018 Methodology and Implementation

Of the nineteen (19) options considered, a feasibility study was recommended to be undertaken to further investigate the potential of two options:

- Voluntary House Raising (VHR) & Voluntary Purchase (VP) Scheme in Wagga Wagga Study Area (Option PR1): This option proposed a VHR and VP Scheme for the study area to reduce flood risk. VHR would involve residents raising their property to the recommended Flood Planning Level (1% AEP + 0.5 m), where possible. The VP Scheme involves residents selling their properties to Council whereby the dwelling will be demolished and rezoned to prevent future development.

- North Wagga Levee Upgrade to the 5% AEP level (Option L4(B)) including Hampden Avenue Upgrade and Conveyance Improvements through Wilks Park: This option assessed the outcomes of raising the levee to a 5% AEP flood level of protection. The works would involve increasing the current levee by up to 0.9 m in some locations as well as increasing the footprint to allow for embankment protection (an additional 5 m width would be required).

4.7.2 BMT Assessment

Although a feasibility study to investigate VHR and VP (i.e. Options PR1) is recommended, the FRMS&P 2018 does not assess the eligibility and practicality of a VHR or VP Scheme within the study area, nor does it assess these options in financial terms (i.e. cost estimates, reduction in AAD and/or BCR). This limits the ability to effectively assess Option PR1 against all criteria in the MCA and complete a meaningful comparison with other proposed options.

Due to the high capital costs associated with this option, VP is typically only considered appropriate in floodway / high hazard areas where other flood risk reduction strategies are impractical or uneconomic, and the existing flood risk is unacceptable. VP may also be considered where purchase of a property enables other flood mitigation works (such as channel improvements or levee construction) to be implemented because the property will impede construction or may be adversely affected by the works with impacts not able to be offset. Guidelines for VP schemes have been prepared by NSW Office of Environment and Heritage (OEH, 2013a) and outline that Government funding is only available for VP of properties that were approved and constructed prior to 1986 when the original Floodplain Development Manual was gazetted. Finally, only residential properties (not commercial and industrial properties) are eligible for VP.

Owner participation in a VP scheme is voluntary and there are limitations on the availability of funding. The inclusion of a property in a scheme places no obligation on the owner to sell the property or the Council or NSW Government to fund the purchase of the property.

The eligibility and practicality of VP in the Wagga Wagga study area has not been considered as part of the FRMS&P 2018. A preliminary assessment could have been undertaken as part of the FRMS&P 2018 by interrogating the flood modelling outputs with existing building footprints to identify houses that may be eligible for VP. More specifically, buildings that fall within the following areas at the peak of the 1% AEP flood could, for example, be considered potentially eligible for VP:

- high flood hazard areas; and
- floodway areas.

The age of buildings within properties that fall within these criteria could then be reviewed to determine their potential suitability (i.e. pre- or post-1986 construction) or to discount them from potential eligibility.

It is noted that the “high hazard” definition in the OEH (2013a) guideline refers to the NSW Government’s *‘Floodplain Development Manual’* (2005) hazard categories. The more recent ‘Handbook 7’ hazard categories have been adopted as part of the current study. In this regard, it could be assumed that the national H1, H2 and H3 categories would fall under the “Low” hazard category in the *‘Floodplain Development Manual’* and the national H4, H5 and H6 categories would fall under the “high” hazard category in the Manual.

The economic viability of a NSW Government funded VP scheme in the study area is underpinned by the median house prices in suburbs within the area. A cost-benefit analysis could be undertaken on the basis of the cost to purchase these properties against the reduction in flood damages associated with these properties. However, the removal of these buildings may also result in adverse impacts on adjoining properties. For example, dwellings with construction on piers may already allow flow beneath the building and there may be little flood impacts, however dwellings with slab-on-ground construction may provide an impediment to flow and their removal could adversely impact on flooding of properties downstream in terms of flood levels and flow velocity. There may also be undesirable impacts on the streetscape if there is only partial uptake of the scheme, resulting in an unpleasant “gap tooth” appearance.

Voluntary house raising (VHR) is a well-established method of reducing the frequency, depth and duration of above floor inundation. VHR can be a suitable measure for reducing the flood damage for individual dwellings or can be used as a compensatory measure where other flood mitigation works are predicted to adversely impact on flood behaviour across individual dwellings.

