Technical flood risk management guideline: Flood hazard

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CONTENTS

Tables

Figures

PREFACE

As outlined in Australian Emergency Management Handbook 7 (AEM Handbook 7), *Managing the floodplain: Best practice in flood risk management in Australia* (AEMI 2013), flooding is a natural phenomenon that occurs when water covers land that is usually dry. Floods can create hazardous conditions when communities are exposed to these conditions, creating a risk.

This technical guideline expands information on flood hazard provided in Chapter 5 of AEM Handbook 7, to provide a basis for quantifying the variations in flood hazard. Together with the technical guideline for flood emergency response classification of the floodplain, it replaces technical advice on flood hazard quantification provided in Appendix J of SCARM Report 73 (SCARM 2000).

ACKNOWLEDGEMENTS

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Duncan McLuckie (New South Wales Office of Environment and Heritage) led the project. The Water Research Laboratory of the University of New South Wales was commissioned to support development of the guideline. WMAwater Pty Ltd assisted by providing the sample figures in Appendix A.

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1 INTRODUCTION

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.

Infrastructure required for community functioning is also vulnerable to flooding. Road surfaces and substructures, rail lines, airfields, and electrical, water, sewerage, stormwater and communication systems are all susceptible to damage from flooding. Moreover, human-made structures and development can exacerbate the damage caused by flooding. They may alter the paths, depths and velocities of flow, and add debris to floodwaters.

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.

Australian Emergency Management Handbook 7 (AEM Handbook 7), *Managing the floodplain: Best practice in flood risk management in Australia* (AEMI 2013), introduces and describes the need for quantifying flood hazard as part of the floodplain-specific management process. 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**. The 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.

In managing flood risk through the floodplain-specific management process, flood hazard assessment assists with identifying the relative degree of flood hazard on a floodplain without the need to understand what is at-risk. Hazard mapping can support constraint mapping for strategic land-use planning in floodplain areas.

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 (i.e. more than 2-metres 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. This meaningfully describes the danger of the flooding to people, buildings and infrastructure in the community.

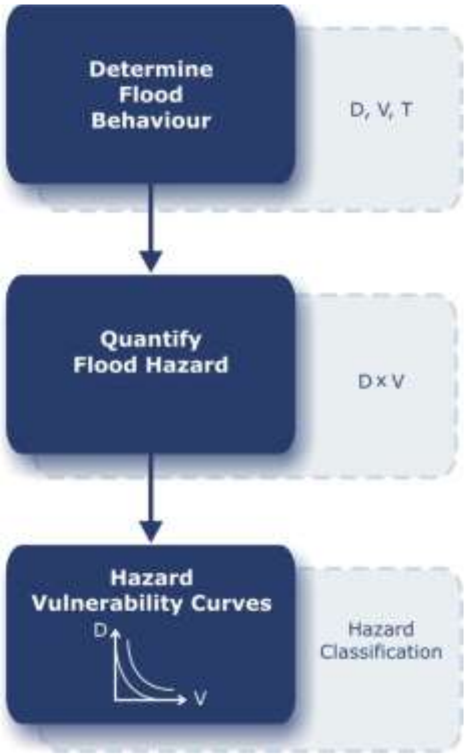
This technical guideline provides supplementary advice to support AEM Handbook 7 by outlining methods to quantify flood hazard.

1.1 How to use this guideline

The following basic sections of this guideline help to assess flood hazard:

- Section 2 describes how to determine flood behaviour parameters from flood studies (primarily based on flood depth and velocity).
- Section 3 quantifies the flood hazard product. This can provide a useful method for categorising flood risk spatially.
- Section 4 indexes a flood hazard product to hazard vulnerability curves for vehicles, people and buildings. These provide a basis for categorising the flood hazard, based on a consideration of depth and velocity. It can inform spatial mapping of areas where conditions are hazardous to vehicles, people and structures. The appendix provides spatial examples of categorisation against the various thresholds.
- Section 5 discusses other factors that in some situations, such as emergency planning and management, influence flood risk. These factors include isolation by floodwaters, the effective warning time available, the rate of rise of floodwaters and the time of day. They can influence the risk of people being exposed to hazardous flood behaviour in a flood event rather than necessarily altering hazard.

Figure 1 illustrates this procedure.



D = depth; T = time; V = velocity

Figure 1 **Process for quantifying flood hazard**

1.2 Relationship to other guidelines and policies

This guideline provides technical advice on the quantification of flood hazard to support the general guidance on best practice in flood risk management outlined in AEM Handbook 7. This guideline, along with *Technical flood risk management guideline: Flood emergency response classification of the floodplain* (AEMI 2014), replaces the technical advice on flood hazard quantification provided in Appendix J of the SCARM Report 73 (SCARM 2000).

This guideline should be read in conjunction with AEM Handbook 7 and other relevant guidance material. Many of the terms used in this guideline are defined in AEM Handbook 7.

Further background technical information supporting the advice in this guide can be found in the report *Flood hazard* (Smith et al. 2014), prepared for the National Flood Risk Advisory Group.

This guideline does not provide policy guidance, which is dependent on the relevant flood risk management policies in place for different jurisdictions. It should not be used to supplant or circumnavigate such policies.

1.3 End uses considered in forming the guideline

AEM Handbook 7 highlights that understanding flood behaviour is essential 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, and preparation for, response to and recovery from flooding. 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 the following areas:

- Flood risk management. The guideline provides information on the scale of, 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. Information on where the varying degree of flood hazard to people, vehicles and buildings occurs across the floodplain is provided. 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. This guideline can inform the development of flood emergency response plans by providing advice on the variation of hazardous conditions to people, vehicles and buildings within the floodplain.

2 DETERMINING FLOOD BEHAVIOUR PARAMETERS

2.1 Flood study

AEM Handbook 7, Chapter 5, describes the need to understand flood behaviour on the floodplain of interest. It highlights the importance of understanding flood behaviour for understanding and managing flood risk. This includes comprehending the:

- range of potential flooding and the implications of a changing climate
- flood function of the area, particularly conveyance and storage of water
- 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.

