

Delineating hazardous flood conditions to people and property

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Abstract

Floods create hazardous conditions to which humans are particularly vulnerable. If floodplains were unoccupied and unused, flooding would not create a risk to the community. It is the human interaction with the floodplain, and the associated exposure to flood hazard, that creates flood risk.

Fast-flowing shallow water or slow-flowing deep water can unbalance people and vehicles, and sweep them away. Similarly, floodwaters can result in significant impacts on the built environment. Structures can be undermined, or have their structural and non-structural elements damaged or destroyed by floodwater and debris. The contents of structures are generally vulnerable to contact with floodwater, and can also be severely damaged or destroyed.

The safety of people and the susceptibility of development and infrastructure to damage are primarily linked to flood behaviour, which will vary across the floodplain, between flood events of different sizes and across different floodplains. Therefore, it is important to understand the full range of potential flood behaviour to comprehend the vulnerability of the community to flooding. This understanding underpins decisions on managing flood risk.

This paper discusses a way to understand the vulnerability of people and/or the built environment to flood hazard by identifying specific flood parameters that can be measured consistently for a select range of flood events and to benchmark these parameters against thresholds. This meaningfully describes the danger of the flooding to people, buildings and infrastructure in the community. The paper also outlines how to use this approach, which forms the basis for national best practice guidance.

Introduction

Australian Emergency Management Institute released *AEM Handbook 7 - Managing the floodplain: a guide to best practice in flood risk management in Australia* (AEMI, 2014) and has recently added to this with additional guidance:

- *Technical flood risk management guideline – Flood hazard.* This helps inform the breakdown of the floodplain into areas where hazard may require different management responses. This is discussed in this paper.
- *Technical flood risk management guideline – Flood emergency response classification of the floodplain.* This provides a basis for breaking down the floodplain into different flood emergency response classifications so that this can be considered in management.
- *Technical project brief template for flood risk management projects.* This provides a starting point for developing a project brief for a specific study.

- *Guideline for using the national generic brief for flood investigations.* This provides advice on where to start when you want to do a flood investigation and helps to scope the project using the technical project brief.

McLuckie (2015) discusses these documents briefly at the conference.

The handbook and guidelines are available at the following web address:
<https://ema.infoservices.com.au/collections/handbook>

AEM Handbook 7 discusses best practice for floodplain management, and introduces and describes the need for quantifying flood hazard as part of the floodplain management process.

Flood hazard assessment is a key input to the understanding of flood risk. In the floodplain management process, flood hazard mapping assists with identifying the relative degree of flood hazard on a floodplain without the need to specifically understand what is at risk. Hazard mapping also feeds into constraints mapping for floodplain areas. Figure 1 provides an interpretation of how flood hazard assessment fits as a component of flood risk assessment.



Figure 1: Components of Flood Risk (after McLuckie, 2012)

The definitions of hazard and flood hazard in AEM Handbook 7 clearly enunciate that flood hazard is independent of the population at risk. The 'population at risk' as a concept relates to flood risk and the translation of a hazard to result in a risk to a community. By way of illustration, a flood with high water depth (> 2 m deep) is hazardous whether people are on the floodplain or not. The flood *risk* comes from exposing people to that hazard.

A way to understand the vulnerability of people and / or the built environment to flood hazard is to identify specific flood parameters that can be measured consistently for a select range of flood events and to benchmark these parameters against thresholds, which meaningfully describe the danger of the flooding to people, buildings and infrastructure in the community. AEM Handbook 7 introduces flood hazard as a concept and makes the following important definitions:

Hazard

A source of potential harm or a situation with a potential to cause loss. In relation to this handbook, the hazard is flooding, which has the potential to cause damage to the community.

Flood hazard

Potential loss of life, injury and economic loss caused by future flood events. The degree of hazard varies with the severity of flooding and is affected by flood behaviour (extent, depth, velocity, isolation, rate of rise of floodwaters, duration), topography and emergency management.

AEM Handbook 7 is supported by a technical guideline which provides guidance for the quantification and classification of flood hazard. This paper provides an overview and discussion of the technical guideline.

End uses considered in forming the AEM Handbook 7 Technical Guideline

AEM Handbook 7 highlights that understanding flood behaviour is an essential basis for making informed decisions on managing flood risk. This includes comprehending the range of potential flooding and the interaction of flooding with the landscape, which can result in varying degrees of hazard.

Effective flood risk management can enable a community to become as resilient as practicable to floods through informed prevention activities, preparation for, response to, and recovery from flooding. The completion of studies that improve our knowledge of flood risk can provide the basis for making informed management decisions. The guideline considers that understanding the variation in flood hazard in different areas of the floodplain can aid decision making in:

- Flood risk management. The guide provides information on the scale, and drivers for, flood hazard to people, vehicles and buildings. This would influence decisions in relation to management of flood risk and the types of mitigation measures that may be considered to manage this risk.
- Strategic and development scale land use planning. Flood hazard mapping can provide information on where the varying degree of flood hazard to people, vehicles and buildings occurs across the floodplain. This can be considered in setting strategic land use directions for a community where it can inform decisions on: where to develop; what type of development is suited to particular areas (e.g. certain developments are less robust than others); and the development conditions necessary to limit the risks created by introducing new development.
- Flood emergency response planning. The use of the guide can provide information for the development of flood emergency response plans by providing advice on the variation of hazardous conditions to people, vehicles and buildings within the floodplain.

