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Flood Risk Mapping — What, Why, How?

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Abstract

The industry in which we work has become specialised to the point that we now refer to ourselves as flood risk managers. Critical to the tasks of a flood risk manager is the preparation of flood maps which depict information about the flood hazard and, in more recent times, often attempt to go further and indicate flood related risks. The mapping of flood hazard can generate its own issues for debate but is generally considered more straightforward than risk mapping. If (simplistically) risk is a product of the probability and consequence of the flood hazard impact, this will vary dependent on existing and future land uses and associated activity. This is a dynamic state, which is not readily reflected on a static map. Therefore what is it that we are actually trying to map if indeed we map flood risk?

The production of maps is an important tool in conveying information to those involved in managing the risks, politicians and the community. Understanding what the relative flood risks are across a floodplain can be an invaluable tool in land use planning and emergency management, and in prioritising expenditure on structural mitigation works. The movement towards universal flood insurance is also generating a need for flood risk maps. The authors believe that there are substantial reasons to support the production of flood risk maps and indeed these are an expectation of contemporary floodplain risk management plans. The difficult question that has been the subject of much informal debate but little formal direction is how should a flood risk map be prepared?

The authors have been producing "flood risk precinct" mapping for over a decade and the maps have been widely accepted and included in nearly twenty Council policies and development control plans (DCPs) under the NSW EP&A Act. Whilst the policies and the flood risk maps are being successfully applied to manage land uses within floodplains, the term "flood risk" and the underlying basis of the maps remain poorly understood.

This paper outlines the case for the production of flood risk maps and discusses the information they should provide and how to produce such maps, with an emphasis on risk mapping for land use planning. The authors' view is that the maps must be prepared as part of a package that identifies the relative risk to different land uses and the associated occupation and activities within the floodplain. The consequence of flood impacts will vary dependent on the nature of a land use at any particular location but also how it interacts with the other activities in the floodplain such as the availability of transport routes, communication and utility services during and after a flood. This should be relevant regardless of whether the land use exists or may occur in the future.

1. WHAT IS FLOOD RISK?

The term "flood risk" has a variety of meanings in the community and amongst floodplain risk managers in Australia. This has lead to confusion over the purpose of flood risk mapping and generated a lack of clarity in identifying, mapping, managing and communicating flood risks by practitioners.

The Concise Oxford dictionary defines "risk" as

> *"hazard, chance of or chance of bad consequences, loss, etc., exposure to mischance…"*

Therein lies a source of the confusion. The term is used in every day speech to mean "hazard", "chance" and "exposure".

The NSW Floodplain Development Manual (NSW Gov't, 2005) uses the following definition of "risk" which is similar to the definition in the Australian standard on risk management, AS/NZS 4360:2004, and Floodplain Management in Australia – Best Practice Principles and Guidelines (SCARM, 2000). (Definitions of "risk" from these various publications are reproduced in the appendix to this paper):

> *"risk: — the chance of something happening that will have an impact. It is measured in terms of consequences and likelihood…."*

A review of the above definition and those in the appendix to this paper leads one to ask whether "flood risk" is:

(a) a chance of something happening? This is apparently the approach adopted by SCARM. They say that the risk of a 1% AEP flood is 1 in 100. In other words, risk is synonymous with likelihood or probability. Or is risk

(b) a hazard or a consequence? The hazard and consequences of flooding relate to both property and people. There are various systems for classifying hazard/consequence of which the most rigorous are those in the NSW Manual, those prepared by Newcastle City Council (NCC, 2005), the Guidelines produced through the Hawkesbury-Nepean Floodplain Management Steering Committee (H-NFMSC, 2006) and those discussed by Walsh, Benning and Bewsher (1998). Defining "flood risk" in terms of hazard and consequence is the approach adopted in the NSW Manual (but not for the definition of "risk" – see appendix to this paper). Or is risk

(c) some combination of the likelihoods and consequences of flooding? This is the approach preferred by the authors and follows the traditional engineering definition of risk as the mathematical product of likelihood and consequence. It is also consistent with the approach presented in H-NFMSC (2006) which is one of the most comprehensive set of guidelines for managing flood risks that has yet been produced in Australia.