Chapter 11 of AEM Handbook 7 further expands on the flood study investigations typically required to assess flood behaviour on the subject floodplain. Flood studies aim to provide an understanding of the full range of flood behaviour and consequences. They typically involve consideration of the local flood history, available collected data, and the development of models that are calibrated and verified, where possible, against historic flood events and extended to determine the full range of flood behaviour.

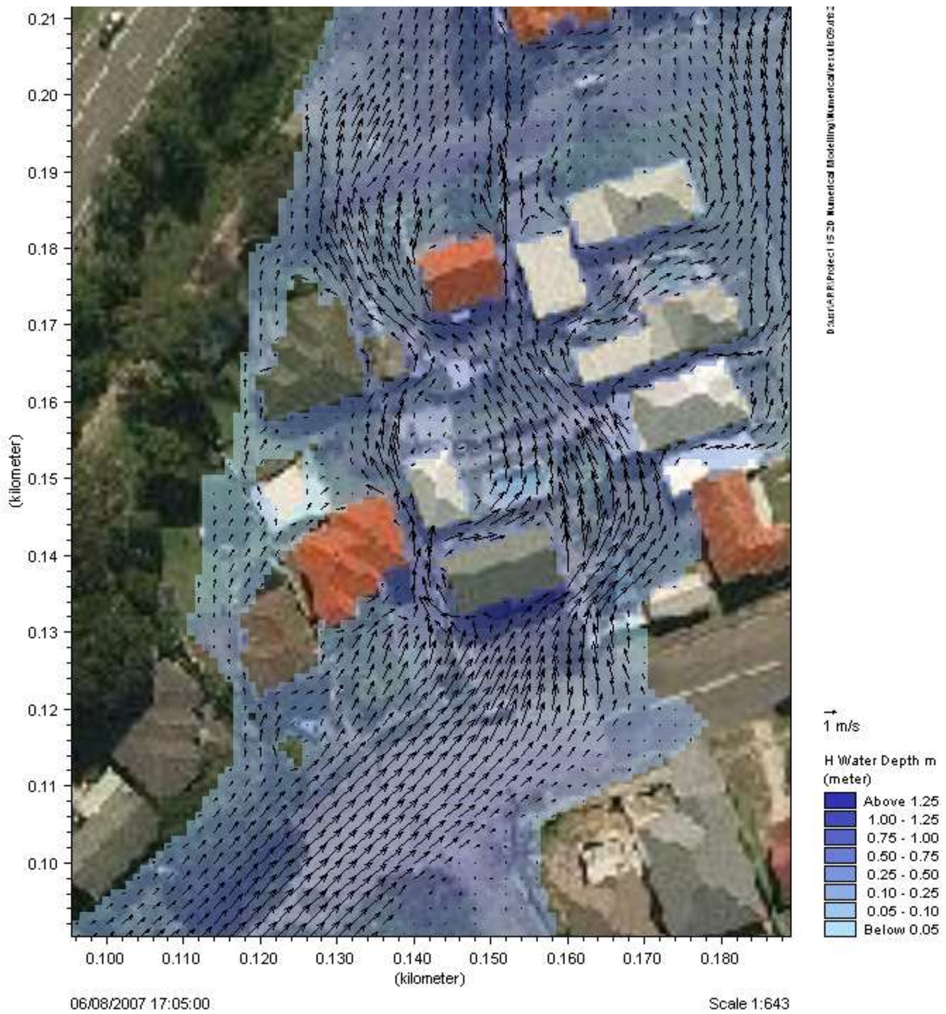
A range of analytical tools and approaches can be used to estimate and quantify flood behaviour in the study area. These tools are typically computer-based flood models and may vary in complexity to suit the complexity and scale of the subject floodplain. A detailed description of flood study outcomes 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 examples in Figure 2 and the appendix). 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 (discussed further in Section 5).

2.2 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 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 for a range of events.



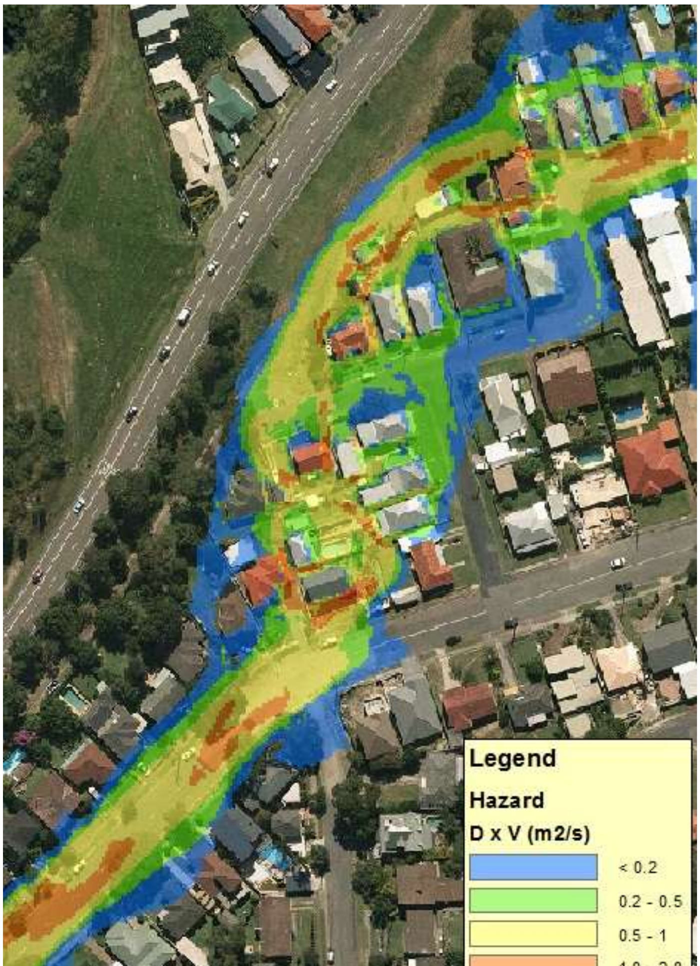
Source: Modelled after Smith and Wasko (2012)

Figure 2 Example flood study results from a two-dimensional floodplain model

3 QUANTIFYING FLOOD HAZARD

Flood hazard is quantified by considering the flood depth and velocity in combination (D × 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 × 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 × V across a floodplain is provided in Figure 3.