The process for quantifying and classifying flood hazard is illustrated in Figure 2.



Figure 2: Process for quantifying flood hazard

Determining Flood Behaviour

An integral component of the floodplain management process is the need to understand the flood behaviour on the subject floodplain. Adequately understanding flood behaviour includes comprehending:

- The range of potential flooding and the implications of a changing climate.
- The flood function of the area, particularly conveyance and storage of water.
- The variation in flood hazard within the floodplain. This depends upon flow depth and velocity, and the interaction of the flood with the landscape, which can isolate areas from flood-free land and result in difficult evacuation situations.

Best practice assessment of flood behaviour aims to provide an understanding of the full range of flood behaviour and consequences through a fit-for-purpose flood study. Flood studies typically involve consideration of the local flood history, available collected data, and the development of models that are calibrated and validated, where possible, against significant historic flood events and extended to determine the full range of flood behaviour.

A range of analytical tools and approaches can be used to estimate and quantify flood behaviour in the study area. These tools are typically computer based flood models and may vary in complexity to suit the complexity and scale of the subject floodplain. A detailed description of flood study outcomes is provided in Chapter 11 of AEM Handbook 7.

Fundamental to the estimation of flood hazard on a floodplain is the estimation of flood depth, flood velocity, and depth and velocity in combination (see example Figure 3). The

outputs of a flood study include the spatial resolution of flood depth and flood velocity estimates across the floodplain, and hence the description of the variability of flood hazard across the floodplain, at a scale that depends on the spatial resolution of the flood study models. Flood studies also allow the extent of flooding to be determined and provide information to determine where communities can be isolated by floodwaters.

The magnitude of flood hazard can be variously influenced by the following factors:

- velocity of floodwaters,
- depth of floodwaters,
- combination of velocity and depth of floodwaters,
- isolation during a flood,
- effective warning time, and
- rate of rise of floodwater.

When quantifying and classifying flood hazard, it is important to understand the underlying causes of the hazard level. For example, if the hazard level is classified as 'high' then it is important to understand the key reason that it is high e.g. high depth, high velocity, high velocity and depth in combination, isolation issues, short warning time? If the core reasons that the hazard is high are not well understood, then attempts to modify and lower the hazard level may not be successful.

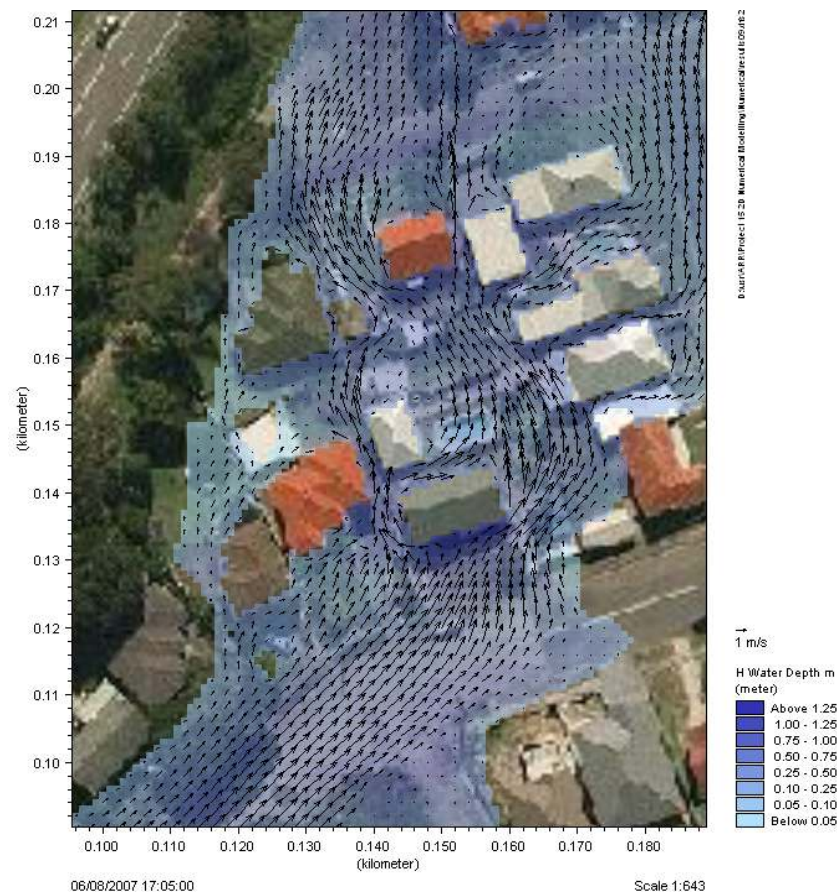


Figure 3: Example flood study results from a two-dimensional floodplain model (after Smith and Wasko, 2012)

Recommended flood events for hazard assessment

Flood hazard varies with flood severity (i.e. for the same location, the rarer the flood the more severe the hazard) and location within the floodplain for the same flood event. AEM Handbook 7 identifies that sound floodplain management practice should consider a full range of design flood probabilities to provide an overview of the full risk profile for the subject floodplain. Similarly, the variability of flood hazard should be assessed across a range of flood probabilities as well as spatially across the floodplain.