Practitioners need to recognise that "flood risk" means different things to different people and that flood risk maps will likely be different and will comprise different indicators of the flood threat. This situation is not going to change. Further, such maps will be used for a variety of purposes as discussed in Section 2 of this paper.

In Section 3 of this paper, the authors describe a system of flood risk mapping based on the definition of risk in (c) above, and which has particular application to land use planning. This system of flood risk mapping has been successfully applied by many Councils in NSW to control land uses within their urban and rural floodplains.

2. WHY MAP FLOOD RISKS?

Flooding has long been recognised as Australia's most manageable natural disaster.

The challenge for practitioners is to effectively manage flood risks in a political climate where the level of mitigation funding is grossly inadequate and the community's awareness of their flood risks is determined largely by their experiences of flooding which are usually very limited or fade rapidly as time goes by. Further, major floods in Australia do not occur frequently enough for an adequate level of flood awareness to be maintained.

Mapping of flood risks is an essential component of the floodplain management process and emergency management planning. Whilst mapping of flood behaviour by practitioners is well established, the same cannot be said for flood risk mapping. The maps which are produced are limited and variable, and are not always included in floodplain management studies. When they are included, they tend to focus on one or two of the principal consequences of flooding such as maps of houses flooded above floor level in a 100 year ARI event, or roads inundated along evacuation routes.

Potentially much more use of flood risk mapping could be made, particularly with the aid of geographical information systems (GIS). The mapping could include:

(a) maps of existing flood risk. By combining flood behaviour mapping with mapping of existing land use and transport infrastructure, a wide variety of flood risk maps could be produced. These could comprise mapping of the flood threat posed to:
  – residential houses;
  – aged persons facilities, hospitals, nursing homes;
  – industries vulnerable to flooding;
  – road, rail and airports;
  – critical utilities;
  – 'shrinking islands' and areas that become isolated; and
  – vulnerable groups within the community caused by their physical capabilities (e.g. the disabled) or their ethnic or socio-economic circumstances.

  Such mapping would need to be dynamic and altered as land use and occupation of the floodplain changed with time. The three key critical uses of maps of existing flood risk comprise:
  – emergency management planning;
  – raising community awareness of flood risks; and
  – evaluating and prioritising flood mitigation works and measures,

  however the maps could also serve a variety of other purposes including insurance.

(b) maps of continuing flood risk. Continuing flood risk is the risk remaining after proposed flood risk management measures have been implemented. By mapping continuing flood risk and comparing it with the existing flood risk maps, the benefits of any proposed flood risk management measures could be evaluated;

(c) maps of flood risk for land use planning purposes. These maps show the underlying flood risk in terms of its suitability for future development, and therefore do not utilise information about existing land uses and occupation. These type of risk maps are the main consideration of this paper and are discussed in more detail in Section 3 below.

3. HOW TO MAP FLOOD RISKS FOR LAND USE PLANNING

Floodplain management practice has undergone a shift from structural to non-structural works and measures since the 1980s. Opportunities to construct works to remove the existing threat of flooding from a community are usually limited because most viable works have already been constructed, or because the works themselves are not cost-effective, have unacceptable environmental consequences, or there is the lack of political will and funds to build them.

Consequently, non-structural works and measures are often the most significant components of floodplain management plans. Certainly it has been the authors' experience that non-structural measures, and predominantly the preparation of land use planning controls, are usually the principal and most important outcomes of these plans.

Mapping of flood risk is a key component in the development of land use planning controls, and in conveying flood information to the community and decision makers.