D × V = depth × velocity; m^2/s = square metres per second
Source: Smith and Wasko (2012)

Figure 3 Example of peak modelled D × V

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, across 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). Additional examples of flood hazard assessments conducted at various floodplain scales and model resolutions are provided in the appendix.

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 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.

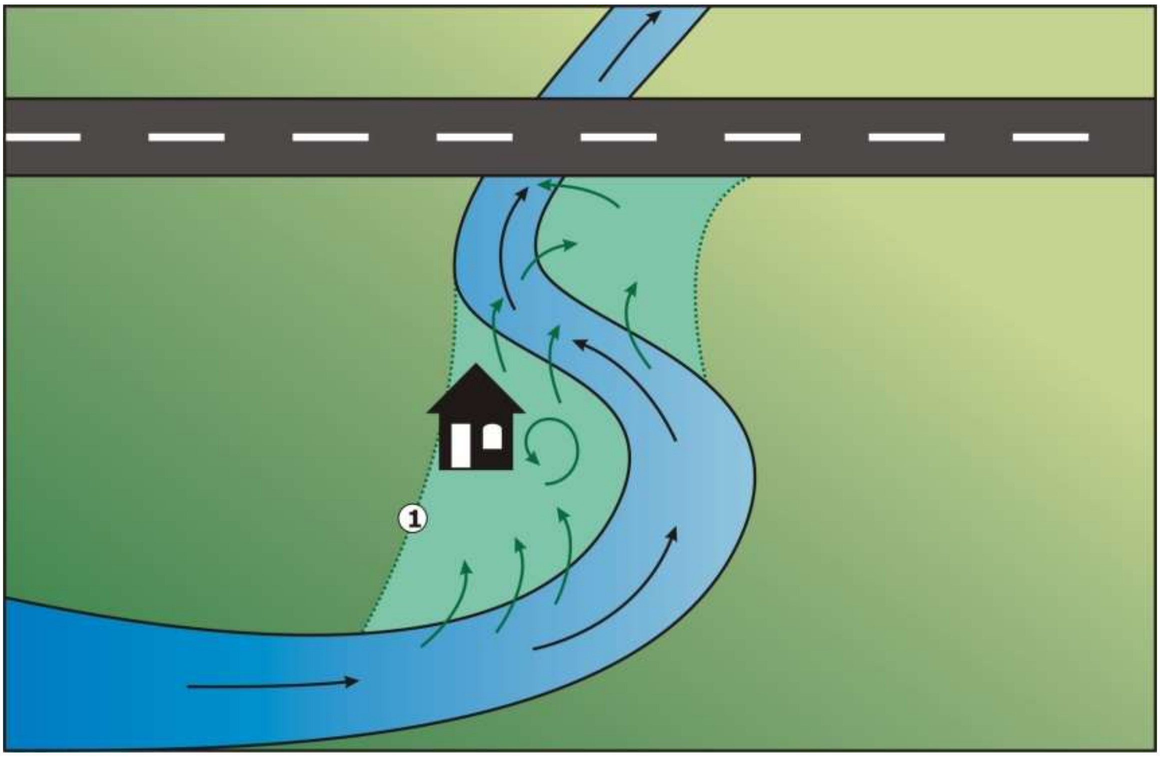
3.1 Peak flood hazard

On large floodplains – where the rate of rise and fall of the flood is slow, and the flood duration is 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 D and V during the flood event.

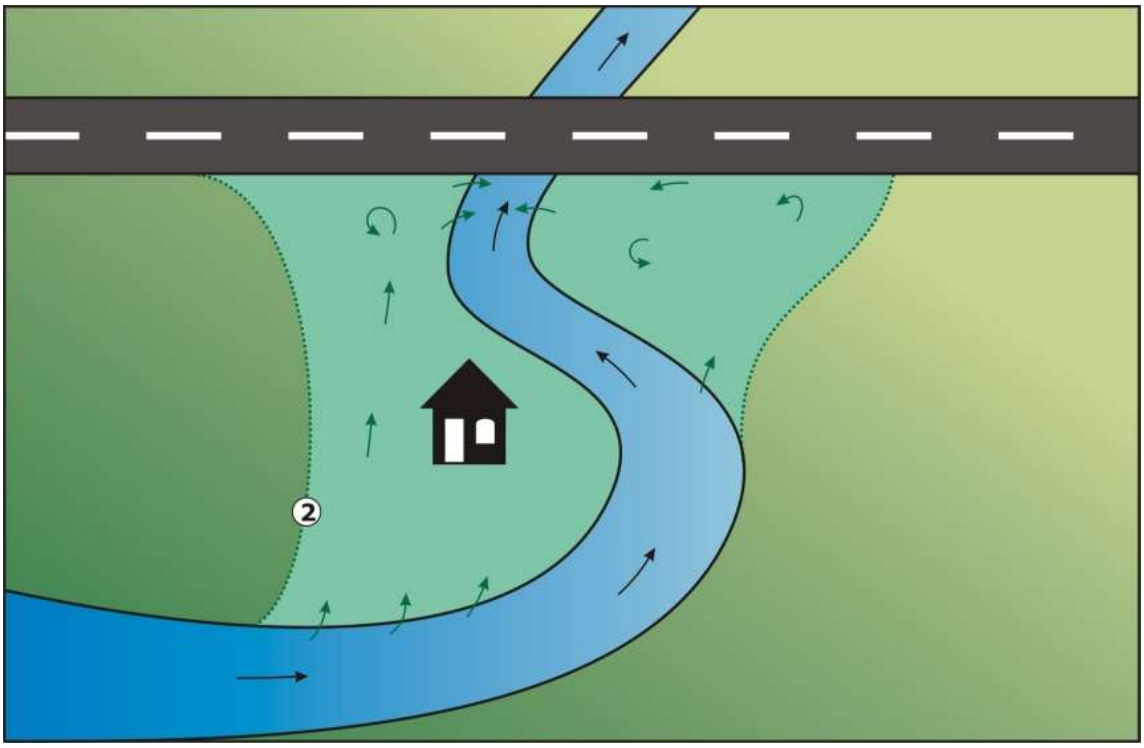
High values of D × V, beyond important hazard thresholds, may often occur on the rising limb of a flood and are an important consideration in flood hazard assessments. For example, when considering the safety of a flood evacuation route, hazard values above the D × V thresholds for vehicle stability may be exceeded before the peak of flood levels. This case is illustrated graphically in Figure 4 and Note: Depth is measured in metres (m); velocity in m/s; D × V in m^2/s.