Since there is typically some effort required to produce flood hazard estimates in addition to baseline flood risk information, flood hazard may be considered for a subset of the full range of flood probabilities developed for the flood study. It is recommended that as a minimum, flood hazard mapping be produced for the design flood event (DFE), a flood smaller than the DFE and the probable maximum flood (PMF) or a representative extreme event. Flood hazard mapping of these events will provide land use planners, flood risk managers and emergency managers with an overview of changes in the severity of flood hazard over a range of events.

Quantifying Flood Hazard

Flood hazard is quantified by considering the flood depth and velocity in combination ($D \times V$ product). When quantifying and classifying flood hazard, it is important to understand the relative degree of hazard and the underlying flood behaviour causing the hazard (e.g. high depth, high velocity, depth and velocity combined) as these may require different management approaches. Flood hazard can inform emergency and flood risk management for existing communities, and strategic and development scale planning for future areas.

Where the site under consideration is small and flood behaviour is relatively uniform, and a simplified method has been used to quantify the flood behaviour on the floodplain, it may be that a single point value of $D \times V$ is appropriate. However, in cases where there is significant variability in the flood behaviour across the floodplain, a map of flood hazard assessing the spatial variability of flood hazard is more appropriate. An example of a flood hazard map showing the variability of $D \times V$ across a floodplain is provided in Figure 4.



**Figure 4: Example of peak modelled D x V
(Source: Smith and Wasko, 2012)**

When interpreting flood hazard from model outputs, it is important to understand the underlying assumptions of the modelling approach and the effects this might have on flood hazard quantification. The modelling approach, model scale and resolution, and the associated level of topographic detail incorporated in a model may all influence flood hazard estimates.

In some cases, larger resolution models may not be suitable for showing locations where localised high hazard conditions might occur, such as near structures, over embankments or between buildings. Where detailed flood hazard estimates are required to support planning and management, a higher resolution of modelling and hazard analysis may be necessary. Further discussion of flood study outcomes is provided in Chapter 11 of AEM Handbook 7. Guidance on contemporary modelling approaches and the selection of model resolution is available in Babister and Barton, 2012 with discussion on the influence of modelling approach and model resolution on flood hazard described in Smith and Wasko, 2012 and Smith et al., 2014.

Where the timing aspects of flooding are important, especially as an input to emergency planning and management, a time varying map of flood hazard can be developed. Many contemporary two-dimensional (2D) floodplain models can produce time varying flood hazard maps as a standard output. The rate of rise of floodwaters at key locations on the

floodplain and the duration of flooding above key flood hazard thresholds are important baseline information when considering isolation aspects of emergency management.

Peak Flood Hazard

In large floodplains where the rate of rise and fall of the flood is slow and the flood duration amounts to weeks or months, it may be sufficient to assess flood hazard at the peak of the flood. However, in small to medium sized catchments where flood levels rise and fall more rapidly, the timing aspects of the flood hydrograph require consideration. In these types of catchments, the maximum hazard value during a flood may not occur at the peak flow rate or the peak flood level, but on some combination of depth (D) and velocity (V) during the flood event.

High values of $D \times V$, beyond important hazard thresholds, may often occur on the rising limb of a flood and are an important consideration in flood hazard assessments. For example, when considering the safety of a flood evacuation route, hazard values above the $D \times V$ thresholds for vehicle stability may be exceeded prior to the peak of flood levels. This case is illustrated graphically in Figure 5 and Figure 6. In this case, the peak flood hazard value occurs at time (1) which is before the peak of the flood at time (2).

The example as presented reinforces that where flood behaviour changes quickly on the floodplain, flood hazard quantification should be assessed at all stages of the flood hydrograph, not just at the peak of the flood flow hydrograph or at the time of peak flood level.