3.1. Considerations in Mapping Flood Risk for Land Use Planning Purposes

Noting the purpose to which the maps are to be put and the likely audience, the following issues need to be considered when preparing such maps:

(a) the importance of keeping it simple. Flooding, and particularly the probabilities associated with flooding, are potentially complicated issues for the community. Simplified terms and concepts need to be used wherever possible;

(b) there are very real community and political sensitivities associated with public maps of flood risk;

(c) flood consequences involve both property damage and public safety. Community views on the relative importance of these consequences may vary but both must be included when considering risk. (A system for classification of the risks associated with these consequences is discussed in Section 3.2 below);

(d) whilst procedures have been developed to quantify the direct tangible damage, indirect damage, social impacts and public safety risks are not easily quantified. Therefore some form of broad classification is required. This is necessarily a subjective process which must be informed by community participation;

(e) floods come in all shapes and sizes. In this regard, best practice requires that the full spectrum of floods be considered from frequent events such as the 5 year average recurrence interval (ARI) event through to rare events such as the probable maximum flood (PMF). Fixation with a singular flood standard such as the 100 year ARI event has long been regarded as a major obstacle to the proper assessment and management of flood risks in Australia; and

(f) flooding is but one of many factors that town planners consider when making land use planning decisions. Town planners do not have the training nor background to deal with merit type assessments involving a number of flood consequences and probabilities. Aggregation of these consequences and probabilities into a single measure and adoption of a simple scaling system such as used with bushfire risks in NSW (i.e. division into 'low', 'medium' and 'high' bushfire risks), is preferred. This removes the need to refer to probabilities.

3.2. Property Damage and Personal Safety Consequences

With risk defined as the product of probability and consequences, identification of flood risks initially requires a comprehensive study of flood behaviour and its potential interaction with people and property.

The impacts of flooding are diverse and comprise both tangible and intangible damage including personal safety threats. This includes direct damage to goods, buildings, utilities and infrastructure, and indirect damage such as clean up costs, loss of wages, loss of production and the opportunity cost to the public associated with the closure of public facilities. Loss of life, social and environmental impacts, and the emotional, mental and physical ill health costs are very real impacts although it is impossible to measure these costs in financial terms.

There are accepted procedures for quantifying the direct and indirect costs of flooding to the community and these are summarised in the NSW Floodplain Development Manual, the Victorian Rapid Appraisal Method (DNRE, 2000) and other guides to best floodplain management practice. By considering the probabilities and consequences of these economic impacts it is possible to construct a matrix of property damage risks as shown in Table 1.

Whilst it is possible to quantify many of these risks because of their economic impact, it is nevertheless beneficial to express the outcomes in terms of relative risk (i.e. low, medium, high and extreme) which is consistent with the approach in both AS/NZS 4360:2004 and H-NFMSC (2006).

A matrix of personal safety risks can also be drawn, such as that shown in Table 2. Safety risks are much harder to quantify and prioritise and are nearly always presented in relative risk terms as shown in Table 2. Views about what levels of safety risks are acceptable to the community vary considerably both inside and outside the profession.

TABLE 1: PROPERTY DAMAGE RISK (PDR)

Probability		Consequences (Property Damage)				
		Insignificant	Minor	Moderate	Major	Catastrophic
AEP	ARI	<$1K[#]	$1K–$5K[#]	$5K–25K[#]	$25K–$100K[#]	>$100K[#]
20%	5 Year	**M**PDR	**H**PDR	**E**PDR	**E**PDR	**E**PDR
5%	20 Year	**L**PDR	**M**PDR	**H**PDR	**E**PDR	**E**PDR
1%	100 Year	**L**PDR	**L**PDR	**M**PDR	**H**PDR	**E**PDR
0.2%	500 Year	**L**PDR	**L**PDR	**L**PDR	**M**PDR	**M**PDR
Rare*	PMF	**L**PDR	**L**PDR	**L**PDR	**L**PDR	**L**PDR

Notes: **L**PDR = **Low** Property Damage Risk
MPDR = **Moderate** Property Damage Risk
HPDR = **High** Property Damage Risk
EPDR = **Extreme** Property Damage Risk
AEP = Annual exceedance probability
ARI = Average recurrence interval
* The AEP of a PMF varies and is typically 10^{-3}% – 10^{-4}% and can be quantified using procedures in AR&R (I E Aust, 2001).
[#] Damage to single story brick veneer residence. For more complete consideration of property damage risks, see (H-NFMSC,2006)

