Planning for Flood Risk

Duncan B. McLuckie
NSW Office of Environment and Heritage
E-mail: duncan.mcluckie@environment.nsw.gov.au

Angela Toniato
NSW Office of Environment and Heritage
E-mail: angela.toniato@environment.nsw.gov.au

Abstract

Floods can cause significant impacts where they interact with the community and the built environment. However, flooding also has the potential to be the most manageable natural disaster as the likelihood and consequences of the full range of flood events can be estimated enabling risks to be assessed and where necessary managed. Design flood estimation provides essential information on a range of key factors that need to be considered in understanding and managing flood behaviour and its consequences. This paper discusses the role that design flood estimation in understanding and managing flood behaviour and making informed decisions on managing flood risk.

1. INTRODUCTION

Flood risk results from the interaction of the community, through human occupation or use of the floodplain, with hazardous flood behaviour. It is the risk of flooding to people, their social or community setting, and the built and natural environment (AEMI 2013). Flood risk is not simply the probability of an event occurring. AEMI (2013) and ANCOLD (2003) express risk in terms of combinations of the likelihood of events (generally in terms of Annual Exceedance Probability (AEP)) and the severity of the consequences of the event. For example, risk is higher the more frequently an area is exposed to the same consequence or when the same frequency of event has higher consequences.

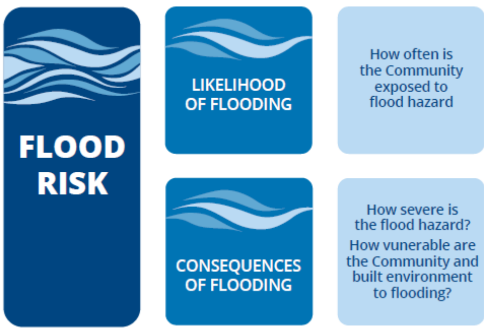


Figure 1 Components of flood risk (After McLuckie (2012))

Consequences depend upon the vulnerability of the community and the built environment to flooding (AEMI 2013). Vulnerability varies with the element at risk, and between and within the cohorts of these elements. It may be measured in terms of the impacts on: *people* (fatalities and injuries); *the economy and assets* (reduced activity and asset losses); *the social setting* (consequences to the broader community such as loss of shops, schools, retail and community events for a prolonged period); *public administration* (ability of communities' governing bodies to deliver core functions); and *the environment (*degradation of critical assets or species). The consequence of the same flood exposure can be different for different elements. For example, a flood may have major consequences for community assets but minor consequences in terms of fatalities and injuries. The likelihood of exposure to flooding and therefore flood risk also varies significantly between and within floodplains and flood events of different magnitudes. Flood risk is discussed in terms of existing risk (related to current development from legacy decisions), future risk (created in making decisions to place new development in the floodplain) and residual risk (the risk to both existing and future development after management measures are implemented).

2. RISK ANALYSIS

Risk analysis is a systematic approach to understanding the nature of and deducing the level of risk. It involves understanding the varying likelihood of events that result in a risk, and the severity of their consequences. These factors are combined to assign a relative risk rating through development of a risk matrix or other tools. Risk analysis can inform decisions on the acceptability of residual risk and the effective and efficient use of scare resources to better understand and manage risk.

Analysis may be quantitative or qualitative. In both cases the probability of events affecting communities may be able to be estimated through design flood estimates. Quantitative analysis is often used where both the probability and the consequences can be measured. For example, consequences may be estimated by determining tangible direct or indirect flood damages to the community for events of different AEPs. Qualitative estimates are generally undertaken where consequences cannot be quantitatively measured. For example, these can include social and environmental impacts which are intangible damages that cannot readily be put in economic terms. Table 1 provides an example of a qualitative risk matrix.

Table 1. Example qualitative risk matrix

	Consequence level				
Likelihood level	**Insignificant**	**Minor**	**Moderate**	**Major**	**Catastrophic**
Almost certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	Extreme	Extreme
Unlikely	Low	Low	Medium	High	Extreme
Rare	Very Low	Low	Medium	High	High
Very Rare	Very Low	Very Low	Low	Medium	High
Extremely Rare	Very Low	Very Low	Low	Medium	High

3. MANAGING FLOOD RISK

Managing flood risk involves a broad risk management hierarchy of avoidance, minimisation and mitigation to address existing, future and residual risks. It can involve a combination of: managing changes within the floodplain that may alter flood behaviour; altering the likelihood (how frequently exposure to flooding occurs); and managing the consequences of flooding (reducing vulnerability to flooding when exposure occurs). Managing risk needs to consider the different elements at risk, which may require different management techniques and be managed to different standards.