VHR is aimed at reducing the flood damage to houses by raising the habitable floor level of individual buildings above an acceptable design standard (e.g. 1% AEP Flood Level +0.5 m). VHR generally only provides a benefit in terms of reduced economic damages but does not eliminate the risk. Larger floods than the design flood (used to establish minimum floor level) will still cause building damages and the option does not address personal safety aspects. Residual risks are still present as the property and surrounds are subject to inundation.

The NSW Office of Environment and Heritage (OEH, 2013b) has prepared a guideline for Councils seeking funding from the NSW Government’s Floodplain Management Program for VHR schemes. This guideline details the objectives, eligibility criteria, funding and implementation procedure for a VHR scheme that has been included in a Council’s adopted Floodplain Risk Management Plan (FRMP) as part of a set of floodplain risk management measures. However, as reported in FRMS&P 2018, this guideline notes that houses in high hazard areas are not eligible as the overarching aim is to completely remove residents from high hazard areas. Therefore, many areas of the floodplain including much of North Wagga, would not be considered eligible.

Furthermore, not all houses are suitable for raising. Houses of brick construction or slab-on-ground construction and multi-story dwellings are generally not suitable for house raising due to expense and construction difficulty. Generally, this technique is limited to single-storey fibro/weatherboard-type structures constructed on piers.

Therefore, a preliminary assessment of the number of suitable and eligible properties for VHR could have been undertaken as part of the FRMS&P 2018. The flood modelling outputs could be interrogated in conjunction with building footprints to identify houses that may be eligible based on the following example criteria:

- subject to frequent above floor inundation - properties that were predicted to be inundated above floor level during say, a 10% AEP flood;
- single storey, non-brick houses constructed on a pier and beam foundation; and
- low flood hazard area at the peak of the 1% AEP flood.

Finally, although two (2) potential options have been recommended for further investigation, including feasibility studies to investigate a Voluntary House Raising & Voluntary Purchase Scheme in Wagga Wagga Study Area (Option PR1) and to investigate North Wagga Levee Upgrade to the 5% AEP level (Option L4(B)), a combined assessment with both of these options in place was not undertaken to inform the overall recommendation of these measures.

In fact, no combined options were assessed to determine the cumulative impacts of the options and the potential for use of multiple options to offset the impacts of individual options.

4.7.3 BMT Recommendations

Recommendations detailed in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
4-18	Assess feasibility of VHR and VP as part of future feasibility study	Gap	Low	Future

5 Floodplain Risk Management Plan

5.1 Implementation Plan

5.1.1 FRMS&P 2018 Methodology and Implementation

An implementation plan has been provided which summarises the recommended works investigated as part of the floodplain risk management study. The plan includes the following items:

- option name and description;
- benefits;
- concerns;
- responsibility for implementation;
- benefit-cost ratio; and
- priority (low or high).

With regard to North Wagga, the Plan recommends a feasibility study for Option L4(B) in conjunction with PR1 to include:

- For Option L4(B): EIS for the park excavation, geotechnical assessment of existing levee, site-by-site assessment of third party impacts and extensive community consultation.
- For Option PR1: Economic appraisal of both VP and VHR, eligibility criteria for participation, identification of construction constrains and extensive community consultation to identify likely participation rates.

5.1.2 BMT Assessment

The provided implementation plan is relatively brief and could be enhanced with one of more of the following items, depending on Council's requirements:

- Identification of any relevant legislation which may affect implementation of the option.
- Timing to implement, which may also include timing for intermediate steps.
- Potential sources of funding, if not covered by Council's standard operational budget.
- Identification of linkages within Council to existing programs, such as the Flood and Stormwater Management Strategy.
- Increased information in 'responsibility' item to list relevant departments from Council.
- Interdependencies of options. The current plan only recognises the interdependency of Option L4(B) – Feasibility Study to investigate the upgrade of the North Wagga Levee upgrade to a 5% AEP level of protection with Option PR1 - VHR and VHP in the Wagga Wagga area.
- Identification or summary of potential obstacles to implementation.
- Trigger for review of plan (generally every five years or major flood, whichever comes first). This will include how the plan will be monitored and who has responsibility for monitoring.

- Identification of required interim measures. For instance, it will be a number of years before levee works are constructed – are there interim disaster management measures which could be implemented to manage flood risk until then.

5.1.3 BMT Recommendations

Recommendations detailed in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
5-1	Include additional detail within implementation plan to improve ability for users to navigate the implementation process	Gap	Low	Future

6 Consultation

Implementing a robust community consultation program is considered crucial to the overall success of a floodplain risk management study and plan. The community can have very diverse and passionate views on flood issues, particularly following first-hand experience of flooding. This is considered to be the case in the Wagga Wagga floodplain, which covers a range of floodplain precincts that have unique communities, history of flood experience and flood characteristics.