TABLE 2: PERSONAL SAFETY RISK (PSR)

Probability		Consequences (Personal Safety)				
		Insignificant	Minor	Moderate	Major	Catastrophic
AEP	ARI	SI: Few stability problems	SI: Children washed off feet	SI: Parked vehicles unstable	SI: Adults and vehicles easily washed away	SI: Extreme danger
		EI: >3	EI: 1.5—3	EI: 1–1.5	EI: 0.5—1	EI: <0.5
20%	5 Year	**L**PSR	**M**PSR	**H**PSR	**E**PSR	**E**PSR
5%	20 Year	**L**PSR	**M**PSR	**H**PSR	**E**PSR	**E**PSR
1%	100 Year	**L**PSR	**L**PSR	**M**PSR	**H**PSR	**E**PSR
0.2%	500 Year	**L**PSR	**L**PSR	**M**PSR	**H**PSR	**E**PSR
Rare*	PMF	**L**PSR	**L**PSR	**M**PSR	**M**PSR	**E**PSR

Notes: **SI** = **Stability index** — stability of persons and vehicles in flood waters. Determined from Appendix L of NSW Floodplain Development Manual and Chapter 14 of AR&R (I E Aust, 2001).
EI = **Evacuation index** — ratio of the actual time available for evacuation to the time needed for evacuation.
Note that the combinations of SI and EI into consequence categories will vary with number of persons at risk and various other factors including local conditions. More rigorous measures than EI are often required to assess PSRs associated with evacuation.
LPSR = **Low** Personal Safety Risk
MPSR = **Moderate** Personal Safety Risk
HPSR = **High** Personal Safety Risk
EPSR = **Extreme** Personal Safety Risk
AEP = Annual exceedance probability
ARI = Average recurrence interval
* The AEP of a PMF varies and is typically 10^{-3}% – 10^{-4}% and can be quantified using procedures in AR&R (I E Aust, 2001).

Table 2 includes two of the most important considerations, evacuation and the potential for floodwaters to destabilise and wash away vehicles and pedestrians, as these threats frequently lead to loss of life during major flood events.

3.3. Aggregate Risk Exposure

For the purpose of land use planning, it is useful to reduce the complexity of information presented in Tables 1 and 2 and to derive the aggregate risk exposure of a parcel of land to the flood threat. This aggregate risk exposure is a single measure of risk and is similar to other natural hazard risk classifications such as bushfire risk, which are utilised by planners.

The mapping of aggregate risk exposure for flooding results in the division of land into what the authors refer to as "flood risk precincts". Over the past 10–15 years, the authors have mapped flood risk precincts for more than twenty floodplains and developed planning controls to manage the consequences of flooding in these precincts.

The aggregate risk exposure combines the property damage risks and the personal safety risks shown in Tables 1 and 2 over all floods for a single piece of land, and can be expressed in mathematical notation as follows:

$$\textit{Aggregate Risk Exposure} = \int_{\textit{all floods}} \textit{Probability} * \textit{Consequence} \quad \rightarrow \quad \boxed{\text{Flood Risk Precinct}}$$

The symbol shown above represents mathematical integration which aggregates the probability and consequences over the full spectrum of flooding at a given site. Thus the consequences of flooding during say a 5 year, 100 year and PMF event are all combined in one measure. (This is similar to the way average annual damage is used by practitioners to present the property damage over all floods that might be experienced at a site). Note that defined in this way, aggregate risk exposure and flood risk precincts are quite different from flood hazard. This is because hazard is flood-specific (i.e. it relates to a particular flood such as the 100 year ARI event) and focuses on the characteristics of that particular flood (i.e. depth and velocity), rather than the consequential impacts upon the built and natural environments.