Figure 5 . 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.

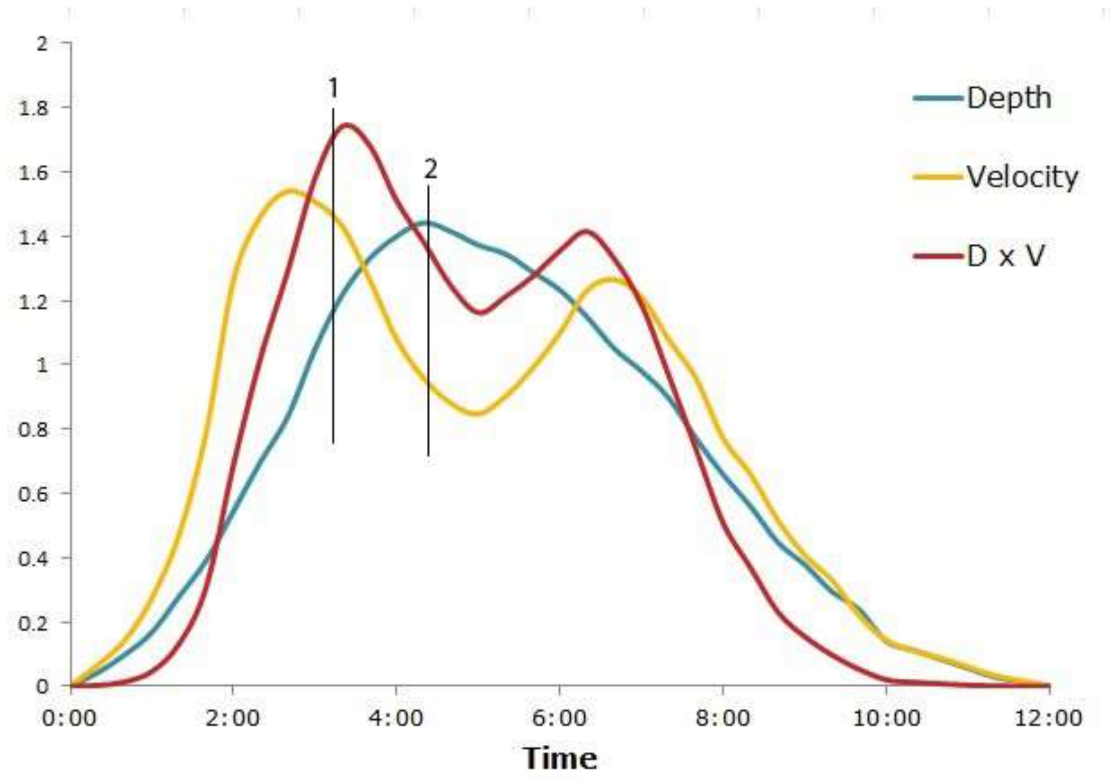


Time 1 – on rising limb of flood



Time 2 – at peak flood level

Figure 4 **Peak hazard occurs at Time 1, before the peak flood level at Time 2**



Note: Depth is measured in metres (m); velocity in m/s; D × V in m^2/s.

Figure 5 Flood hydrographs for the subject floodplain in Figure 4

4 INDEXING TO FLOOD HAZARD VULNERABILITY CURVES

Once the 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, for example, 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.

4.1 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 land-use planning, a combined set of hazard vulnerability curves such as those presented in Figure 6 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 6 is available in Smith et al. (2014).