Under the Floodplain Development Manual (2005), community consultation during the floodplain risk management study and plan process should aim to inform and engage the community. This requires:

- informing the community of the study and its purpose;
- identifying community knowledge and concerns in relation to flood issues;
- gaining an understanding of the flood awareness of the community;
- collecting information on historic flood behaviour, levels and responses;
- providing information on management measures and their benefits and disadvantages; and
- providing an opportunity for the community to provide input and feedback on potential flood risk management options.

The 'Floodplain Development Manual' (2015) has a suggested format for community consultation that includes:

- involving and informing the community through media releases, newsletters and public meetings;
- calling for representatives of the general community and action groups to self-nominate for the committee, as well as clearly defining the role of committee members;
- using established local groups (if they exist) to encourage their representation on the committee;
- making one or two key contacts known to the community for a study (usually Council);
- defining clear goals and timeframes for a study;
- releasing information to the community at regular intervals, rather than waiting until the completion of formal stages of the plan or meetings of the committee; and
- ensuring clear and simple language is used to explain information and relate any implications to property owners that are affected.

More broadly, best practice consultation approaches (as outlined by the International Association for Public Participation – IAP2) recommends that consultation be planned at the commencement of the study to ensure that consultation activities support and enhance a project. One of the key elements of the IAP2 "spectrum of public participation" is the need to communicate the purpose of each engagement activity and the 'level of influence' that the community can have over decisions at each stage of the consultation. The level of influence ranges from simply providing timely information to empowering the community to make decisions which the project team commits to implement. Floodplain risk management studies typically use a range of levels across a study. There is no single correct approach which is suitable for every study; the approach must be tailored to suit the study,

stakeholders, community etc. It may also be necessary to refine the approach throughout the life of the project if unexpected concerns or issues are identified. Irrespective of the approach used, it is important to clearly convey the process to the community to clarify whether input is sought, how this input will be used (i.e. will Council simply acknowledge concerns or will they work with the community to ensure that concerns are considered and understood), and what the next steps are (e.g. Council will report back on consultation and how the feedback is shaping the study).

Whilst flood-related consultation activities were also undertaken as part of past projects, this peer review focusses on the consultation completed as part of the FRMS&P 2018.

6.1 Consultation Process for FRMS&P 2018

6.1.1 FRMS&P 2018 Methodology and Implementation

It is understood from the report that the key elements of the FRMS&P 2018 consultation process included:

- consultation with the Floodplain Risk Management Advisory Committee (FRMAC) through meetings and presentations;
- phone conversations, emails and one-on-one meetings with stakeholder groups and representatives; and
- public exhibition of the Draft FRMS&P.

6.1.1.1 Stakeholder Engagement

Engagement with key stakeholders was undertaken in the early stages of the FRMS&P 2018 in August and September 2016. This involved consultation in the form of phone conversations, emails and one-on-one meetings with a range of representatives and/or representative groups from floodplain precincts, including:

- Oura Progress Association;
- Gumly Gumly community representative;
- Wagga Floodplain Residents Protection Association;
- North Wagga Residents Association;
- CoWW (current and former personnel);
- SES (current and former personnel); and
- Bureau of Meteorology.

Further stakeholders and agencies were also contacted for input into the FRMS&P 2018. This included Council's planners and engineers, DPIE, Murray-Darling Basin Authority, Department of Primary Industries, Local Land Services, Riverina Water County Council, Essential Energy, Transport for NSW and Australia Rail Track Corporation.

Key comments from the initial consultation are summarised in Appendix B of the FRMS&P 2018. It is noted that comments are included from the Gumly Gumly community, Oura community and Wagga

Floodplain Residents Protection Association. However, there is no feedback reported from the North Wagga Residents Association, nor any commentary as to either why there is no feedback from this group or why no feedback is reported.

