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Flood risk management measures

Flood risk management guideline MM01

Department of Planning and Environment

Acknowledgement of Country

The Department of Planning and Environment acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

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1. Introduction

Management of flood risks to the community can involve a combination of prevention, preparedness, response and recovery (PPRR) activities, as shown in Figure 1.

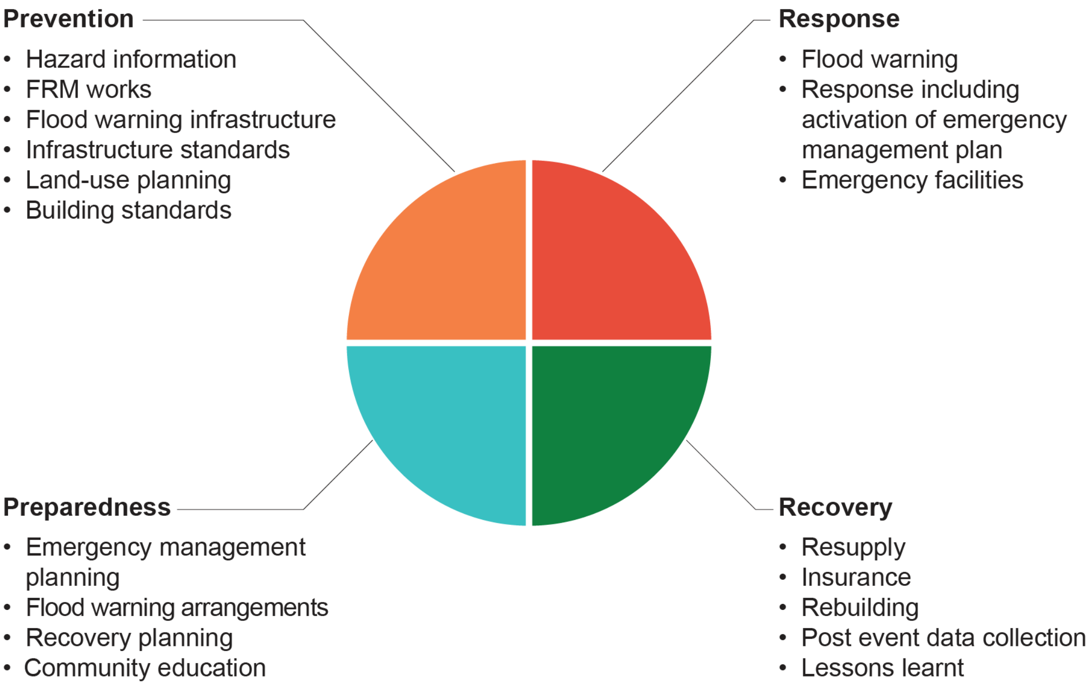


Figure 1 Types of flood risk management response

These activities support risk management through:

- risk avoidance or prevention measures that reduce exposure to flooding and/or limit the frequency or scale of flooding
- risk reduction measures that mitigate the consequences or likelihood of flooding
- risk acceptance, accepting the risk that exists.

The flood risk management (FRM) process outlined in the Flood risk management manual: the policy and manual for the management of flood liable land (the manual; DPE 2023) as outlined in the Administration arrangements: flood risk management guideline AG01 (FRM guideline AG01) focuses on prevention and preparedness activities. The outcomes it produces also influence, inform and support response and recovery activities.

The flood risk management process aims to provide:

- an understanding of the full range of flood behaviour and the associated flood risk to the community and how these may change over time
- the opportunity to consider whether current FRM measures are adequate or may need to change to address flood risks now and into the future
- advice on managing flood risk through FRM measures that are suited to the needs of the specific community.

Management of flood risk typically requires consideration of a mix of measures and their effectiveness to manage the risks to the community. It involves making informed decisions on changes to current, or the implementation of new, FRM measures.

The manual identifies the aim of FRM measures as limiting residual risk to levels that are more acceptable to the community. This involves managing risks to the existing community and future development through measures that modify flood behaviour, properties or community response to flood events (see Table 1). Management should also consider how flood behaviour and the associated risks may change over time with climate change and the cumulative impacts of development.

Table 1 Categories of flood risk management measures

Flood modification measures	Response modification measures	Property modification measures
Flood control dams	Community awareness	Land-use planning
Retarding basins	Community readiness	Zoning
Levees	Flood prediction and warning	Building and development controls
Bypass floodways	Local flood plans	Voluntary purchase
Waterway modifications	Evacuation arrangements	Voluntary house raising
Flood gates	Recovery plans	Flood-proofing buildings
		Flood access

This guideline aims to support effective consideration and decision-making for FRM measures as part of the FRM process. It provides advice on:

- **assessment of FRM options** (Section 2). This aims to assist decision-makers to make informed decisions on FRM measures that are suited to the community and the flood threat it faces
- **flood damage assessment** (Section 3). Understanding flood damage and assessing how flood damages change with decisions is an important part of assessing the effectiveness of FRM measures
- **typical FRM measures** (Section 4). Describes a wide range of typical FRM and complementary measures available that may influence the flood risk to the community.

1.1 Relationship to the manual and guidelines

This guideline builds on the advice provided in the manual. It supports councils in their role in delivery of the *NSW Flood prone land policy* (the policy) through the FRM framework and process outlined in the manual.

This guideline refers to other FRM tools and guidelines, relevant state agencies and legislation. Details on these FRM guidelines and tools are provided in FRM guideline AG01. Links to FRM guidelines and relevant websites can be found in the 'More information' section below.

More information on the terms used in this guideline is available in the FRM guideline AG01.

1.2 Audience

This guideline is written to support local council staff, state agencies and their consultants in understanding and managing flood risk to local communities.

2. Assessment of flood risk management options

Decisions on changing current or implementing new FRM measures for communities need to be made in a strategic way. This is supported by the FRM process and is discussed in *Understanding and managing flood risk FRM guideline FB01* (FRM guideline FB01).

The assessment of FRM options should consider:

- their practicality and feasibility, including the timeframe within which they may be implemented
- the social, economic and environmental costs, benefits and disbenefits of FRM measures relative to the base case
- the upfront, ongoing and complementary work and lifecycle costs involved in implementation of the measure (see Table 30, Table 31 and Table 32 of this guideline)
- input from the community and the acceptability of measures to the community
- consistency with industry guidance and government direction, policy and guidance.

It needs to be undertaken consistent with the following principles.

Principles to consider in flood risk management option assessment

Assessment of FRM measures needs to be fit for purpose.

It should be undertaken in consideration of the:

- current management measures and practices. Maintenance of current arrangements which form a base case for assessment of options
- available information and the resources required to collect more information
- effort required for assessment. This should be proportionate to the:
  - intent (stage) of the analysis
  - scale of the cost of the measure
- value factors (e.g. benefits and disbenefits) that are likely to materially change due to the proposed FRM measures, for example, if no works are proposed that are going to influence the frequency or severity of flooding of an environmental area, then there is no need to try to quantitatively measure the impacts of flooding on this aspect. It can be assessed qualitatively or excluded from the analysis
- ability to quantify change. Quantitative methods should only be used where change can be measured and monetised and where the change is likely to be of sufficient scale relative to other factors to warrant the effort involved. Qualitative methods can be used where quantitative measures don’t meet these criteria
- relevance to the types of risk that need to be managed
- relevance to the FRM options being considered

- NSW Treasury guidelines when undertaking an economic assessment.

Table 2 provides some general advice on methods used to assess the consequences of flooding on different elements within the study area that inform consideration of FRM measures.

Table 2 Methods generally used to assess the consequences of flooding

Element	Consequences	Assessment of consequences
People in the community	Floods can cause injuries and fatalities. The vulnerability of people in the community varies based on a number of factors, including age, fitness and ability. Both vulnerability and the degree of exposure to flooding influence risk.	This is generally considered qualitatively as quantitative benefits can be difficult to assess. However, Section 3.5.1 provides some advice where quantification is desired and supported by available information.
The economy	Floods can have significant impacts on the community that may have implications, depending on scale, for the local or broader economy.	These impacts are generally measured quantitatively in terms of flood damages to the community that are measurable and likely to be influenced by FRM measures (see Section 3). The benefits of FRM measures are assessed based on the reduction in flood damages.
Social and cultural aspects	Floods can have significant impacts on social and cultural aspects important to the community.	The impacts of flooding on these aspects are generally considered qualitatively and may be site-specific or more general. Section 3.5.2 provides some advice).
Services to the community	Floods can impact on the short- and long-term ability to maintain services to the community.	The consequences of loss of services to the community are generally considered qualitatively.
The natural environment	Floods can have significant impacts and benefits for the environment. FRM measures may have adverse or beneficial impacts on the environment, including ecosystems that depend on floods or flows for sustainability.	Environmental impacts are generally examined qualitatively where FRM measures may have adverse impacts on the environment.

2.1 Staged approach to assessment

The approach used to assess FRM measures needs to be practical, feasible and cost-effective. It needs to cover the principles for assessing options outlined above and the staged nature of the FRM process and implementation of FRM measures:

- FRM studies examine the conceptual feasibility of FRM measures and make recommendations that are considered in formalising an FRM plan (see Section 2.2.5).
- The FRM plan should identify both the recommended FRM measures and the next steps in implementation. For works with significant investment, plans generally recommend the work and identify investigation and concept/detailed design as the next step in implementation as this represents the next stage of investment.
- Implementation projects from FRM plans generally go through investigation and concept / detailed design prior to implementation, as discussed in Section 2.3. This provides the opportunity to refine the option and to review, update and where necessary expand on the assessment undertaken in FRM plan development. This information can then be considered in final implementation decisions.

This approach is applicable for FRM measures that may or may not require an economic assessment as discussed below. Assessment will generally involve a combination of quantitative and qualitative assessments as part of a multi-criteria assessment (MCA) as discussed in Section 2.2.3.

2.1.1 Assessment of measures that do not require economic analysis

As flood risks vary within the community and between different communities, the combination of FRM measures needed to address these risks will also vary. For example, FRM may involve considering measures that require minimal investment but are known to have an intrinsic benefit for the community. They may have a significant benefit in terms of reduction of risk to life or damages. These types of measures may include:

- updated emergency management (EM) arrangements or flood intelligence such as that outlined in local flood plans and intelligence systems
- improved community awareness of flood risk and how to respond to a flood threat
- strategic land-use planning to limit the growth in flood risk due to development or redevelopment by managing the impacts of development on the existing community and to minimise the flood risk to the development and its users.

These measures are described in Section 4 of this guideline and discussed in FRM guideline FB01.

2.1.2 Economic assessment

The FRM measure economic assessment framework (Figure 2) provides a practical, feasible and cost-effective approach to assessing FRM options. It considers the assessment principles and the staged nature of the FRM process and implementation of FRM measures as outlined in Section 2.1.

Table 3 describes and provides information on considerations on the 3 different levels of assessment that may be used in assessing FRM measures. Their use in FRM plan development and implementation is discussed in Sections 2.2 and 2.3, respectively.

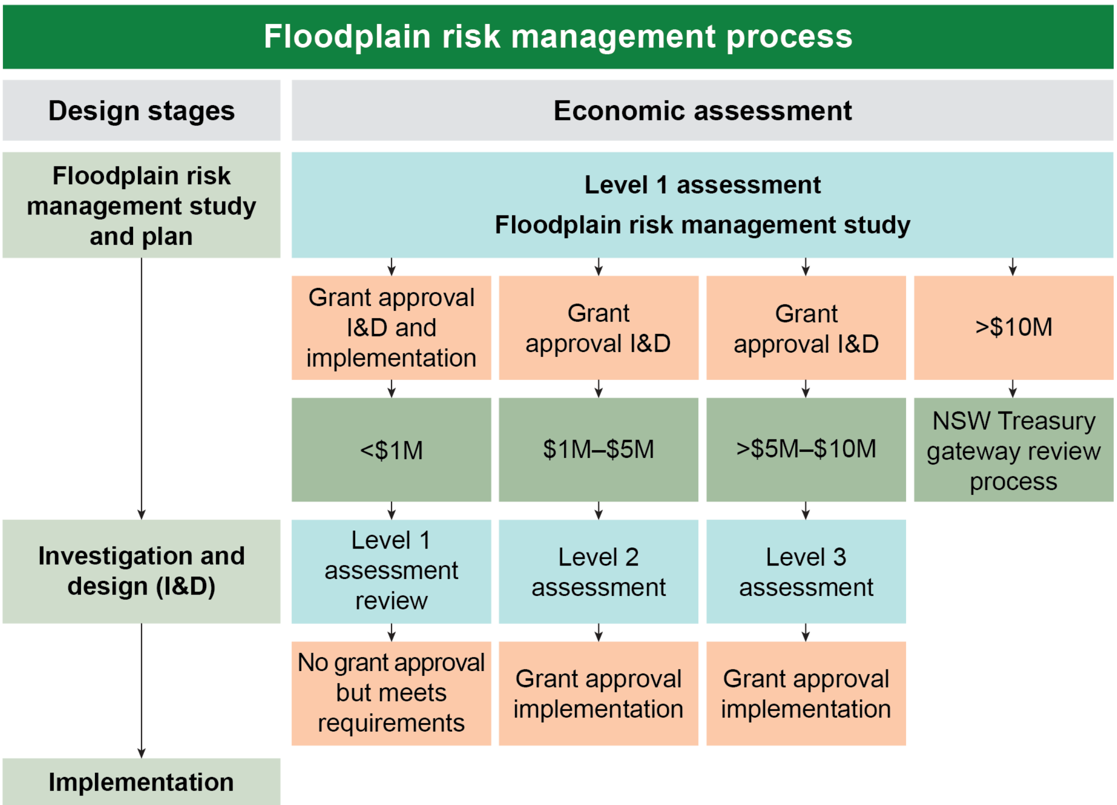


Figure 2 Detailed flood risk management measure economic assessment framework

Table 3 Different levels of economic assessment for flood risk management measures

Element	Level 1	Level 2	Level 3
Description	Economic assessment, including MCA and cost–benefit analysis using the methodology outlined in Section 2.2.3.	Update the Level 1 analysis to include cost estimates from investigation and design phase (Section 2.3). Consider whether additional damage assessment factors (likely to influence the outcome) should be included using the techniques in Section 3.	Similar to Level 2, but potential to include more detailed techniques for monetary valuation, where available. For all projects where the total estimated cost is >$10 million, adopt the procedures outlined in NSW Treasury (2023a). This may also be adopted for complex projects where the total estimated cost is <$10 million.
Costs	Preliminary costings during the FRM study.	Update of costings with cost estimates from the investigation and design phase.	Update of costings with cost estimates from the investigation and design phase.
Benefits [1]	Direct property-related damages quantified.	As per Level 1, but consider whether additional damage	As per Level 2, but consider the use of more detailed

Element	Level 1	Level 2	Level 3
	Indirect and intangibles (see Table 4) to be incorporated where reasonable guidance is available. MCA for other non-quantified benefits. If the plan recommends a particularly high value (>$1 million) option which is reliant on non-quantified benefits (e.g. evacuation and risk to life) then consider quantifying these (see techniques in Section 3).	assessment factors (likely to influence the outcome, i.e. make a material difference to the cost–benefit analysis) should be included using the techniques in Section 3.	assessment techniques, for example, evacuation modelling may be appropriate to identify risk to life more readily, if this is a key factor.
Sensitivity analysis	Test variation to included discount rate.	Test variation to included discount rate, and increases and decreases in benefits and costs.	As per Level 2. Include additional sensitivity on specific assumptions related to key benefits estimated.
Reporting	Contained within the FRM study. This is likely to include a summary in the report, an appendix with the details, and the provision of the different assessment tools and raw data.	Incorporated in the investigation and design report. This is likely to include a summary in the report, an appendix with the details, and the provision of the different assessment tools and raw data.	Standalone report or appendix to the investigation and design report. This is likely to include a summary in the report, an appendix with the details, and the provision of the different assessment tools and raw data.

[1] General guidance. Further detail can be prepared in any level if required.

Table 4 Categories of flood damage

Direct tangible damages	Indirect tangible damages	Intangible damages
Property (public and private) including structure, contents and external damages Infrastructure Agricultural Vehicles	Clean-up Disruption to public services, businesses and households Alternative accommodation Infrastructure disruptions and associated costs (e.g. transport infrastructure)	Loss of life (mortality) Injury and other health-related flood impacts, including stress and mental health Social and cultural values Environmental values Loss of memorabilia Inconvenience

Notes: Direct tangible damages relate to actual contact with flood water.

Indirect tangible damages relate to disruption caused by the flood.

Intangible damages relate to health, social, cultural and environmental issues.

2.2 Assessment in flood risk management plan development

Assessment needs to start with an understanding of the full range of flood behaviour that can support the selection and analysis of FRM measures. This assessment needs to be fit for purpose and tailored to the flood situation.

Table 5 provides advice on some typical aspects to consider in the assessment of measures.

Table 5 Typical aspects to consider in selecting and analysing flood risk management measures

Issue	Consideration
Types of storms that drive flooding	Consider plausible flood events derived from the storm types and varied patterns that lead to major flood impacts on the community in the study area and consider how management measures influence these.
Antecedent conditions	Consider the natural range of antecedent conditions and the conditions prevalent before major flooding and how these are influenced by management measures.
Catchment size and configuration	This influences the types, and variability of locations and patterns of storms that drive flooding in different areas of the catchment. It can influence the modelling technique chosen, model set-up and complexity, and the range of modelling scenarios needed to understand flood behaviour and assess FRM options.
Storm durations and patterns	The flood events that lead to critical flood behaviour in different areas of the catchment need to be considered along with the influence of FRM measures on key events.
Flowpath variation between small and rare to extreme events	The flowpaths taken by floodwaters in rare to extreme events can be significantly different than in smaller events that are confined to the waterway. This may be influenced by FRM measures.
Time for the benefit to be realised	Benefits of any FRM measures can only be built into decision-making when they are realised and can be relied on. For example, a levee can only be considered in decisions after it is constructed and operational.

Issue	Consideration
Natural variability	This needs to be considered in assessing the potential benefits and reliability of FRM measures. For example, vegetation varies naturally over its lifecycle (Table 33) and due to the impacts of natural hazards.
Confluences of multiple waterways	The timing and scale of the flow contribution from different waterways that converge at a location to downstream flooding may vary significantly which needs consideration. This may be affected by FRM measures.
Full range of flood behaviour and events	The impacts of FRM measures need to be considered across the full range of flood behaviour and events and resulting changes due to FRM measures.
Variability with location	Flood behaviour and impacts vary across the floodplain. The impacts of FRM measures need to be considered across the study area.
Flood behaviour at hydraulic structures, such as bridges	FRM measures can block with debris. The potential for FRM measures to influence the blockage of key hydraulic structures needs to be considered.

Fit-for-purpose modelling can assist in identifying the risk faced by the existing community with existing FRM measures in place, that is, the base case. This is discussed in FRM guideline FB01 with an example of how relative risks to different elements may be displayed on a qualitative risk assessment matrix as shown in Table 6.

Table 6 Example of relative flood risks faced by an existing community

Likelihood of consequence	AEP range %	Level of consequence						Legend
		Insignificant	Minor	Moderate	Major	Catastrophic		Legend
Likely	>10	Community services People Property/economy Social/cultural Environment (Low)	(Medium)	(High)	(Extreme)	(Extreme)		Extreme High
Unlikely	1 to 10	Social/cultural Environment (Low)	(Low)	Community services (Medium)	People (High)	(Extreme)		Medium
Rare to very rare	0.01 to 1	(Very low)	Social/cultural Environment (Low)	(Medium)	People Property/economy (High)	Community services (High)		Low
Extremely rare	<0.01	(Very low)	Social/cultural Environment (Very low)	(Low)	Property/economy (Medium)	Community services People (High)		Very low

Note: AEP = annual exceedance probability.

The assessment of FRM options occurs in the FRM study. Assessment typically goes through a number of stages including:

- option identification (Section 2.2.1)
- preliminary option assessment (Section 2.2.2)
- detailed option assessment (Section 2.2.3)
- optimisation (Section 2.2.4)
- recommendation in FRM studies and decision-making in FRM plans (Section 2.2.5).

2.2.1 Option identification

Option identification should be inclusive. It should gather ideas from those contributing to, or affected by, floods and their management. This includes the council, the community, government agencies and other stakeholders. It should consider the flood risk to the community, the factors that influence this risk, the elements at risk, and the desired FRM outcomes for the community. These can be compared with information on the general suitability and limitation of FRM measures to address risks (see Table 28 and Table 29).

The outcome of this stage should be the identification of:

- a range of FRM options to address local or broad FRM issues for the existing community and new development considering the elements being treated (see Table 2)
- where FRM options may be able to be packaged to address risk more effectively.

An example of option identification is provided below.

Example of option identification

Table 6 provides an example of the risks faced by the community. FRM options to address these issues may involve measures to:

- address the frequency of flooding of existing property
- improve the response of the community to floods
- manage the increase in flood risk due to the growth of the community in new development areas and manage infill and redevelopment in existing areas.

A decision has been made to examine options to address medium to extreme risks identified in Table 6. The factors that influence this risk are:

- the current limitations on protection to the existing community and its infrastructure services. Options could include:
    - specific protection for critical infrastructure
    - upgrade of the levee system to increase protection levels
    - voluntary house raising to reduce damage to individual properties
- the lack of formal flood warning for the community which limits EM planning. Options could include:
    - establishing a warning system to provide specific warnings to the community that aim to provide sufficient time for EM action
    - establishing formal flood warning arrangements
    - updating the local flood plan to address any related EM issues

- improving community awareness of flooding and how to respond to a flood threat

- limitations on effective land-use planning controls to address growth in risk due to new development, infill development and redevelopment. Options could include:
  - ensuring available information on flood behaviour and constraints is being used to inform planning decisions
  - reviewing the local environmental plan (LEP) and development control plan (DCP) and supporting information considering available information on flood behaviour and constraints and NSW Government circulars and guidance
  - updating and implementing of the LEP and DCP and supporting information to limit the growth of flood risk due to development.

Packages of these options would aim to address the range of issues identified above.

2.2.2 Preliminary option assessment

Having identified the FRM issues to address and an inclusive range of FRM options worthy of consideration, the viability of these options needs to be tested to determine if they warrant more detailed assessment. This step can screen out options that are:

- not physically and technically feasible for the location
- not likely to be supported by the community or key decision-makers
- not likely to be compatible with the management of other hazards and other issues
- not likely to be effective at reducing the risk to the community
- likely to have significant impacts on flooding to the existing community that cannot be offset
- likely to involve substantial costs and disbenefits relative to their potential benefits
- not able to be readily adapted to address changing risks into the future.

Preliminary assessment through option screening can also allow the results of an investigation into one FRM option to inform consideration of similar options, for example, if several levee locations or heights are proposed to protect a similar area, then one could be examined in more detail. Alternatives could then be examined as part of optimisation or later investigation if this type of option is considered viable.

The outcome should be a range of FRM options that address the range of risks faced by the community. If this isn't achieved it may warrant:

- revisiting options that have been dismissed to see if issues can be overcome or they can be altered to get improved outcomes
- identifying and screening additional options that may address the gap in risk management.

This review also assists in determining complementary FRM measures that can be considered as packages in more detailed analysis.

Once there is an agreed set of FRM options or package of options to assess in more detail, the next step is to plan out and undertake the more detailed assessment.

Example of preliminary assessment of options

The earlier option identification example found a range of options to consider in addressing risks to the community in the study area. These options underwent preliminary assessment by screening considering the aspects discussed above. This led to the following options not being taken forward for further assessment:

- specific protection for critical infrastructure. This was not considered practical due to the number and varied locations of critical infrastructure sites in the floodplain
- voluntary house raising to reduce damage to individual properties. This was not considered viable due to a range of factors including:
  - the scale (number of houses to be raised)
  - the likely cost-effectiveness (likely very low benefit–cost ratio)
  - the limited ability of owners to pay their share of costs
  - the benefits being limited to buildings where other options may have broader benefits.

This led to the decision to undertake a detailed assessment of the remaining options (included below) and to consider the benefits of packaging options to address medium to extreme risks. The factors that influence this risk are:

- the current limitations of protection to the existing community's assets and its infrastructure services. The option considered further is the upgrade of the levee system to increase the level of protection to the community. This is expected to have benefits in terms of protecting both infrastructure and community assets and improving community safety in events up to the design flood for the upgraded levee
- the lack of flood warnings for the community, which limits EM planning for the community. Effectively addressing this issue may rely on a number of the following options being implemented:
  - establishing formal flood warning arrangements, assuming flood warning infrastructure is in place
  - putting systems in place to provide specific warnings to the community that aim to provide sufficient time for EM actions
  - updating the local flood plan to address any related EM issues
- limitations on effective land-use planning controls to address growth in risk due to new development, infill development and redevelopment. Options could include:
  - ensuring available information on flood behaviour and constraints is being used to inform planning decisions
  - reviewing the LEP and DCP and supporting information considering available information on flood behaviour and constraints and NSW Government circulars and guidance
  - updating and implementing the LEP and DCP and supporting information to limit the growth of flood risk due to development.