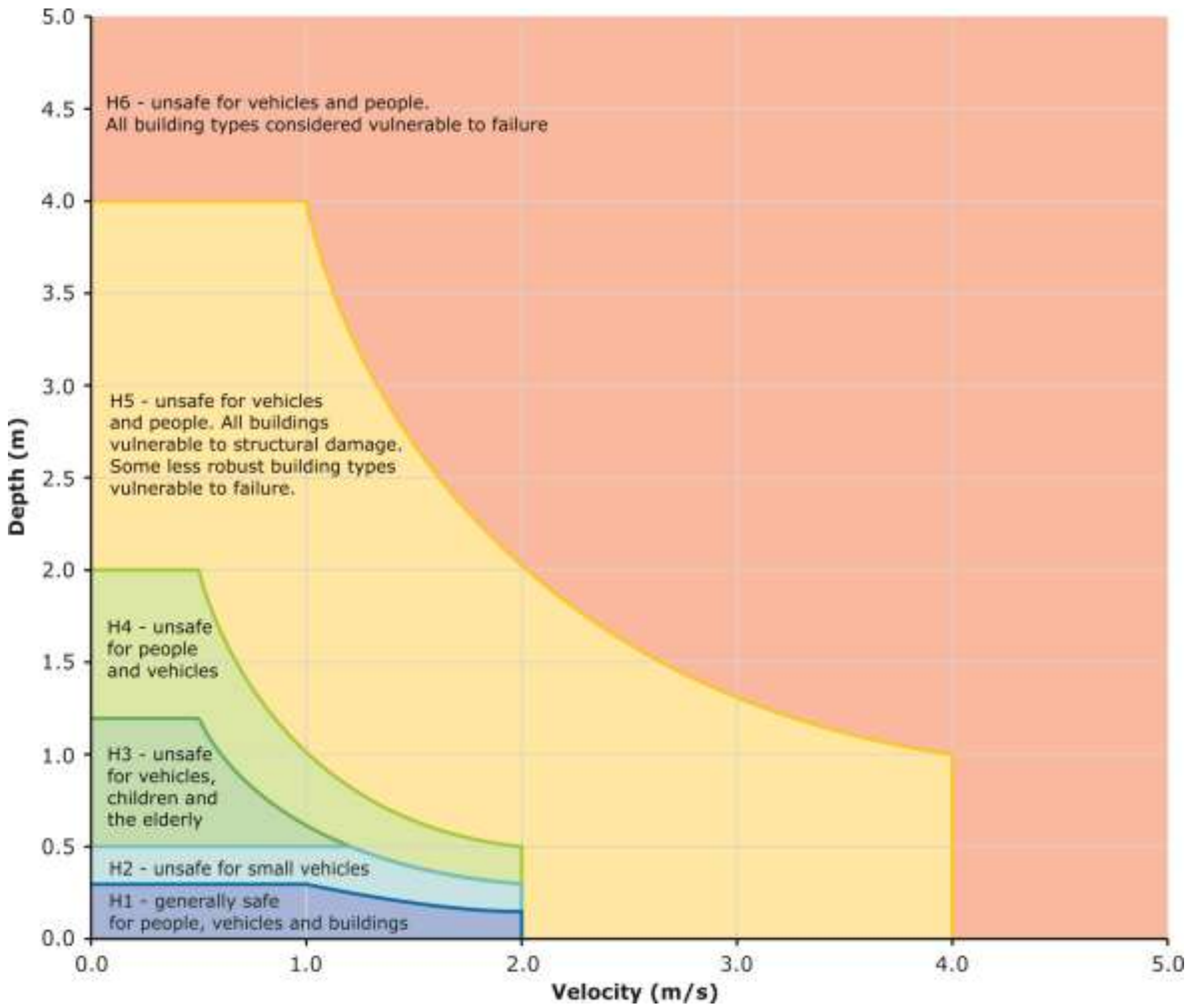


Figure 6 **General flood hazard vulnerability curves**

The combined flood hazard curves presented in Figure 6 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 2 provides the limits for the classifications provided in Table 1.

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 7. Additional examples are provided in the appendix.

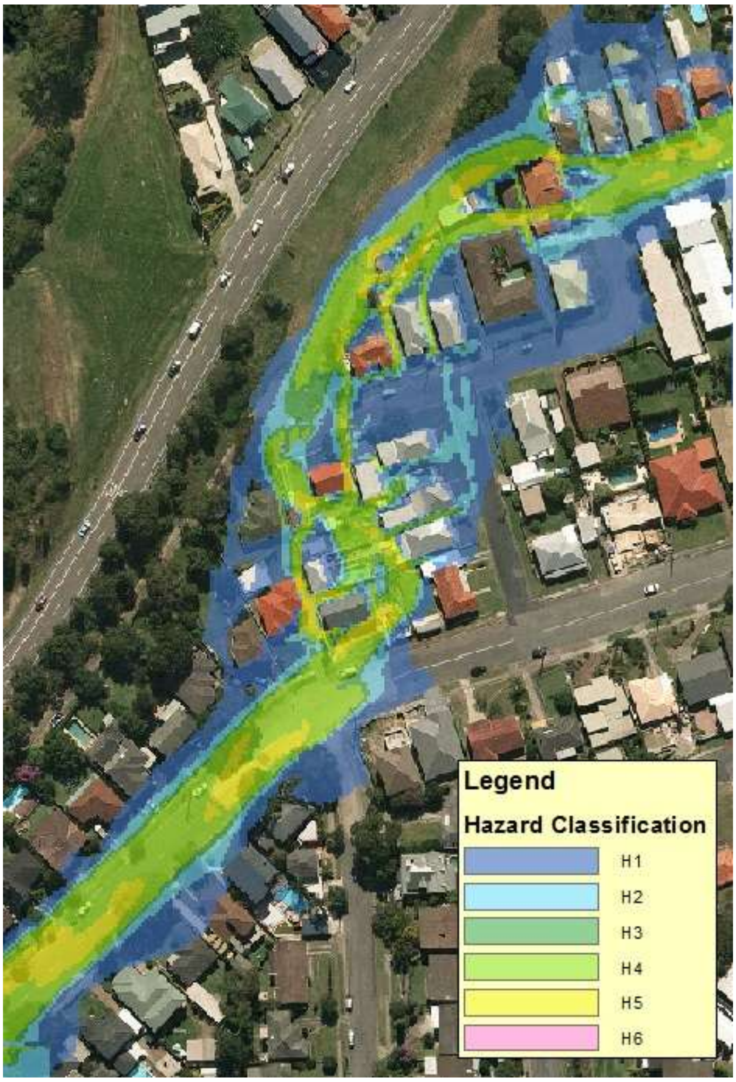
Table 1 **Combined hazard curves – vulnerability thresholds**

Hazard Vulnerability Classification	Description
H1	Generally safe for vehicles, people and buildings.
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. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure.
H6	Unsafe for vehicles and people. All building types considered vulnerable to failure.