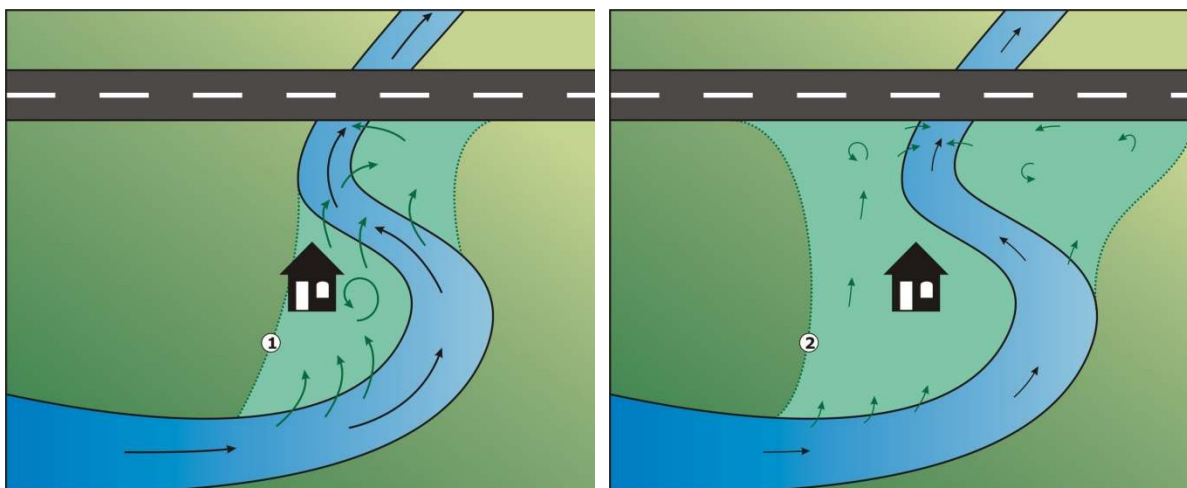


Figure 5: Floodplain Case –Time (1) on the rising limb of the hydrograph has higher hazard than Time (2) corresponding to the peak flood level

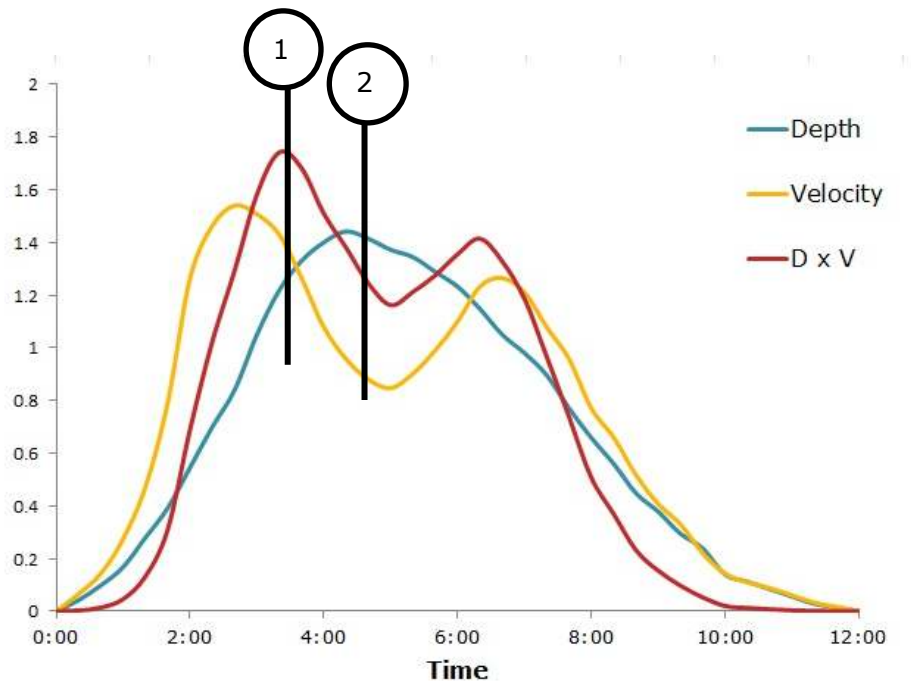


Figure 6: Flood hydrographs for the subject floodplain in Figure 5

Indexing to flood hazard vulnerability curves

Once flood hazard has been quantified, and the timing aspects of flood hazard understood, the potential of the flood flows to cause damage or danger can be indexed against vulnerability curves linked to meaningful hazard thresholds.

The vulnerability of the community and its assets can be described by using thresholds related to the stability of people as they walk or drive through flood waters, or shelter in a building during a flood. The vulnerability to hazard will also be influenced by whether the primary consideration is e.g. strategic land use planning, which is aimed at ensuring land use is compatible with the flood risk, or assessing development proposals or emergency management planning, which is aimed at addressing residual flood risks.

An international literature search building on the findings of the Australian Rainfall and Runoff review process has been used to define flood hazard thresholds based on people stability, vehicle stability and building stability. This report has found that hazard classifications based on these stability thresholds are suitable for flood hazard quantification and analysis to underpin the floodplain management process.

General flood hazard classification

A flood hazard assessment conducted as part of a flood study often provides baseline information for general consideration as part of an initial scoping exercise for a floodplain management study. In such a preliminary assessment of risks or as part of a constraints analysis for strategic planning, a combined set of hazard vulnerability curves such as those presented in Figure 7 can be used as a general classification of flood hazard on a

floodplain. Further information on the source of the hazard vulnerability curves presented in Figure 7 is presented in Smith et al., 2014.