3.4. Classifying Floodplains into Flood Risk Precincts for Land Use Planning

The most common use of flood risk precincts maps is to determine the appropriateness of new developments within a floodplain. For this purpose, it is the inherent or underlying risk associated with the land's flood characteristics that is important, not the actual risks associated with the existing buildings and occupation. In other words, if one is considering the redevelopment of a site, the flood risks associated with the existing buildings and occupation are irrelevant[1]. Consequently, the risk assessment and mapping of flood risk precincts is carried out ignoring existing land uses and assuming typical residential land uses are in place[2].

The flood risk precincts are usually expressed as a relative risk, i.e. 'high', 'medium' and 'low' and the authors have found that this three tiered system works well for land use planning in most floodplains. Nevertheless they have on occasions used four or five tiers where the local circumstances required it.

The process of determining flood risk precincts is shown diagrammatically in Figure 1 below.

[1] Redevelopment of highly flood prone sites is often encouraged as a flood mitigation measure. In such circumstances, it may not be possible always to meet current standards for floodplain developments and it may be appropriate to grant concessions to allow development at a lower standard rather than see no redevelopment take place at all. In these cases, it is normally appropriate to ensure the development achieves a meaningful net reduction in flood risk. In such a situation, the risks to the existing buildings and its occupants cannot be ignored.

[2] Nevertheless the associated land use planning policies (see Section 3.6) which accompany and embellish the flood risk precinct maps, address all possible land uses.

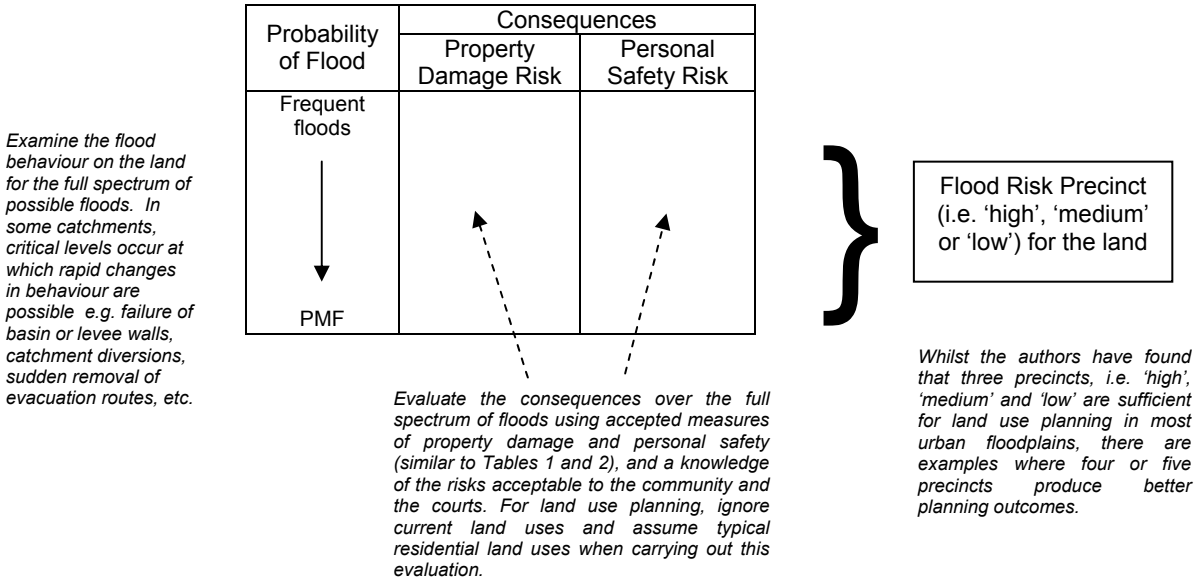

FIGURE 1: DETERMINING FLOOD RISK PRECINCTS

3.5. Simplified Procedures for Mapping Flood Risk Precincts

Through aggregating risk and mapping flood risk precincts using the procedure depicted in Figure 1, it has been found that for many urban floodplains, the areas of the low, medium and high flood risk precincts can often be mapped using the following simplified procedure:

(a) the high flood risk precinct is mapped as all areas of the floodplain experiencing high hazard conditions in a 100 year ARI flood event. (This is determined using the provisional hazard criteria for depth and velocities defined in Appendix L of the NSW Floodplain Development Manual). In addition, areas where there is a significant threat to human life due to inadequate evacuation capability in a 100 year ARI flood are also included in the high flood risk precinct;

(b) the medium flood risk precinct is mapped as all other areas of the floodplain inundated in a 100 year ARI flood event, excluding those mapped as high flood risk precinct; and

(c) the low flood risk precinct is mapped as all remaining areas of the floodplain (i.e. within the extent of the PMF) that have not been mapped as either high or medium flood risk precinct.