Table 2 Combined hazard curves – vulnerability thresholds classification limits

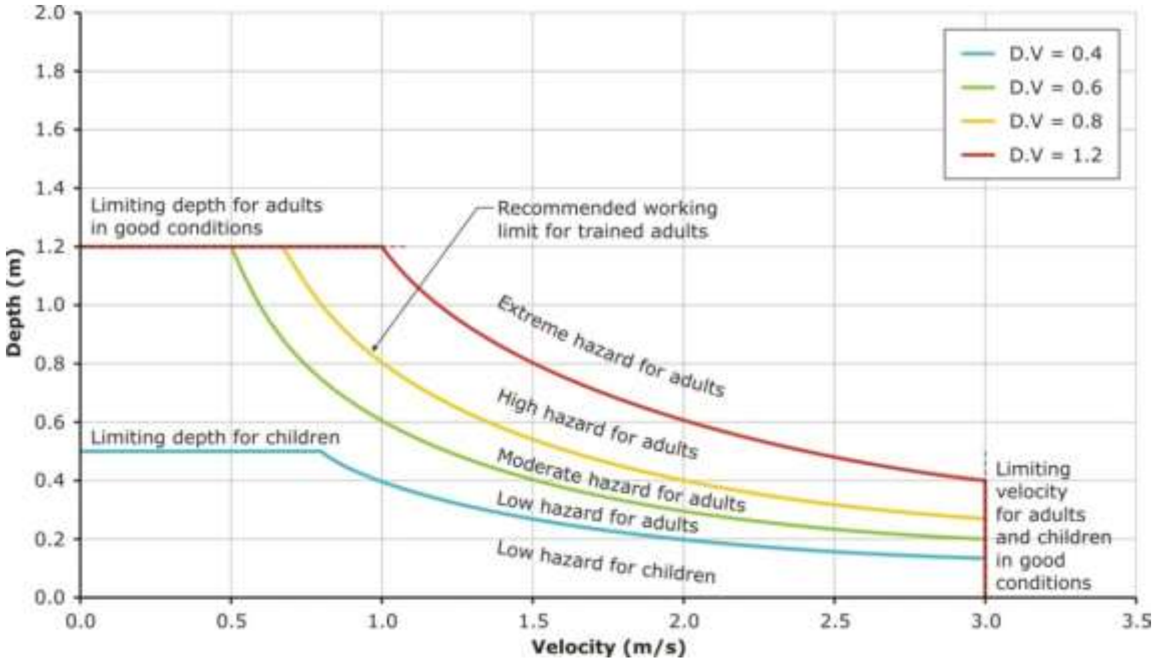
Hazard Vulnerability Classification	Classification limit (D and V in combination) m^2/s	Limiting still water depth (D) m	Limiting velocity (V) m/s
H1	D*V ≤ 0.3	0.3	2.0
H2	D*V ≤ 0.6	0.5	2.0
H3	D*V ≤ 0.6	1.2	2.0
H4	D*V ≤ 1.0	2.0	2.0
H5	D*V ≤ 4.0	4.0	4.0
H6	D*V > 4.0	-	-



Source: Modelled after Smith and Wasko (2012)

Figure 7 Floodplain hazard classification map

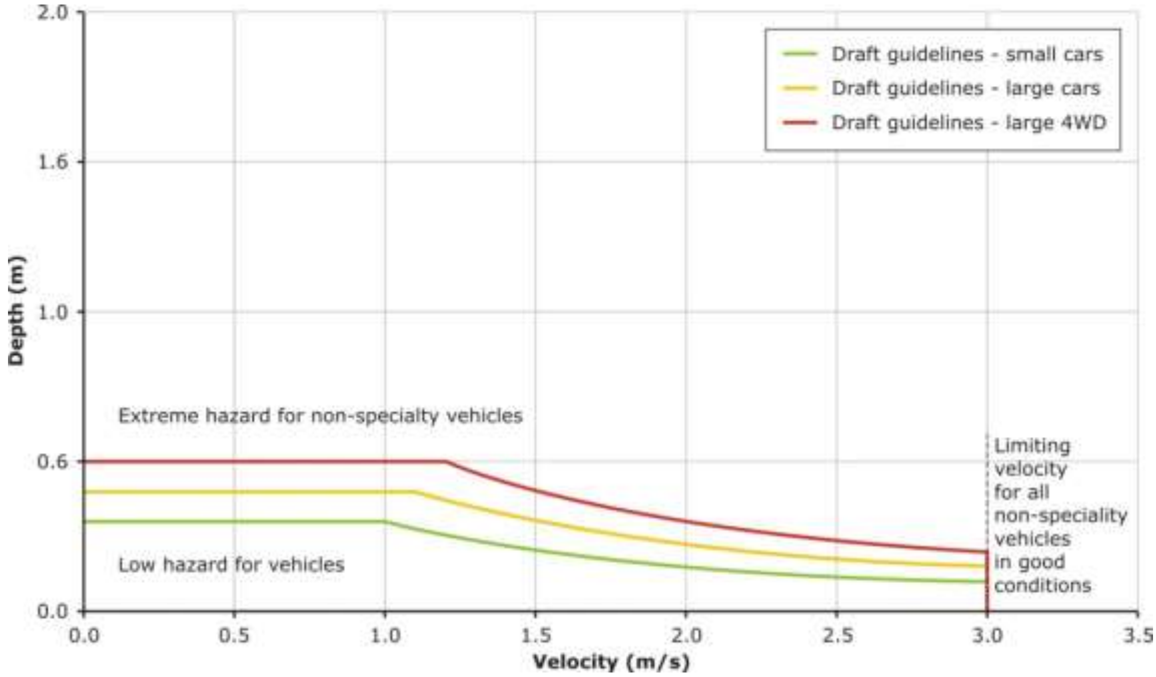
In some instances, specific hazard classifications are more appropriate than the general curves suggested in Figure 6. For example, if the hazard assessment is required as the basis of an evacuation plan, then a hazard analysis should be guided by vulnerability curves specifically for people stability (Figure 8) and vehicle stability (Figure 9) 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 10 may be applied. Additional background information on these individual flood hazard curves is available in Smith et al. (2014).