3.1. Managing Changes to Flood Behaviour

Changes within the floodplain that can significantly affect flood behaviour include: development (including filling) within the floodplain (particularly in flow conveyance and flood storage areas); land use change within the catchment; and construction or upgrade of above ground infrastructure across waterways and the floodplain. These may result in significant changes to flood behaviour including changes to flow paths, peak flow and velocities, flood levels and extents, distribution of flood waters, and the timing and duration of flooding. These changes can lead to changes in flood behaviour which have adverse impacts on the existing community including emergency response to flooding. Therefore new development projects generally have constraints relating to minimising adverse impacts of changing flood behaviour on existing development, its occupants, infrastructure and the environment.

3.2. Managing Risk by Limiting Likelihood and Consequences

Approaches to managing the likelihood or consequences of flood risk to a community or assets generally fall into the following types: use of design standards that relate to a particular flood event; providing a certain level of service; and use of risk based management approaches.

3.2.1. Design Flood Standards

Design flood standards generally aim to limit the frequency of exposure to flood risk. For example, the use of a minimum floor levels for a building relative to a design flood level aims to reduce the exposure to flooding by excluding flooding from above the floor level of the building in the design flood event. Inbuilt to this approach is acceptance of the residual risk to the building and its occupants inherent in adopting a building standard, i.e. the building is designed to be flooded in events larger than the design flood event. When used in isolation, this approach assumes that the location is suitable for the development, i.e. the development will not impact upon flood behaviour (and adversely impact on flood risk elsewhere in the community) and that the residual risks to the building and its occupants are acceptable or are being managed by other means.

3.2.2. Level of Service Standards

Level of service standards are generally aimed at maintaining serviceability during an event of a particular magnitude. For example, having a road that can provide effective service in a certain AEP design flood event. This approach assumes: that the road will not impact upon flood behaviour and have adverse impact on the community; that the impacts of flooding on the road are acceptable or can be managed by other means; and that the residual risk remaining is acceptable.

3.2.3. Risk Based Decision Making Processes

Risk based decision making processes (such as outlined in AEMI 2013) are used to develop management strategies that consider the risks associated with a full range of flood events and the associated consequences to the community and its supporting built environment. These techniques have been increasingly used to manage dam safety risks (ANCOLD, 2003). This approach can be used in a manner that is complementary to the use of design flood and levels of service standards by examining the residual risk and examining whether additional management measures, including increasing the design flood or level of service may be necessary. For example, the use of a design flood event as a standard for development may reduce the frequency of exposure of people and property to flooding. However, due to changes in flood behaviour outside the development area, the limitations of flood warnings or the flooding of evacuation routes in larger flood events, the risk to people in the community may remain high. Additional management measures such as allowance for flood conveyance and storage areas, development or improvement of a flood warning system so the community can be advised of a flood event and have more time to respond to calls for evacuation; and upgrade of evacuation routes to improve traffic capacity to enable the community to be effectively evacuated within the available warning time may reduce these residual risks.

4. MANAGING FLOOD RISK TO COMMUNITIES

Risk assessment provides an informed basis for the effective and efficient use of often scarce resources to better understand flood risk, manage the growth in risk due to the introduction of new development into the floodplain, and reduce risks to the existing community where warranted. Different treatment solutions may be necessary depending upon the element at risk, the location and whether the risk is to existing or future development. Treatment options may involve a combination of flood mitigation, emergency management, flood warning and community awareness, together with land-use planning arrangements that consider the flood situation. For flood risk to existing development it is important to understand the current flood exposure for the full range of flood events, how the risks to different elements are currently being managed, and whether changes may be warranted to reduce risks to a more acceptable level. Where treatment options to reduce risks are being considered their impacts on flood behaviour need to be considered in decision making.

For flood risk to future development it is important to understand how the flood behaviour varies across the floodplain for the full range of events so that the constraints that this may place on development can be considered in deciding where to develop (and where not to develop), the types of development that may be suitable in different areas, and the flood related development constraints within the site necessary to reduce risks to acceptable levels (in areas suitable for development).