It must be stressed that this is a simplified procedure which cannot be applied to all floodplains. This simplified procedure should always be accompanied by at least a cursory overview of the potential consequences arising from the full range of floods (frequent to PMF). This is essential to determine that there are no particular characteristics of the floodplain that would warrant an alternate classification system. As a rule of thumb, where the difference between the height of a 100 year ARI flood and a PMF exceeds 2.5m then the simplified procedure may not be appropriate without further detailed analysis.

The advantages of the simplified procedure include:

(a) it can be readily mapped in a GIS system;

(b) it lends itself to use by Council staff and consultants, and others not directly involved in the initial flood risk precinct mapping (and which usually involve subjective assessments

of risk). As many flood studies are undertaken subsequent to the initial mapping (e.g. as part of development applications), this simplified procedure removes the need for subjective assessments and ensures that new risk areas are mapped consistently with the original mapping;

(c) the high flood risk precinct, (which often leads to the most controversial development outcomes), is based largely on the flood characteristics of the 100 year ARI event. Whilst this approach is somewhat simplistic, it appears to be readily accepted by the courts and councillors, given the past reliance on this event as the 'flood standard' in many council areas;

(d) it cannot be used where there is a large flood height range (e.g. Hawkesbury–Nepean Valley) or where there are unusually serious safety threats caused by floods larger than the 100 year ARI. (Examination of flood behaviour intermediate between the 100 year ARI and the PMF must be undertaken before the procedure can be applied); and

(e) the procedure utilises as a minimum, detailed flood behaviour modelling of depths and velocities for a frequent flood event (e.g. 5 year or 20 year ARI), the 100 year ARI and the PMF. Within NSW, such modelling is usually a minimum requirement of government funded flood studies and is therefore often readily available.

3.6. Combining Flood Risk Precinct Maps with Land Use Planning Policies

The value of the flood risk precincts maps arises when used in conjunction with planning controls developed specifically for the risk precincts. Most commonly in NSW this involves the preparation of development control plans (DCPs) tailored to the risk precincts. The authors have written a number of papers relating to the preparation of such policies including those listed in the References section below.

Figure 2 below provides an overview of typical planning outcomes obtained from the application of the risk precinct mapping and planning policies (in this case assuming use of the simplified mapping procedure).