D.V = depth × velocity

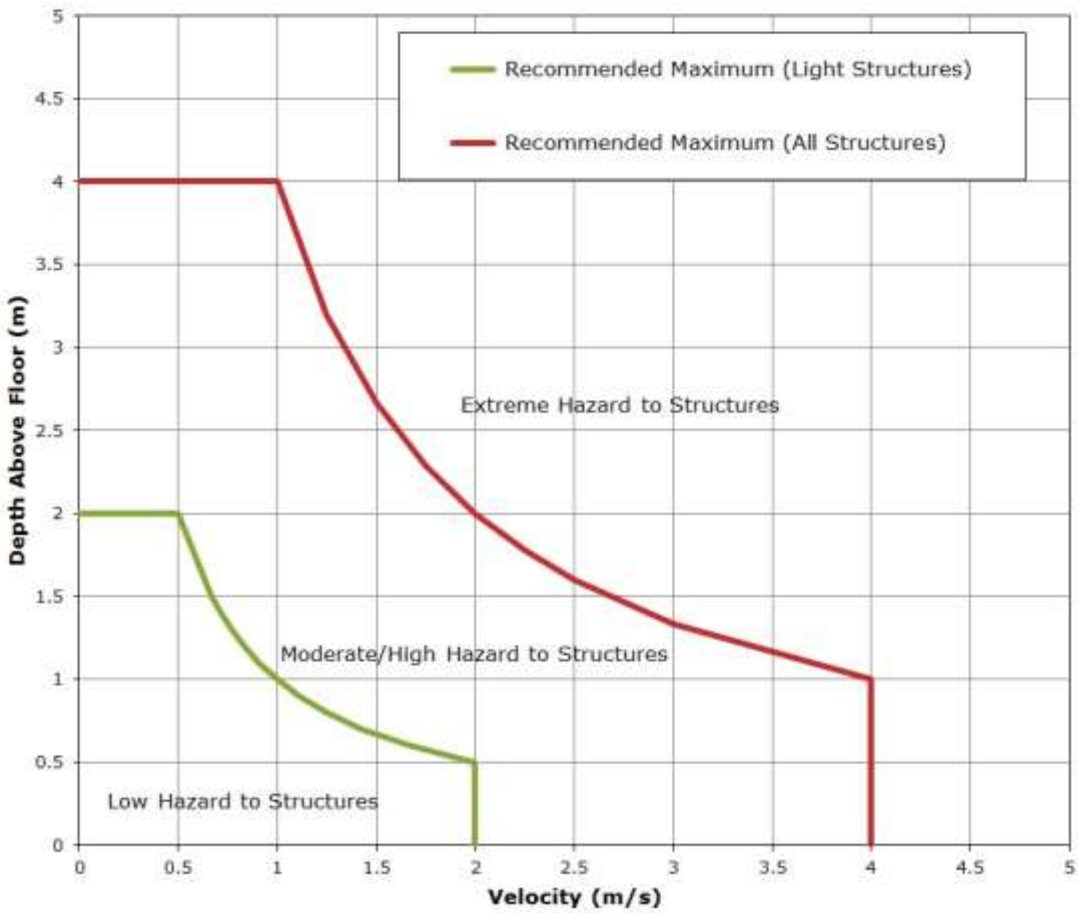
Source: Modelled after Cox et al. (2010)

Figure 8 Thresholds for people stability in floods



Source: Modelled after Shand et al. (2011)

Figure 9 Thresholds for vehicle stability in floods



Source: Modelled after Smith et al. (2014)

Figure 10 Thresholds for building stability in floods

5 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. These factors are important considerations that influence the vulnerability of communities to flooding and are important considerations in managing flood risk.

5.1 Isolation

As outlined in Section 5.3.3 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: Flood emergency response classification of the floodplain* (AEMI 2014).

5.2 Effective warning time

As outlined in Section 5.3.4 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.

5.3 Rate of rise

Rate of rise of floodwaters is discussed in Section 5.3.5 of AEM Handbook 7. A rapid rate of rise can lead to people who are 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.

5.4 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.

APPENDIX FLOOD HAZARD EXAMPLES

The following figures provide both a broad-scale and more localised example in the same floodplain of the base data (variation in velocity and depth across a floodplain) and hazard mapping using the categories outlined in this guideline. Examples are also given combining categories H2–H4, which relate to different scales of risk to people and vehicles, as this may be appropriate for some management techniques.