2.2.3 Detailed analysis of FRM options

Detailed assessment and subsequent optimisation of FRM options and packages of options needs to consider their costs, benefits and disbenefits in managing risk. It needs to be informed by flood modelling that effectively considers the complexity of flooding in the area (see examples in Table 5) and the changes that would result from option implementation.

A range of benefits are considered intangible as they cannot be readily quantified. Therefore, performance can most effectively be assessed in an MCA that considers a broad range of factors (see Table 7 and Table 8) quantitatively or qualitatively.

An MCA can provide a sound basis for determining the relative benefits, disbenefits and costs of different options and packages across a range of relevant criteria. It can be used to consider different options as well as different levels of service (such as protection for the 5%, 1% and 0.5% AEP floods) of mitigation works. This can enable assessment of which options are most practical, feasible and beneficial to the community relative to their cost and disbenefits and in consideration of community aspirations and other relevant factors.

Some FRM options (e.g. the construction of a levee, relocation of development, the clearing of vegetation, or the reshaping of a waterway to reduce flood levels) can, in some cases, have relatively high social and environmental impacts.

Table 7 Typical benefits/disbenefits and costs to consider in a multi-criteria assessment

Issue	Description
Benefits/disbenefits	
The effect on flood behaviour	Construction of a levee, detention basin or some other measures can change flood levels, velocities, durations and flowpaths. It may have negative impacts on some in the community.
The level of flood protection that is feasible	There may be a practical level of protection that can be provided by mitigation works beyond which the works need to significantly increase in scope and scale. This may be influenced by the natural terrain and constrained by development. For example, there may be limited space available to cost-effectively construct a structure, which may limit the available protection it can provide without changing to a less cost-effective approach. Another example could be the length of a levee that could be limited by building between 2 natural high points with protection limited by the level of these high points. More protection would require raising and extending the levee.
Changes in flood damage due to FRM measures	Understanding the benefits/disbenefits of management measures to the community and where they may accrue can be informed by a flood damage assessment with and without FRM measures in place. This will vary with the scope and scale of the option and the level of protection provided.
Impacts on people	An FRM measure may change the frequency or scale of impacts of flooding on people, including potential changes in fatalities and negative health outcomes.
Environmental impacts of works	An FRM measure may alter flood behaviour, which can affect the environment. The acceptability of the change relates to the environmental significance of the area and scale of the change. For example, does it isolate or reconnect a flood-dependent ecosystem from flooding, or is it likely to bring the location closer to or further away from its natural state?

Issue	Description
Environmental enhancements	Involves additional works included with an FRM works project to provide an additional environmental benefit or an environmental enhancement work that has the potential to have some FRM benefits.
Adaptability to changing conditions	The non-stationary nature of hydrology, the floodplain and the catchment means that design flood behaviour may change within the design life of an FRM measure. Adaptive designs can support modification over time to address changes. Climate change is a well-known factor contributing to changes in flood behaviour. FRM guideline FB01 discusses consideration of climate change. Testing the sensitivity of the design flood to change can inform the need for adaptation.
Costs	
Costs of implementation of FRM measures	Cost estimation should consider industry guidance on costings of works, and information from previous projects. They should be based on lifecycle costs, which include: • investigation, design and construction, including work integral to the project such as any compensatory works to offset impacts of flooding on other properties • land acquisition, any associated demolition costs and service relocation • construction limitations and restrictions that often occur in existing urban environments • environmental enhancement measures • operation and maintenance (separately identified from upfront costs) • other changes in costs due to implementation. • Contingencies should be included that consider the uncertainties in estimates at this stage of investigation.
Financial efficiency	Comparing the net present value of benefits with net present costs of the FRM measure.

Table 8 Other factors that may influence the outcomes of multi-criteria assessments

Issue	Description
Lifecycle affordability for the local community	Investigation, design and construction costs may be eligible for subsidy under some funding programs; whereas ongoing operation, maintenance and monitoring costs are generally not.
Standards, physical and technical constraints	Standards for new development and infrastructure can influence the level of service the existing community expects from mitigation works. Physical constraints can affect whether a mitigation work is suitable to a location or is capable of meeting community expectations.
Community expectations	The choice of options, packages or the service level for an FRM measure may depend on the level of flood risk the community is willing to accept, and the cost. Factors the community may consider include: • the service level provided to new development in the community • the cost of works to the community and individuals, and their ability to pay • any potential change to the cost of flood insurance due to reduction in average annual damages (AADs) due to the works • any negative effects of the works on existing flood immunity.
Community attitude	Mitigation works can have widespread or localised community support or opposition. It is important to understand the community's attitude and its basis so that this can be considered in option design or decision-making.
Land ownership	If a mitigation work, such as a levee, cannot be constructed and operated on public land, land may need to be acquired or access to private land gained. Alternatively, the design may need to be changed to go through public land, which may reduce the area protected and therefore the benefits.
Visual impacts	The crest level for levees, dams and detention basin embankments and similar structures can affect the amenity of the surrounding land and is often a key consideration for those living nearby.
Social setting	Floods and FRM measures can disrupt important community social and cultural events, destroy or damage culturally important artefacts and recreational facilities, reduce community connectedness to the river, affect the social wellbeing of the community and limit the ability of the community to grow. These factors need consideration in decisions.
Social equity	Mitigation works can change flood behaviour, which may influence the degree that floods affect certain properties, their value and amenity, and their flood insurance costs. The implementation of some FRM measures may benefit particular groups in the community while disadvantaging, or at least not benefiting, others. For example, protecting those living inside a levee may not benefit, and may potentially impact, those living outside a levee due to adverse changes in flood behaviour. Considering social equity can identify whether the works result in 'winners and losers' and enables consideration of how to address any inequities. It may influence who contributes to paying for the works and may identify the need for compensatory measures to offset or reduce negative effects.
Interaction of FRM options	Some options are complementary whereas others are mutually exclusive.

To compare issues and FRM options objectively, it is necessary to gather a variety of socioeconomic data. Scoping of the detailed assessment should be fit for purpose, practical and cost-effective for the decisions and the financial risks associated with the decisions being made. It should consider the principles and the staged nature of FRM measure implementation as discussed in Section 2.1.

Assessment in FRM studies should be limited to a Level 1 assessment (Figure 2 and Table 3). They should focus efforts on factors that may be influenced by FRM measures resulting in substantial benefits, costs or disbenefits, rather than where they make no substantial change to the status quo.

Assessment of FRM options should consider:

- the full range of flood events
- the limitations, and the social, economic and environmental benefits and costs of options
- existing development and infrastructure
- any impacts on infrastructure to support EM, for example, existing or proposed flood warning systems, evacuation routes and response strategies
- any impacts of FRM options on flood risk elsewhere in the floodplain.

Quantitative assessment of benefits and disbenefits usually relates to flood damage changes against the base case of the existing FRM measures and arrangements, which is discussed in Section 3.7 of this guideline.

Quantitative assessment of costs generally relates to costs estimated for FRM measures. Cost estimates for projects should be indicative but as close to reality as possible, and consider relevant industry advice on costs of relevant types of works. There are a number of industry sources of unit rates for different types of works (e.g. the current version of Rawlinsons Australian construction handbook).

Cost estimates should be fully documented in reports. They should identify the option they relate to, the estimated quantities and the unit rates used in estimation and the sources of this information. Cost estimates should include an appropriate contingency allowance that reflects the stage of the project and the scale of unknown factors.

Cost estimates need to consider lifecycle costing as all options come with upfront, operation, maintenance and complementary costs, and may be interdependent or interact with other options (see Table 30, Table 31, Table 32 and Table 34). Cost estimates from FRM studies should be refined in investigation and design.

The benefits of FRM options can be compared to their costs and disbenefits to determine their relative merit for cost-effectively addressing risk to the community. This can be supported by qualitative assessment of benefits and disbenefits (where quantitative assessment is not feasible or cost-effective) as part of an MCA.

The *Flood damage assessment FRM tool* DT01 (FRM tool DT01) assists in estimating the benefits (reduction in flood damages) of FRM options. It also provides the ability to incorporate cost estimates for works which supports the assessment of cost–benefit analysis. As part of cost–benefit analysis the tool also allows for the consideration of the uncertainty in the timing of future flood events. It does this using a Monte Carlo analysis approach which is outlined in NSW Treasury (2023b). Monte Carlo assessment may be considered in complex situations where FRM have a high life cycle cost.

The long-term viability of options can be tested considering future scenarios (see FRM guideline FB01) relating to the impacts of climate change and other factors on existing flood behaviour with existing FRM in place. FRM options can then be assessed for these future scenarios, to see if their benefits are likely to be maintained or diminish over time.

This may provide information to consider in decisions on FRM options and may involve considering how an option could be adapted in the future or whether the option has long-term viability.

2.2.4 Optimisation

Optimisation may be used to refine options to improve benefits and reduce costs or disbenefits. For example, it can involve looking at different levels of service or design heights for a levee, or alternative levee routes or designs that may change upfront costs but reduce operations and maintenance costs.

A package of options will often contain measures, such as flood warning systems, that may not relate to a specific design flood. Therefore, the benefits they provide are unlikely to be affected by a change in the design flood for the mitigation work. However, the level of service provided by a flood warning system to the community can vary from a simple to sophisticated service when balancing the needs of the community.

2.2.5 Decision-making on FRM measures

A balanced FRM plan addresses existing, future and continuing risk to reduce residual risk to a level more acceptable to the community; and in doing so generally involves assessing, deciding on and prioritising a range of FRM measures.

Cost–benefit analysis and associated MCA can support informed decision-making by the FRM committee by developing recommendations in FRM studies that are considered in the formalisation of FRM plans.

One way of considering the outcomes of an MCA of different options or packages of options is the establishment of an options assessment matrix (see example in Table 9) that considers a range of criteria that can influence decision-making.

Table 9 Example option assessment matrix

Criteria	Weight of criteria (–5 to +5)	Raw scores – options				Weighted scores – options			
		Maintain current practice	Design flood for FRM works	Flood warning	Development controls	Maintain current practice	Design flood for FRM works	Flood warning	Development controls
Feasibility									
Technical									
Affordability to community considering the potential to attract funding									
Adaptability to change for long-term feasibility									
Community acceptability									

Criteria	Weight of criteria (–5 to +5)	Raw scores – options				Weighted scores – options			
		Maintain current practice	Design flood for FRM works	Flood warning	Development controls	Maintain current practice	Design flood for FRM works	Flood warning	Development controls
Flood behaviour – impacts and benefits									
In area served by FRM measure									
In other areas									
Hazard in DFE or FRM works design flood									
Hazard in extreme event									
People – impacts and benefits									
Frequency/scale of exposure									
Availability of warning									
Ability to evacuate									
Environmental									
Environment impacts of works									
Inclusion of environmental enhancements									
Social set – impacts and benefits									
Wellbeing									
Social disruptions									
Recreation									
Property values									
Insurance costs									
Cultural impacts and benefits									
Cultural heritage sites									
Cultural events									
Cultural flows									
Public administration – impacts and benefits									
Infrastructure outages									

Criteria	Weight of criteria (–5 to +5)	Raw scores – options				Weighted scores – options			
		Maintain current practice	Design flood for FRM works	Flood warning	Development controls	Maintain current practice	Design flood for FRM works	Flood warning	Development controls
Ability of community to recover									
Ability to manage risks as the community grows									
Economic efficiency									
Lifecycle benefits and costs									
Cost–benefit ratio									
Combined score									

The criteria used can vary with the flood situation and community. Some may not be relevant to the circumstances or the options being considered. In addition, different communities, decision-makers and groups may consider different criteria and specific elements to be more or less important. One way of addressing this variation is to weight the relative importance of these criteria so this can be factored into the assessment. For example, weightings could go from highly important (5) to relatively unimportant (1).

The selection of criteria and weighting should be completed independent of scoring and should actively involve the FRM committee and its technical working group (TWG). Selection and weighting should be undertaken with the recognition that not all criteria are mutually exclusive so the potential for double counting can be avoided. For example, whilst understanding lifecycle benefit and lifecycle cost is important for considering the feasibility of FRM options, these both directly inform the cost–benefit ratio, so only the cost–benefit ratio is used to inform any combined scoring.

The relative effectiveness of options to address the selected criteria may then be assessed using a scoring system. Examples of the range of scoring for an FRM work in addressing specific criteria may include:

- highly beneficial could be 5 (positive 0.1–5), no change could be 0 (zero), and significant negative impacts could be –5 (negative –5 to –0.1)
- highly adaptable could be 5, not adaptable at all could be –5
- a cost–benefit ratio (CBR) of <0.1 could be –5, a CBR of 1 could be 0 (zero), and a very high CBR could be 5
- significant adverse impacts on flood behaviour in other areas could be –5, no change in flood behaviour in other areas could be 0 and significant positive benefits in other areas could be 5.

After raw scores are developed by the FRM committee with input from the TWG and the consultant, weightings are used to translate these into weighted scores.

Weighted scores may be used by the FRM committee to compare different FRM options, packages and service levels. This can assist in selecting a preferred package of options to address the risks to the community. It can highlight the feasibility of FRM options, their relative benefits, impacts and limitations, and their effectiveness and efficiency in addressing flood risk to the community.

Overall scoring for an FRM option may provide an understanding of the balance across the criteria, but should not be used without careful consideration of the individual aspects. For example, the benefits of an FRM option generally cannot overcome issues with feasibility. In addition, the ability to implement an FRM option, including its budgetary requirements and ongoing asset management and operation, is an important part of this decision-making. These issues may mean that the project is not viable to take forward unless these limitations can be addressed, perhaps through redesign or rescoping of the FRM option. This may lead to an alternative FRM option being put forward and scored.

Decision-makers are ultimately responsible for which options are recommended. The assessment can only provide guidance on the relative feasibility, effectiveness and efficiency of FRM options in addressing the FRM issues faced by the community.

Prioritisation and implementation planning during the FRM plan development

An FRM plan also involves agreement of those responsible to implement the FRM measure and prioritisation of recommended FRM measures for implementation.

Prioritisation should consider the benefits to the community, the resources needed to implement, the practicality and ease of implementation as well as relative feasibility, effectiveness and efficiency.

Example of prioritisation

The following measures have been identified as being of benefit to the community and are proposed for implementation:

- a levee to reduce impacts to the existing community. Levees may be very effective at reducing how frequently development and people in the community are exposed to flood risk. Implementation involves investigation and design and then construction phases before benefits are realised, and may rely on external financial assistance. Levees also require effective upfront and ongoing community engagement to understand their benefits and limitations during flooding
- update of flood intelligence and EM planning arrangements. EM planning is informed by information produced under the FRM process. Using this to inform intelligence and update of EM planning helps reduce risk to people in the community by supporting improved emergency response. This relies on action from the NSW State Emergency Service (NSW SES) for implementation and therefore any specific recommendations for EM improvement requires agreement
- land-use planning controls may be effective in limiting growth in flood risk as a result of new development. Altering land-use planning controls could be undertaken within the available resources and linkages of the council.

The levee is seen as the highest priority for implementation due to the benefits it provides to the existing community, however, other actions are also complementary and important to manage risk to the existing and future community. The implementation plan may involve council:

- working on implementation of land-use planning arrangements as a priority
- working with the NSW SES to prioritise the update of the local flood plan
- commencing implementation of the levee by inclusion in forward and operational planning, examination of funding options, and applying for funding for investigation and design.

Information to support business cases for funding

Sufficient information should be provided in reports to facilitate funding applications for eligible projects under relevant funding programs. Information currently needed to support these applications relates to the council's commitment to FRM, how FRM measures were identified and assessed, community involvement in FRM plan development, and the FRM benefits of the project for the community. Table 10 and Table 11 identify some of the key information to be identified in plans for different types of projects recommended for implementation or further investigation.

Table 10 Information required to inform assessment for all flood risk management projects

Item	Description	Example measures for the DFE (1% AEP or flood of record) for the urban area benefiting
Source of flood information	Identifies the source of information for considering the FRM measure	Recorded flood history, flood or FRM study consistent with FRM process, anecdotal evidence
Flood behaviour and impacts	Identifies some important factors affecting the existing flood risk	Whether urban area benefiting is in a floodway; is high hazard H5–H6*; has little warning time (less than 24 hours), rapid water level rise 0.1 m/hr; typical depth above floor >1 m
Number of dwellings affected by flooding	Provides an indication of the number of people affected by flooding	Number of dwellings affected above floor level
Percentage of dwellings affected by flooding	Provides an indication of the scale of the problem from a local perspective	Percentage of dwellings in study area affected by over floor flooding
Occurrence of over floor flooding	Identifies the frequency/regularity of damaging flooding and therefore impact on the community	Number of times over floor flooding has been experienced by a significant number of dwellings (25% or more of dwellings affected by flooding is considered to be significant)
Evacuation requirements	Indicates the degree of evacuation problems to which the community is exposed	Identify evacuation characteristics, e.g. any issues with getting to evacuation location, time available for evacuation, time for damage reduction, evacuation assistance required (e.g. evacuation route cut early but arrangements in place to facilitate evacuation)
Community involvement	Indicates the degree of consultation in project development	Most relevant of: • developed by a committee in accordance with the manual • developed with a project steering committee with community membership • input from one or more community meetings • no public consultation or input • public comment invited on environmental impact statement or project development application

Statutory planning in place	Identifies the degree to which statutory planning is being used to control new development and redevelopment in the floodplain	Most relevant of: • DCP with flood related controls • FRM plan not supported by other planning controls • FRM plan supported by a LEP and DCP • individual application assessment and conditions • LEP with specific flood related controls • policy that provides that floor levels must be above a nominated flood standard
Benefit–cost ratio	Identifies the economic efficiency of the project in reducing flood damages	Benefit–cost ratio for the project
Community flood awareness	Examines the accessibility of flood information to the community and activities undertaken by councils to provide information	Most relevant of: • flood information publicly available • flood information freely available on request • affectation identified through planning certificates • community flood information distributed in last 12 months or 3 years
Environmental consideration and enhancement	Considers how the project has dealt with environmental impacts and addressed ecologically sustainable development (ESD) principles and whether it includes environmental enhancement	Highest level of compatibility, e.g. alternative options investigated, environmental consideration; structural solution only; compatible with ESD; incorporates environmental enhancement

* Refer to Flood hazard FRM guideline FB03.

Table 11 Additional information for specific project types

Project consideration	Project type (for design flood for works – typically 1% AEP or flood of record for the urban area benefiting)				
	Schemes and structural works	**Evacuation management**	**Flood warning**	**Voluntary house raising**	**Voluntary purchase**
Existing damage /dwelling and reduction	• Average $ damage per dwelling in design flood • $AAD per dwelling • % reduction in $AAD per dwelling			• Average $ damage per dwelling in design flood • $AAD per dwelling • % reduction in $AAD per dwelling	• $AAD per dwelling
Social improvements	Identify whether: • community and key infrastructure is now protected • impacts on business viability is now limited	Identify whether: • flood depth over evacuation route reduced to hazard H1 or depth <0.3 m, velocity (V) <2 m/s • arrangements in place to minimise damage and restart time for essential services • arrangements in place to manage long-term flooding (accommodation etc.) • warning strategy in place to support community response	Outline if: • effective warning time matches community safety and damage reduction needs • the community now aware of actions required during flooding • community EM arrangements now in place • flood protection and restart arrangements in place for essential services	n/a	Identify whether: • danger to personal safety reduced/removed • land to be rezoned to appropriate community use • personal trauma due to flooding significantly reduced • potential for significant debris loadings removed • social disruption from floods reduced • rescue of residents no longer a risk for rescuers
Flood behaviour and impacts	n/a	Outline whether: • urban area in floodway • high hazard or H5–H6	Outline whether: • urban area in floodway • high hazard or H5–H6	n/a	Outline whether: • houses are in floodway • high hazard or H4–H6

Project consideration	Project type (for design flood for works – typically 1% AEP or flood of record for the urban area benefiting)				
	Schemes and structural works	Evacuation management	Flood warning	Voluntary house raising	Voluntary purchase
		• isolated from community evacuation destination with insufficient time to evacuate • isolated area can be completely inundated in extreme events • flood depth >0.5 m • flood depth >1 m above habitable floor level • rapid rate of water at site (>0.1 m/hour)	• isolated from community evacuation destination • buildings with >0.5 m or >1 m in flooding above habitable floor level		• part of floodway clearance scheme • residents can't be evacuated within available warning time • rescue of residents poses substantial risk to rescuers
Improving EM and warning	n/a	Improving EM – outline whether: • community EM strategy and evacuation centre arrangements are in place • people now able to self-evacuate without external assistance within available warning time • external evacuation resources no longer required with change	Improve flood warning – identify whether: • available warning time >6 hours • project part of the total warning system for flood • flood warning to be issued by Bureau of Meteorology • project assessed as technically feasible • funding available for ongoing operation and maintenance	n/a	n/a

Project consideration	Project type (for design flood for works – typically 1% AEP or flood of record for the urban area benefiting)				
	Schemes and structural works	Evacuation management	Flood warning	Voluntary house raising	Voluntary purchase
		• areas no longer isolated in extreme floods with change			
Scale of problem	n/a	Identify the number of evacuees to benefit	Identify whether: • no warning system exists and evacuation required or trafficable access lost • previous warnings inadequate and evacuation is required • existing warning system involves extrapolation from another location and evacuation is required • the system is only for supplementing warning for local tributaries	n/a	n/a
Suitability for location	n/a	n/a	n/a	Location and benefits: • area is not in floodway or high hazard or H5–H6 • EM arrangement allow evacuation within available warning time	Alternatives – identify whether: • no other viable FRM options able to adequately manage risk to life • redevelopment not viable to minimise risk to life

Project consideration	Project type (for design flood for works – typically 1% AEP or flood of record for the urban area benefiting)				
	Schemes and structural works	Evacuation management	Flood warning	Voluntary house raising	Voluntary purchase
				• no mitigation options are viable to address damages • dwelling habitable floor levels to be raised above flood planning level (FPL) • current floor levels relative to flood level – below 5% or 10% AEP	• houses not able to be relocated within their property to reduce risk to life • if removal needed for floodway clearance

2.3 Considering measures in plan implementation

FRM plans may recommend a range of implementation measures, such as those identified in Section 2.2.5 that:

- can be implemented within council's own resources, such as updating land-use planning arrangements. Council should progress these measures in a timely manner considering the priorities in the plan
- are the agreed responsibility of, or require agreed input from, external parties to implement. Examples include updating EM planning arrangements. Council should work with external parties to support implementation, considering the priorities in the plan
- will generally require external funding support, such as new or upgraded FRM works, including levees, basins and flood warning systems.

Where external funding is required, the FRM economic assessment framework, as shown in Figure 2 and outlined in Table 3, provides the basis for further assessment of the FRM measures as part of the investigation and design phases of implementation. As outlined in Figure 2:

- for projects with a total implementation cost of less than $1 million, the Level 1 assessment (see Section 2.1.2 and Table 3) undertaken in developing the FRM plan should be updated based on any additional information collected since the completion of the FRM plan
- for projects with a total implementation cost between $1 million and $5 million, a Level 2 assessment (see Section 2.1.2 and Table 3) is recommended
- for projects from $5 million to $10 million in grants a Level 3 assessment (see Section 2.1.2 and Table 3) is recommended
- projects greater than $10 million need an assessment in accordance with relevant NSW Treasury guidelines.

The investigation and design assessments required for individual projects should build on the analysis undertaken in the FRM plan. Information from this analysis can then be used to inform decisions to proceed with implementation of the measure. It can also inform applications for external funding.

3. Flood damage assessment

Floods can result in significant impacts on the community resulting in damages. Flood damages can be due to actual contact with flood waters (direct damages), or disruption caused by a flood (indirect damages) from exposure of the community. Impacts can be readily measured (tangible damages) or difficult to measure (intangible damages). Table 4 breaks down the typical damages from floods according to these distinctions.

The purpose of a flood damage assessment is to support decision-making on FRM options. It provides the basis for understanding the scale of benefits or disbenefits FRM measures may have on flood damages to the community. The damage assessment is not intended to be a precise estimate of damage at a given location. Rather, it is intended to provide a reasonable understanding of the relative scale of damage across the study area and how this may be altered with the implementation of FRM measures.

This information can then be used with information on the costs of FRM measures to understand the monetary benefit and cost of the works. This is supported by broader consideration of other factors in an MCA as outlined in Section 2.

Consistent with the principles outlined in Section 2, quantitative flood damage assessments need to:

- be done in a cost-effective and efficient manner considering the flood situation and the scale of the community
- focus efforts on those cost elements that are going to materially change due to the implementation of FRM measures
- exclude elements where FRM measures will have limited positive or negative impacts on flood damages.