4.1. Using Design Flood Estimation to Inform Flood Risk Management

Design flood estimation can support management of flood risk to the community by improving knowledge of the potential range of flood behaviour and providing tools and information to support decision making. The selection of a modelling approach needs to consider how it will meet the requirements of the project specification. Many management decisions, such as emergency management planning, rely upon an understanding of the full range of floods rather than a specific design event, and need time varying information across of the whole event rather than just at the peak of the event. Critical timing may also relate to the time at which an evacuation route is cut rather than the time to reach the peak flood level and could occur in events that have shorter duration but lower peak flood levels. Managing flood risk involves a range of different groups with different information needs (AEMI (2013)).

Managing flood risk to the community generally requires more knowledge than can be gained from historic flood events as this information is generally incomplete and is unlikely to represent the full range of potential flood events. In addition, there may have been changes within the floodplain or catchment since the historic event that would alter the behaviour or impacts if the same magnitude flood were to occur again today. The use of information from an historic flood event without an understanding of the potential range and severity of flood events and an understanding of how this may vary within a floodplain can result in poor management decisions.

Knowledge of historic floods and their consequences provides a starting point for understanding flood risk. Modelling historic flood events can assist to: calibrate and validate models against known data and the community's experience of flooding; better understand flood behaviour and its variation within the floodplain; and understand the probability of historic flood levels being exceeded in future. Information from historic flood events can be improved using investigative and more sophisticated modelling techniques to increase understanding of the relative frequency of historic events, facilitate extrapolation to provide a greater understanding of the full range of flood behaviour and risk, consider timing during events, and enable assessment of treatment options to inform management decisions.

Design flood estimates can be used for a range of purposes including:

- understanding flood behaviour and risk and how this varies across the floodplain over the duration of a flood event, and between flood events of different magnitudes;
- understanding the time constraints placed on evacuation due to flood behaviour and any limitation of evacuation routes (which can be critical to the safety of the existing community and the inhabitants of future development);
- understanding how flood behaviour, hazards and risks may change due to floodplain, catchment and climate changes;
- establishing design standards based upon a specific design event and assessing whether desired levels of service are met;
- making decisions on the need for risk treatment, comparing and assessing treatment options, and deciding on which options to implement; and
- designing waterway structures, basins, levees, improving warning systems and evacuation routes, and other mitigation measures.

Design flood estimation for the full range of flood behaviour provides the basis for assessing the frequency and severity of flood exposure of different parts of the floodplain and the consequences of flooding to the community. It can also provide a spatial understanding of: where floods of different magnitudes occur; areas that are important for flow conveyance and storage; where conditions are hazardous to people, vehicles and buildings (AEMI 2014b); and the variation in flood evacuation difficulty within the floodplain (AEMI 2014a). Outputs from design flood estimation and flood risk management processes are essential in informing government and industry through input to information systems. This can improve the accessibility of flood information so it can be considered in investment and management decisions by government, industry and the community.

4.2. Using Design Flood Estimation to Support Management of Future Development

Developing on the floodplain places the new development and its occupants at risk from flooding as well as having the potential to impact on flood risk to the existing community. These issues need to be considered in setting strategic directions for the community and determining development constraints. This risk is primarily managed by considering flood risk and the associated constraints into strategic planning and the land use planning system.

Strategic planning provides the opportunity to: limit development within areas where it may impact upon the flood risks faced by the existing community; provide direction on the type of development preferred in different areas; and set development controls in consideration of the risks to the new development. Land use planning systems provide the ability to implement strategic planning. They often use flood standards as a basis for flood related controls and decisions. However, they may also allow consideration of larger floods to examine whether additional development constraints are necessary to deal with residual risks to new development and its occupants, particularly risk to life.

Design flood estimation provides essential information for understanding constraints that include:

- Information to inform decisions on where to (and where not to) develop and the limits on what type of development to place in different areas of the floodplain. For example, development within a flow conveyance area may have significant impacts upon flood behaviour and should generally be restricted to allow the flow conveyance area to perform its natural flood function. Another example is developments whose occupants are particularly vulnerable in evacuation (e.g., aged care homes) would logically be located in areas that are readily evacuated.
- The assessment of the cumulative impacts of development within the catchment and floodplain on flood flows and behaviour. This can enable the examination of catchment scale solutions to offset the impacts of development on flood flows in an efficient manner. Such solutions may include a single series of basins whose interaction is considered.
- Development constraints (such as minimum fill and floor levels and other constraints) that aim to reduce the residual flood risk to the new development and its occupants to an acceptable level.

Interpretation of the outputs of design flood estimation can provide better information on flood behaviour and on related constraints to facilitate more informed decision making. For example Figure 2a shows locations A, B, C and D are all within the design flood extent and therefore would have some flood constraints. However what constraints are important is unclear and therefore these sites might all be expected to have the same flood constraints.