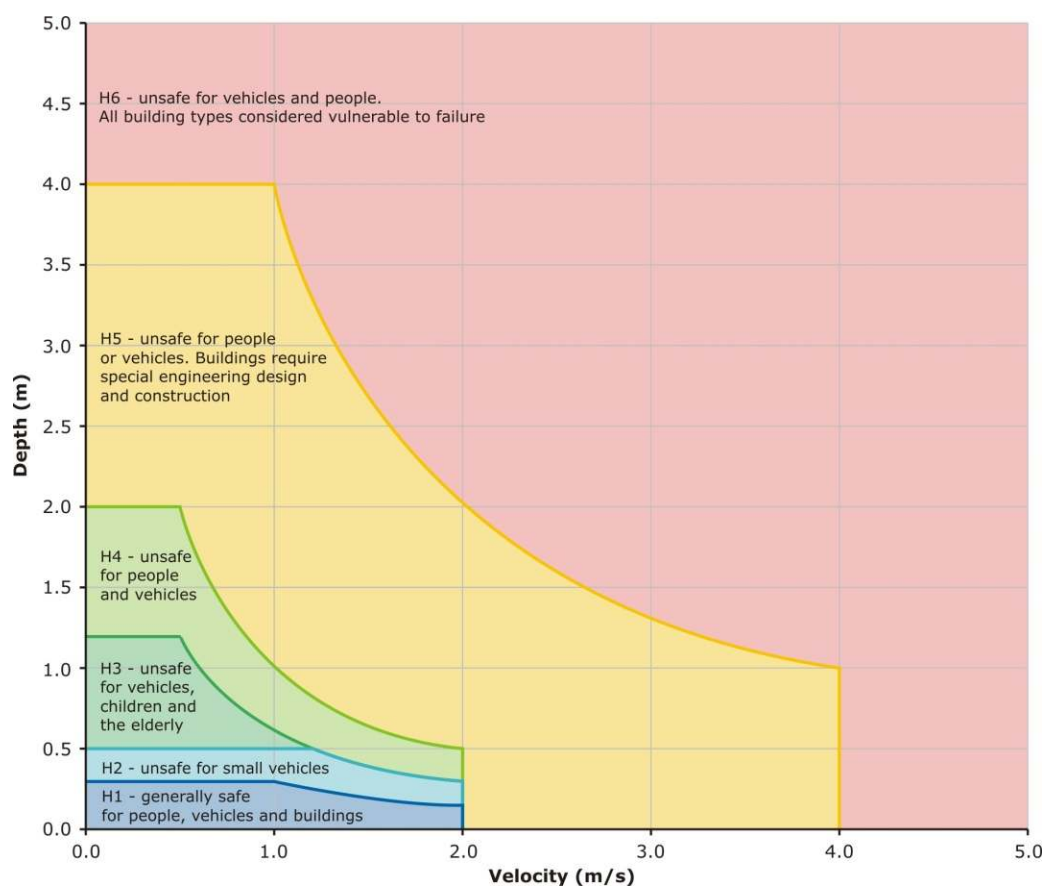


Figure 7: General flood hazard vulnerability curves

The combined flood hazard curves presented in Figure 7 set hazard thresholds that relate to the vulnerability of the community when interacting with floodwaters. The combined curves are divided into hazard classifications that relate to specific vulnerability thresholds as described in Table 1.

Table 1: Combined hazard curves – vulnerability thresholds

Hazard Vulnerability Classification	Description
H1	Generally safe for vehicles, people and buildings. Relatively benign flood conditions. No vulnerability constraints.
H2	Unsafe for small vehicles.
H3	Unsafe for vehicles, children and the elderly.
H4	Unsafe for vehicles and people.
H5	Unsafe for vehicles and people. Buildings require special engineering design and construction.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

A flood hazard map classified against these general vulnerability thresholds based on the flood behaviour derived using flow modelling for the example floodplain presented in Figure 3 is shown in Figure 8.



Figure 8: Floodplain hazard classification map (After: Smith and Wasko, 2012)

Similarly, flood hazard classification for a broad, complex rural floodplain is presented in Figures 9 and 10. Figures 9 and 10 demonstrate the breakdown of the floodplain into various degrees of flood hazard classification. The recommended general hazard curves have been demonstrated to provide a more detailed and textural classification of flood hazard compared to hazard classification methods used in other floodplain management guidance.