6.1.1.2 Public Exhibition

The 'Draft Wagga Wagga Revised Murrumbidgee River Floodplain Risk Management Study and Plan' was placed on Public Exhibition between 24 October 2017 and 6 December 2017. The following details of the public exhibition are reported within the FRMS&P 2018:

- The report was made available digitally on Council's website, however the report does not indicate whether hard copies of the Draft FRMS&P 2018 were also made available for viewing. Landowners, residents and businesses were invited to participate in the Study by providing comments on the Draft Report.
- Council held nine (9) drop-in sessions during the exhibition period for members of the public to provide feedback to staff from WMAwater and Council. These meetings were held across the Wagga Wagga floodplain and within a number of the floodplain precincts.
- 439 submissions were received during the exhibition period. These submissions related to a range of issues associated with the floodplain risk management process, public exhibition process, modelling, reporting, responses to proposed options, clarification of scoring within the MCA, difference in approach for the Wagga CBD and North Wagga Levees, development within levees, flood insurance, and environmental considerations (e.g. vegetation management, sediment control).
- All submissions were read and logged by Council and WMAwater. Submissions were categorised into key issues and responses were prepared in line with these issues, as documented in Appendix M of the FRMS&P 2018.

Whilst the overall findings were unchanged from the exhibition draft, comments received during exhibition are reported to have been addressed in the Final Report. As documented in Appendix M, this included the following:

- amendments for noted and identified errors;
- wording amended for clarity (e.g. description of PL1);
- addition of information on how houses would be valued in a VP scheme;
- addition of table of 'Risk to Life; scores in Section 10 of the Final Report and adjustment of scoring based on submissions received and feedback from the SES;
- clarification of the different approach in various floodplain communities;
- clarification of the level of protection afforded by the existing North Wagga Levee;
- adjustments to cost estimates for flood mitigation options; and
- inclusion of summary of public exhibition.

6.1.2 BMT Assessment

The 'Floodplain Development Manual' (2005) recognises that an adopted management plan may disadvantage certain individuals and advantage others, but the community as a whole will be better off. This process may require compromise and trade-offs. Therefore, the local community has a key role in the development, implementation and acceptance of a management plan, whilst Council and the Floodplain Risk Management Advisory Committee (FRMAC) has an important role in the presentation and resolution of conflicting needs and requirements of various individuals and community groups.

In terms of the consultation process, engagement strategies and outcomes reported in the FRMS&P 2018, this review raises the following concerns:

- The FRMS&P 2018 report indicates that extensive consultation with the community and stakeholders was undertaken during the initial and later stages of the project, however from the documentation within the FRMS&P 2018 there appears to have been limited communication/consultation with the public during the assessment and scoring of the options.
- 439 is a high response rate to the Public Exhibition and indicates an engaged community. Considering this high response rate and diverse opinions with regard to selected options, it is reasonable to expect that it may have prompted greater changes in the Final Report or overall study findings, and should have triggered further consultation.

It is understood that the proposed feasibility studies recommended as part of the FRMS&P 2018 will involve further detailed consultation with properties significantly affected by the North Wagga Levee options, as well as wider consultation on other proposed options such as VP and VHR. It is considered that this would be important in both providing and collecting further information at a property level rather than a community level.

6.1.3 BMT Recommendations

Recommendations detailed in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
6-1	Ensure the future feasibility study incorporates more extensive consultation than the FRMS&P 2018 to ensure the conflicting views and diversity of floodplain precincts and communities are heard, understood and considered	Not best practice	High	Future

6.2 Engagement with NSW State Emergency Service

6.2.1 FRMS&P 2018 Methodology and Implementation

Appendix J of the FRMS&P 2018 includes details of emergency management considerations for raising the North Wagga Levee. This includes discussion of concerns that a higher levee (and also possibly raised floor levels due to VHR) might cause residents behind levees to increasingly reject

evacuation orders, thereby adding to the risk to life for larger magnitudes/rare events when levees are breached or overtopped. Specifically, Appendix J includes discussion of:

- evacuation compliance in recent Australian floods, including in North Wagga in 2010 and 2012;
- increased catastrophe potential with a higher levee; and
- mitigating the increased catastrophe potential.

6.2.2 BMT Assessment

Whilst Appendix J is portrayed as an Emergency Management Services perspective and engagement with SES (current and former personnel) was reported as part of the stakeholder engagement, no specific details of the SES consultation (who was consulted and when?), nor any specific references to SES documentation and/or correspondence is provided in Appendix J or the wider FRMS&P 2018 report. If available, this should be added to the report to support the discussion presented, particularly the assertion that a higher levee might cause residents behind levees to increasingly reject evacuation orders, thereby adding to the risk to life for larger magnitudes/rare events when levees are breached or overtopped.

6.2.3 BMT Recommendations

Recommendations detailed in the previous section are summarised below.