To support flood damage assessments, this section of the guideline and the FRM tool DT01 provide a fit-for-purpose approach for consistent assessment of damages and reduction in damages whilst providing flexibility to go into more detail where required. It provides:

- background and guidance on assessment using FRM tool DT01, with more information provided in the tool itself
- base information for analysis. This includes advice on:
  - residential flood damages as discussed in Section 3.1
  - non-residential (commercial, industrial and public) building flood damages as discussed in Section 3.2
  - general public infrastructure as discussed in Section 3.3
  - other damage factors and intangible damages that can be considered for inclusion on a case-by-case basis where warranted, as discussed in Sections 3.4 and 3.5. These factors should only be used in studies funded under the NSW Floodplain Management Program (the program) where agreed to by the Environment and Heritage Group of the Department of Planning and Environment (DPE)
  - adjustment factors for damage calculations as discussed in Section 3.6
  - flood damage assessment and links to advice on estimating average annual damages (AAD) and net present values (NPV) are discussed in Section 3.7.

This guideline and FRM tool DT01 will be updated as needed, therefore, before starting a flood damage assessment it is important to access the latest version of the guideline and tool. The background report (Rhelm 2020) considered in the development of this guideline provides further information on the references and background material.

3.1 Residential flood damages

Residential flood damages are generally assessed based on assessments of structural damage, damage to contents, external damage, relocation costs and clean-up costs. In limited cases, the additional damage costs related to structural integrity due to building failure may also warrant consideration, as discussed in Section 3.4.2.

Table 12 gives a summary of the residential property-related damage costs that have been specifically attributed to individual properties and will influence derivation of damage curves for individual properties. These curves are used with the ground and floor levels of habitable structures and flood levels from a range of flood events as part of the derivation of overall flood damages. This is discussed further in Section 3.6.

The damage index approach has been adopted for the structural and contents damages. It expresses the damage to the building as a proportion of its replacement value (in the case of structural damage). For contents damages, it may be expressed as a proportion of the total contents' value for the property.

This supports transposition of the damage curve to differing locations and time periods, where key information to support this transposition is available, as the damage function is more independent of the value of the house or the timeframe in which it is assessed.

3.1.1 Structural damages

The structural damage index curves are provided in Figure 3. The curves are based on work by Geosciences Australia (2017) and adjusted based on the recommendations of Mason et al. (2012) for single storey dwellings. The double storey damage curve was separately derived based on available literature on the proportions relative to the single storey residential property. For other residential developments:

- multi-unit developments – 70% of the damage index for a single storey detached dwelling was adopted
- townhouse developments – 70% of the damage index for a double storey detached dwelling was adopted.

Information on the property's value is required to convert the damage index to an appropriate damage value. Table 13 provides some suggested replacement values, expressed in terms of cost per square metre (m^2) and average floor areas. This information can be updated with local data where available. When using local information, the source needs to be identified.

Table 12 Property-related residential damage costs summary

Type/Element	Damage index/ time	Values	Specific adjustments	Adjustment from 2019
Tangible direct damages				
Structural	Damage index from relevant curve (Figure 3)	Replacement cost value (2019) for relevant type (Table 13)	Average size of residential dwellings (Table 13) Adjustment by 0.7 for townhouse/multi-unit where relevant (Section 3.1.1) Adjustment for structural integrity (Section 3.4.2) [1] Regional cost variation (Table 22)	Consumer Price Index (Section 3.6.1)
Contents	Damage index from relevant curve (Figure 4)	Replacement cost value $490/m^2 (Section 3.1.2)	Actual vs potential damage (Section 3.1.2) Adjustment for structural integrity (Section 3.4.2) [1]	
External damage		$15,000 (Section 3.1.3)	Applied per site not per unit for townhouse/multi-unit (Section 3.1.1)	
Vehicles at home [1]	Relates to minimum depth of flooding of 0.3 m above ground level. No. of vehicles per property defaults to 1.5 but can be adjusted if better relevant information is available (e.g. Australian Bureau of Statistics data)	$3,750 per vehicle (Section 3.4.4)		
Tangible indirect				
Relocation costs	Time weeks (flooded time + estimated relocation period due to depth above floor level) (Table 14)	$430/week (Section 3.1.4)		

Type/Element	Damage index/ time	Values	Specific adjustments	Adjustment from 2019
Clean-up costs		$4,000 (Section 3.1.5)		
Intangible damages				
Social and wellbeing impacts [1]	Relates to threshold frequency of above floor flooding	See Table 21		

Note: [1] Social and wellbeing impacts (Section 3.5.2), vehicle damages (Section 3.4.4) and the adjustment for structural integrity (Section 3.4.2) should only be used in studies under the program where agreed to by DPE Environment and Heritage Group and they meet the requirements of their specific section and Section 3.4.1.

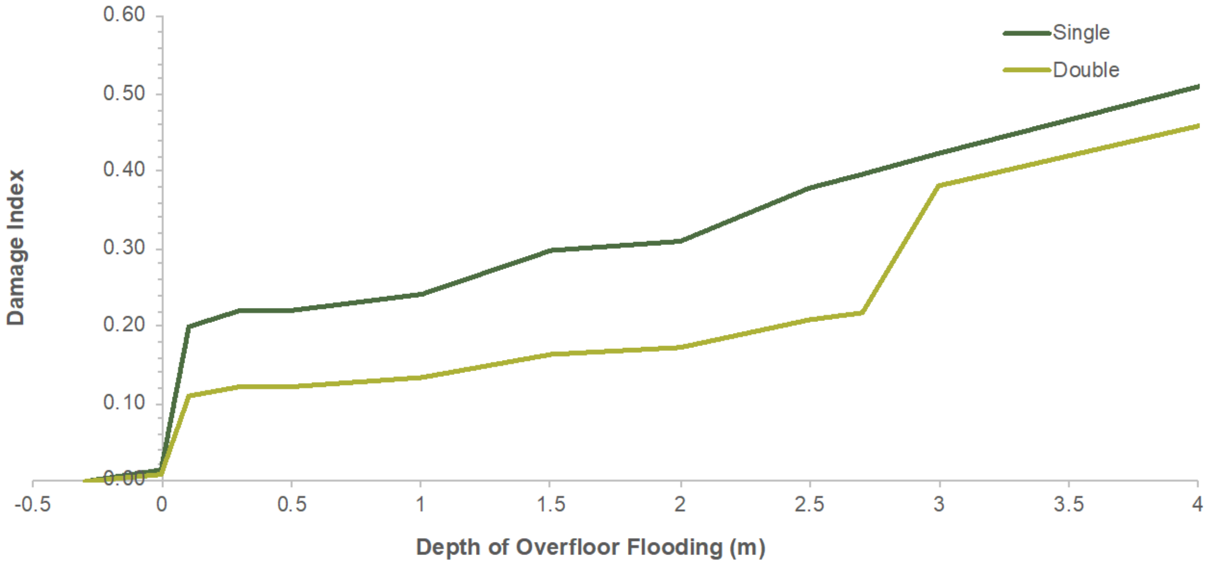


Figure 3 **Residential housing structural damage index**

Table 13 **Suggested residential property replacement cost values (2019 dollars)**

Dwelling	Type	Assumed floor area (m²)	Cost per m²	Single storey
Detached dwellings – single storey	Small	90	$2,000	$180,000
	Medium	180	$2,000	$360,000
	Large	240	$2,000	$480,000
	Recommended average	220	$2,000	$440,000
Detached dwellings – double storey	Small	90	$2,300	$210,000
	Medium	180	$2,300	$415,000
	Large	240	$2,300	$552,000
	Recommended average	220	$2,300	$506,000
Multi-unit dwellings		100	$2,400	$240,000
Townhouse		160	$2,300	$368,000

3.1.2 Damage to contents

The contents damage index curves are provided in Figure 4, and were derived based on BMT WBM (2018). A typical contents value of around $490/m² (in 2019 dollars) was estimated. The average floor area can be estimated based on Table 13, or local data if available. For multi-unit developments, the appropriate damage curve (e.g. single storey for multi-unit developments, double storey for townhouses) should be adopted for each unit.

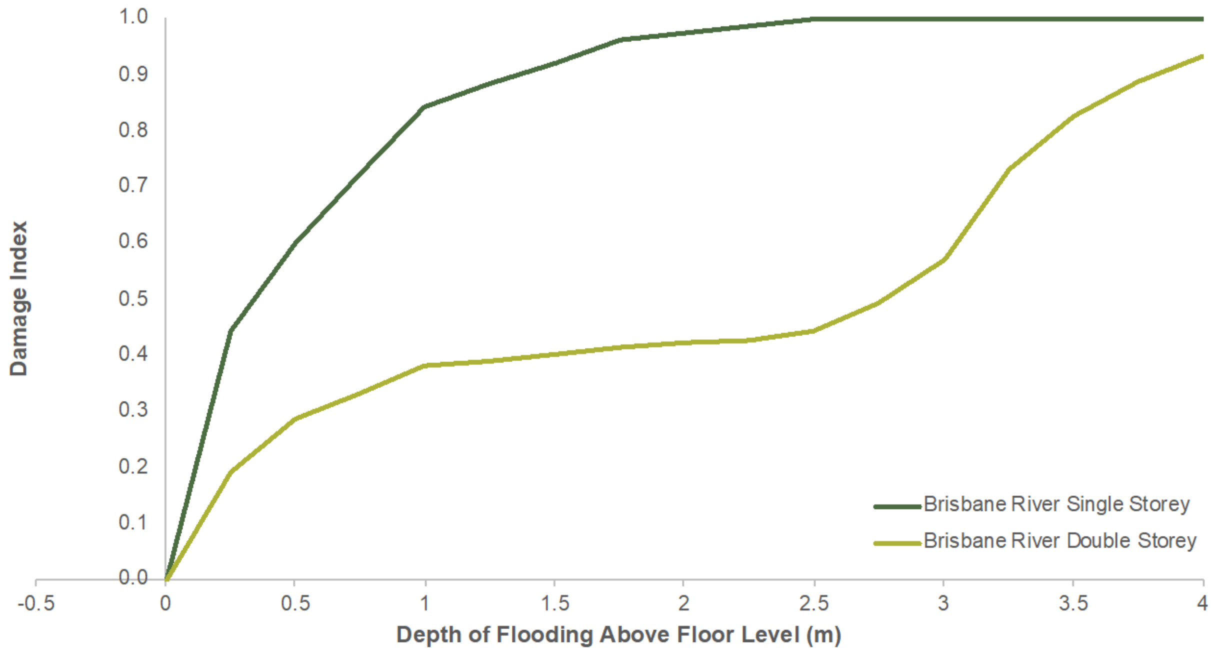


Figure 4 Recommended residential contents damage curves

Actual:potential damage ratio for contents

The actual damage to contents in an event can be reduced by actions taken during the warning time available in response to a flood threat. These actions may include raising goods and furniture, moving valuable items to the kitchen benchtop, onto tables, or up to the second storey, and taking some valuables as part of evacuation, if possible.

The actual:potential damage ratio used in contents damage reduction is 0.9 by default. In limited cases, generally involving longer warning times, contents damages can be further reduced by relocating contents to locations outside of the influence of flooding.

Using a ratio lower than 0.9 requires strong evidence based on realistic assumptions. The potential for substantial reduction depends on all the following factors:

- availability of a specific flood warning for the location
- the length of warning time for people to act
- the duration of flooding
- the awareness of flood impacts in the community
- the experience of the community in responding to flooding. In general, the experience of the community is relatively short-lived compared to the timeframe for economic analysis. For example, an 'experienced community' today may have become an 'inexperienced community' in 10 years when the next major flood occurs. Unless there is very frequent flooding in a community, the most likely scenario is that the community is 'inexperienced'
- the likelihood for least one household member being present at or able to get home
- the ability and capability of individuals to lift goods to higher ground (i.e. benchtop or tables) or into a vehicle that is being used for evacuation, and the available capacity in the vehicle
- the height to which goods can be lifted (bench height or second floor) relative to the potential above floor flood depths.

All these factors should be considered if developing a case that proposes reduction in the ratio below the default factor. Even with reasonable justification that all these factors are effectively considered, this ratio should only be reduced to a minimum of 0.5.

3.1.3 External damage

A fixed external damage of $15,000 (in 2019 dollars) is to be used for each dwelling site and for each site that contains multi-unit dwellings. This is used when flood depths above the ground level adjacent to the building are at least 0.3 m or are above the habitable floor level of the house.

3.1.4 Relocation costs

Flooding of a dwelling or area can make a house unavailable for occupation and require relocation to another location. As the house cannot be occupied there is an opportunity cost related to loss of rent for this house while it can't be occupied. This is considered the cost of relocation.

Relocation costs are based on a NSW average household cost for renters of $430 per week (in 2019 dollars). More specific values can be used for the actual location where this is sourced and justified. Length of relocation can be derived from a combination of the time of inundation of the area (in weeks) and the times outlined in Table 14, which relate to depth of typical above floor flooding in the area.

Table 14 Estimated relocation period

Depth over floor (m)	Duration relocated (weeks)
0	0
0.05	5
0.15	10
0.25	11
0.45	14
0.8	17
>1	29

3.1.5 Clean-up costs

Clean-up costs are to be based on $4,000 per household (in 2019 dollars) where flooded above habitable floor level, including individual units in multi-unit sites that are flooded above floor level.

3.2 Non-residential buildings

Property-based flood damages for non-residential buildings have been derived for commercial and industrial buildings (see Section 3.2.1), and public buildings (see Section 3.2.2).

Table 15 gives a summary of the non-residential property-related damage costs that have been specifically attributed to individual properties and will influence derivation of damage curves for individual properties. The damage costs include loss of trading for commercial and industrial buildings and clean-up costs for commercial, industrial and public buildings.

They also include vehicle damages (see Section 3.4.4), which should only be used where they meet the requirements of Sections 3.4.1 and 3.4.4. These curves are used with information on individual non-residential properties' ground and floor levels and flood levels from a range of flood events as part of the derivation of overall flood damages. This is discussed further in Section 3.7.

Table 15 Property-related commercial, industrial and public building damage costs summary

Type/Element	Damage costs	Specific adjustments	Adjustment for time since 2019
Direct damages			
Commercial and industrial	Damage costs (Figure 5) for relevant value classifications (Table 16)	Floor area m^2	Consumer Price Index (Section 3.6.1)
Public facilities	Damage costs (Figure 5) for relevant value classifications (Table 17)	Floor area m^2	
Vehicles at work [1]	$3,750 per vehicle (Section 3.4.5)	Relates to minimum depth of flooding of 0.3 m above ground level in car park. Number of vehicles onsite per property needs to be reasonably estimated. This needs to consider vehicles kept onsite overnight and to assume average utilisation rates during business hours and days and adjust for opening days (e.g. by 5/7 for 5-day working week)_ and hours (by one-third for 8-hour opening or half for 12-hours opening)	
Indirect damages			
Loss of trading costs	20% of direct damage for commercial and industrial. No allowance for public buildings		
Clean-up costs	10% of direct damages for commercial, industrial, and public buildings		

Notes:

[1] Vehicle damages (Section 3.4.4) should only be used in studies under the program where they meet the requirements of their specific section and Section 3.4.1.

3.2.1 Commercial and industrial structure and content damages

Commercial and industrial property damages are highly variable, with the particular use and associated contents (rather than the structure) generally dominating the overall damage.

The general approach recommended for use is outlined below, however, where the additional investment is considered warranted, a more detailed approach (e.g. based on the specific businesses in different locations, noting that the business type using a site can vary over time) can be used. If this approach is being considered in studies funded under the program, it requires reasonable justification and agreement by flood staff from DPE Environment and Heritage Group.

Table 16 and Figure 5 support the general practical approach to the assessment of non-residential damages. These provide damage curves and examples for 3 different value classes. They can be used in several ways depending on the information available. Two possible options are:

- where information is available to classify the premises against the categories, the individual premises should be categorised accordingly based on low to medium and medium to high. Where it is unsure what category to use, the average category should be used. This is the preferred option
- where little or no information is available on use of commercial or industrial premises, the medium/default figures should be used for all assessments.

Table 16 Proposed commercial and industrial value classifications

Proposed classification	Adjustment to average value curve	Representative uses
Low to medium	60% of average	Restaurants, cafes, offices, doctor's surgeries, retail/food outlets, butchers, bakeries, newsagencies, service stations, hardware
Medium/default	100%	Proposed as a representative average, where the particular use is not known
Medium to high	150% of average	Chemists, electrical goods, clothing stores, bottle shops, electronics

Note: Derived from BMT WBM (2018).

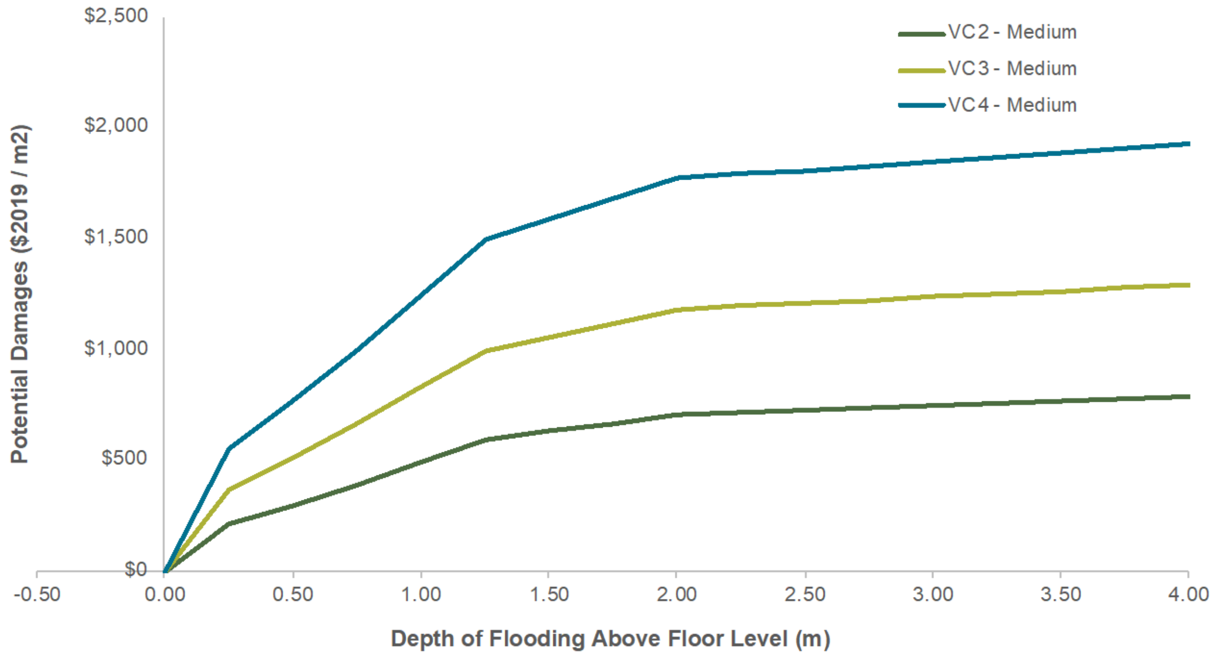


Figure 5 **Value class curves related to structure/industrial building**

Translating the per m² damages in Figure 5 to total damages for a specific commercial, industrial or public facility building needs to consider floor area. Three possible options for translating this information include:

- Where information is available or can readily be derived, the actual floor area of the building should be used. This is the preferred option.
- Where some information is available on the relative size of the building, then the figures for small to medium (186 m²) and medium to large (650 m²) can be used.
- Where no information is available regarding the size of the building, an average value of 418 m² can be used. This is the least preferred option.

3.2.2 Public buildings structural and contents damage

NSW Treasury (2023b) has provided curves to account for the damage value attributed to different types of public buildings. Detail is provided in Section 1.2.4 of the NSW Treasury Technical Note (2023b).

The proposed approach for use in the FRM tool DT01 is to classify public buildings into 3 categories which are schools, hospitals, and other buildings. The “other” category should be used as the default and includes the following uses:

- Health
  - aged care
  - nursing home
- Emergency services
  - police, fire, or ambulance stations
  - SES facilities
  - Emergency Management Facility
- Government buildings
  - courthouse
  - government administration (e.g. Medicare, Centrelink, local government offices)

– diplomatic facility
– consulate facility
– major defence facility
– correctional facility
– immigration detention facility.

3.3 General public infrastructure

Public infrastructure damage can vary substantially depending on its vulnerability and exposure to flooding. One method for estimating damages to public infrastructure is through an uplift factor, which assumes damages to public infrastructure can be directly correlated to the direct damages to residential properties.

In the absence of more detailed estimates, for damage to general public infrastructure such as roads, rail, lower power lines, etc., residential damages should be increased by 10%. This is based on research undertaken in the United Kingdom (UK), as summarised in Rhelm (2020). This would be appropriate for Level 1 and 2 studies (Table 3). More specific estimates may be required for more detailed studies, such as Level 3 (Table 3).

Damages for specific facilities are discussed in Section 3.4.3.

3.4 Other damage factors

There are also other factors that may need to be considered in estimating benefits/disbenefits of FRM measures and therefore warrant inclusion in damage calculations. These factors include structural integrity of residential buildings, social and wellbeing factors, vehicle damages, specific infrastructure facilities servicing the community, fatalities and injuries, travel time, agricultural damages, and environmental damages.

For residential properties the damages in relevant parts of this section, as discussed in Section 3.1 and shown in Table 12, should only be included where they meet the criteria of Section 3.4.1 and their individual sections.

For non-residential properties the inclusion of vehicle damages where considered warranted (as discussed in Sections 3.4.1 and 3.4.4) in damage assessments for individual properties is shown in Table 15.

Other damage factors should only be assessed where warranted, as discussed in Section 3.4.1 and Sections 3.4.5 to 3.4.7 respectively.

In addition, intangible damages estimates should typically only be included in large-scale projects, as discussed in Section 3.5.

All these factors should be added to the damage estimates separately, to the curves for individual residential and non-residential properties. Where these are used, adjustment may be required to account for the Consumer Price Index as discussed in Section 3.6.1.

Estimates of these other factors and the methodologies used in their estimation are likely to vary on a case-by-case basis and would generally be undertaken outside of FRM tool DT01 with proper documentation. However, provision has been made in FRM tool DT01 for these other damage factors to be summarised so they are incorporated into the overall assessment. The information page of the tool provides advice on how this can be done.

3.4.1 When to consider other damage factors

In general, other damage factors should only be considered in quantitative assessment where they are:

- likely to be substantially altered by the proposed FRM measures
- likely to be of a scale where they make a material difference to estimates and influence FRM decision-making
- able to be cost-effectively estimated in a fit-for-purpose way considering the size and scope of the study and the available information.

Other specific considerations that may influence the decision to incorporate these factors in the assessment may be identified in sections that relate to individual categories (Sections 3.4.2 to 3.4.7 and Sections 3.5.1 and 3.5.2).

Justification is needed and agreement sought from DPE Environment and Heritage Group where these factors are intended to be included in studies under the program. Where included, their contribution to damage and benefit estimates is clearly identified, by reporting these separate to estimates determined from Sections 3.1 to 3.3. They should be incorporated into damage assessments.

3.4.2 Structural integrity of residential buildings

The damage curves for residential structures incorporated in this report assume that dwellings will remain intact and will be generally structurally sound following the flood event.

Consideration can be given to substituting building structure damage with an uplift factor based on available literature (Rhelm 2021) if:

- the criteria outlined in Section 3.4.1 are met
- the flood is the defined flood event (DFE) or a more frequent event
- there are significantly more dwellings in H6 and H5 hazard category areas compared to lower hazard areas.

This may involve adding an additional damage multiplier value so the total structural damage index for the building (include depth-dependent structural damages, as discussed in Section 3.1.1) is equal to but not greater than 1.0 (potentially with some reduction for building age) with the suggested replacement cost rates from Table 13. Consideration should also be given to the inclusion of a separate allowance for removal and disposal of debris due to the destruction of the structure. They should be incorporated into reporting and damage assessments.

3.4.3 Specific infrastructure facilities servicing the community

The uplift factor added to residential development for general public infrastructure (see Section 3.3) does not allow for specific infrastructure facilities servicing the community (e.g. water and wastewater treatment plants).

If the criteria outlined in Section 3.4.1 are met, and these facilities are likely to be significantly damaged in the DFE or more frequent floods, consideration can be given to including them in damage estimates.

These will require specific estimates considering relevant industry advice. How this estimate is derived and its information sources needs to be identified and incorporated into reporting and damage assessment.

3.4.4 Vehicle damage

If the criteria outlined in Section 3.4.1 are met and if there is knowledge of floods of the scale of the DFE causing substantial damage to vehicles, inclusion of vehicle damage in estimates may be relevant. However, this decision should also consider the:

- nature of the flooding. Rapid onset flooding provides less time to respond and evacuate and move cars to less affected locations
- possibility that isolation of the area may occur before evacuation is possible
- threshold of depth, or velocity by depth (VxD) that is likely to result in inundation or movement of vehicles due to flotation outlined in FRM guideline FB03 and its related background report.

Where vehicle damage is to be included, it should be estimated based on the following advice unless agreed otherwise. The average cost of a written-off vehicle as a result of flood damage is $3,750 (in 2019 dollars, allowing for depreciation, average age of a vehicle and the typical price of a new car). This equates to is $5,700 per household assuming 1.51 vehicles per household (Rhelm 2021). This figure may be used, where relevant, for residential properties.