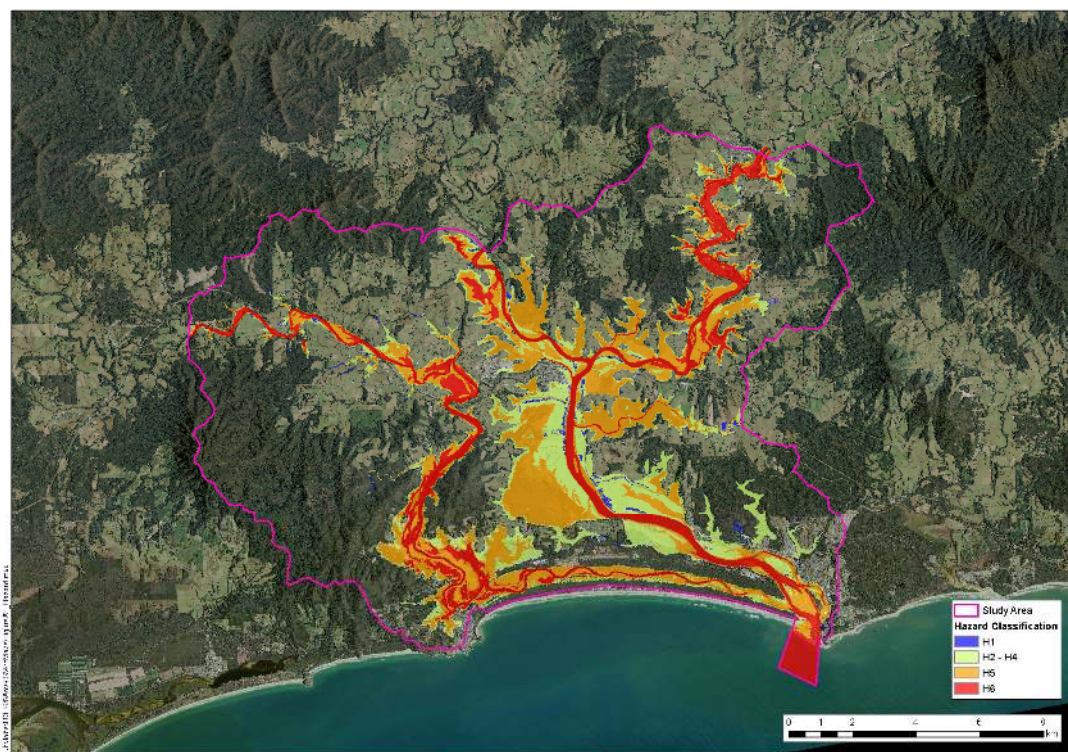


Figure 9: Flood hazards for categories H1, combined H2–H4, H5 and H6 for a broad floodplain (Courtesy of WMAwater Pty Ltd)

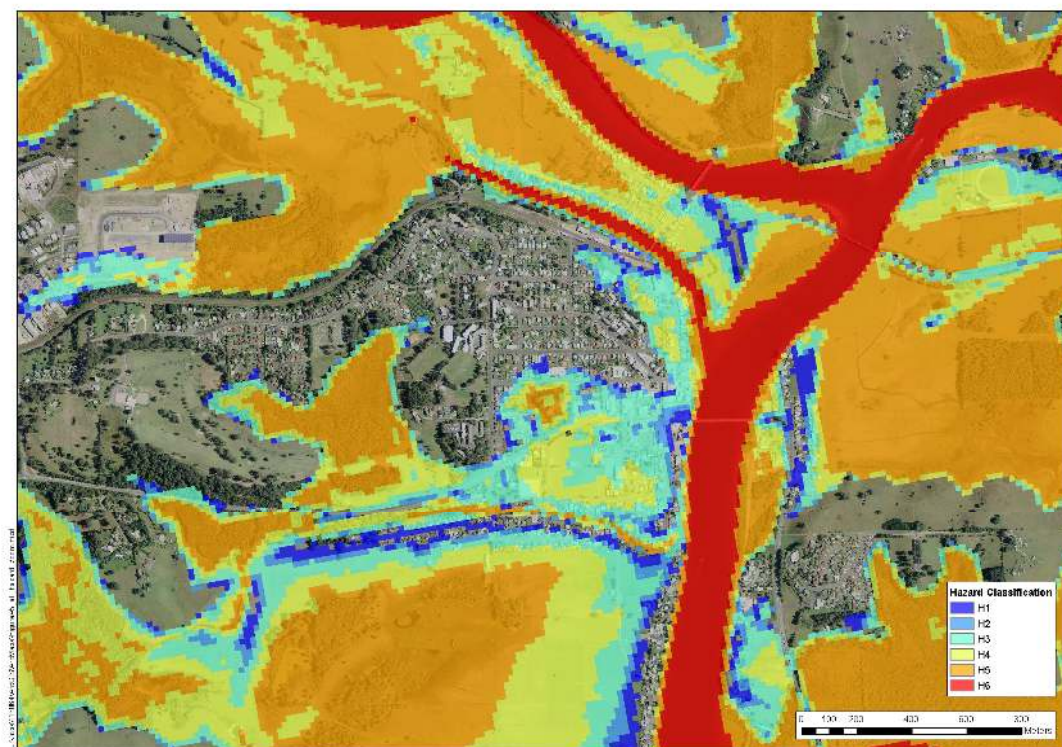


Figure 10: Flood hazards for categories H1–H6 for a more localised area of floodplain (Courtesy of WMAwater Pty Ltd)

In some instances, specific hazard classifications are more appropriate than the general curves suggested in Figure 7. For example, if the hazard assessment is required as the basis of an evacuation plan, then a hazard analysis should be guided by vulnerability curves specifically for people stability (Figure 11) and vehicle stability (Figure 12) to assess the suitability of various evacuation routes. Alternatively, if an assessment of buildings suitable for use as flood shelters is required, then the building stability curves presented in Figure 13 may be applied. Additional background information on these individual flood hazard curves is available in Smith et al., 2014.