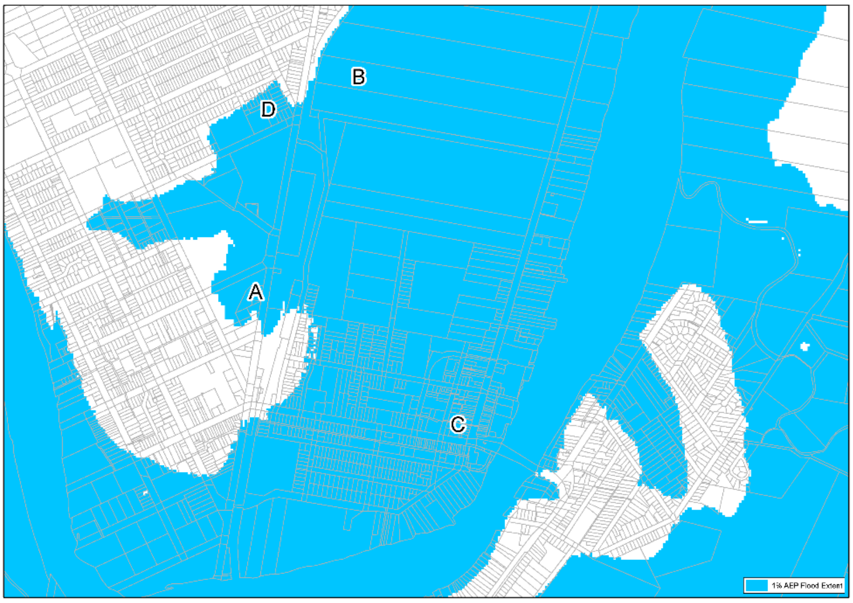


Figure 2a - Extents for single design flood.

Figure 2b shows the same location but having considered flood function, flood hazard and emergency response limitations (due to larger flood events) resulting in a variety of potential options to treat the different flood constraints at each location. Understanding these differences provides better information to inform strategic directions that are more compatible with the differing flood risks.

Design flood estimation also provides essential information to inform consideration of individual development proposals through the planning system. Studies for specific developments generally aim to assess: whether the development will have significant impacts upon existing flood behaviour and the flood risk of the existing community, the impacts of flooding on the proposed development site, and how the risks to the development and its occupants can be effectively managed.

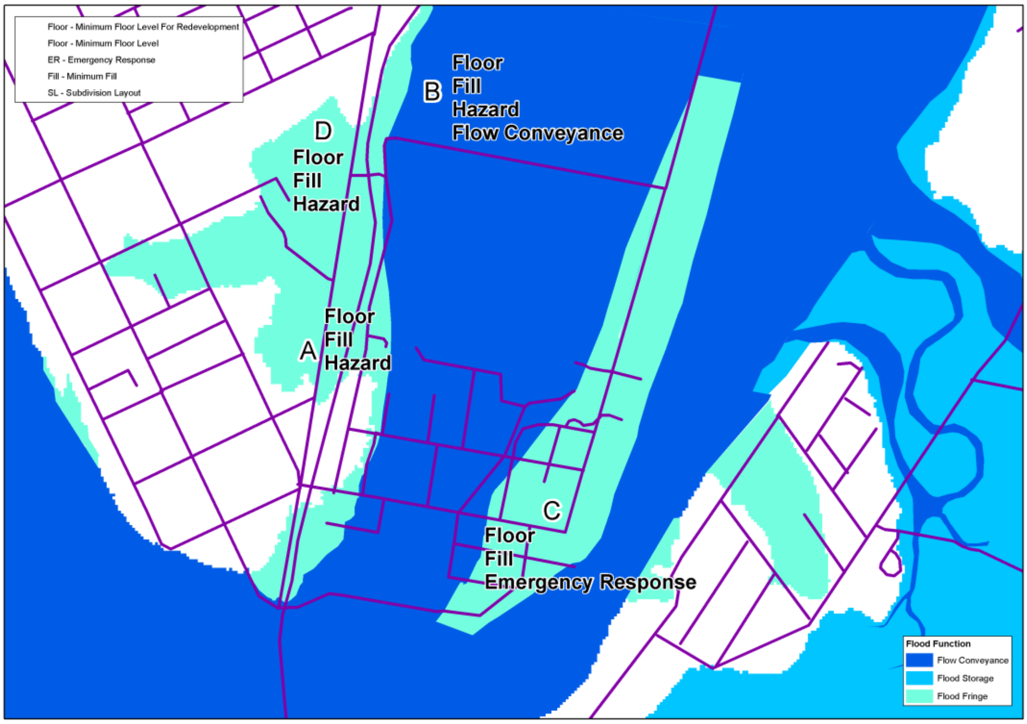


Figure 2b Mapping considers different design events, flood function, flood hazard & differences in evacuation difficulty at each location.