ID	Recommendation	Issue Type	Issue Significance	Timing
6-2	Include details/outcomes of SES stakeholder engagement and any specific reference correspondence within FRMS&P 2018 report	Gap	Medium	FRMS&P 2018

6.3 Consultation and Feedback from this Peer Review

Following the exhibition period and as part of this peer review, representatives from the main community groups within the Wagga Wagga floodplain were invited to submit feedback and/or meet with BMT to discuss their views on the FRMS&P 2018, including:

- Wagga Floodplain Residents Protection Association;
- North Wagga Residents Association;
- Gumly Gumly community representative (Donna Argus); and
- East Wagga Industrial area representative (Tony Balding).

BMT met with and received submissions from the Wagga Floodplain Residents Protection Association and North Wagga Residents Association in March/April 2021. The issues raised as part of this consultation are summarised below.

6.3.1 Wagga Floodplain Residents Protection Association

The Wagga Floodplain Residents Protection Association (WFRPA) is a group of property owners and residents on the North Wagga floodplain outside the protection of levees. The key issues of

concern raised by the WFPRA during the meeting with BMT on 29 March 2021 and within their submission dated 5 April 2021 include that the association:

- Has never supported an upgrade to the North Wagga village or East Street levees (i.e. the North Wagga Levee).
- Has supported and advocated for more thorough investigation of impacts of the Wagga CBD Levee upgrade and assessment of options to mitigate and/or compensate for those impacts (and other Murrumbidgee River flood impacts) for North Wagga and other properties in the floodplain impacted by levee upgrades.
- Provided conditional support to the Wagga CBD Levee upgrade based on:
  - Those most impacted in the North Wagga floodplain getting equitable and appropriate investigation and assessment of impacts, mitigation and compensation options.
  - The floodplain being de-developed in the long term or a least development being limited behind levees.
- Are concerned that development intensification behind levees is increasing the future flood risk and making AAD estimates an underestimation of future AAD.
- Are concerned that levees result in communities being falsely reassured that they are flood safe.
- Support the FRMS&P 2018 investigations and assessment of the Wagga CBD Levee upgrade and North Wagga upgrade. They also note that options were investigated for the Oura and Gumly Gumly communities, but no specific options were investigated for the floodplain outside the levees.
- Believe the 2015 NSW Public Works Report H15/01 ‘North Wagga Wagga Levee Options and Third Party Impacts’ (2015) was flawed in its methodology, assessment and findings. They also note that it only recommended that a ‘1 in 20’ and ‘1 in 100’ levee for North Wagga be shortlisted, not upgraded.

6.3.2 North Wagga Residents Association

The North Wagga Residents Association (NWRA) is a group of property owners and residents inside the current North Wagga Levee. The key issues of concern raised by the NWRA during the meeting with BMT on 29 March 2021 and within their submission dated 10 March 2021 include concerns that the FRMS&P 2018 is contrary to the floodplain guidelines and flawed for the following reasons:

- Critical information pertaining to the unsustainable emotional and financial trauma endured by residents as a direct result of flooding and inadequate protection was omitted from the social and economic assessment completed as part of the FRMS&P (e.g. flood damages, BCR).
- Critical feedback from all prior community consultation, conducted in the aftermath of the 2012 flood, all favouring a 1% AEP levee for North Wagga, was omitted and targeted feedback skewed towards a conclusion of a 5% AEP levee has been included.
- Critical information presented in preceding flood reports that favour a 1% AEP levee as the best option for North Wagga is omitted, and the argument against a 1% AEP levee for North Wagga

contradicts arguments used in the 2009 FRPMP to support the recommendation of a 1% AEP levee upgrade for Wagga CBD.

- No consideration of the cumulative effects on flood levels of thickened vegetation due to revegetation of the floodplain between North Wagga and the river and the Wagga CBD Levee upgrade, which expose North Wagga to the increased flood risk.
- Lacks assessment of intermediate levee options (design protection between 5% and 1% AEP levels).
- Relies on a weak Multi-Criteria Assessment matrix.