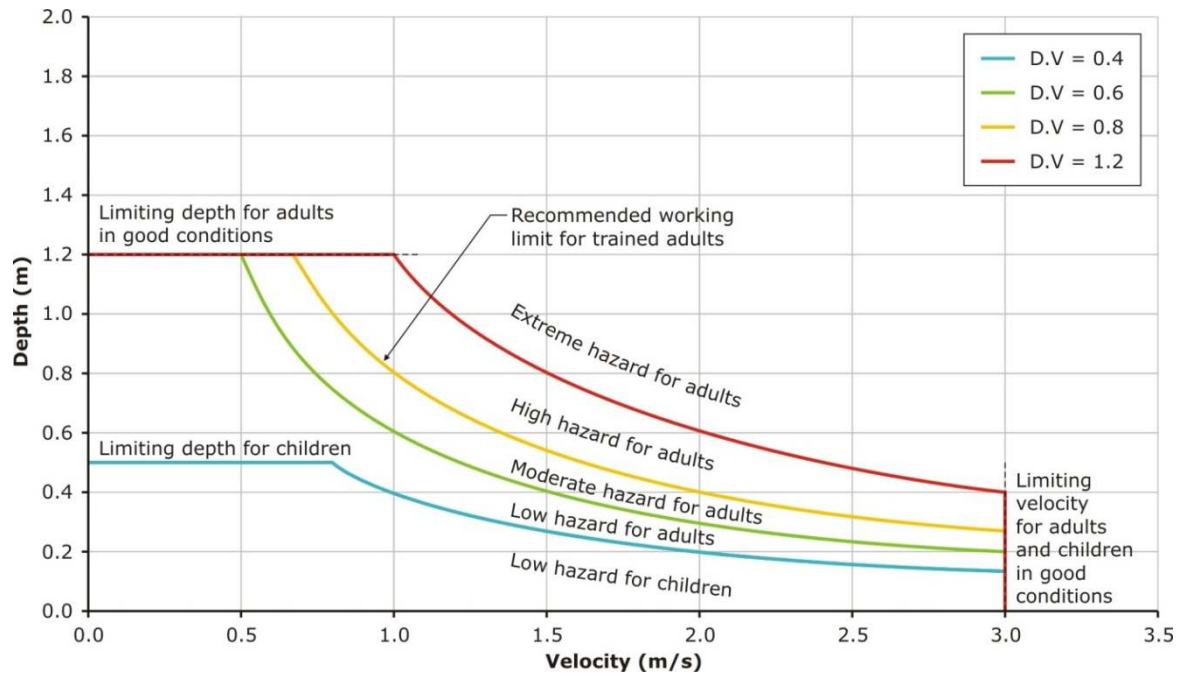


Figure 11: Thresholds for people stability in floods (After Cox et al., 2010)

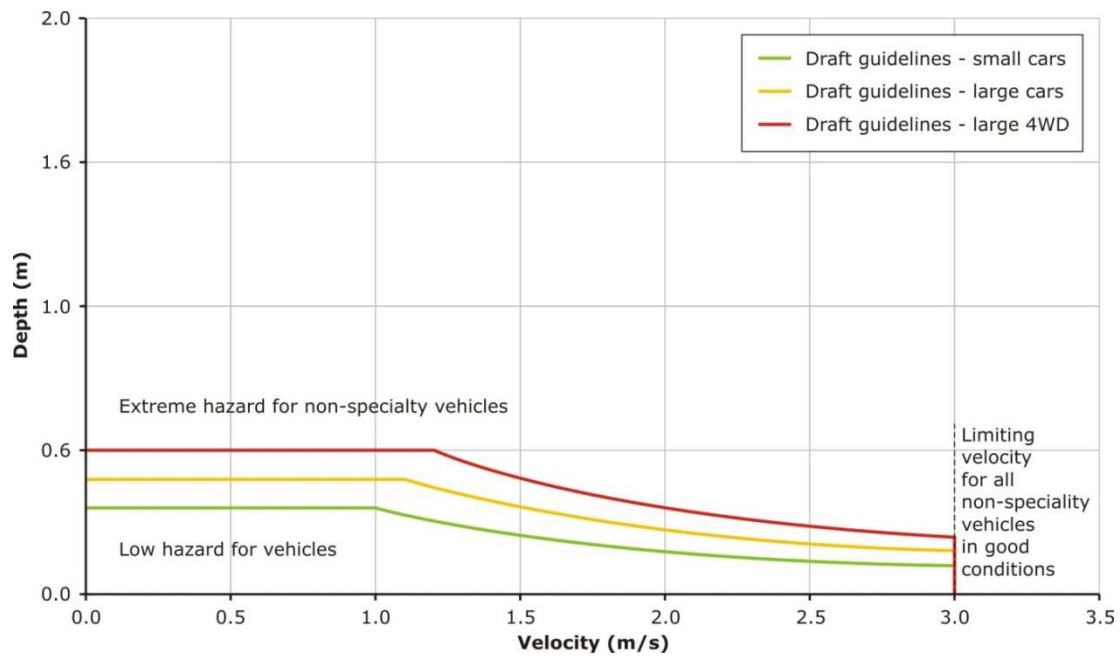


Figure 12: Thresholds for vehicles stability in floods (After: Shand *et al.*, 2011)