For non-residential properties it is reasonable to assume average utilisation rates during business hours and to adjust for non-business hours and days, considering vehicles that remain on premises overnight as outlined in Table 15.

3.4.5 Travel time on major transport routes

If the criteria outlined in Section 3.4.1 are met and where traffic flow on major transport routes may benefit substantially from flood mitigation works, the value of travel time can be considered for inclusion. However, care needs to be taken to consider whether benefits are actually likely to accrue or whether flooding at another location on the route will negate any benefits.

Examples of where major transport routes may benefit include a levee or detention basin upstream that reduces the overtopping time of roads and therefore the waiting time for traffic, or the raising of a road used as an evacuation route.

Table 17 displays the value of travel time per vehicle hours of travel (VHT) (Transport for NSW 2019). These values are conservative as they do not include operating costs associated with rerouting or alternative longer routes.

More detailed studies (e.g. Level 3) may consider more detailed assessment, such as the use of traffic models, to understand the impact of flooding on the transport network.

Table 17 Value of travel time ($/vehicle/hr)

Road type	Light vehicle on road	Heavy vehicle on road	Travel time cost ($/vehicle/hour)
Urban	94%	6%	$31.48
Rural	89%	11%	$37.41

3.4.6 Agricultural damages and values

If the criteria outlined in Section 3.4.1 are met, agricultural damages may be considered.

Agricultural damages may relate to the impact on the incomes and expenditures of individual farm businesses, including extra unpaid family labour required. They may also relate to impacts on the local and national economy as a whole, including indirect effects, such as impacts on businesses beyond the flood area, and on non-market goods, such as wildlife and the natural environment. Agricultural values may relate to or overlap with environmental values, therefore, some of the resources mentioned in Section 3.4.7 may aid in estimation of agricultural values.

NSW Treasury (2023b) also provides data on the annual value of agricultural commodities in dollars per hectare and the land share of each commodity type across New South Wales. This information may be useful for particular assessments, however, should be used with care due to the uncertainty of annual crop cycles and their coincidence with flood events.

3.4.7 Environmental damages and values

If the criteria outlined in Section 3.4.1 are met, environmental damages or changes in environmental values due to FRM measures may warrant consideration.

In most cases, environmental controls and regulations will restrict impacts on high value environmental assets. These need to be considered where relevant in the detailed design phase and any environmental impact assessment of an FRM measure. Therefore, assessment during an FRM study is not generally warranted. Assessment, where needed, would generally be considered as part of the early stage of implementation, where feasibility is assessed further.

A potential scenario where environmental values might be considered is where a flood mitigation option may enhance environmental values, or where additional funds could be invested in the flood mitigation options to enhance environmental values. In the latter scenario, it may be difficult to justify the additional investment if environmental values are not considered.

There are a number of references available that provide some indicative values for different types of environmental assets. These can vary, and there may be specific values associated with different types of assets. Therefore, it is difficult to provide easy rapid assessment techniques for these types of economic values. Some references that attempt to quantify environmental values include:

- Guidelines for using cost–benefit analysis to assess coastal management options (Department of Planning and Environment 2020)
- Transport for NSW cost–benefit analysis guide (Transport for NSW 2019)
- UK guidance: Flood and coastal erosion risk management: a manual for economic appraisal (Penning-Rowsell et al. 2013)
- UK guidance: *Flood and coastal erosion risk management*: economic valuation of environmental effects, Handbook for the Environment Agency for England and Wales (eftec 2010)
- UK guidance: Environmental value look-up (EVL) tool (eftec 2015)
- Canadian guidance: *Environmental Valuation Reference Inventory* (Environment and Climate Change Canada n.d.)
- New Zealand guidance: Quantification of the flood and erosion reduction benefits, and costs, of climate change mitigation measures in New Zealand (Blaschke et al. 2008)
- The Netherlands: Update of global ecosystem service valuation database (de Groot et al. 2020).

3.5 Intangible damages

Intangible damages incorporate impacts to individuals and the overall community that typically do not have a market or dollar value. Examples are stress and anxiety (post-traumatic stress disorder), psychological impacts, living disruptions and loss of community. There are a variety of economic methods that can be used to estimate the monetary value of some of these impacts, such as willingness to pay methodologies, however, these are typically only undertaken in very large projects. In other cases, these methods are used to derive reference values that can be adapted for wider use. Due to the nature of intangible damages, it is difficult to estimate them to a high degree of accuracy.

Some studies have adopted uplift factors ranging anywhere from a 60% increase on direct damages to 120% of direct damage, however, these uplift factors can be limited by studies that have focused on the outcomes of large and extreme events, which can skew the intangible damage impacts.

Incorporating such large uplift factors, based on relatively uncertain information, is generally not appropriate in the estimating of damages, particularly where these will be used for a cost–benefit analysis. Therefore, it is recommended that more specific estimates are made for intangibles where these are considered important to include.

Two potential methods have been explored in this section:

- fatalities and injuries including risk to life – estimates of risk to life where it is a key purpose of the FRM measure and would be useful to incorporate
- social impacts – an approximate method for estimation of social and wellbeing impacts, related to over floor flooding, is proposed. This typically results in a lower estimate than the uplift factors mentioned above, and is therefore considered conservative.

These estimates are unlikely to encompass the full range of intangibles, and are therefore likely to represent a low-bound estimate.

It may be appropriate for more detailed studies (e.g. Level 3) to undertake additional studies and surveys into intangible values in a floodplain, where these are likely to be a significant portion of the damages and likely to be altered by FRM measures.

3.5.1 Fatalities and injuries

If the criteria outlined in Section 3.4.1 are met, consideration could be given to inclusion of the value of the loss of human life during flood events. This requires 2 key components:

- an estimated value of a statistical life (VSL), representing the economic value of a typical person
- an estimate of the likely loss of life in a floodplain in any given flood event.

There are a range of methods that can be used to estimate fatalities as outlined in Smith and Rahman (2016).

The work provided in this section is preliminary and is included to allow for testing on projects where it is considered relevant. Alternative methods can be applied in the context of the flood situation and the mitigation options being proposed.

In general, a risk to life estimate should only be considered for flood projects that would potentially have such a benefit. These may be projects that allow for an increased warning time, such as a flood warning system or projects that provide more time for community response such as a road raising project to allow for timely evacuation as described in Section 4.3.3.

Value of a statistical life

Transport for NSW (2019) provides a detailed review of the available literature for VSL, and based on this review it adopted willingness to pay values for casualties for transport-related accidents. These are summarised in Table 18 and recommended for all Transport for NSW assessments. These have been adopted in the absence of more detailed assessments in the flood sector.

In the estimation of the value of injuries, using the moderate value is recommended in the absence of more detailed information.

Table 18 Cost (value of statistical life) per casualty

Scale of injury	Value of statistical life (2019 dollars)
Fatality	$7,752,786
Serious injury (requiring hospitalisation)	$495,874
Moderate (emergency department) or minor injury	$77,472

Source: Transport for NSW (2019).

Probability of loss of life

Empirical methods and agent-based modelling (which uses more deterministic, often semi-empirical methods) have both been used to estimate probability of risk of life relating to natural hazards. Empirical models are often derived for specific purposes and their application to a specific flood situation can give widely varying results (as discussed by Smith and Rahman [2016]). Agent-based modelling can be costly and difficult to apply and may only be relevant in very large-scale projects where improvements to community evacuation are key objectives.

An empirical approach to estimating the potential loss of life (PLL) is to adapt the UK DEFRA/Wallingford method (Equation 1 below) for information typically derived for studies in New South Wales. Parameters used in Equation 1 are provided in Table 19.

The key advantage of this method over some other methods is the ability to estimate the potential reduction in risk to life associated with changes to flood behaviour (such as flood hazard).

Initial assessment from Smith and Rahman (2016) suggested that this method may underestimate the risk to life, and therefore may provide a conservative estimate.

This method is intended to estimate the potential risk to life and injury across an overall floodplain. While the population at risk can be estimated based on the number of residential properties, it should not be used to estimate the risk to life at the property scale.

This methodology should only be used in studies under the program with agreement from and in consultation with FRM staff in DPE Environment and Heritage Group.

Equation 1 Forecasting the number of injuries and fatalities for a flood event

$$Injuries\ N(I) = 2 \cdot N_z \times \frac{HR \cdot AV}{100} \cdot PV$$

$$Fatalities = 2 \cdot N(I) \times \frac{HR}{100}$$

Table 19 Parameters used in Equation 1

<table>
<tr><th>Parameter</th><th colspan="5">Description/estimation</th></tr>
<tr><td>N_z</td><td colspan="5">Population at risk. This can be based on the number of residential properties in the different hazard categories</td></tr>
<tr><td>HR</td><td colspan="5">Hazard rating based on FRM guideline FB03. This varies from:
0 for H1–H2
0.3 for H3
0.8 for H4
2.8 for H5
4 for H6
These figures are derived from $\text{Hazard Rating [HR]} = \mathrm{d} \times (\mathrm{v} + 0.5)$ in the UK DEFRA/Wallingford method.</td></tr>
<tr><td rowspan="7">AV</td><td colspan="5">Area vulnerability = speed of onset + nature of area + flood warning factor</td></tr>
<tr><td colspan="5">Speed of onset:
1 for very gradual – many hours
2 for gradual – an hour or so
3 for rapid flooding – less than 1 hour</td></tr>
<tr><td colspan="5">Nature of area:
1 for multistorey apartments
2 for detached residential dwellings, commercial and industrial properties
3 for caravan parks, schools, campsites</td></tr>
<tr><td rowspan="4">Flood warning factor =3–(P1x(P2+P3))</td><td>Parameter</td><td>0</td><td>0.5</td><td>1</td></tr>
<tr><td>P1</td><td>No effective warning system</td><td>Warning system in place, will reach 40% of flood affected population</td><td>Warning system in place, will reach 80% of flood affected population</td></tr>
<tr><td>P2</td><td>0–2-hour warning time</td><td></td><td>>2 hours warning</td></tr>
<tr><td>P3</td><td>No education program or understanding of flood warnings</td><td></td><td>Well-educated community on flood warnings and actions to take</td></tr>
<tr><td>PV</td><td colspan="5">People vulnerability = % people with a disability plus % aged 75+ from the Australian Bureau of Statistics (ABS) (average for area)</td></tr>
</table>

3.5.2 Social and wellbeing impacts

If the criteria outlined in Section 3.4.1 are met, consideration can be given to including additional factors for social and wellbeing impacts based on frequency of above floor flooding (see Table 20) and mental health costs (NSW Treasury 2023b). The figures in Table 20 are based on research in the UK (DEFRA 2004) into intangible damages from flood events. This involved national surveys to recently flooded and 'at-risk' properties, and focused on the intangible health impacts following the flood event. The information from this research was converted into Australian dollar equivalents and converted to an estimated willingness to pay to avoid over floor flooding.

Table 20 Approximate intangible indirect social and wellbeing damages

Event probability (AEP)	Cost per household per year
0.5%	$0
1%	$49
2%	$391
5% or more	$555

Note: Based on DEFRA (2004), with threshold event based on where over floor flooding occurs. Uses 2019 $AUD values.

Supplementary to the social and wellbeing costs are costs directly attributable to mental health. NSW Treasury (2023b) outlines the costs of depression, anxiety, and post-traumatic stress disorder, correlated to the depth of over floor flooding.

3.6 Adjustment factors

3.6.1 Price adjustments relative to base information

It is recommended that damages be inflated by the Consumer Price Index. Information on changes in the Consumer Price Index over time can be found on the Australian Bureau of Statistics (ABS) *Consumer Price Index, Australia* webpage.

3.6.2 Regional cost variation

Regional cost variations are differences in costs that are experienced in different regions of the state. For example, costs to construct a home in Broken Hill may differ from those to construct the same home in Western Sydney. This may be reflective of available tradespeople, supplies of materials, cost of transport, etc.

The estimates of residential building replacement costs included in this guideline are more representative of major urban centres, therefore, their application to regional areas may require an adjustment. To provide some broad guidance, a review was undertaken on uplift factors, such as those presented in Rawlinsons (2019). Figure 6 was developed from this review of information, which splits New South Wales into 3 land divisions and informs the basis for recommended adjustments included in Table 21.

These figures can be used where more specific values are not obtained from relevant cost estimate references such as Rawlinsons. Alternatively, Section 3 of NSW Treasury (2023b) provides information on building costs (in 2022 dollars) across each LGA in New South Wales. These values were derived from the National Exposure Information System (NEXIS) dataset (Geoscience Australia 2022) and are incorporated into the FRM tool DT01. These values enable the practitioner to substitute the default values for building replacement costs per m^2 with LGA-specific values in the tool.

Table 21 Regional cost adjustment factor variation with location

Regional cost adjustment factor	Location
0%	Sydney metropolitan, as well as the area bounded by Newcastle in the north, the Blue Mountains in the west and Canberra/Ulladulla in the south Albury and Wagga Wagga
Add 5%	Eastern Land Division north of Newcastle
Add 10%	Eastern Land Division south of Canberra/Ulladulla Central Land Division, excluding Albury and Wagga Wagga
Add 20%	Western Land Division

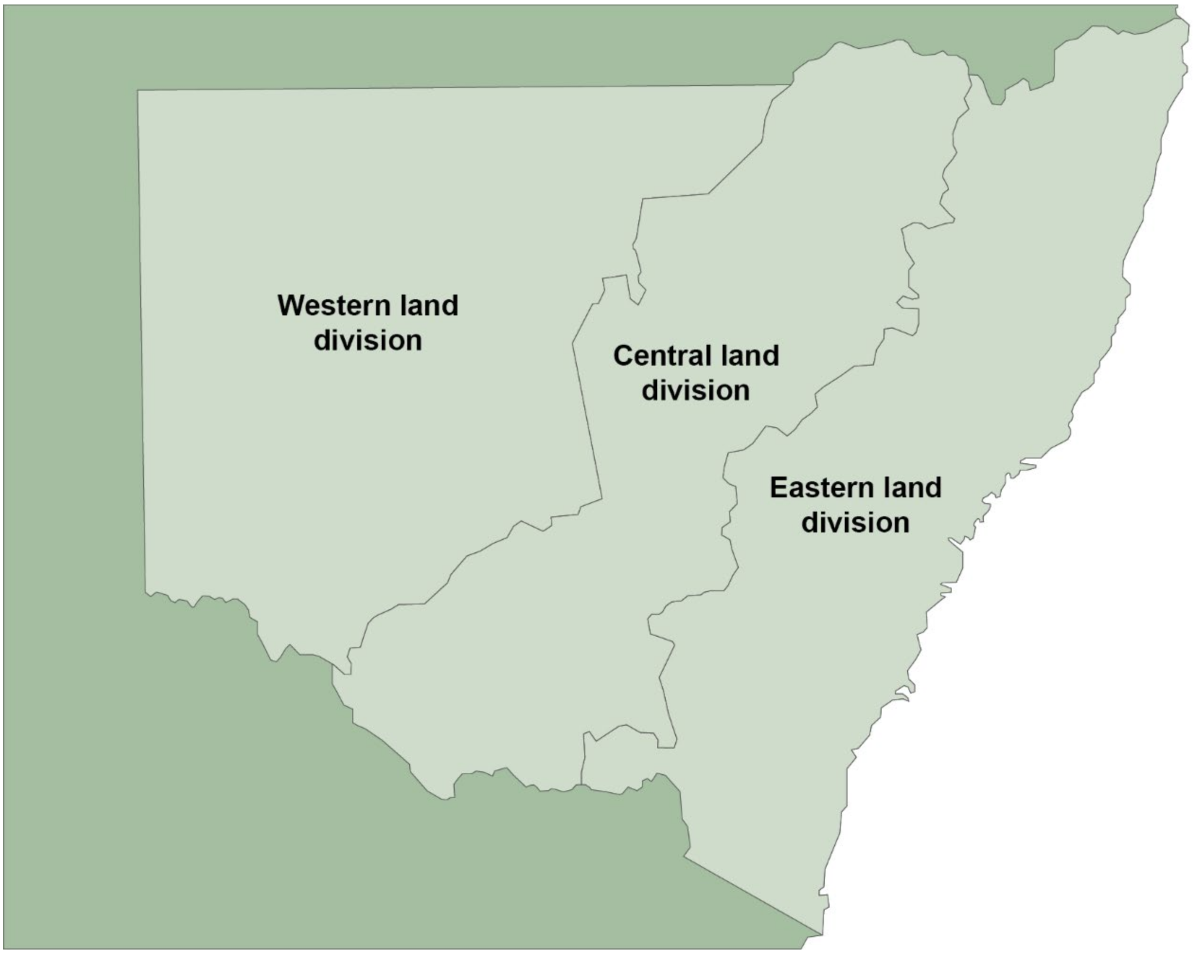


Figure 6 NSW land divisions

3.7 Estimating flood damages

Property-related costs for residential and non-residential properties are discussed in Sections 3.1 and 3.2 and summarised in Table 12 and Table 15, respectively. These can be used in combination with information on the portfolio of properties (see Table 22) and on flood behaviour (see Table 23), and other specific flood damage information (considering relevant sections of Sections 3.4 and 3.5) where warranted, to understand overall damages for different flood events. FRM tool DT01 will facilitate the derivation of property and flood information in the correct format.

Reporting should include a summary table of the factors that have been selected and used in the derivation of flood damage estimates.

Flood damage estimates are derived for different AEP flood events for different cases including the base case (for both existing and relevant future scenarios) and cases with management measures or packages of measures implemented (for both the existing and future climate).

The flood damage estimates for each AEP for each different case can be plotted on an AAD curve. The area under the curve is the flood damage for the case. The difference between the area under the curve for 2 different cases – for example, the base case and with an FRM option implemented (for both the existing and future scenario) – identifies the benefit of the option in terms of reduced flood damages and how this may change into the future. Therefore, it is important the shape of the curve reasonably represents damages and in particular the change in damages between events, and can reasonably represent the change in damage that occurs with implementation of an FRM option.

Several important aspects to support the development of the AAD curve include:

- the selection of the event in which zero damages is assumed to occur for the purposes of the assessment. This event should be a reasonable approximation of the event in which zero damage is expected to occur considering the factors incorporated in the flood damage assessment
- assessing damages for the full range of events examined
- having events on either side of tipping points where flood damages change substantially, so the change in damage can be effectively captured

> Example: For an existing FRM measure providing protection for a 5% AEP flood, which can be considered a tipping point for changes in damages. Damages should be assessed for at least that event, the 10% AEP flood, and either or both of the 2% and 1% AEP and extreme floods. This provides an understanding of the growth in damages up to the tipping point, the change at the tipping point, and the growth in damages beyond the tipping point.

- having events that effectively capture the change due to a mitigation work.

> Example: Continuing the example above, where the FRM option being developed is to upgrade the existing FRM measure to provide protection for a 1% AEP flood, damages for both the base and FRM implemented option cases should be assessed for at least that event, the 10%, 5% and 2% flood, and either or both of the 0.5% and 0.2% AEP floods and an extreme flood. This provides an understanding of the changes to the damage curve considering the implementation of the work and its impacts on the tipping point.

Table 22 **Information on land parcels**

Information	Residential	Non-residential
Sub-type	Detached dwelling, townhouse or multi-unit (including number of ground flood units per site), and number of storeys	Commercial, industrial or public infrastructure, then relevant value class and number of storeys
Location, lowest habitable floor, ground levels	x, y, z coordinates and ground floor, and estimated subsequent floor levels	x, y, z coordinates and ground floor, and estimated subsequent floor levels
Area of building total	Average dwelling square metres or relative size	Building square metres
Construction type	Slab on ground or timber bearers and joists, brick veneer or timber construction	

Table 23 **Information from flood scenario runs – flood levels and hazard category**

Flood scenario runs	Existing climate	Future climate
Flood events	Range of floods – above ground in property starts flooding to extreme event, generally the probable maximum flood (PMF)	
Existing floodplain conditions	Base case	Base case with relevant future scenario (see FRM guideline FB01)
Changed floodplain conditions with FRM measures in place	Changed case	Changed case with relevant future scenario (see FRM guideline FB01)

As NPV assessment (discussed below) is significantly influenced by the frequency of events it is important to derive an understanding of where damages to the community are low or negligible. This ensures NPVs of damages are not over or underestimated. Damages may also be broken down into specific areas of the floodplain to enable consideration of whether localised or broadscale FRM measures may be warranted.

Flood damage estimates should identify the contribution to total flood damages of different factors outlined in Table 12 and Table 15, as well as any additional factors added from Sections 3.4 and 3.5.

Table 24, Table 25 and Table 26 provide an example of how this can be shown in reporting.

The sensitivity of key factors should be tested to understand their influence on the overall assessment. Default sensitivities based on +/–10% change should be used on agreed or specified factors.

Having information across a wide range of events and for different scenarios enables the derivation of AADs and NPV of damages. These can be used to understand how damages can change with different FRM measures in place and how the benefits of FRM measures in reducing flood damages may change over time considering future scenarios. It may highlight limitations of FRM measures as the climate changes and the need to consider how these can adapt in the future to maintain community benefits.

McLuckie et al. (2019, ‘Chapter 5: Risk based design’) in Book 1 of *Australian rainfall and runoff* (Ball et al. 2019) includes advice on estimates of:

- AADs and NPV of damages for the base case and for management options
- annual average benefits (AABs) and the NPV of benefits based on the reduction of damages and costs due to the implementation of an FRM measure or series of FRM measures.

Table 24 Example of residential damage disbenefits and costs summary for base case

AEP event or PMF	Residential		Total damages	Damage/cost components						
	No. of properties flooded above ground	No. of properties flooded above floor	AAD contribution	Structural	Contents	External	Relocation	Clean-up	Social and wellbeing	Vehicles at home
Total area – base case										
PMF										
0.5%										
1%										
2%										
5%										
10%										
Total AAD										

Table 25 Example of commercial/industrial and public buildings damage disbenefits and costs summary for base case

AEP event or PMF	Commercial			Total damages	Damage/cost components			
	No. of properties flooded above ground	No. of properties flooded above floor	Total floor area flooded	AAD contribution	Structure & contents	Loss of trading (industrial/ commercial only)	Clean-up	Vehicles at work
Total area – base case								
PMF								
0.5%								
1%								
2%								
5%								
10%								
Total AAD								

Table 26 Example of other disbenefits and costs summary for base case

AEP event or PMF	Base information		Total damages	Damages/costs					
	No. of fatalities	No. of injuries	AAD contribution	Fatalities	Injuries	Specific facilities	Agricultural	Environmental	Travel time
Base case									
PMF									
0.5%									
1%									
2%									
5%									
10%									
Total AAD									

4. Management measures

Management of flood risk is discussed in more detail in FRM guideline FB01.

Management of flood risks to the community can involve a combination of prevention, preparedness, response and recovery activities (PPRR) activities as shown in Figure 1. The relevance of these measures to individual communities and locations will vary as discussed in Section 3.

This section outlines a range of typical FRM measures that are available to support the management of the flood risk to an existing and future community.

Table 27 provides advice on the types of risk different types of FRM measures generally influence and the section of the guideline where further advice on different FRM measures is available.

Table 27 Examples of management measures to deal with various risks

Type of risk addressed	Management measures
Risk to existing development in communities (Section 4.2)	Improving the availability of flood information (Section 4.1) Permanent levee system (Section 4.2.1) Temporary barriers (Section 4.2.2) Floodgates (Section 4.2.3) Improved flow conveyance (Section 4.2.4) Temporary water storage during a flood (flood mitigation dams and basins) (Section 4.2.5) Modifying or removing residential building structures (Section 4.2.6) Managing the waterway–ocean interface (Section 4.2.7)
Future risk due to new and modified development (Section 4.4)	Improving the availability of flood information (Section 4.1) Land-use zoning (Section 4.4.1) Development controls (Section 4.4.2) Flood impact and risk assessment (Section 4.4.2)
Continuing risk to the whole community (Section 4.3)	Improving the availability of flood information (Section 4.1) Flood prediction and warning (Section 4.3.1) Community-scale flood EM planning (Section 4.3.2) Evacuation route upgrade (Section 4.3.3) Community flood preparedness (Section 4.3.4) Capturing lessons learnt after a flood (Section 4.3.5) Encouraging the availability of flood insurance (Section 4.1.1)

In the remainder of this section, FRM measures are broken down into their general intent. Options are broken down into measures that are primarily aimed at:

- providing an understanding of flood risk so it can be considered in decision-making, as discussed in Section 4.1
- limiting risks to the existing community by reducing exposure or vulnerability to flooding, as identified in Table 27 and discussed in Section 4.2

- limiting continuing risks to the existing and future community, thus limiting the scale of residual risks, by supporting flood warning and emergency response. These are outlined in Table 28 and discussed in Section 4.3
- limiting risks related to, and due to, new and modified development in the floodplain. These are outlined in Table 31 and discussed in Section 4.4
- environmental enhancement. Section 4.5 discusses options such as catchment management or nature-based solutions and integrated water cycle management measures, such as water-sensitive urban design (WSUD).