A submission was also provided by Mr Peter Morris, a member of the North Wagga Residents Association, dated 24 March 2021. A summary of key issues regarding the FRMS&P 2018 raised in this submission are provided below:

- Both the FRMS&P 2018 and 2009 FPMS have attempted to comply with the process of the 'Floodplain Development Manual' (2005), however the Cost-Benefit Analysis and MCA did not assess the best options in accordance with the manual.
- The FRMS&P 2018 attempted to summarise the 'merit' approach by adding scores that only have public opinion rating rather than analysing each social, environmental, economic and flood risk parameter as documented in the 'Floodplain Development Manual' (2005).
- In terms of the methodology of assessment:
  - The 'Floodplain Development Manual' (2005) suggests Council canvass local opinion on a number of issues and incorporate their assessment concerning flood mitigation proposals (e.g. social impacts, technical feasibility, environmental impacts, flood risks and hazard, social costs, etc).
  - Options should be assessed on a Benefit-Cost in dollar terms and the ratios can then be assessed robustly.
  - Concern regarding the MCA scoring not supporting the findings of the FRMS&P 2018.
  - Lack of data to substantiate the sum of Benefits or Costs in the 'Economic Merits' scores of the MCA.
  - 'Impact on Property Damage' as a negative score appears to be at odds with the benefits to AAD in North Wagga which would outweigh impacts outside of North Wagga.
  - 'Impact on Flood Behaviour' appears to double dip as other scores are also the result of impact on flood behaviour.
  - Suggested inclusions for additional columns are: impact on property damage (adjusted for flood frequency); technical feasibility (could be costed); future economic merit (adjusted for current values); environmental merits; ecological merits; cost of loss of life; cost of accidents; variations in travel costs; and costs inflicted on/saved by SES.
  - If all columns were given dollar values, a fair and reasonable total scoring system could be achieved.

7 Conclusions

7.1 Findings of the Peer Review

BMT has undertaken an independent peer review of the 'Wagga Wagga Murrumbidgee River Floodplain Risk Management Study and Plan' (WMAwater, 2018) ("FRMS&P 2018") which has been informed by a range of data supplied by CoWW for the purpose of this review. Additional feedback was also provided by community groups within the North Wagga area.

The peer review has determined a number of compounding errors which have the potential to affect the study outcomes. These are:

- Errors in the property data set, at least some of which are significant (properties with more than 0.5 m error in ground level).
- Errors in the flood damage calculations which have caused underestimation of property damage and have not presented damages in present (or at least 2017) dollars.
- Inappropriate application of levee freeboard within the modelling of levee options for North Wagga.

These errors have potential implications on other aspects of the FRMS&P 2018, including flood damage values, AAD and number of flood affected properties reported in the FRMS&P 2018 for both existing and with-options conditions. Subsequently, BCR calculated for the options will also be incorrect.

In addition, the following is not considered to be in line with best practice guidance for floodplain risk management studies and plans:

- No consideration of combining options, schemes, mitigating impacts or overcoming technical, feasibility and environmental constraints to improve options.
- No consideration of direct public and infrastructure damages, or intangible damages.

Further issues within the MCA are not considered in line with best practice and common approaches undertaken by BMT for similar work, particularly considering known conflicting views and diversity of floodplain precincts and communities affecting this study area, and the need for the findings to be robust and defendable. These issues include:

- Design of the MCA meaning some items are double counted and different criteria are not weighted to reflect prioritisation and values.
- Inappropriate application of MCA using inconsistent interpretation regarding the safety of levees, leading to risk to life being rated higher (worse) for no levee than a raised levee.
- Incorrect interpretation of MCA results, such that poorly ranking options were recommended for future investigation. This included Option L4(B) (North Wagga Levee upgrade to the 5% AEP level of protection including Hampden Avenue upgrade and conveyance improvements through Wilks Park) which was recommended for further investigation, suggesting that either the scoring was not appropriate or that this option should not have been recommended. If negatively scored

options were selected based on other justification (e.g. political decision, etc), this should be stated in the report.

Parallel to these issues with the technical approach, the consultation process appears to be insufficient by not engaging during the options assessment process, not engaging residents of North Wagga during the initial stages of consultation (or lack of reporting on the issues and/or outcomes), and not consulting further based on the high number of responses received during exhibition.

7.2 Recommendations

The key issues outlined in Section 7.1 and additional (but less critical) issues identified through the peer review process are summarised in Table 7-1. As described in Section 1.3, categorisation of these recommendations has also been made to assist in assigning responsibility and prioritisation.

Issue type categories are:

- Errors – these are errors that have been noted and require correction. They are typically implementation errors.
- Not best practice – these are methodology issues that are not in alignment with current best practice.
- Gap – this is either missing detail or additional work that provides beneficial information and/or flood intelligence that may improve outcomes for the community.