4.3. Understanding and Treating Risk to the Existing Community

The consequences of flooding and the associated risks to the existing community may warrant changes to management practices to reduce residual risks to a more acceptable level. Treatment of risk to existing development is often a compromise between the benefits and costs of treatment in consideration of what is feasible and practical. Design flood estimation provides a basis for understanding flood behaviour across a range of flood events to support our understanding of risk and to assess treatment options. Figure 3 provides an example of a graphical representation of the variation of relative risk to different elements over the full range of flood behaviour for a location. Risk levels are determined using qualitative and quantitative estimates of consequences using Table 1. In this example, for events more frequent than a 10% AEP event the consequences to people and the community are insignificant and risks are low whilst the consequences for property are minor and risk is medium. Consequences to people rises to major for floods rarer than the 10% AEP flood event and consequences to property rise to major in unlikely to extremely rare floods. Impacts upon the community and its supporting infrastructure are moderate for events greater than the 10% AEP and do not reach major levels. The risks people and property are high for events between a 10% and 0.01% AEP event and there is a medium risk to the community. The low likelihood of extreme events without significant additional consequences results in a lower risks. In this example risks to people and property may be considered high and the effectiveness of options to reduce risk assessed.

Where treatment options are proposed that may change flood behaviour the calibrated and validated models that define the existing flood situation are altered to incorporate proposed options and design flood event estimates developed for the changed conditions. This information, in combination with other information, can indicate changes in the consequences of flooding to the existing community. These changes can be used to assess the benefits and costs of the treatment option to the existing community and the limitations of options in managing risk. Benefits and costs of treatment options may be assessed singularly, as well as in combination with complementary treatment options, as it is rare for a single treatment option used in isolation to effectively manage flood risk to a community. For example, a levee may be built (to reduce flood damage) in combination with a flood warning system and upgraded evacuation routes (increasing evacuation capacity) to improve community safety during floods.

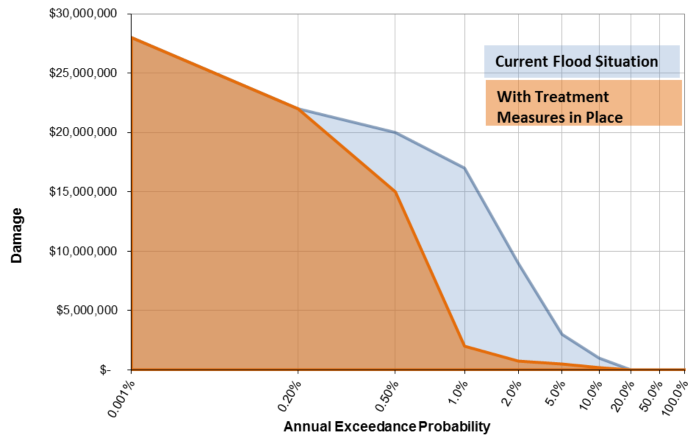
Likelihood of Consequence	AEP Range %	Level of Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likely	>10	People Community (Low)	Property (Medium)	(High)	(Extreme)	(Extreme)
Unlikely	1 to 10	(Low)	(Low)	Community (Medium)	People Property (High)	(Extreme)
Rare to very rare	0.01 to 1	(Very Low)	(Low)	Community (Medium)	People Property (High)	(High)
Extremely Rare	<0.01	(Very Low)	(Very Low)	Community (Low)	People Property (Medium)	(High)

Legend

Risk Scale	*Very Low*	*Low*	*Medium*	*High*	*Extreme*

Figure 3 Example of estimating relative existing and residual risk in a community due to flooding