Table 28 provides advice on the relative effectiveness of different FRM measures in addressing risk to the existing and future community. This table considers the limitations of a wide range of measures relative to their design flood (for FRM measures such as levees) and the DFE (relevant for minimum requirements for new development).

Table 28 Typical ability of management measures to address flood risks

Report section	Option type	Existing community			Future community (development)		
		Risks of events up to the design flood for FRM works or the DFE for development		Risks of events rarer than the design flood for FRM works or the DFE for development	Risks to new development of events up to the DFE used for development controls		Risks of events rarer than the DFE used for development controls
		Safety	Damage	Safety	Safety	Damage	Safety
4.1	Flood information	Medium[1]	Low[1]	Low[1]	High[2]	High[2]	Medium[1,2]
Flood modification measures							
4.2.1	Levees	High	High	Negative[3]	High	High	Negative[3]
4.2.4	Bypass flow conveyance	Medium	Medium		Medium	Medium	
4.2.4	Hydraulic channel improvements	Medium	Medium		Medium	Medium	
4.2.5	Detention/retarding basins	Medium	Medium	Negative[2]	Medium	Medium	Negative[2]
4.2.5	Flood control dams	Medium	Medium		Medium	Medium	
4.2.7	Water entrance to ocean management	Medium	Medium	Low	Medium	Medium	Low
Property modification measures							
4.2.6	Voluntary house purchase and rezoning to limit use	High	High	High			
4.2.6	Voluntary house raising	Low	Medium	Negative[4]			
4.2.6	Relocation and rezoning	High	High	High			
4.2.6	Flood-proofing of buildings	Low	Low				
	Access from within site to external roads	Medium[1]		Medium[1]	Medium[1]		Medium[1]

Report section	Option type	Existing community			Future community (development)		
		Risks of events up to the design flood for FRM works or the DFE for development		Risks of events rarer than the design flood for FRM works or the DFE for development	Risks to new development of events up to the DFE used for development controls		Risks of events rarer than the DFE used for development controls
		Safety	Damage	Safety	Safety	Damage	Safety
4.4.1 to 4.4.2	Zoning and development control following strategic planning considering the full range of flood risks				High[2]	High[2]	High[2]
Response and recovery modification measures							
4.3.1	Flood predictions and warnings[1]	Medium[1]	Low[1]	Medium[1]	Medium[1]	Low[1]	Medium[1]
4.3.2	Emergency response planning for floods[1]	Medium[1]		High[1]	Medium[1]		High[1]
4.3.3	Evacuation route upgrade	High		High	High		High
4.3.4	Community flood awareness and readiness[1]	Low[1]	Low[1]	Low[1]		Low[1]	Low[1]
Environmental enhancement							
4.5.1	Catchment management or nature-based solutions	Very low[5,6]	Very low[5,6]		Very low[5,6]	Very low[5,6]	
4.5.2	Water-sensitive urban design		Very low[5,6]			Very low[5,6]	

Notes: The ratings in this table are a guide only. Effectiveness will vary with individual situations and should be assessed accordingly.

Blank squares/cells are either not applicable or options have nil effect.

High/Medium/Low relates to positive effects. Negative relates to potential adverse impacts.

1. These options all generally rely on each other to be effective.

2. These options all generally rely on each other to be effective.

3. Experience has shown that levees can result in the community being more complacent in response to a flood threat.

4. Voluntary house raising may result in occupiers making delayed evacuation decisions, which may reduce their safety.

5. These measures typically only deal with short duration, more frequent events and will have very limited benefit for the rarer events of importance in flood risk management.

6. The reliability of environmental enhancements as FRM measures is likely to vary substantially across their lifecycle. Variability in reliability needs to be factored into assessments of benefits and associated decisions. They are more likely to influence flooding in more frequent flood events. In addition, if poorly located they can have negative impacts on flood behaviour.

4.1 Flood information

Flood information is essential to understanding flooding. Flood risk to existing communities can, in some part, be traced back to a lack of understanding and consideration of the full range of potential flooding, the scale of its potential consequences of flooding on the community and the associated risks in developing communities.

Having good quality flood information that is readily available enables flooding to be more effectively considered in decisions both inside and outside of government. This can lead to more informed and better outcomes for communities.

Flood information may come from observations of historic events, such as historic rainfall and water level data, or studies into flood behaviour.

Flood studies and FRM studies and plans can inform or make recommendations for changes to current FRM, EM and land-use planning practices and individual decisions. It can also influence the availability and pricing of flood insurance, though pricing of insurance depends on the business practices of the insurer. These different uses may require different information, which should be considered in scoping studies.

Support for emergency management planning FRM guideline EM01 and FRM guideline FB01 provide advice on the general flood information needs of EM planning and land-use planning, respectively.

4.1.1 Improving flood information

The quality or extent of flood information can vary with location, the scope of the study and can also vary depending on when studies were undertaken.

As such, existing flood information can have limitations that limit its effectiveness in managing risk. Limitations can include:

- gaps in information to support management of communities. This is generally urban areas that are not covered by studies
- incomplete information that may not provide sufficient information for decision-making. It may not include or consider information on recent significant floods, cover the full range of flood behaviour, or changes in development or landform
- information that does not consider current knowledge on climate change or government or industry standards or practices.

Where limitations exist, a review of the value of updating information to support informed decisions should be considered. It is recommended that a review occur where there are known data limitations, after a significant flood event, when new information on climate change is available, and to consider any changes to government and industry standards.

A review may lead to the need to remodel flood behaviour and update information to support improved management. However, this will not always be the case. For example, in an area where the full range of flood behaviour is known, and the flood range is relatively small, a minor change in climate change advice on the frequency and severity of flood-producing rainfall events may be able to be considered based on existing information, and may not result in any significant changes in management.

4.1.2 Improving availability of flood information

Active steps need to be taken to make flood information readily available across government and to key stakeholders and the community.

The NSW Flood Data Portal and related projects in the NSW Flood Data Access Program, support the secure storage of flood project materials, the searchability and sharing of information under appropriate arrangements, and the public availability of key project outputs, including reports and key spatial and non-spatial information.

Flood projects completed with financial assistance from the program require:

- licensing of key project outputs to allow for public access and use
- licensing that allows the management of access to project tools (such as hydrological and hydraulic models) by the owner of the tools, generally councils. Project tools are developed as fit for purpose for specific projects. Further, these tools are not static and may be updated over time in consideration of changing catchment and floodplain conditions. As such, the owners of these tools may wish to control access to them so updates and usage is managed in a way that is efficient and fit for purpose. This access may come with specific requirements including provision of reports, updated tools and information from the use of the tool for projects back to council, and may involve some handling costs
- the upload of all project materials to the NSW Flood Data Portal for safe and secure storage. This enables flood information specific to end users to be easily identifiable and, where appropriate, accessible. The NSW Flood Data Portal has guidance on how flood information should be described and stored on the portal
- reports and key project outputs to be made readily publicly available. Councils should make them publicly available by placing them on their website or making them available through the NSW Flood Data Portal and providing a link to them on their website.

Where studies for councils are being undertaken following the FRM process but outside of funding under the program, councils are encouraged to use similar arrangements to support data sharing.

Encouraging the availability of flood insurance

The availability of flood insurance to commercial, industry, farming, residential and government sectors is important to ensure the community, these sectors and individual companies or families within these sectors or communities can recover financially from a flood event.

Insurers use many sources of information to inform their decisions on providing and pricing insurance and therefore availability of information from flood studies is important.

Information from government studies can facilitate the availability of flood insurance. The better the flood information available to insurers on the full range of flooding and the vulnerability of land and structures to flooding, the lower the uncertainty of the frequency and consequences of flooding to properties.

Reducing uncertainty may give insurers more confidence in their understanding of risk and may enable them to price insurance accordingly. Making information available on the ground levels and habitable floor levels of structures relative to different likelihoods of flooding can also allow this information to be considered in flood insurance decisions.

4.2 Flood risk management measures for existing development

This section discusses FRM measures that primarily aim to reduce the risk of flooding to the existing community by reducing the likelihood or consequences of flooding. Table

29 identifies the upfront, ongoing and complementary work that typically needs to be done to implement these FRM measures.

Table 29 Typical considerations for management measures used for existing development

Option	Upfront work	Ongoing work	Complementary work
Permanent levees and related works (Section 4.2.1)	Analysis of impacts. Investigation, design and construction. Operation and maintenance manuals.	Maintenance, operation and upgrade. Regular monitoring of condition (including during and after floods) and rectification of issues. Regular trial and testing of operation.	Addressing impacts. Drainage of areas behind the levee may require upgrade, floodgates, detention and pumping. Interaction with flood warning, EM and community awareness. Management of development in the vicinity of the levee.
Temporary barriers (Section 4.2.2)	Analysis of impacts. Investigation, design and construction. Operation and maintenance manuals.	Maintenance and operation. Regular monitoring of condition and rectification of issues. Regular trial and testing of installation. Monitoring during floods.	Addressing potential impacts. Drainage from behind the structure which may require pumping. Access across the structure for evacuation/rescue. Interaction with flood warning, EM and community awareness.
Floodgates (Section 4.2.3)	Investigation, design and construction, and operation and maintenance manuals. Considering gate operation in non-flood periods for environmental reasons.	Maintenance and operation. Regular monitoring of condition and rectification of issues. Regular trial and testing of operation. Monitoring during floods.	Addressing potential impacts. Timely gate closure and ensuring closure occurs in automated systems. Community awareness.
Waterway modifications, e.g. altering flow conveyance (Section 4.2.4)	Investigation, design and construction considering environmental issue.	Ongoing monitoring, maintenance and rectification of issues.	Interaction with flood warning, EM, community awareness and environmental; management.
Temporary storage of water, e.g. basins and flood mitigation dams (Section 4.2.5)	Analysis of impacts. Investigation, design and construction. Operation and maintenance manuals. Dam safety requirements as relevant.	Maintenance and operation. Regular monitoring of condition and rectification for dam safety requirements. Regular trial and testing of operation.	Dam gate operation, where relevant. Interaction with flood warning, EM and community awareness. Downstream zonings and development controls to limit

Option	Upfront work	Ongoing work	Complementary work
		Monitoring during floods.	impacts on development.
Voluntary house raising (Section 4.2.6)	Investigation and justification. Understand limitations. Building application and approval.	Monitoring and enforcement to ensure no filling in below raised floor level. Notification of future purchasers.	System to ensure no infill development below raised floor levels. Notification to future purchasers of risk and limitations. Interaction with flood warning, EM and community awareness.
Flood-proofing (Section 4.2.6)	Investigation, justification and understanding of limitations and operation.	Operation and maintenance. Awareness of emergency managers.	Awareness of owner. Interaction with flood warning, EM and community awareness.
Voluntary house purchase (Section 4.2.6)	Investigation and justification. Remove existing development. Rezone for flood compatible purposes.	Ensure vacated land remains zoned for flood compatible purposes.	Ensure knowledge of purpose of zoning remains. Disposing of building materials appropriately.
Relocation of development & rezoning land (Section 4.2.6)	Investigation and justification. Remove or relocate existing development. Rezone for flood compatible purposes.	Ensure vacated land remains zoned for flood compatible purposes.	Availability of suitable areas and zoning that are compatible with risk. Appropriate development controls to manage flood risk.
Managing the waterway–ocean interface (Section 4.2.7)	Analysis of impacts, investigation and development of entrance management plan in consideration of ocean conditions, relevant approvals.	Monitor condition of the entrance. Maintain (approval) and implement entrance management plan as needed.	Interaction with EM and community awareness. Management of community expectations on limitations of the plan.

Note: Derived from Table 9.1 AIDR (2017).

4.2.1 Permanent levee systems

A permanent levee system is a common flood mitigation measure that aims to reduce the frequency of exposure of the protected community to flooding. It generally has a number of components that may include:

- the levee itself. This is typically an earthen embankment, a concrete retaining structure, or a combination of both. This separates the community from the flood impacts of the waterway in flood events up to the selected design flood
- local drainage systems through the levee to drain the catchment in the area it protects to the waterway

- backflow devices to prevent floodwaters entering the protected area through local drainage systems
- pumping systems with localised storage to facilitate discharge of water from the catchment protected by the levee into the waterway when the water levels in the waterway are higher than in the protected area. These may be permanent or temporary and more likely to be needed when flood levels in the waterway remain high for a number of days or weeks
- temporary components, such as gates or barriers, as part of permanent protection. These would be installed as part of the operation of the levee when a flood threat is expected. They are generally located where access needs to be maintained across the alignment of a levee (e.g. a roadway or bridge) when there is no flood threat, or where infrastructure cannot be designed to go over the levee (e.g. railway lines). They can sometimes be used to raise the existing level of protection provided by the permanent levee structure, where the permanent raising of the levee may not be viable and there is sufficient time, access, space, equipment and trained staff to be able to install these in the lead-up to a flood event.

Levee systems reduce the frequency of flooding from waterways and can significantly reduce damage in protected areas. They can also allow communities to function during long duration floods up to their design flood level, provided the structural integrity of the levee is not compromised and the community can be kept safe, or subsequently evacuated, where required.

The design crest level of a levee is different from its design flood level by a freeboard. Design floods and freeboard are discussed in FRM guideline FB01.

As levees overtop in floods rarer than their design floods, overtopping should be designed to occur in a controlled manner. This aims to ensure the resultant flooding can enter the protected area in a manner that limits the additional consequences to the community that can result from levee overtopping. This may involve the incorporation of purpose-built spillways with scour protection to promote controlled overtopping at a particular location (e.g. in the vicinity of vacant land) behind the levee with an identified overland flowpath or initial ponding area where it will result in the most manageable impacts on the community. EM planning needs to consider the potential variations in the manner and location of overtopping of the levee. This is particularly important where levee design does not facilitate controlled overtopping.

Key considerations

Levees require large capital investments to investigate, design and construct. There is also an ongoing asset management investment and resource commitment to monitor levee condition, operate and maintain the levee system, and undertake rectification works to enable a levee system to perform its intended function for its design life. Without this, the levee system may not be fit for purpose when a flood occurs, and the value of the initial capital investment will be significantly reduced.

Appropriate design (considering the environmental conditions it is exposed to) and effective ongoing maintenance and management that is adaptive to the changing condition of the levee can maximise its effective life by reducing any resultant loss of integrity. Loss of integrity can occur relatively quickly after construction if the levee is not effectively maintained.

Levee systems can have significant impacts on EM arrangements and how a community responds to a flood threat. As such any change to the levee system, including deterioration in condition, that significantly impacts on the level of protection provided or how the community needs to respond to a flood threat, needs to be clearly articulated to those responsible for EM planning.

To ensure levees are effectively understood and managed, it is recommended each levee system be included in the owner's asset management system; have sufficient resources allocated for monitoring, operation and maintenance; and have a levee owner's manual developed and maintained to:

- document the design details (where known) including components of the levee system, their purpose and design limitations and freeboard considerations
- outline monitoring including an inspection regime, maintenance and operational requirements
- outline where changes may influence EM planning and response
- indicate how changes to condition are communicated to relevant stakeholders.

The feasibility and effectiveness of a levee system will depend on a wide range of factors including:

- the lifecycle benefits and costs
- the ability of the owner to resource effective monitoring, maintenance and operation of the levee system
- impacts the levee is likely to have on flood behaviour (estimated or modelled) and how any impacts can be managed
- the safety of occupying the area behind the levee during a flood event, noting these areas can be without infrastructure services during a flood
- ongoing community education and awareness programs
- appropriate flood warning services.

4.2.2 Temporary barriers

Temporary barriers may be erected in response to an expectation of flooding. They may be relocatable systems, earthworks or sandbags and be used on a local property scale or to manage the impacts of flooding on a broader scale. Similar to permanent levees, temporary barriers may reduce the impacts of flooding to property in protected areas.

Key considerations

Temporary barriers may be appropriate for reducing the impacts of flooding of buildings as discussed in Section 4.2.6. Used in this way, they may stop or delay water intrusion into residential, commercial or industrial buildings, particularly where water is shallow.

In broader use, such as protecting an area of a town, they would have the same impacts on flood behaviour as permanent levee systems at the location and therefore need to consider similar issues (see Section 4.2.1), including their potential impact on flood behaviour, local drainage and EM planning. They are ideally used where hydraulic investigations have been completed into the impacts on flood behaviour of a barrier at the intended location and with consideration of broader FRM implications.

The suitability of temporary barriers as part of a permanent management approach will depend on the ability to have the system erected and operational before the flood arrives. This can limit their feasibility for flash flood environments where there is limited effective warning time.

Some of the key questions to be considered when examining or relying on such systems relate to operational logistics. These may include:

- Is the location appropriate considering its proximity to the riverbank and the potential for riverbank erosion or failure? Are the foundations adequate? Will water flow under the foundations?

- Where are the materials for the temporary barrier stored? Will they be secure? Will they be available when needed? Will the storage facility be accessible during a flood?
- Is there sufficient time (including a safety buffer) to erect the temporary barriers? This depends on the effective flood warning time available and whether materials are accessible and they can be collected, handled, transported and erected with the available resources within the available time.
- Who is responsible for storing, handling, transporting, erecting, packing up, maintaining and monitoring the temporary barriers?
- Are there sufficient and appropriately trained staff and equipment available to handle, transport and erect the system within the available time?
- Can the system be put up safely or will workers be put in dangerous situations?
- Once installed, will the systems be secure or are there safety issues that need to be considered and overcome?
- What are the ramifications to the community if they are not erected in time or the barrier fails? Is there an effective backup plan?
- How can emergency service personnel and equipment cross the barrier to perform evacuation, rescue or resupply operations where necessary?
- How can the town be accessed across the barrier during a flood? This may be important in long duration floods if people are still living in the floodplain outside the barrier and need to get to town for resupply and medical attention.

The use of temporary barriers independent of long-term strategies and beyond flood-proofing of buildings (see Section 4.2.6) should be carefully considered due to their potential impacts on flood behaviour. There may be situations or areas where suitably qualified technical staff consider that a temporary system will not adversely affect flood behaviour and therefore may be a viable short-term emergency option without the need for significant additional investigation. These include:

- to fill a gap in a partially constructed levee system
- along the agreed alignment of a proposed levee that has been investigated
- installation in inactive flow or backwater areas or other areas where it is considered by suitably qualified technical staff it will not adversely impact on flood behaviour.

4.2.3 Floodgates

Floodgates, non-return valves and other backflow prevention devices may be designed for a range of purposes and are often a key component of levee systems.

They may:

- allow drainage through levees but prevent backflow through the drainage system from rivers into protected areas during a flood
- allow for regular tidal inundation of areas behind structures but be closed during floods to reduce the flood impacts on protected areas. Where this is the case, arrangements need to be put in place and maintained to ensure that gates can be closed to perform their intended FRM function in the lead-up to and during flood events.
- allow limited flows into protected areas to facilitate environmental flows
- control flow discharge into a bypass flow system until design conditions are reached
- control minor discharges on spillways of major dams.

Floodgates may be operated manually or automatically. In either case, they require regular maintenance and operation as they can readily become stuck open or blocked closed when fouled by debris.

4.2.4 Waterway modifications

Depending on the intent of the project, modifications to waterways can lead to either increased or reduced waterway flow conveyance.

In either case, this can have both positive and negative impacts on flood behaviour and subsequently to the flood risk faced by the community. When examining the benefits or impacts of these measures the aspects raised in Table 5 need to be considered. The benefits of these measures are likely to be lower in the large to extreme flood events (of particular interest to FRM as risks to the community are greater) as significant flow in these events can occurs outside of waterways.

The effectiveness of these measures also depends on the characteristics of the channel and the floodplain. They are unlikely to have a significant effect in flood situations with extensive areas of overbank flow conveyance or where flood effects are dominated by downstream hydraulic controls, whether natural (such as restrictive gorges or tidal or oceanic influences) or constructed (such as dams, weirs, basins and waterway structures).

The fitness for purpose of any of these measures depends on the specific circumstances, and consideration needs to be given to their benefits and disbenefits to the community. It will also vary across the lifecycle of these measures. As such, these aspects need to be carefully considered in understanding the reliability of these measures when weighing up using them to manage flood risk to communities over the long term. Additional advice on waterway modifications that aim to reduce flow conveyance is provided in Section 4.5.1.

Waterway modifications to increase flow conveyance

Waterway modifications to increase channel flow conveyance can reduce peak flood levels upstream of locations where additional capacity is provided by widening, deepening or realigning the channel; clearing the channel banks and bed of obstructions to flow; or adding capacity in a bypass channel.

These changes can have a number of potential disadvantages, including:

- they can facilitate the transfer of flows more quickly downstream, which can accentuate downstream flooding problems. This can be exacerbated by stream straightening and lining, which increases flow velocity. Maintaining a natural stream length and appropriate riparian vegetation whilst providing additional channel capacity can reduce this impact
- the impacts of works on waterway bed and bank stability both upstream and downstream of the site. Careful design in consideration of the impacts can reduce this potential
- the destruction of riparian habitat. Appropriate design with reinstatement of riparian habitat may offset some impacts
- the visual impact of replacing naturally varying channel sections with sections of more uniform geometry but with similar vegetation. Careful design can reduce this impact.

Environmental benefits may accrue where exotic riparian vegetation can be replaced with native vegetation as part of the process of improvement works.

Where modifications to natural streams are proposed they:

- need to outline how any potential environmental impacts are managed
- address ESD principles
- identify whether options provide for environmental enhancement
- should be designed considering guidelines for the rehabilitation and restoration of streams.

The replacement of existing concrete-lined channels with channels and vegetation aimed to provide more natural flow regimes is encouraged given the added environmental and community benefits. Natural channels generally require wider cross-sections and more land as they are not as hydraulically efficient due to their increased length and roughness.

The use of concrete-lined channels to replace natural streams is particularly undesirable from an environmental perspective and should be avoided.

4.2.5 Temporary water storage during a flood

Temporary water storage can only influence flood risk to the community where flood-producing rainfall occurs upstream of storages. Benefits generally diminish the further you are downstream of the storage as they are able to influence flow from less of the catchment.

Dams and basins that provide for the temporary storage of water during floods can reduce downstream peak flood conditions. They can do this by being designed or operated to have 'air space' available to influence peak flood behaviour in events that cause significant impacts on the downstream community. These are discussed below.

Depending on the size of the dam or basin and resultant consequences of failure on downstream communities, a basin may be 'declared' by Dams Safety NSW. A dam owner must comply with dam safety legislation once a dam is declared by Dams Safety NSW. Even if a particular structure is not considered by Dams Safety NSW to be a basin/dam for declaration purposes, owners have a responsibility to the community to address the failure risks associated with their structure. An owner of such a structure (that endangers life through releasing its contents if it fails) could consider using the principles embodied in the dams safety legislation to manage failure risk.

Temporary storage devices, such as rainwater tanks and onsite detention systems, are only relevant to smaller catchments and more frequent stormwater flooding issues. They are generally only relevant for new development. These devices and their limitations are discussed in Section 4.5.2.

Dams

In addition to the limitations outlined above, dams, as temporary water storages, can only be relied on to influence flood risks to the community where they have, or can be reliably operated in all flood events to have, sufficient air space to influence the peak of flooding to a degree where it influences flood risks to the downstream community.

Many dams are built primarily for water supply purposes with the aim of providing security of supply over extended periods of drought. They are generally operated with the aim of keeping them as close to full supply level as possible whilst meeting managed water supply demands. This can conflict with the aim of a flood mitigation dam, which is to keep significant air space available to alter flood conditions to reduce downstream impacts on the community.

Water supply dams may have some mitigation effect due to their configuration (surface area and spillway capacity) but cannot necessarily be relied on to provide significant volume capacity to mitigate a flood threat, if this is not their design purpose. Some may also have operational protocols which enable them to influence discharge during a flood whilst still meeting their water resource aims. Where they have available air space below full supply level due to drawdown, multiple or long duration floods can fill the available capacity even where operations allow for managed pre-release of water considering predicted dam inflows.

Therefore, it is prudent to consider any major dams in the catchment in studies to understand their potential to reduce downstream flood flows due to routing of flows through the dam and considering inflows relative to the dam discharge rating curve.

The construction of a dam purely for flood mitigation purposes cannot often be economically justified, however, some dams are built with flood mitigation as either their primary purpose or as a component of their design function. These dams have a built-in storage volume or air space that is kept free for use during a flood. To complement this, they may have operating mechanisms and procedures that enable active discharge management with the aim of reducing peak downstream flood flows. Flexibility in operating arrangements can allow the management to respond to the varying nature of floods when they occur, as actual events can vary significantly from design events. In addition, after a flood the effective release of floodwater temporarily stored in the air space is needed to make air space for the next flood. This needs to be undertaken whilst managing downstream impacts on the community.