Timing type categories are:

- FRMS&P 2018 (short-term) – these are items that have been found to be incorrect, unclear, missing or misaligned in the FRMS&P 2018 and are recommended for short-term remedy.
- Future – these are items which go beyond the scope of the completed FRMS&P 2018 and should be pursued as additional tasks in the short to medium-term or as part of the feasibility study for recommended options (when/if it proceeds).

Significance of issue categories are shown below. Significance is defined as the potential impact of the issue on the overall outcomes for the community (e.g. robustness of the FRMS&P 2018 outcome and/or the importance of filling a gap in intelligence). In many cases, the significance (impact) of the issue cannot be determined until the issue is addressed appropriately and its impact (or otherwise) then noted.

Low	The issue should be addressed but is not timing critical and does not relate specifically to an issue with the FRMS&P 2018.
Medium	Important issue that should be addressed either now to strengthen the FRMS&P 2018 or in the future to strengthen flood-related outcomes for the Wagga Wagga community.
High	Potentially significant issue which may have impact on FRMS&P 2018 conclusions and recommendations and/or for the community in the short term. If not addressed, future work that is dependent on this component may not be robust or defendable.

Please note that the final set of prioritisation was updated to reflect Council input. Council may elect to move recommendations from one category to another based on their immediate requirements and priorities or their knowledge of the scope of the FRMS&P 2018.

Note that some of the items are dependent on others and need to be undertaken in sequential order. For instance, if the property database is updated, this will prompt update of the flood damages assessment, BCR, MCA, recommended options and FRMP.

Table 7-1 Summary of Peer Review Outcomes and Recommendations

Component	ID	Recommendation	Issue Type	Issue Significance	Timing	Report Section
Flood Risk Assessment	2-1	Develop timing-related flood intelligence in conjunction with disaster managers	Gap	Low	Future	2.2
	2-2	Map susceptible infrastructure, vulnerable infrastructure and high ecological significance with flood extents and flood impacts	Gap	Medium	Future	2.3
	2-3	Additional flood risk assessment tasks	Gap	Low	Future	2.3
	2-4	Develop flood risk framework	Gap	Medium	Future	2.3
	2-5	Undertake community vulnerability mapping	Gap	Low	Future	2.3
	2-6	Undertake evacuation capability assessment	Gap	Low	Future	2.3
Flood Damages Assessment	3-1	Collect detailed floor level survey if flood impacts are predicted at properties	Gap	Medium	Future	3.1
	3-2	Review and rectify errors in property database, in particular floor levels. Update all subsequent study components that rely upon the property database up to and including options assessment and the FRMP. Update all relevant report sections and add clarification on methodology used and source of data upon which the assessment is based.	Error	High	FRMS&P 2018	3.2
	3-3	Review assumptions and calculations in developing stage-damage curves. Undertake a sensitivity assessment to determine impact of errors and assumptions on stage-damage curves, damage calculations and BCR of options. If sensitivity assessment indicates actionable impact on study outcomes, update stage-damage curves and redo all subsequent tasks. If no actionable impact, as a minimum, update methodology discussion in the report to be consistent with the actual detail of implementation.	Error	High	FRMS&P 2018	3.3
	3-4	Undertake a sensitivity assessment to determine impact of considering 0.2EY event on damage calculations and BCR of options. If sensitivity assessment indicates actionable impact on study outcomes, update damages and AAD, and redo all subsequent tasks. If no actionable impact, as a minimum, update discussion in the report to be consistent with the actual detail of implementation.	Error	High	FRMS&P 2018	3.3