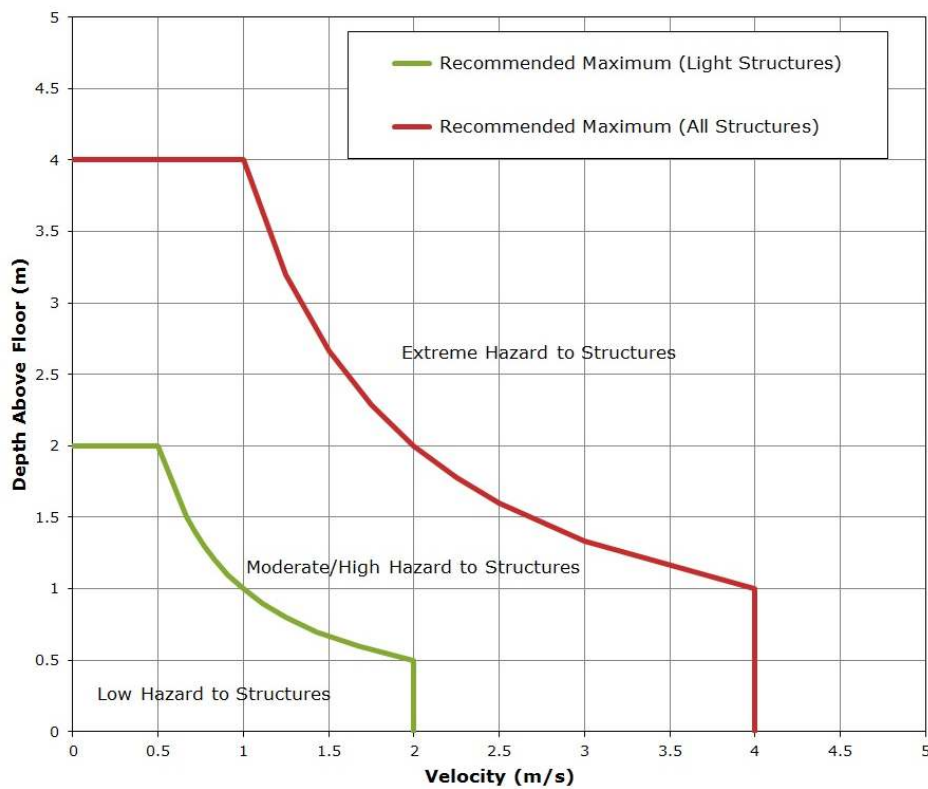


Figure 13: Thresholds for building stability in floods (After Smith *et al.* 2014)

Isolation, warning time, rate of rise and time of day

The effective warning time available to respond to a flood event, the rate of rise of floodwaters, the time of day a flood occurs, and isolation from safety by floodwaters and impassable terrain are all factors that may increase the potential for people to be exposed to hazardous flood situations, rather than altering the exposure to flood hazard. These factors are important considerations that influence the vulnerability of communities to flooding in managing flood risk.

Isolation

As outlined in Section of AEM Handbook 7, flooding can isolate parts of the landscape and cut-off evacuation routes to flood-free land. This can result in dangerous situations, because people may see the need to cross floodwaters to access services, employment or family members. Many flood fatalities result from the interactions of people, often in vehicles, with floodwaters. Any situation that increases people's need to cross floodwaters increases the likelihood of an injury or fatality.

AEM Handbook 7 recommends that the floodplain be classified by precinct or community based on flood emergency response categories. This classification is separate to the quantification of hazard outlined in this guideline and is addressed in the complementary *Technical Flood Risk Management Guideline on Flood Emergency Response Classification of the Floodplain*.

Effective warning time

As outlined in Section 5 of AEM Handbook 7, effective warning time is the time available for people to undertake appropriate actions, such as lifting or transporting belongings and evacuating.

Lack of effective warning time can increase the potential for the exposure of people to hazardous flood situations. In contrast, having plenty of effective warning time provides the opportunity to reduce the exposure of people and their property to hazardous flood situations.

Rate of rise

Rate of rise of floodwaters is discussed in Section 5 of AEM Handbook 7. A rapid rate of rise can lead to people evacuating being overtaken or cut off by rising floodwaters. It is often associated with high velocities but it can be an issue if access routes are affected by flooding.

Time of day

The time of day influences where people are and what they are doing. This can influence their ability to receive any flood warnings and respond to a flood threat. Inability to receive and respond to a warning can increase the potential for people to be exposed to hazardous flood situations.

Conclusions

Floods create hazardous conditions to which humans are particularly vulnerable. As indicated in this paper if floodplains were unoccupied and unused, flooding would not create a risk to the community. It is the human interaction with the floodplain, and the associated exposure to flood hazard, that creates flood risk.

Understanding how hazard varies across the floodplain is important making informed decisions in managing flood risk to existing property and the growth in risk resulting from introducing new development into the floodplain.

This paper outlines how to understand the vulnerability of people and the built environment to flood hazard by identifying specific flood parameters that can be measured consistently for a select range of flood events and to benchmark these parameters against thresholds. This meaningfully describes the danger of the flooding to people, buildings and infrastructure in the community

The paper provides as basis for breaking down the floodplain into areas where the hazard may require different management responses. The paper and the work upon which it is based informed best practice in flood risk management through the development of *Technical flood risk management guideline – Flood hazard* (AEMI 2014).

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