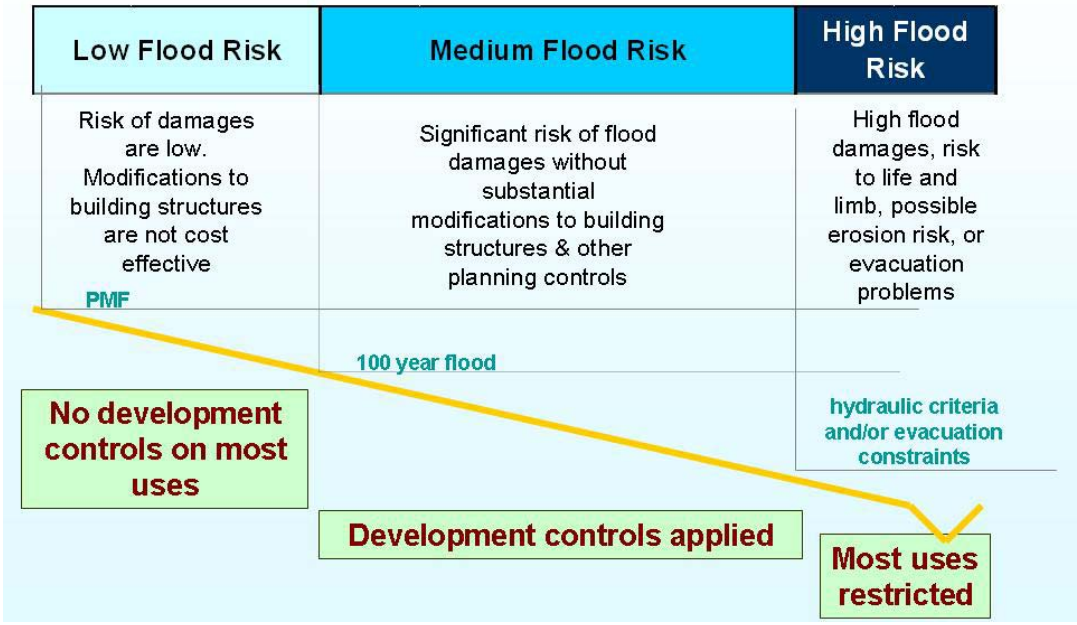

FIGURE 2: TYPICAL LAND USE PLANNING OUTCOMES

The primary aim of the risk precinct mapping and its associated planning policies is to produce effective land use controls. Consequently, the ultimate test of the risk mapping described in this paper, is whether the land uses that result from the application of the mapping and the policy, produce outcomes[3] that are acceptable to the community and are consistent with best practice (including the courts).

4. CONCLUSIONS

(a) The term flood risk has a variety of meanings. This has lead to confusion in identifying, mapping, managing and communicating flood risk. Defining flood risk as the product of likelihood and consequences (to property and people) has been adopted in this paper.

(b) Flood risk mapping can be prepared for different purposes and take various forms. Most importantly, such mapping of existing flood risks (based on existing land uses) should inform emergency management planning, raise community awareness and allow evaluation of flood mitigation works and measures.

(c) A further system of flood risk mapping to serve land use planning within floodplains has been described in detail. This system is based on aggregating property and personal safety risks across all floods, into a single measure of relative risk. This is mapped as high, medium and low flood risk precincts (or similar relative risk tiers).

(d) When accompanied by planning controls for each risk precinct, this risk mapping has proved an effective method of informing the planning process and ultimately for evaluating and conditioning floodplain developments in many NSW local government areas.

(e) A simplified procedure for mapping flood risk precincts based on model output typically available from government funded flood studies is also described.

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[3] For example, assume an area is mapped as a 'medium flood risk' and the associated planning controls allow residential development (albeit with conditions) but do not allow aged care developments. The litmus test is whether this outcome results in a level of risk that is acceptable to the community and consistent with best practice, without unnecessarily sterilising the floodplain.

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APPENDIX – VARIOUS DEFINITIONS OF RISK

These definitions have been extracted from the glossaries of recognised publications on risk management in Australia:

AS/NZS 4360:2004

Risk — the chance of something happening that will have an impact upon objectives.

> Note 1: A risk is often specified in terms of an event or circumstance and the consequences that may flow from it.
> Note 2: Risk is measured in terms of a combination of the consequences of an event and their likelihood.
> Note 3: Risk may have a positive or negative impact.
> Note 4: See ISO/IEC Guide 51, for issues related to safety.

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NSW Floodplain Development Manual, 2005

Risk — chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual, it is the likelihood of consequences arising from the interaction of floods, communities and the environment.

Flood Risk — potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods…

Floodplain Management in Australia – Best Practice Principles and Guidelines, 2000

Risk — … the chance of something happening that will have an impact on objectives. It is measured in terms of consequences and likelihood. For example, if the 50 year ARI flood causes $20 million in flood damage, the risk of a flood causing $20 million damage is 1 in 50. ….

Flood Risk — see *Annual Flood Risk*

Annual Flood Risk — a way of specifying the likelihood of flooding on an annual basis. For example, the 1% AEP flood has a probability of 0.01 of occurring in any year. The *risk* of this flood occurring in any one year is 1 in 100 or 1/100.