Component	ID	Recommendation	Issue Type	Issue Significance	Timing	Report Section
	3-5	Correct inconsistency between reported methodology and implementation within the modelling undertaken in relation to freeboard and levee failure for North Wagga. Undertake a sensitivity assessment to re-model reported freeboard and approach and determine impact on results and damages. If sensitivity results are not actionable, as a minimum, update report to be consistent with actual modelling implementation. If actionable, update assessment and all subsequent tasks.	Error	High	FRMS&P 2018	3.4
	3-6	Undertake a sensitivity assessment of the following scenarios: 1. Full freeboard with no levee failure 2. Full freeboard with partial (upstream) levee failure	Gap	Medium	Future	3.4
	3-7	Correct error relating to property database (refer to Recommendation 3-2), as well as other damage-related errors associated with inconsistencies between reported methodology and implementation (as required), and update damages assessment.	Error	High	FRMS&P 2018	3.5
	3-8	Include direct and indirect (tangible) public and infrastructure costs, and intangible damages in total damage assessment	Not Best Practice	Medium	FRMS&P 2018	3.5
Flood Risk Management	4-1	Locate and map vulnerable communities (using higher resolution Census data) and vulnerable institutions. Refer also to Recommendation 2-2.	Gap	Medium	Future	4.1
	4-2	Assess combined options/scheme to complement and/or mitigate options and ensure potential cumulative impacts are considered	Not Best Practice	High	FRMS&P 2018	4.2
	4-3	Consider impact of climate change on option assessment	Not Best Practice	Medium	Future	4.2
	4-4	Review and correct inconsistency between reported methodology on freeboard and modelled freeboard. This is likely to require updates to the modelling and damage assessment.	Error	High	FRMS&P 2018	4.3
	4-5	As per Recommendation 3-6, undertake a sensitivity assessment of the following scenarios: 1. Full freeboard with levee failure; 2. Full freeboard with partial (upstream) levee failure.	Gap	Medium	Future	4.4

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Component	ID	Recommendation	Issue Type	Issue Significance	Timing	Report Section
	4-6	Provide details of how the proposed levee works will impact disaster management	Gap	Medium	Future	4.4
	4-7	Develop concept designs for options to provide a better understanding of what is proposed and how it aligns with the cost estimates	Gap	Low	FRMS&P 2018	4.5
	4-8	Update report to include estimated design life, discount value and NPV. This should align with best practice.	Gap	Medium	FRMS&P 2018	4.5
	4-9	Include consideration of pumps or flap gates on pipes to prevent backflow through levee, including in the costings	Gap	Medium	Future	4.5
	4-10	Include maintenance costs for options in calculation of costs and recalculate BCR for each option.	Not Best Practice	Medium	Future	4.5
	4-11	Update damages assessment for options as per Recommendation 3-7	Error	High	FRMS&P 2018	4.5
	4-12	Provide damage and BCR calculations for the options to enable peer review	Gap	Medium	FRMS&P 2018	4.5
	4-13	Review and refine MCA criteria to remove any cases of double-counting	Not Best Practice	High	FRMS&P 2018	4.6
	4-14	Review MCA weightings to ensure the weightings are appropriately designed.	Not Best Practice	High	FRMS&P 2018	4.6
	4-15	Consider potential options to overcome environmental or technical issues and impact on scoring/outcome of MCA	Not Best Practice	High	FRMS&P 2018	4.6
	4-16	Review application of criteria within MCA to ensure that a criterion is not applied inappropriately (e.g. ‘risk to life’).	Not Best Practice or Error	High	FRMS&P 2018	4.6
	4-17	Review outcomes of corrected MCA (i.e. upon completion of Recommendations 4-13 to 4-16). It is not known why options with negative scores (e.g. Option L4(B)) were recommended. Either the scoring was not appropriate, an error was made in recommending this option or further justification of selection is required.	Not Best Practice or Error	High	FRMS&P 2018	4.6
	4-18	Assess feasibility of VHR and VP as part of future feasibility study	Gap	Low	Future	4.7

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Component	ID	Recommendation	Issue Type	Issue Significance	Timing	Report Section
Flood Risk Management Plan	5-1	Include additional detail within implementation plan to improve ability for users to navigate the implementation process	Gap	Low	Future	5.1
Consultation	6-1	Ensure the future feasibility study incorporates more extensive consultation than the FRMS&P 2018 to ensure that the conflicting views and diversity of floodplain precincts and communities are heard, understood and considered.	Not best practice	High	Future	6.1
	6-2	Include details/outcomes of SES stakeholder engagement and any specific reference correspondence within FRMS&P 2018 report.	Gap	Medium	FRMS&P 2018	6.2

7.3 Conclusions

Due to errors within the damage calculations and potential for revision of the MCA (in particular) undertaken for the FRMS&P 2018, it is difficult to provide a meaningful assessment of the suitability of the recommended options and whether additional / alternate options should be recommended for further investigation and consideration. This could only be undertaken once the above issues are investigated and resolved, and their impacts understood.

Accordingly, BMT welcome the opportunity to review the updated findings of the FRMS&P 2018 once identified issues have been addressed by Council and WMAwater, and updated information is provided to BMT. At that time, BMT should have sufficient information to be able to determine if there is cause to reasonably conclude that a flood protection levee greater than a 5% AEP level of protection should be considered in the feasibility study.

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