The viability of a dam for flood mitigation purposes is affected by its location relative to the area of interest. It is rare to find a suitable dam site that commands a significant number of tributaries or a large percentage of the catchment area, and it may be uneconomic or environmentally inappropriate to construct dams on all tributaries of a river system where this would be necessary to have a significant effect on flooding. Therefore, there is often a significant catchment area downstream of the dam, and tributaries that bypass a dam, thus reducing its effectiveness. Consequently, the benefits of flood mitigation dams are generally limited to mitigating the effects of a flood generated in only one portion of the catchment and for a limited area downstream.

Where storage dams are designed with some ability to mitigate flooding, they do this by absorbing some of the flood volume. This will usually have greater benefits for reducing the impact of minor or moderate floods, with the benefits diminishing as the scale of the flood increases. Dams with gated spillways have a greater potential to be operated to reduce the impacts of flooding on downstream areas.

Retarding and detention basins

Retarding or detention basins are small dams that are kept mainly empty to provide air space for the temporary storage for floodwaters. They are being increasingly used to reduce peak discharge from newly urbanised areas to predevelopment levels in their design event.

Basins are similar to flood mitigation dams but do not involve active operational arrangements (such as being able to regulate flow through discharge gate operation) and are generally on a much smaller scale and owned by local councils. Like levees, basins also require a significant investment in investigation, design and construction, along with ongoing asset management including inspections, maintenance and repairs for the life of the structure.

In urban areas, basins are most suitable for small streams that respond quickly to rapidly rising floods. They have inherent disadvantages that should be carefully considered. These include:

- the land take required
- the need for sufficient difference in upstream and downstream ground level to enable a reasonable depth of water to be detained whilst limiting upstream impacts
- their sensitivity to storm pattern which needs careful consideration in design
- safety considerations, for example, they may be located on land generally used for recreational purposes, presenting safety issues during floods.

In addition, basins may provide little attenuating effect in larger floods than the design flood, which results in overtopping (see Figure 7). Downstream flows can rise quickly, requiring careful consideration in downstream design, EM planning and community awareness. Consideration of these aspects can result in differences in design and configuration of downstream development. Figure 8 highlights the importance of considering this aspect.

The land set aside for basins may have other benefits. It may be able to be used for recreational purposes in non-flood times, where safety issues can be effectively addressed, and basins may also be able to be designed to have water quality benefits.

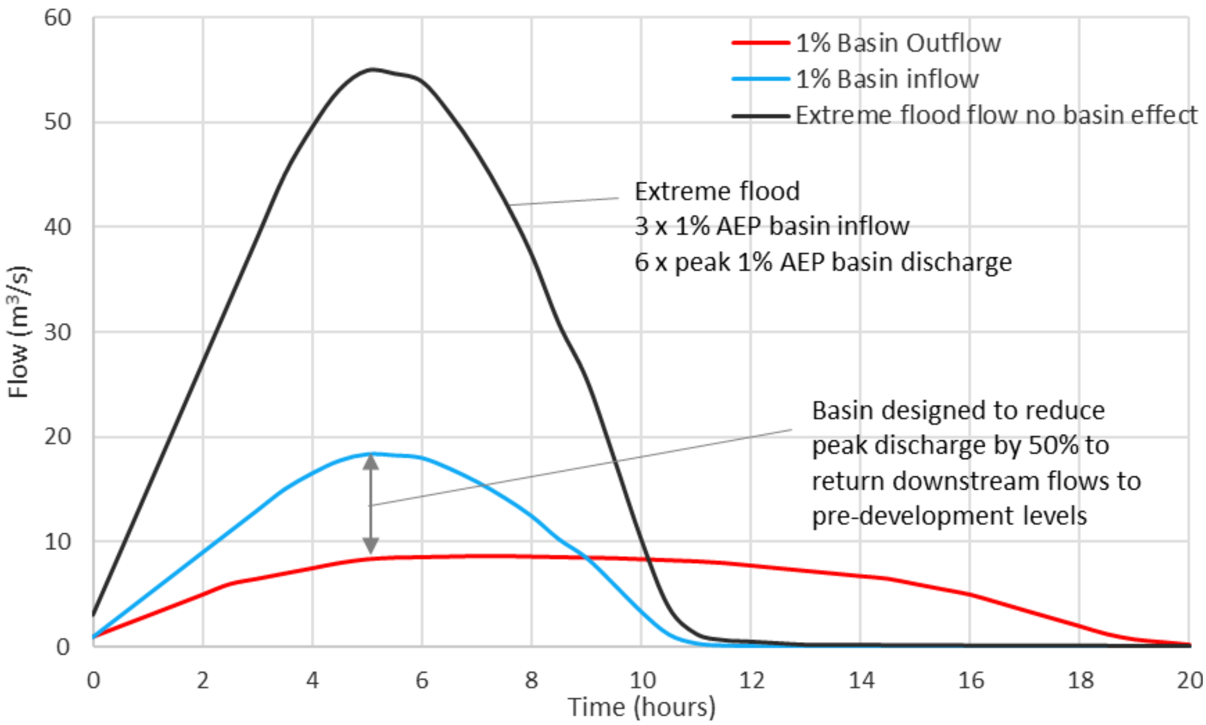
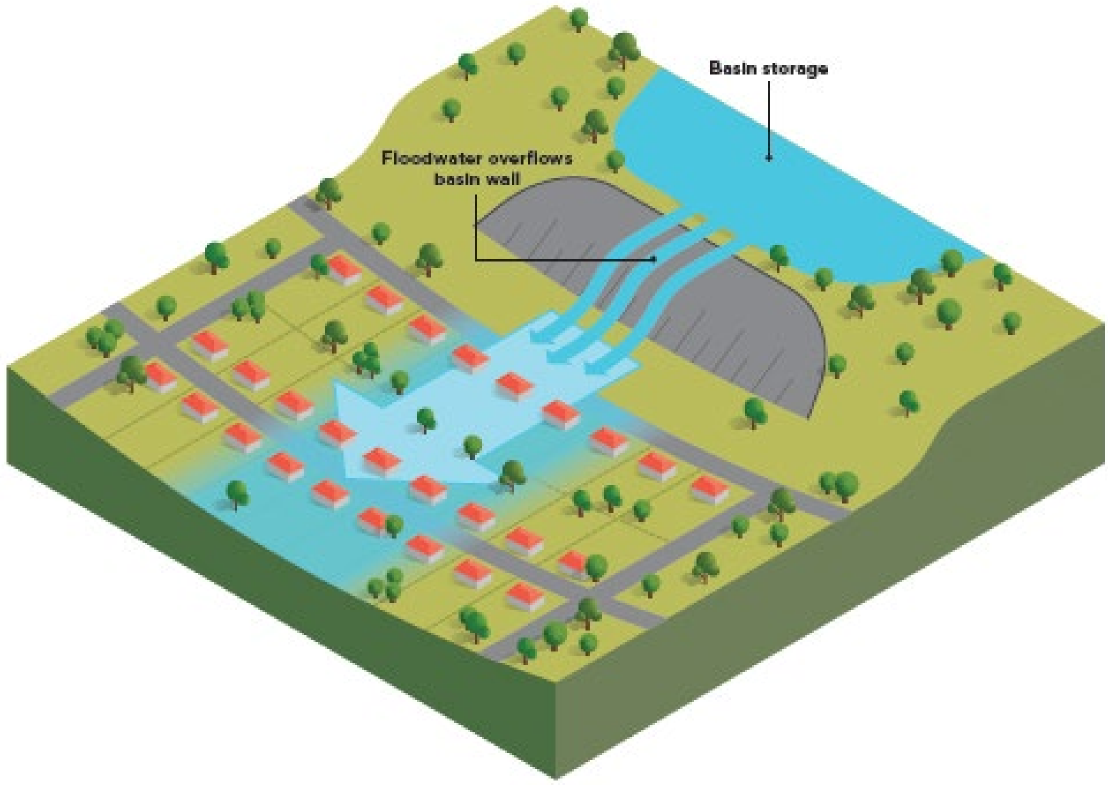


Figure 7 **Detention basins may have limited impacts in floods larger than their design flood**



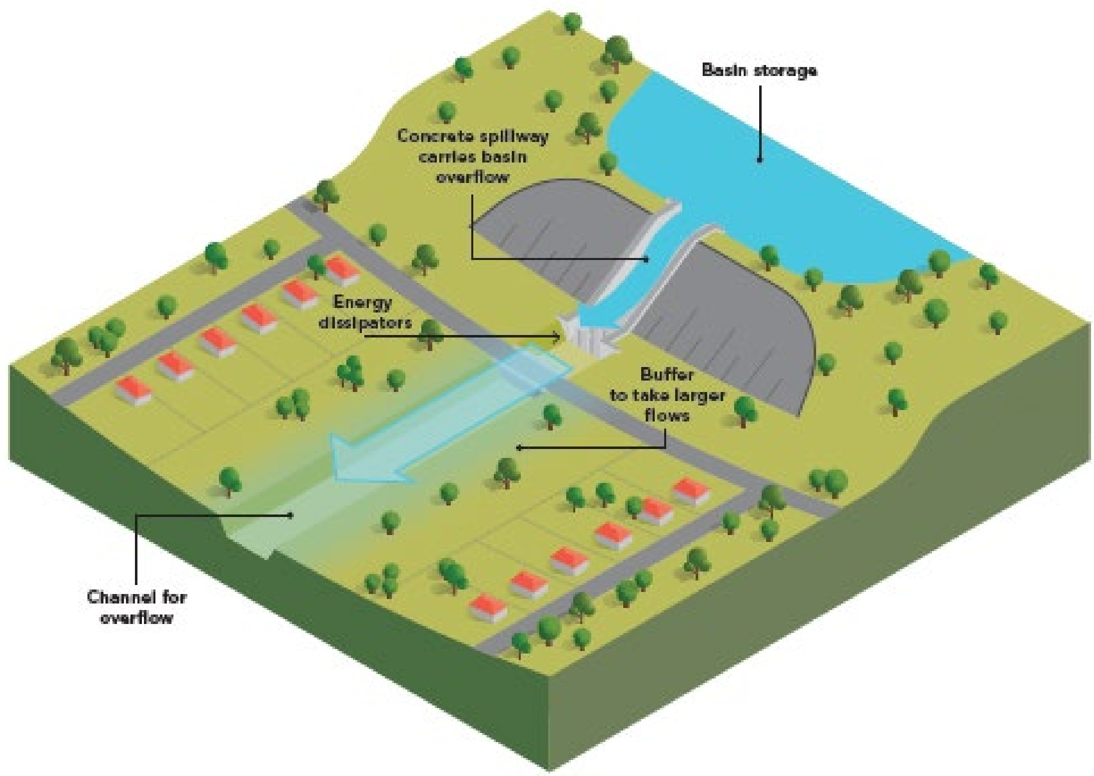


Figure 8 **Basins without (top) and with (bottom) provision of safe overflows when capacity is exceeded**

4.2.6 Modifying or removing property

Flood impacts can also be reduced by modifying a property to reduce its vulnerability to flooding or by removing it from particularly hazardous areas. Some relevant options are discussed below, with redevelopment of property discussed in Section 4.4.

Voluntary house raising

The damage to a structure and its contents due to flooding generally increases significantly once its floor level is overtopped. For some structures, houses in particular, the habitable floor level can be raised to reduce the frequency of above floor flooding and the associated damage and losses, post-event clean-up, and post-flood trauma and associated stresses.

Raising habitable building floor levels aims to reduce damages. It is generally only suitable in areas where flood flow velocities and flood hazard are limited (inactive flow areas). It is generally best suited to timber framed and clad buildings and is generally applied to houses with non-masonry products. Houses of single or double brick or slab-on-ground construction may be impractical or, in some cases, cost-prohibitive to raise.

The structural elements of the raised building need to be designed to cater to the potential flood forces (static and hydrodynamic water forces and associated debris loadings) at the location for the design event.

Voluntary house raising does not remove the need for occupants to respond appropriately to a flood threat. It can, however, result in occupants feeling less need to evacuate and they may leave evacuation until the flood threatens to overtop their raised floor level when external flood conditions are worse and more dangerous to cross. Local flood planning, ongoing community education, and clear advice on responding to flood threats is needed to support the safety of occupants during a flood.

People may initially refuse to evacuate in the face of a flood threat and then later change their minds. The extended period of isolation with a lack of services (water, wastewater, electricity, communications and other services), medical emergencies, lack of supplies, or floodwaters that continue to rise and threaten floor levels may cause them to rethink their position. This can lead to people evacuating when flood conditions are deeper and more hazardous. Haynes et al. (2018) provides some insight into the experience of people who remained in their homes during flooding in Lismore and Murwillumbah in 2017.

Flood-proofing

Flood-proofing involves design and construction or retrofitting of buildings with appropriate water-resistant materials to reduce damage when inundation occurs. This can involve the design of structures to withstand inundation, debris and buoyancy forces from floods up to a nominated design event.

Some construction methods and certain types of materials are better able to withstand inundation than others. For example, many internal wall linings and cupboard fittings are badly damaged by water and may need replacement. In contrast, double brick construction can withstand inundation and only requires washing and scrubbing down when the water subsides.

Dry flood-proofing generally aims to restrict the entry of water into buildings, whereas wet flood-proofing tries to let floodwater into the building to reduce the potential for structural damage due to differential hydrostatic pressure between the outside and inside of the house. This approach is more likely to be used in areas where there are significant differences between the design floor level and the level of an extreme event.

Flood-proofing is generally only considered in conjunction with other FRM measures. Whilst it can minimise structural and possibly contents damages to flooded buildings, the users still suffer the social and economic disruption of flooding, which needs consideration.

Flood-proofing may also involve temporary measures to exclude floodwater from structures. They may include a range of built-in automatic and manually erected barrier systems that aim to prevent water penetration into the building during the design flood. The use of these measures needs to consider the overall design of the building, the potential for alternative ways for water to penetrate the structure, and the potential flood forces on the structures that need to be managed. These systems are likely to have design limitations (i.e. maximum depths of water they can withstand before failure) that need to be considered. Design may also need to consider the need for people to leave the property.

Property purchase

Voluntary property purchase is generally an expensive option and as such is targeted to specific locations to achieve one or more of the following objectives:

- remove urban development from floodways and flowpaths to improve flood flows and reduce upstream flood levels. This is done as part of floodway clearance schemes to reduce upstream flood impacts. This land should be rezoned to limit uses to those compatible with its flow conveyance function
- voluntarily remove houses from areas where the risk to life to the occupants and their potential rescuers during a flood event are very high and cannot be feasibly or cost-effectively managed by other means. This aims to remove the people and the structure from the floodplain. It involves the removal or demolition of the building and rezoning the land to limit allowable uses to those compatible with flood function and hazard.

Property purchase may also be undertaken to enable the construction of flood mitigation measures, such as levees. This is usually done as part of the construction or maintenance requirements of the mitigation measure or to offset its impacts on existing development.

Relocation of development and rezoning of existing locations

Where flood hazards for users and potential rescuers are very high and cannot be feasibly or cost-effectively managed by mitigation works, an alternative to voluntary purchase may be relocation of urban development to a less hazardous location and rezoning of original land to limit its development potential. This has been done on a number of occasions in New South Wales and interstate with a recent example being in Grantham in Queensland following flooding in 2011. It can be used to:

- remove urban development from flow conveyance areas and thereby improve flood flow
- remove people and property from hazardous areas where they and their potential rescuers will be in significant danger during flood events
- limit future development to purposes compatible with flow conveyance and flood hazard.

Relocation may involve a land swap to appropriately zoned development sites in areas where flood risk is limited, with the existing site being transferred to government and rezoned so it can only be used for flood compatible purposes. The existing structure on the site may be relocated to the new site, or new buildings may be constructed on the new site and the existing structure demolished.

4.2.7 Waterway–ocean interface management

Flooding in coastal waterways is influenced by a combination of catchment flooding, tidal and storm-related ocean conditions, and the waterway–ocean interface (or entrance) condition. The combination of conditions that dominate can vary with location and the configuration of the entrance. *Modelling the interaction of catchment flooding and oceanic inundation in coastal waterways FRM guideline FB05* provides guidance on the variations in entrance conditions and how these influence flooding.

Entrances in New South Wales are generally either open entrances (some of which rely on entrance training to remain open) or intermittently closed and open lakes and lagoons (ICOLLs).

ICOLLs are a natural barrier where the configuration is influenced by ocean levels, wave action and the variability of discharge from the waterway. The height and width the barrier can reach between discharges and how it might erode during a flood event can influence flood behaviour in the waterway and can lead to higher flood levels than when the entrance is fully open. In some cases, outlet barrier systems can prevent astronomic tides, storm surge and wave action penetrating into a waterway. As the condition of the entrance varies, so will its impact on flooding and the level of influence of these various factors.

Changes to entrance configurations or conditions that can influence flood behaviour and impacts include:

- training of waterway entrances using measures such as entrance walls to assist in maintaining the entrance in an open condition. This can improve the entrance efficiency and reduce the potential for barriers and berms to form that may otherwise have a significant influence on flood levels. Dredging of the waterway entrance, often to maintain a navigable channel, may assist in maintaining the entrance in an open condition. These entrance modifications improve flow conveyance through the entrance, which will lead to increased tidal range in the waterway
- management strategies to artificially induce entrance opening by berm breakout when certain estuary conditions (water level for flooding or water quality for broader estuary objectives) or entrance berm (level) conditions are met. This intervention can reduce the maximum height of the berm or barrier and temporarily re-establish flow from the waterway to the ocean. This can reduce the influence of the entrance on flood behaviour but will not alter the influence of ocean water levels on flooding.

Varying ocean conditions such as astronomic tides, storm surge and storm wave action influence entrance conditions and waterway flooding. As such they require consideration when entrance management is being considered as an FRM measure. In particular, sea level rise will influence:

- mean sea level and mean water levels in coastal waterways
- astronomical tide conditions in the ocean and coastal waterways and how far, and to what level, these tides penetrate into coastal waterways
- the configuration and conditions of entrances from the waterway to the ocean, for example, it will affect the height to which outlet barriers or berms will develop in ICOLLs
- the water level that ocean conditions driven by storm events will reach as these are directly influenced by the baseline astronomic tide conditions. Where the entrance is open these conditions will penetrate further into coastal waterways and have more influence on flooding in these areas.

Consideration of the influences of climate change is also important to assess the long-term effectiveness of an entrance management strategy. In most cases, this effectiveness will reduce, which should be considered in investment decisions in the vicinity of the waterway. Future scenarios discussed in FRM guideline FB01 can be used to understand changes to flood behaviour over time.

4.3 Preparedness, response and recovery measures

This section discusses some of the key measures related to preparedness, response and recovery, shown on Figure 1. Table 30 identifies the upfront, ongoing and complementary work that typically needs to be done to implement these options. The remainder of this section discusses some of these options in more detail.

Flood EM planning is discussed in FRM guideline EM01. Recovery planning is outside the scope of the guideline with relevant Acts outlined in FRM guideline AG01.

Table 30 Typical work needed to support preparedness, response and recovery options

Option	Upfront work	Ongoing work	Complementary work
Flood prediction and warning (Section 4.3.1)	Investigation, design and installation. Operation and maintenance manuals for gauges and information systems or networks.	Maintenance, operation, testing and calibration. Upgrade as technology and requirements change. Monitoring during floods.	Gauging during a flood. Interaction with EM and community awareness.
Review of local flood planning (Section 4.3.2)	Information gathering, investigation, analysis, strategy development, formalisation and communication.	Operational use. Review with changes in flood data and intelligence and FRM measures.	Interaction with flood warning, EM and community awareness.
Evacuation route capacity improvement (Section 4.3.3)	Investigation, design and construction.	Ongoing maintenance.	Interaction with flood warning, EM and community awareness.
Community flood awareness (Section 4.3.4)	Flood behaviour, exposure, impacts and evacuation limitations understood. Flood information available. Clear advice available on how to respond to a flood threat.	Maintain up-to-date advice with changes in knowledge and the implementation of FRM measures. Maintain through regular advice to the community.	Interaction with flood warning, EM, community awareness, FRM plan implementation and flood information through data collection or studies.
Capturing lessons learnt after a flood (Section 4.3.5)	Capture flood behaviour using marks, photos, videos, aerial footage, survey. Collate and report on information.	Securely store information and make it available (see Section 4.1) to inform the FRM, EM and land-use planning as relevant.	Communication with other relevant parties to coordinate and consolidate surveys and information capture and analysis.

Option	Upfront work	Ongoing work	Complementary work
	Post-event behaviour assessment where necessary.		

Note: Derived from Table 9.2, AIDR (2017).

4.3.1 Flood prediction and warning

Flood predictions or forecasts and associated warnings are critical for emergency response to limit loss of life and property damages.

The ability to provide flood warnings relies on flood warning arrangements and the equipment and information available to predict floods. These arrangements need to be in place before the onset of a flood event. During and in the lead-up to a flood event these arrangements and the associated systems are used to develop flood predictions and warnings.

New South Wales has mature flood warning systems and arrangements for communities as discussed in FRM guideline EM01. Further information is provided in the Bureau of Meteorology's *Service level specification for flood forecasting and warning services for NSW and the ACT* (BOM 2013).

The development and management of local flood warning systems that fall outside these arrangements is generally the responsibility of councils. Councils are encouraged to have a local flood warning system/gauge owner's manual for their locally managed flood warning systems and gauges. This aims to ensure these systems meet the requirement of the total warning system for floods, as outlined in the Australian Institute for Disaster Resilience's *Application of the total warning system to flood* (AIDR 2022).

FRM studies should include a review of the adequacy of the existing flood warning arrangements for the location. Where the system is covered by the current service-level specification, studies should consider whether the existing system is fit for purpose to meet the requirements of the current service-level specification. Studies should also consider whether the lead time required in the service-level specification provides adequate effective warning time for the community.

Studies under the FRM process may identify the need for the development of new warning systems, the upgrade of an existing flood warning system, or the need for new water level or rainfall gauges within an existing network to support flood warning at existing or new locations.

A new flood warning service location may warrant recommendation of:

- upgrades to existing flood warning equipment to ensure they meet current requirements including the *Flood warning infrastructure standard* (BOM 2019)
- upgrades to the existing NSW flood warning system to address warning deficiencies. This may involve the installation of new river or rain gauges
- upgrades to an existing local flood warning system or improvements to documentation of the system to meet the requirements of the guideline for application of AIDR 2022
- a new local flood warning system to meet the requirements of AIDR 2022. Any such recommendation should provide guidance on the scope and scale of the scheme, identify the need to document the scheme, and outline how it fulfils the intent of a total warning system for flood.

The assessment of a warning project in an FRM study and plan is considered a pre-feasibility assessment, and it should be documented and costed on this basis. It should identify the effectiveness of the system, that is, whether it can improve community response to the flood threat. This is a key consideration in assessing the priority for new or upgraded flood warning systems.

Implementation of flood warning projects would generally be in 2 stages:

1. Final system scoping including a review of its capability to deliver fit-for-purpose advice to the community through the total warning system. This should include:
   a. a draft of the owner's manual including an outline of the agreed roles of the different parties in delivery of the total warning system for flood in this project
   b. advice on the triggers for action by the community, based on minor, moderate and major flood classifications
   c. updated estimated lifecycle costs including installation, maintenance and renewal
   d. a design report documenting and specifying the system requirements.
2. System implementation including installation, testing, commissioning, handover, full documentation of the gauge/system in an owner's manual (incorporating information on system operation and maintenance). Where this involves any change to community flood response or associated triggers it should include advice to support update of the local flood plan and a community awareness campaign to ensure the community understands these changes.

4.3.2 Flood EM planning

Having a robust EM plan that can provide the basis for responding to various scales of flood threat and be altered to fit the particular circumstances of an event can assist with flood preparation, response and recovery.

Flood EM planning and the information required from the FRM process to inform flood intelligence and plan update is discussed in FRM guideline EM01.

Flood studies and FRM studies provide key flood information that may lead to a review of flood intelligence and result in recommendations for updating the local flood plan.

FRM studies will generally involve a review of the local flood plan to assess whether there is a need to update information on:

- the flood problem faced by the community and how this varies with flood severity. The currency of the information available on the flood threat and the impacts on the community should be checked, and any limitations or gaps in this knowledge identified
- any key limitations on EM logistics, such as the vulnerability of an evacuation route to flooding or limitations on its capacity
- any tipping points that impact on the scale of impact on the community. A tipping point can indicate a step change in relation to the flood threat to the community, which would generally impact response actions. Examples include a levee overtopping or an evacuation route being cut. The flood level at which these step changes are expected to occur needs to be related to the relevant flood warning gauge as this can be used to link flood predictions to response actions. Advice on the variation in the effective warning time for flood waters to reach these levels and the frequency at which this occurs is important as this can inform evacuation decisions and logistics and recommendations for evacuation route improvements.

The review of local flood plans should also include:

- a review of the current flood warning classifications (minor, moderate and major) for the location relative to the impacts on the community and any associated recommendations
- clarification of the scale of impacts and the scale of the emergency response required in relation to key events and the associated flood timings so this can inform decisions and logistics. For example, for a levee protected community, having a plan in place on how to respond to floods that do not threaten the levee, threaten to result in minor overtopping of the levee, and for extreme floods that overwhelm the levee and town, can provide flexibility
- a review of other key information in the plan in light of the information in this study.