One quantitative method of determining the financial efficiency of the project involves understanding the benefits in reduction in flood damages and comparing this to the costs of achieving and maintaining this benefit. Damage reduction can be estimated by determining the reduction in annual average damages (AAD) and exposure of the community to flooding with treatment options in place. For example a levee designed to exclude the 1% AEP design flood from an affected area will reduce flood damages for events up to the design flood. The consequences of floods rarer than the design flood may not change significantly and may still have substantial impacts upon the community. AAD calculations across a broad range of flood events (including events more frequent and rarer than the design flood for the treatment option) provides a sound basis for understanding the financial benefits and limitations of an option so this can be considered in decision making. Figure 4a shows an example of the estimation of the financial benefits (average annual benefits, AAB) of a treatment option based upon the difference between the AADs for treated and untreated cases (i.e. blue shaded area in Figure 4a). In this example the treatment option is a levee which aims to reduce flood damages and the frequency of community exposure to flooding and associated risks flood events up to the 1% AEP design flood. In a 0.2% AEP event the damages with and without the treatment option would be the same. Translating both the AAB and lifecycle costs (Figure 4b) into net present value figures for the design life of the project enables a direct comparison to determine the relative financial efficiency of the option by developing a benefit to cost ratio.



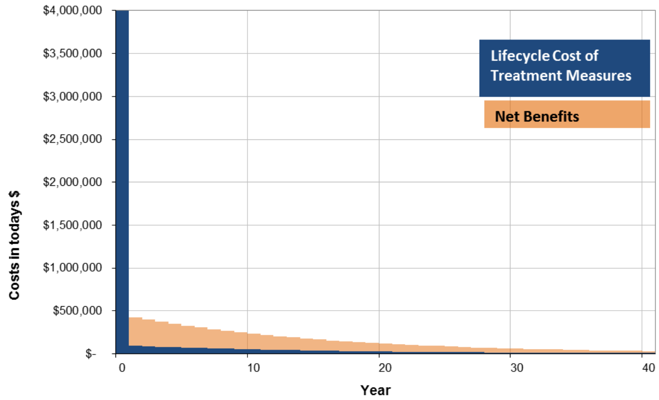


Figure 4a Flood damage with and without treatment and Figure 4b Lifecycle costs versus net benefits

The benefit cost ratio calculated can be used in conjunction with consideration of other benefits, such as reduction in risk to life, reduction in the impacts upon community function and infrastructure and consideration of environmental impacts, community attitudes and broader feasibility with similar information for other treatment options (including those providing protection for different AEP events) to inform decisions on treating risk. The potential changes in risk to the community can also be displayed, as shown in Figure 5. This example shows a levee for a 1% AEP design flood. It shows a reduction in risk to property from a maximum of high to a maximum of medium in events above a 1% AEP event but low in events less than the design event. However, risk to people is still high due to the impacts of events greater than the 1% AEP event and may warrant additional treatment. Depending on why this risk remains high, options to address this risk may include but not be limited to flood warning systems and improvements to evacuation route capacity.

Likelihood of Consequence	AEP Range %	Level of Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likely	>10	People Community PROPERTY	~~Property~~			
Unlikely	1 to 10		PEOPLE COMMUNITY PROPERTY	~~Community~~	~~People~~ ~~Property~~	
Rare to very rare	0.01 to 1			Community PROPERTY	People ~~Property~~	
Extremely Rare	<0.01			Community	People Property	

Legend **Consequences before treatment or where risk unchanged**, **Consequences after risk treatment where changed**

Risk Scale	***Very Low***	***Low***	***Medium***	***High***	***Extreme***

Figure 5 Example of estimating changes in relative existing & residual flood risk with treatment

5. CONCLUSIONS

An understanding of flood behaviour is essential to be able to understand flood risk and consider the treatment necessary to manage the risks to the existing and future community and the built environment.

Design flood estimation provides a sound basis for taking the limited knowledge from historical events and using this information to better understand how flood behaviour varies across a floodplain, between events over a range of different magnitudes and over time during a flood event. This information is important to our understanding how flood risks to people, the community and the environment may vary and considering whether current management approaches are adequate to address this risk. Where current management approaches for existing development need improvement, design flood estimation can provide essential information to inform our understanding of the potential changes in flood behaviour due to the instigation of treatment options. Combining this with other information on the treatment option, such as benefits to the community in reduced exposure to risk and reduced damages and impacts on flood behaviour can support decision making on options.

Design flood estimation can also provide important information to inform strategic land use planning, where decisions are made on where to develop and the types of development preferred in different areas. As Figure 2 shows, where more sophisticated information on flood constraints is available, more specific controls can be put in place to deal with the local flood risk factors. For instance, an understanding of the variation in likelihood of flooding, flood hazard, flood function and evacuation difficulty can provide important information on constraints that can be considered in this decision making. This information can then feed into planning instruments and policies which can support development controls to reduce impacts of development on flood risk to the existing community and reduce the residual risks to the new development and its occupants.

6. ACKNOWLEDGMENTS

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