An FRM plan may incorporate a range of recommendations for updating or improving EM planning based on the outcomes in the FRM study.

4.3.3 Evacuation route improvement

Evacuation may rely on having sufficient evacuation route capacity to enable flood-affected residents to self-evacuate within the time available.

Where this is not available, improving an evacuation route can support more effective EM. For example, it may:

- provide more time to evacuate the community based on existing evacuation triggers. Raising an evacuation route or low points on the route means the route is less vulnerable to flooding. This may provide more time to evacuate the community when the same evacuation trigger is used
- provide more capacity on the route to enable the evacuation of more vehicles and people within the same evacuation window. This may involve widening the evacuation route, reducing any bottlenecks to traffic flow, and altering traffic signalling to increase capacity. The use of contra-flow lanes must consider the need for emergency vehicles to enter areas being evacuated and potentially to clear accidents on evacuation routes
- enable the use of a higher evacuation trigger. This may allow for an evacuation decision to be made later in an event where there is more certainty of the scale of the flood and the need for evacuation of the community.

FRM studies may examine the benefits and options of route upgrade at a pre-feasibility scale. The upgrade of evacuation routes needs to consider the relative benefits of improved safety versus their costs. The benefits of these upgrades to general traffic improvements should also be considered. Works to upgrade evacuation routes may be more cost-effectively incorporated into the upgrades of existing roads for other purposes. It may also be possible to provide additional evacuation capacity through the upgrade of road shoulders and bike lanes, to enable them to take vehicular traffic when required in response to a flood threat.

The outcomes of the FRM study result in recommendations in an FRM plan. Implementation is likely to need staging through investigation and design, prior to construction.

4.3.4 Community flood awareness

Effective FRM and flood emergency response requires a community that is aware of the potential impacts of floods and their role in responding (including preparation, evacuation and damage reduction efforts) to a flood threat.

Advice to the community on preparing for flood events should not be solely focused on more common and/or less severe floods. Advice also needs to be prepared for the rare floods that are outside the community's experience. For example, there will eventually be a flood that overwhelms access routes the community may use in response to more frequent floods, overtops levees that have not been overtopped before (such as the levee in Lismore that overtopped for the first time in 2017 after being built in 2005), or that inundates areas not affected by more frequent floods.

The key message is that for these rare floods, different actions may need to be taken from those that are appropriate in the smaller events some community members have experienced, and the timeframe for taking action will be shorter.

The first step in creating readiness is creating awareness of the potential for flooding. Other steps will follow that may be specific to particular areas and will seek to create learning about particular issues such as how to utilise warnings, means of protecting property, how to prepare, what to do before and while evacuating, and how to manage household recovery from flooding.

Developing and maintaining flood awareness in the community is a shared responsibility between flood forecasters, flood risk managers, emergency managers and the community. It requires strong partnerships between councils and the NSW SES, and ongoing commitment and resourcing. Those responsible may work in partnership to provide information to the community on the flood threat, advice to the community on preparing for floods and how to respond to a flood threat, and flood warnings. Studies under the FRM process provide essential information to support community understanding and management of flood risk.

The community is responsible for finding out about their flood risk, preparing for floods and responding to flood warnings. Advice for the community on preparing for floods is widely available through government websites. The NSW SES has online tools to assist in the development of emergency plans for homes or businesses.

The AIDR handbook *Community engagement for disaster resilience* (AIDR 2020) provides guidance to support community education, awareness and engagement. Community engagement professionals in councils and state agencies can also assist with scoping and planning engagement activities suitable for specific communities.

4.3.5 Capturing lessons learnt after a flood

A flood event provides an ideal opportunity to capture information on the flood and learn from it. It helps understand the event, the consequences for the community, successes and limitations in current management practices and how the community recovered. Information can be captured in coordinated community surveys.

This information should be collated and a report produced to catalogue what has been captured and its availability and format. The data should be securely stored and made publicly available. The information can be used in both explaining this event to the community and in considering future flood risk, EM and land-use planning decisions within and potentially beyond this community. This may lead to a review of the FRM study and plan. The AIDR handbook *Lessons management* (AIDR 2019) incorporates some relevant advice.

Capturing information during and after a flood

Information to support our understanding of flood behaviour in an event can include rainfall and water level gauge information, radar, aerial and satellite images and meteorological charts.

Information from a combination of daily read and pluviograph rainfall gauges can provide an understanding of the amount of rainfall that fell and the pattern it fell in. Meteorological charts, and satellite and radar images can provide an understanding of the spatial extent and variation of the storm and how the storm developed and moved through the affected area.

Understanding how waterways responded to the flood event is also important. Information from water level gauges can capture the timing and level of the rise, peak and fall of the flood. This can be compared to historic and design floods so the relative frequency of the flood can be understood.

The performance of the individual rain and water levels gauges, and the communication and data sharing systems can be assessed to see if any problems impacted on the performance of the system in fulfilling its role in the application of the total flood warning system to flood. Where gaps in knowledge or problems occurred, these may be considered as part of improving flood warning or flood risk or EM planning in the area. Performance issues can include:

- permanent loss of a gauge due to flood impacts requiring replacement (perhaps in an alternative location or to a higher standard). Gauge equipment, particularly water level recorders are often located in the vicinity of waterways and can be vulnerable to flooding and erosion of the riverbank
- temporary loss of a gauge due to a power outage or malfunction of the gauge, communications or instruments for part or all of the event. Consideration needs to be given to whether changes are needed to reduce the vulnerability of the gauge or system or whether other secondary gauge locations provide a redundancy
- incorrect information from a gauge, often due to equipment failure, such as blockage.

Flood and debris marks, drone, aerial and satellite images, and other information including ground-based images and videos can also assist in providing a better understanding of the scale and extent of the event, the flood behaviour during the event and how the event travelled along the waterway. An important aspect of images and video, whether aerial, satellite or ground-based, is the location of the instrument, the direction it is filming and the location being captured, as well as the time this information is being collected, so it can be examined in the context of the overall event. Without this knowledge, materials may be misinterpreted as being at the peak, where flood levels and behaviour may be different from at other times.

Physical survey and documentation of flood marks is important for capturing and presenting this information in a way that can be readily interpreted and used into the future. For long duration flooding, lasting weeks to months, satellite imagery can be useful to provide an understanding of how the flood and the peak of the flooding moves down the waterway. This understanding assists in flood predictions for downstream communities and for future studies.

The impacts of flooding on the community can include information on public and private infrastructure that is damaged or destroyed, social impacts, financial losses, and environmental impacts. Some of this information may be captured in rapid impact assessment as the event recedes. Rapid assessments help inform government of the scale of the disaster and the short- and long-term assistance that may be needed for community recovery. The AIDR handbook *Community recovery* (AIDR 2018) provides some advice on post-disaster survey and assessment.

Understanding damage to public or community infrastructure can assist with recovery by presenting short- and long-term ways to address this loss. For example, even though a local rural community may have had limited damage from a flood, loss of the only bridge into a community can cut it off from areas where individuals work and study and stop the transport of goods in and out.

Surveys of community health care facilities and the community can gauge the social impacts of flooding. This may include developing an understanding of the immediate impacts, such as identifying the scale of fatalities and injuries relating to the flooding, as well as longer-term assessments of any increase in medical visits due to longer-term health problems such as post-traumatic stress and associated health issues.

Physical surveys of damaged properties, surveys of owners of residential and commercial premises, and information from the insurance industry can assist in understanding the financial cost of the disaster for the community. This can assist in informing both short- and long-term recovery efforts and inform studies to examine the potential for additional works to reduce the vulnerability or exposure of the community to flooding.

Information captured during and after an event may support a review of flood warning performance. This can be used to determine the success and limitations of the application of the total warning service to flood relative to the needs of the community. This can help identify:

- where warnings met expectations and the circumstances, systems, resourcing and approaches that supported this successful outcome
- gaps in flood warning networks that may have inhibited or delayed flood predictions
- problems with gauges, communication or data sharing systems impacting on warnings
- locations where flood warnings are not available but may be desired by the community
- limitations in flood forecasting models
- problems with communication of flood warnings to the community.

Understanding successes and limitations provides important information to support the design, prioritisation and resourcing of improvements to services into the future.

Post-event flood behaviour assessment

Post-event flood behaviour assessments can assist in understanding the flood behaviour that occurred during a specific event. They are particularly important for floods:

- where behaviour was at, or near historic record levels
- where they are the first significant event with a new mitigation work in place
- where a mitigation work such as a levee overtops for the first time or fails to perform as expected
- where actual flood behaviour is significantly different to that expected based on modelling or past experience.

For example, a town is protected by a levee designed to overtop at a spillway at its downstream end and flood into the town before water overtops the levee’s spillway at the upstream end of town. If the opposite occurs, this can have significant repercussions for EM planning. This situation may trigger the need for a post-event flood behaviour assessment to investigate whether this was due to physical changes in the floodplain or to the specifics of the storm and flood event.

4.4 Land-use planning related measures

FRM guideline FB01 provides advice on using land-use planning to address the growth in flood risk resulting from introducing new or intensifying existing development in the floodplain.

This section of the guideline discusses some of the key land-use planning measures that can influence the growth of flood risk related to new development and redevelopment. These are outlined in Table 31, which identifies the upfront, ongoing and complementary work that typically needs to be done to implement these options. The remainder of this section discusses some of these options in more detail.

FRM measures such as detention basins (see Section 4.2.5), and waterway modifications (see Section 4.2.4) may be proposed to offset the impacts of development on flood behaviour, with varying effectiveness.

Complementary measures such as catchment management measures (see Section 4.5.1) and WSUD (see Section 4.5.2) may be proposed to support development. Their influence on flood behaviour and their efficacy in FRM should be carefully tested considering the aspects discussed in Sections 4.5.1 and 4.5.2 and in Table 5.

Table 31 Upfront, ongoing and complementary work to support land-use planning measures

Option	Upfront work	Ongoing work	Complementary work
Land-use zones	Allow developments that are compatible with flood constraints on land including the flood function and risk. These should be developed considering future scenarios (FRM guideline FB01).	Ensuring intent of zonings is maintained and they are accompanied by appropriate development controls. Monitor effectiveness and revisit if outcomes unsatisfactory.	Complementary development controls to maintain flood function, offset development impacts and reduce residual risk to the development and its users. May rely on other FRM measures.
Development controls	Development controls support zoning. Together they aim to manage development impacts on flood and EM risks to the existing community as well as managing the flood and EM risks to the new development and its users.	Ensure development controls are effectively applied. Monitor effectiveness and adjust if outcomes unsatisfactory.	Complementary with zonings. Place development controls into LEPs and DCPs, considering varying flood constraints and land uses. May rely on other FRM measures.

Note: Derived from Table 8.1 AIDR (2017).

4.4.1 Land-use zones

Land-use zones provide a statutory expression of the intended use of land by establishing the objectives for development, what is prohibited, and approval pathways for permissible development (see Section 4.4.2).

Development of land may have detrimental impacts on flood behaviour risks to the existing and future community. It may alter flood behaviour by diverting or altering flowpaths due to changes to topography within the floodplain. Filling, reshaping or placing infrastructure can alter flowpaths or result in a loss of flood storage. Land clearing and increasing impervious areas in the catchment may increase flow off the land, which may have downstream impacts that need to be considered and managed.

The development of land and the added population may also impact on flood emergency response risks where it impacts on the ability of the existing community to evacuate on constrained evacuation routes. Land-use zones can limit these impacts by managing the allowable use of land so it is compatible with flood function and hazard and the associated risks. Zones may also be used to limit the scale of development to curb detrimental impacts on the existing community. To achieve this, decisions on setting or changing land-use zones in LEPs should consider the full range of flood behaviour and the cumulative impacts of development on flood behaviour. Changes in flood behaviour due to climate change may also warrant consideration.

Land-use zones can be used to restrict activities within areas of the floodplain needed to perform their natural flood functions (including flow conveyance and storage), to uses compatible with this function. This limits the impacts of activities in these areas on existing flood behaviour. They can be used to discourage development incompatible with flood hazard in areas where the flood hazard is considered too high and cannot be effectively managed. Land-use zones can limit exposure of people and development to excessive risk or may limit the type of development permissible due to a particular driver for risk. For example, developments expected to have inhabitants who are more vulnerable in terms of their independence of action (such as aged care homes and hospitals) should be placed in areas where evacuation is not necessary, or can be more readily managed. Other types of development housing inhabitants who are more agile may be better suited to these locations.

Land-use zones can also curb the scale of intensification of development by limiting development types or density. This can help control the scale of development in evacuation-constrained areas unless constraints such as road capacity are increased.

If strategic land-use planning decisions are required before flood investigations are complete, these should be made in a precautionary way using the best available information in a conservative manner. Where there is insufficient information to inform decisions, flood investigations may be warranted.

4.4.2 Development controls

Development controls are not standalone solutions for managing flood risk to new development. They need to be used in conjunction with land-use zoning that identifies permissible development and in consideration of the:

- full range of flood behaviour and risk to the existing community
- influence development may have on flood behaviour and the risks to the existing community
- risks to the new development and its users.

The development controls necessary to manage impacts and risks associated with permissible development will vary depending on the:

- range of permissible land uses
- flood constraints on the land
- access to the site
- impacts and risk for flooding on the development
- scale of the development
- potential for development to impact on flood behaviour

- potential for the development to impact on the existing community.

It can also vary dependent on whether the development is:

- a subdivision to create new lots
- infill development
- redevelopment
- a rezoning to allow different land uses or development intensity.

Development controls typically consider:

- management and design
- impacts of the development on flooding or emergency response of other properties and associated environmental issue such as scour
- emergency response
- minimum fill levels
- fill and compensatory excavation
- minimum floor levels
- building components and methods
- structural requirements for buildings.

These different development controls are discussed in the section below.

In addition, development controls may be needed to further reduce vulnerability for a particular development type. For example, caravan and mobile-home parks may be required to have detailed site-evacuation plans, awareness documents and signage.

Management and design

Development can have a significant impact on flood behaviour and flood risks to the existing community. Flooding can also have significant impacts on the new development and its users. Flood-related management and design requirements in DCPs may require demonstration that development can be done in a manner that:

- addresses detrimental impacts on the existing community
- limits the risk to the new development and its users to acceptable levels
- minimises the potential for pollution (e.g. requires management of hazardous material so they remain contained in a flood).

Addressing these aspects may require a flood risk and impact assessment (FIRA) (discussed below) and may result in development limitations and controls.

Emergency response arrangements and impacts

The development of a location can be influenced by the limitations presented by the EM constraints and community EM arrangements relevant to the site. Development needs to consider these aspects and any impacts the development will have on the emergency response of the existing community. This has the potential to influence both zonings and development controls.

Depending on the flood EM constraints on the land, development controls may include consideration of the:

- location of the egress point from the site to facilitate egress from the areas affected by flooding
- ability to get to the egress point from within the site

- ability to evacuate the site considering the capacity of the evacuation route relative to current traffic levels and the available warning time.

FRM guideline EM01 provides additional advice on EM considerations.

Minimum fill levels

For new development it is common practice to fill land, where allowable, to at least a minimum level to reduce the frequency of exposure of the developed land and its users to flooding. Minimum fill levels are generally directly related to development standards, such as the use of the DFE.

However, filling of the floodplain can have a detrimental impact on flood behaviour both locally and cumulatively. Cumulative assessments can be undertaken as part of future scenarios (FRM guideline FB01) in studies under the FRM process. For a development, these impacts should be assessed as part of a FIRA (see *Flood impact and risk assessment FRM guideline LU01*).

Limiting filling to areas outside floodways and flood storage areas can limit the potential detrimental impacts. For example, filling in a floodway can redirect the flowpath into another area, potentially increasing hazard and impacting other developments or the community. Fill is therefore generally excluded from floodways so they maintain their flood function. The exception is very wide floodways where isolated areas of filling, even cumulatively assessed, may have limited impacts on flood behaviour, if effectively managed.

Management of the cumulative impacts of filling may result in limits being placed on the location, level and quantity of fill that can occur in flood storage areas.

In some cases, maximum fill levels may be applied to developed land in consideration of the cumulative impacts of fill on flood behaviour in events rarer than the DFE.

Fill and compensatory excavation

Some development projects may seek to offset the impacts of filling by providing compensatory excavation. However, excavation and filling are not comparable, as fill is more likely to take place on the lower part of the floodplain (to increase the land available for development), while extraction of fill material may occur in higher parts of the floodplain, from land outside the floodplain or from outside the catchment.

The net effect is that any additional storage created through excavation may fill with floodwaters earlier in a flood event than the newly filled area and therefore may not have the same influence on peak flood behaviour, potentially resulting in detrimental impacts.

As such, these approaches need to be carefully considered and the net impacts of any proposed changes assessed.

Minimum floor levels

It is also common practice to set minimum floor levels, particularly for habitable rooms in residential buildings and key areas of other types of developments. Setting minimum floor levels can reduce the frequency of exposure of the development and its users to flooding and can reduce the frequency and extent of flood damage.

Minimum floor levels generally relate to specific development standards, such as the flood planning levels (FPLs), relevant to the development type. Different development standards may also be used, for example, higher development standards may be adopted to reduce the risk exposure of more vulnerable developments or for developments with an emergency response role (e.g. hospitals).

Structural requirements for building

Flow velocities, flow depths and associated debris loads can affect the structural soundness of buildings in a number of ways. Structural soundness of buildings can be tested by examining the resultant impacts of flooding, including buoyancy, and debris on the structure.

Certification of the soundness of structures against relevant standards (including use of appropriate materials able to maintain their structural soundness once inundated) for the local hydraulic conditions should be considered in flood affected areas.

Building components and methods

Some building components are less susceptible to damage by floodwaters, and some may allow for easier clean-up after a flood event. Development controls may require the use of flood compatible building components to reduce damages and the potential for failure of the structure.

Fencing

Fencing, and the debris it can trap, has the potential to have a significant impact on flood behaviour and risk.

The areas that are most likely to be susceptible to adverse impacts are floodways and flowpaths as these active flow areas tend to carry more debris and are sensitive to blockage, even if this is only partial.

Fences, whether solid or open, can affect flood behaviour by altering flowpaths. The impact will depend on the type of fence and its location relative to the flowpath and the potential for debris from the catchment. Where a significant impact on flood flow is expected in an area, controls should be considered in relation to the type of fencing permitted, or to limit its location or height. In general, solid fencing, especially to ground level, should not be erected across flowpaths where it might act as a dam.

Fencing within floodways should consider continuity of their flow conveyance function. To achieve this, fencing should be as open as possible and be designed to limit debris trapping (considering the types of debris likely from the catchment). It may also need to be designed to safely collapse as floodwaters rise to minimise its impacts on flood behaviour.

Provision of essential community infrastructure services

Studies from councils under the FRM process may provide information to enable the assessment of the impacts of flooding of infrastructure services to the community.

These services might be disrupted at key infrastructure facilities (e.g. water and wastewater treatment, power generation and communication exchanges) or along their distribution networks.

To reduce interruption caused by floodwaters, service providers should consider, and may need to manage, the risk to their service facilities and to service provision to the community. This may involve locating key infrastructure facilities in areas where they are less vulnerable to flooding or where works can limit their flood vulnerability. Distribution networks may need to adhere to minimum government or industry design standards.

Overall, service provision should consider limiting the loss of continuity of community services and the ability to restore them in a timely and efficient manner. This may involve considering alternative supply arrangements and flood emergency response and recovery planning for key assets.

Flood impact and risk assessment

Development in the floodplain may have detrimental impacts on flood behaviour risks to the existing community and expose the new development and its users to flooding. A FIRA (see FRM guideline LU01) may be required to assess and address these impacts and risks. The scope and scale of this assessment will vary with the type and scale of the development, its location and its consistency with existing zonings and FRM and EM planning for the area.

4.5 Environmental enhancement

Urban FRM focuses on events that cause significant flood risk to the community and built environment. These risks are primarily from water flowing outside of waterways in large to extreme events whose impacts are concentrated in and around urban areas, townships and villages. These areas are the focus of most council-led FRM studies carried out under the program.

Where FRM measures are proposed, they need to outline how any potential environmental impacts are managed, address ESD principles, and identify whether options provide for environmental enhancement.

There are a number of environmental management or enhancement measures that can complement FRM for communities. These measures include catchment management measures or nature-based solutions and related waterway modification measures (discussed in Section 4.5.1) and WSUD (see Section 4.5.2). Where these measures are proposed to support FRM for communities they need to be considered in a fit for purpose way. This includes considering the aspects outlined in Table 5 and the additional advice in Table 32. Other aspects to consider are land tenure and maintenance.

Table 32 Additional aspects to consider when proposing catchment management or nature-based solutions to enhance flood risk management

Issue	Consideration
Types of storms that drive flooding	Consider plausible flood events derived from the storm types and varied patterns that lead to major flood impacts on the community in the study area and consider how management measures influence these.
Antecedent conditions	The scale of pre-burst rainfall has been shown to increase with the intensity of flood events, which can negate any changes in initial losses due to changes in catchment management practices in rare to extreme events. Section 4.5.2 provides an example.
Natural variability	Catchment and waterway vegetation vary naturally over their lifecycle and with the impacts of natural hazards This variation needs to be considered in assessing potential benefits as FRM measures. For example: catchment vegetation can be reduced by fire, reducing the catchment initial losses that would occur during flood events. It can take considerable time for regrowth to match pre-event conditions floodplain vegetation can be reduced by fire. Fires can reduce both catchment initial losses and the time for flows to flow across the landscape due to loss of vegetation and impacts on soil permeability floodplain vegetation can be altered by floods. Floods can reduce the vegetation in the floodplain, however, it can increase debris from vegetation in the floodplain and riparian corridors

Issue	Consideration
	riparian vegetation on larger water courses can vary significantly on a multi-year basis with the natural wet and drought cycles riparian vegetation can be altered by floods and take time to re-establish variability can by influenced by maintenance works.
Variability with flood depth	The impact of vegetation on flood behaviour generally reduces with the flood depth and therefore the scale of flood behaviour.
Flood behaviour at hydraulic structures, such as bridges	The potential for catchment and waterway management measures to increase debris loading impacting on flood behaviour at hydraulic structures.

Table 34 provides advice on typical upfront, ongoing and complementary works for these aspects.

Table 33 Upfront, ongoing and complementary work to support environmental enhancement measures

Option	Upfront work	Ongoing work	Complementary work
Catchment management, nature-based solutions and WSUD	The effectiveness of techniques needs to be tested relative to flood events with significant community impacts, using realistic assumptions that consider lifecycle variations against the existing case.	Monitor effectiveness versus expectations to inform future work.	Consider the ability for these options to be cost-effectively maintained.

4.5.1 Catchment management and nature-based solutions

The size, shape and location of a catchment can influence flood behaviour as can vegetation and land use, including urbanisation and farming practices in the floodplain. Some of the impacts of changes that result from moving away from more natural conditions in catchments are provided in Table 35. These impacts are likely to be larger in smaller events and diminish with distance from the change. Where not carefully considered these changes have the potential to lead to adverse flood impacts on the community.

Table 34 Typical impacts on flood behaviour of changes away from natural conditions

Type of change	Initial losses	Runoff	Timing		Downstream peak flow	Downstream flood levels
			Time to peak flow	Length of inundation		
Reducing catchment vegetation	Reduced	Increased	Reduced	Reduced	Increased	Increased
Reducing floodplain vegetation	Slight reduction	Slight increase	Reduced	Reduced	Increased	Increased

Type of change	Initial losses	Runoff	Timing		Downstream peak flow	Downstream flood levels
			Time to peak flow	Length of inundation		
Reducing riparian vegetation	Negligible	Negligible	Reduced	Reduced	Increased	Increased
Waterway straightening	n/a	n/a	Reduced	Reduced	Increased	Increased
Waterway lining	n/a	n/a	Reduced	Reduced	Increased	Increased

Catchment management measures, sometimes called nature-based solutions (examples in Table 36), are generally undertaken to alter catchment conditions so the water cycle can mimic more natural processes for the benefit of the community and environment. These approaches may, in some cases, have the benefit of increasing infiltration and reducing run-off, particularly in the early stages of rainfall events, and may influence more frequent flooding.

However, their benefits and impacts vary with distance from their location. They are also less noticeable in large to extreme floods and for longer duration events that are critical to flood behaviour and risks to communities in many catchments in New South Wales (as shown in Section 4.5.2). These options may also create additional risk to communities where not carefully considered in a strategic and fit-for-purpose way.

Table 36 provides advice on the general impacts of these types of measures on flooding. However, the scale of these impacts and their effects on flood risk to the community will vary dependent on the size of the event and on factors such as their location, type, size of any proposed structures, type and placement of vegetation, and the shape of the waterway and floodplain. Some examples are included in Box 1 and in Section 4.5.2.

Table 35 Typical impacts on flood behaviour of catchment management measures or nature-based solutions

Type of change	Initial losses	Catchment runoff	Timing		Downstream peak flow	Flood levels	
			Time to peak flow	Length of inundation		Upstream	Downstream
Increasing catchment vegetation	Increased[1]	Reduced	Increased	Increased	Reduced[4]	Increased	Reduced[4]
Increasing floodplain vegetation[2]	Slight increase[1]	Slight reduction	Increased	Increased	Reduced[4]	Increased	Reduced[4]
Increasing riparian vegetation[2]	Negligible	Negligible	Increased	Increased	Reduced[4]	Increased	Reduced[4]
Stream restoration[3]	NA	NA	Increased	Increased	Reduced[4]	Increased	Reduced[4]
Leaky/porous weirs	NA	NA	NA	NA	NA	Increased	Reduced[4]

Notes:

1. Also need to consider whether increased vegetation will result in increased soil moisture, which may reduce the impacts of these measures on losses during flood events.

2. The effectiveness of vegetation changes reduces with flood depth and therefore the scale of flood event.

3. Involves re-establishing more natural stream length and vegetation. Maintenance of hydraulic capacity requires a substantial increase in flow area.

4. The changes also need to be considered in the broader context of the flood situation. For example, considering whether they may result in increased downstream peak flows when these combine with flows from other catchments.

Where these measures are proposed for FRM purposes, their benefits and impacts, and their reliability need to be considered in the local context of managing flood risk to the community and built environment. This should consider issues raised in Table 5 and the additional advice provided in Table 33.

Like all measures proposed for managing flood risk, their reliability, benefits and disbenefits and the associated uncertainties need to be understood within the complexity and variability of flood behaviour relevant to the location.

This variation and the changes expected due to implementation of management measures need to be modelled to provide a realistic understanding of their varying impacts (benefits and disbenefits) on flood behaviour and risks to the community so they can be considered appropriately in decision-making. This can be extremely complex and involve the consideration of a wide range of hydrologic and hydraulic modelling scenarios and should include key historic events where possible. Simplistic assessment approaches are unlikely to provide a reliable basis for recommending these options as being effective measures suitable for FRM for communities. Their influence on FRM works, land-use planning and EM planning decisions in the short and long term needs to be carefully considered in relation to the performance and reliability of these measures and their ability to effectively influence behaviour in a major flood when this next occurs in the future.

Box 1: Examples of impacts of catchment management measures or nature-based solutions on flood behaviour

Increases in riparian vegetation within the riparian corridor and floodplain may impact flood conveyance. This additional vegetation may alter downstream flood flows and increase the travel time for floods to reach downstream communities. These changes have the potential to alter downstream flood behaviour. However, this change can also increase upstream flood levels and may extend the time of inundation in upstream areas. These changes in behaviour may extend the isolation or inundation time of upstream communities and may impact on upstream vegetation, including crops. In addition, they may result in flow redistribution with more floodwater flowing down alternative flowpaths or new flowpaths being created with associated impacts and risks.

Increased vegetation in waterways can also lead to additional debris being mobilised during a flood, which may lead to more blockage of downstream structures.

Leaky or porous weirs may act as a dam and have the potential to capture additional flood debris. The ramifications of these structures on upstream communities and of their potential failure on downstream structures and communities need to be considered in location and design decisions. In urban streams there may not be adequate space for these measures to effectively increase infiltration without impacting on flood conveyance or storage capacity or causing an afflux in large flood events. Their impacts on the community in rural areas would generally be expected to be lower.

4.5.2 Water-sensitive urban design measures

Urbanisation increases the volume and flow rate of run-off by:

- modifying natural systems with impervious surfaces like roads, roofs and driveways, reducing the area available for infiltration
- increasing the speed of run-off by efficient flow conveyance. This includes roof and street gutters and drainage pipes. Each of these drainage structures is designed to convey run-off much faster than natural systems
- reducing temporary depression storage in the landscape.

The philosophy of WSUD is to reduce these impacts by constructing systems that respond closer to natural systems. WSUD and related stormwater management measures are often used to reduce the impacts of development on the:

- level of service of existing stormwater drainage conduit networks
- urban water cycle and water quality by mimicking many of the natural processes that capture, store and use run-off.

These measures may include approaches such as rainwater tanks, infiltration devices, permeable pavements, green roofs and onsite detention.

WSUD and related stormwater measures are primarily intended to:

- reduce water demand and usage by capturing a portion of the volume from storm events. The proportion captured reduces as the scale and duration of the event increases
- encourage infiltration into groundwater, given the loss of infiltration area with the loss of pervious area due to new development. This aims to reduce impacts of development on groundwater
- reduce the impacts of development on water quality in waterways by capturing the first flush
- reduce changes in the frequency of flows and flow velocities in frequent events in streams due to development to limit increases in stream erosion
- allow frequent flows from developed areas to mimic the natural flow regime more closely in more frequent events – typically up to 1 event per year. This may involve capturing very frequent run-off from sites and reducing the frequency of run-off and the peak flows in frequent events and supporting infiltration into groundwater
- maintain the same level of service (generally 50% to 10% AEP storms) in relation to frequency of failure of the downstream drainage network
- reduce peak flows off developed sites to predevelopment levels in events relevant to flows from the site. These events are generally of short duration.

The effects of WSUD measures are much more pronounced at smaller catchment scales and smaller rainfall events and in areas where design rainfalls are lower. At the lot or street scale the impact of urbanisation is much greater as efficient conveyance systems and extra run-off combine. At large waterway scales the conveyance networks are natural and the longer duration and larger-scale storms are generally required to cause flooding. In these situations, WSUD measures may minimise the increase in peak run-off to existing stormwater systems for a limited range of events.

The focus of FRM is on understanding and managing the rare to extreme flood events that have significant impacts on and risks to communities. These may be risks to people or may relate to damage to property and infrastructure. These events are typically of significantly longer duration than those that are relevant to WSUD.

The relevance of the scale of WSUD and its influence on flood behaviour is generally very limited to negligible, particularly given the:

- pre-burst rainfall that typically occurs before events and its potential to reduce the available storage volume when an event occurs. An example is provided in Box 2 below
- nature of flood events that cause significant impacts on the community and therefore are of interest in FRM. In many catchments with significant flood impacts, large-scale weather events, for example, east coast lows (ECLs) (see example in Box 3) may be the dominant event. These events are significantly longer in duration and scale than events used to design local drainage, which is where WSUD techniques are most effective
- key drivers for flood impacts and risks at a location. These drivers can be influenced by structures or by downstream influences such as waterway entrance conditions and coastal processes in the lower portion of coastal waterways.

Box 2: Example – Pre-burst in Sydney

Australian rainfall and runoff (Ball et al. 2019) recognised that in some parts of Australia intense storm bursts are often preceded by significant rainfall (pre-burst rainfall) that is often larger that the initial rainfall lost to infiltration. The table below shows the distribution of pre-burst rainfall in Sydney in millimetres. These values are broadly representative of the NSW east coast, with pre-burst reducing as you move further down the coast.

Pre-burst rainfall (mm)

	20% AEP (1 in 5-year ARI)				1% AEP (1 in 100-year ARI)			
	10%	50%	75%	90%	10%	50%	75%	90%
1-hour	0	8.3	41.1	98.7	0	1.1	23	110.8
2-hour	0	7.1	48.9	123.2	0	8.1	66.7	137.7
24-hour	0	5.4	28.6	95.2	0	27.9	70.8	127.8

Note: ARI = Average recurrence interval.

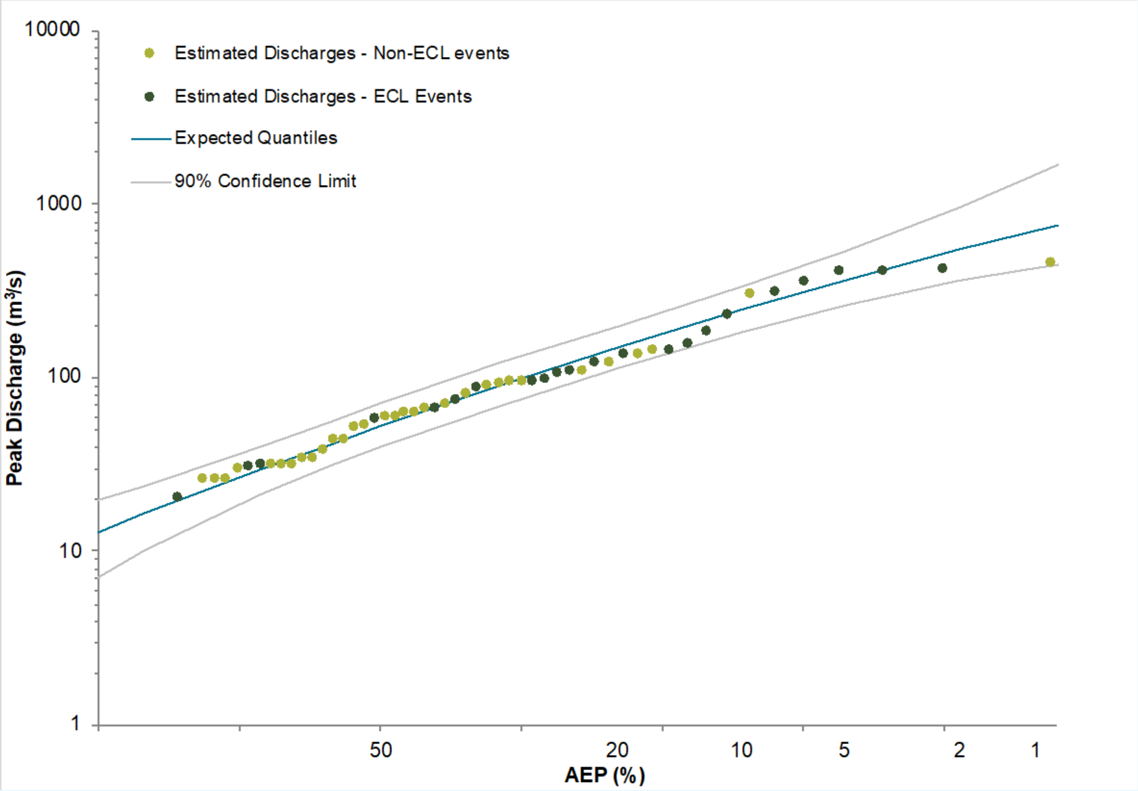
Therefore, WSUD-related measures typically have negligible impacts on flood behaviour in events of the scale and duration that cause significant impacts rather than a nuisance to the community. The ineffectiveness of WSUD to address riverine flooding even in relatively small-scale catchments is highlighted in the study described in Box 4. A separate example in Box 5 discusses the limitations of the benefits of rainwater tanks on flood behaviour.

Investigations into WSUD measures in studies under the program are not generally supported. An agreement from FRM staff in DPE Environment and Heritage Group would be required to examine these measures. If they were examined, like all options, they would need to consider lifecycle costing. This would include the significant costs to ensure the ongoing viability of options with a limited effective life (such as permeable pavements).

Box 3: Example – Influence of storm versus catchment scale

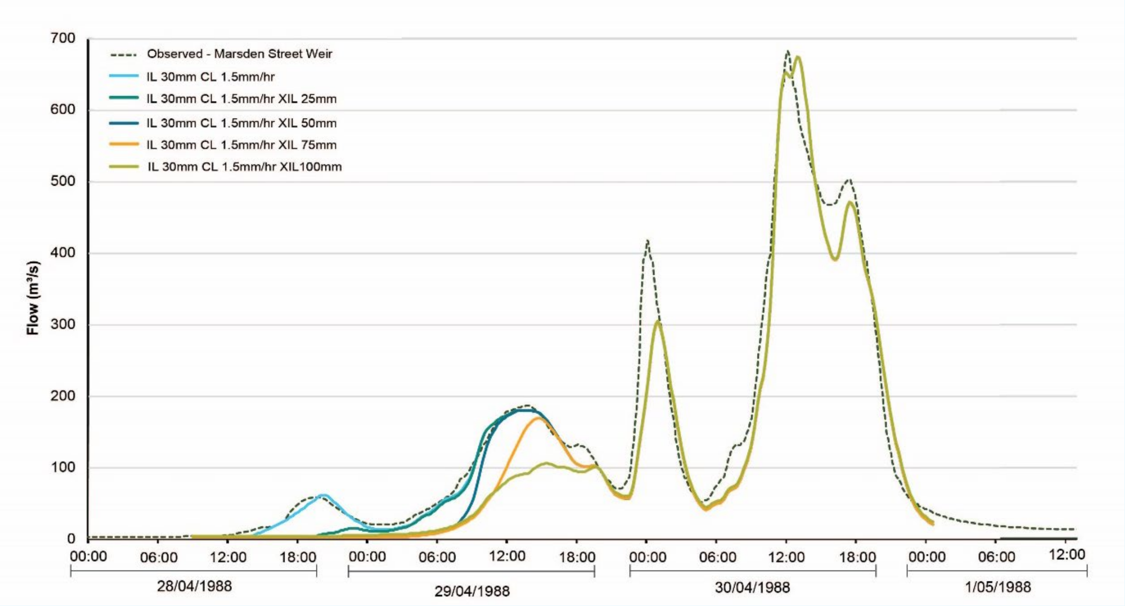
Flooding in larger catchments on the east coast of New South Wales tends to be dominated by larger-scale events, such as east coast lows (ECLs). Convective thunderstorm events are more dominant on small catchments. ECLs have been found to be a dominant on the following catchments (catchment size):

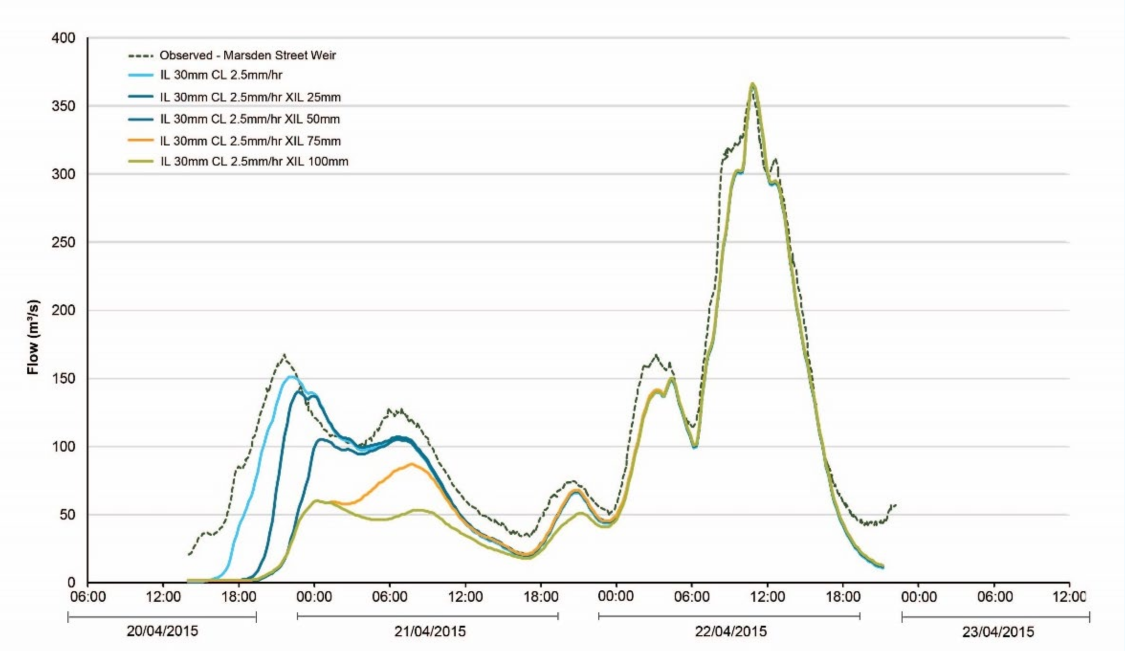
- Hawkesbury River (22,000 km^2). All large-scale events caused by an ECL
- South Creek (620 km^2)
- Eastern Creek (128 km^2)
- Parramatta River (252 km^2)
- Macquarie Rivulet (110 km^2). In addition, on the much smaller 33-km^2 catchment to the gauge on Macquarie Rivulet, nearly every large event was caused by an ECL as the flood frequency analysis below shows.



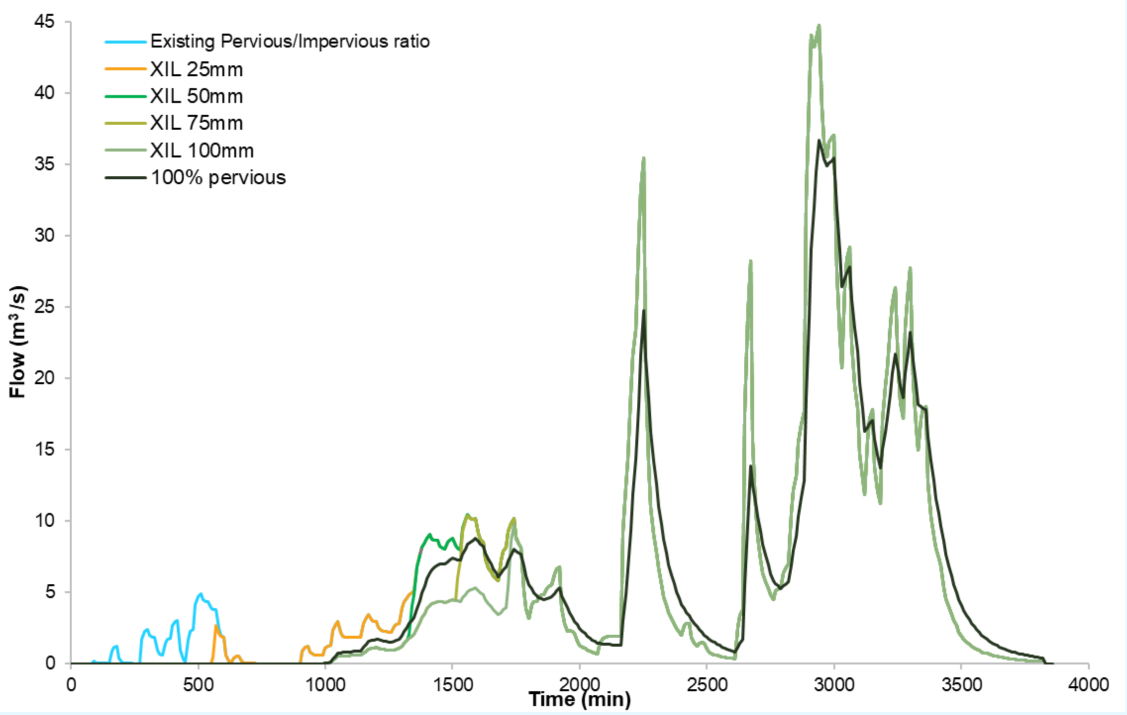
Box 4: Example – Impact of water-sensitive urban design on flooding

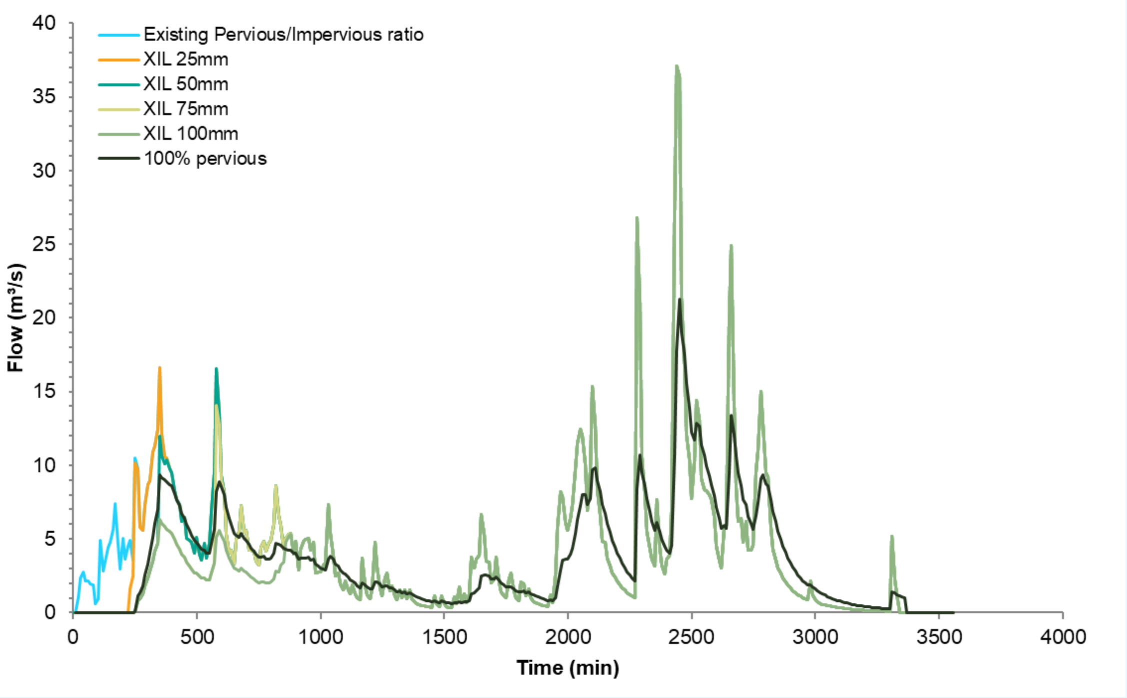
The impact of WSUD on flooding was assessed by examining increased initial loss to mimic additional storage on site. The charts show a 104-km^2 catchment Marsden Weir with the 1988 (1 in 75-year ARI) and 2015 (1 in 12-year ARI) events, respectively. These charts include scenarios for an additional 25–100 mm of initial loss (noted as XIL) across the entire catchment, noting that additional volume capture in WSUD is toward the lower end of these values. In all cases, this additional storage may have influenced flows early in the event but did not impact on peak flows that are critical for FRM later in the event.





The case study was taken further by looking at the impacts of WSUD on this basis on a 400-hectare sub-area in the larger catchment. The charts show the 1988 (1 in 75-year ARI) and 2015 (1 in 12-year ARI) events, respectively. Even at this smaller catchment scale this additional storage influenced flows early in the event but did not impact on peak flows that are critical for FRM later in the event. Note: Green lines overlay other colour lines where these align.





Box 5: Rainwater tanks – limitations on benefits to flooding

Rainwater tanks collect run-off from storm events and therefore have the potential to impact on the peak flows leaving a site. However, their potential to have a significant impact on major flooding external to the site is limited and needs to consider the following points:

- It does not take much rain to fill a tank, for example, 10 mm of rain over 200 m^2 of roof or 20 m over 100 m^2 of roof, would add 2 m^3 or 2,000 litres to a tank.
- Not all water reaches tanks. A significant loss occurs as gutters overtop due to the large volume and high intensity of rainfall associated with a major flood event.
- Using tanks for onsite water demand (e.g. toilet flushing and other uses) means they need a minimum water level for this purpose, with topping up from town water as needed. This reduces the available storage for rainwater.
- Rainwater tanks will have more influence on peak flows in smaller events and may lead to the construction of stormwater pipe systems with less capacity. However, given that the impact of tanks on larger events will be less, there is likely to be more flow outside the pipe system during a major flood, that is, more overland flow to be managed. Therefore, flood problems are unlikely to be reduced if the contribution of rainwater tanks is incorporated into pipe system design.
- Pre-incident (pre-burst) rainfall may result in a considerable amount of water in the tank, reducing its effectiveness. Design procedures consistent with *Australian rainfall and runoff* (Ball et al. 2019) specifically include pre-burst rainfall in addition to the design burst in analysis.
- FRM would generally be interested in events well in excess of 30 minutes and up to days, rather than the shorter 5–15 minutes duration storms that produce peak flows off individual sites. Longer duration storms have significantly larger volumes of rainfall that are more likely to be well in excess of tank capacity, and therefore the influence of tanks will be further limited.
- For small overland catchments, the critical storm duration may change to a higher total volume storm or longer duration storm with broad use of rainwater tanks in a location. This may mean a slight, but not necessarily significant, reduction in peak flows.

Overall, rainwater tanks are very useful in reducing water demand on water supply systems, however, they are unlikely to have a significant impact on flood behaviour and impacts. Therefore, rainwater tanks should not be considered an FRM measure to significantly reduce downstream flood flows.

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More information

Flood risk management manual, guidelines and tools

See links on the following Department of Planning and Environment (DPE) webpages:

- Flood risk management manual
- Flood risk management guidelines
- 'Administration arrangements: flood risk management guideline AG01'

Other links

- Consumer Price Index, Australia – ABS webpage
- New South Wales Treasury guidelines: cost-benefit analysis
- Dams Safety NSW
- Emergency Business Continuity Plan and Home Emergency Plan – NSW SES webpage
- EVRI: Environmental Valuation Reference Inventory

- Floodplain Management Program
- Flood Warning Infrastructure Standard – BOM webpage
- NSW Flood Data Portal
- Plan now for what you will do – NSW SES webpage with link to online tools