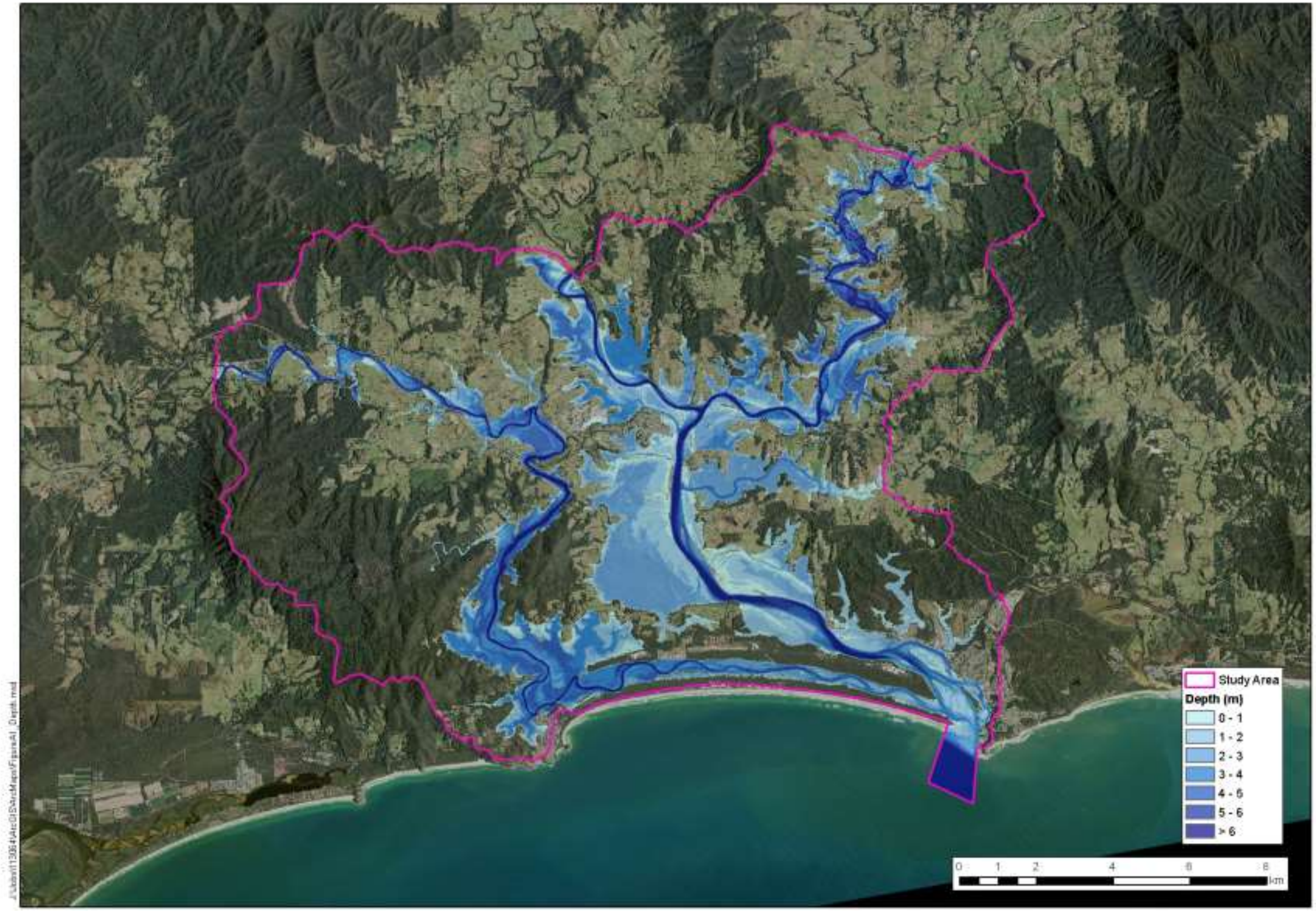

Study Area
Depth (m)
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
> 6
0
1
2
4
6
8
km

Figure A1 Flood depth variation within a broad floodplain

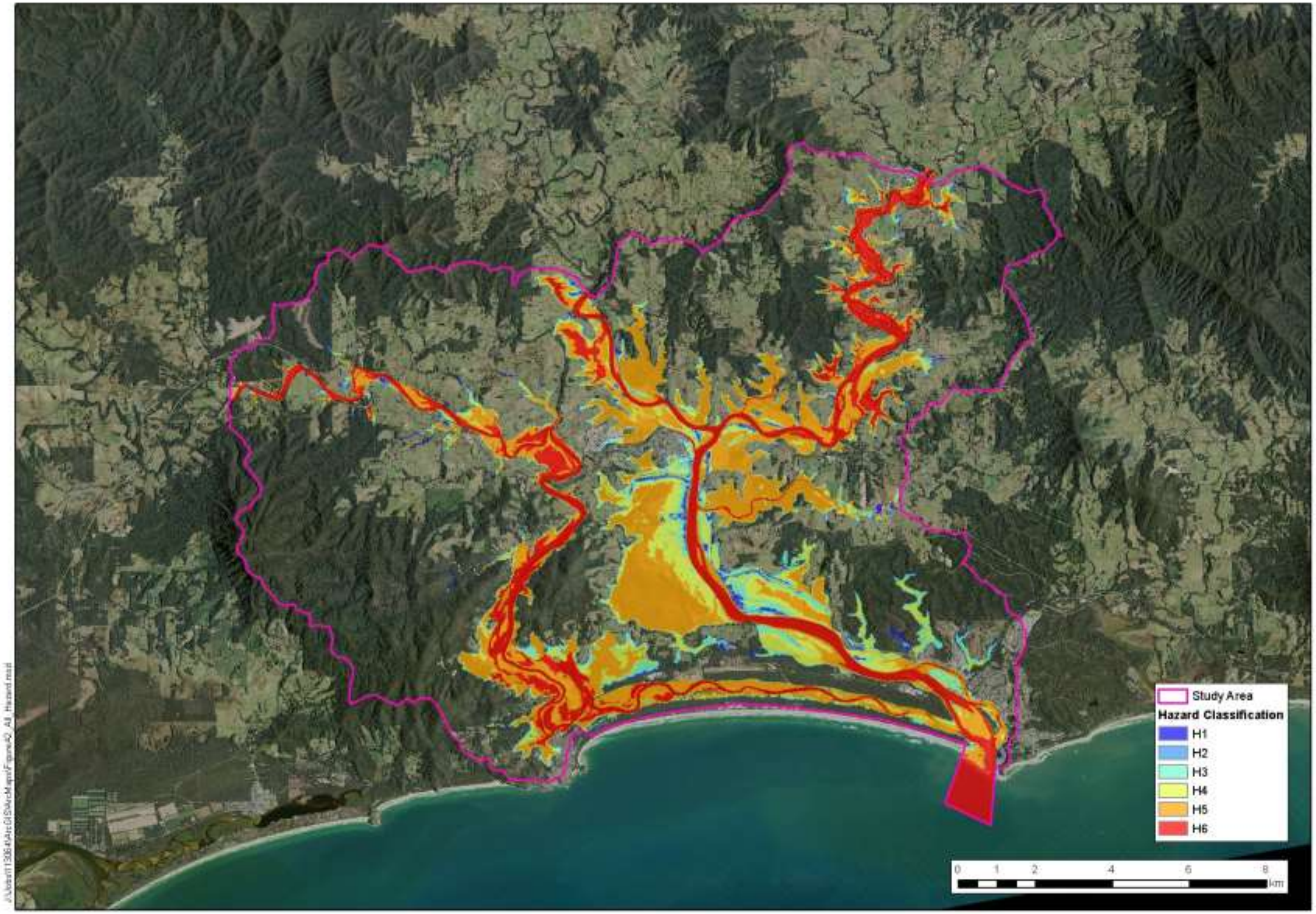


Figure A2 Flood hazards for categories H1 to H6 for a broad floodplain

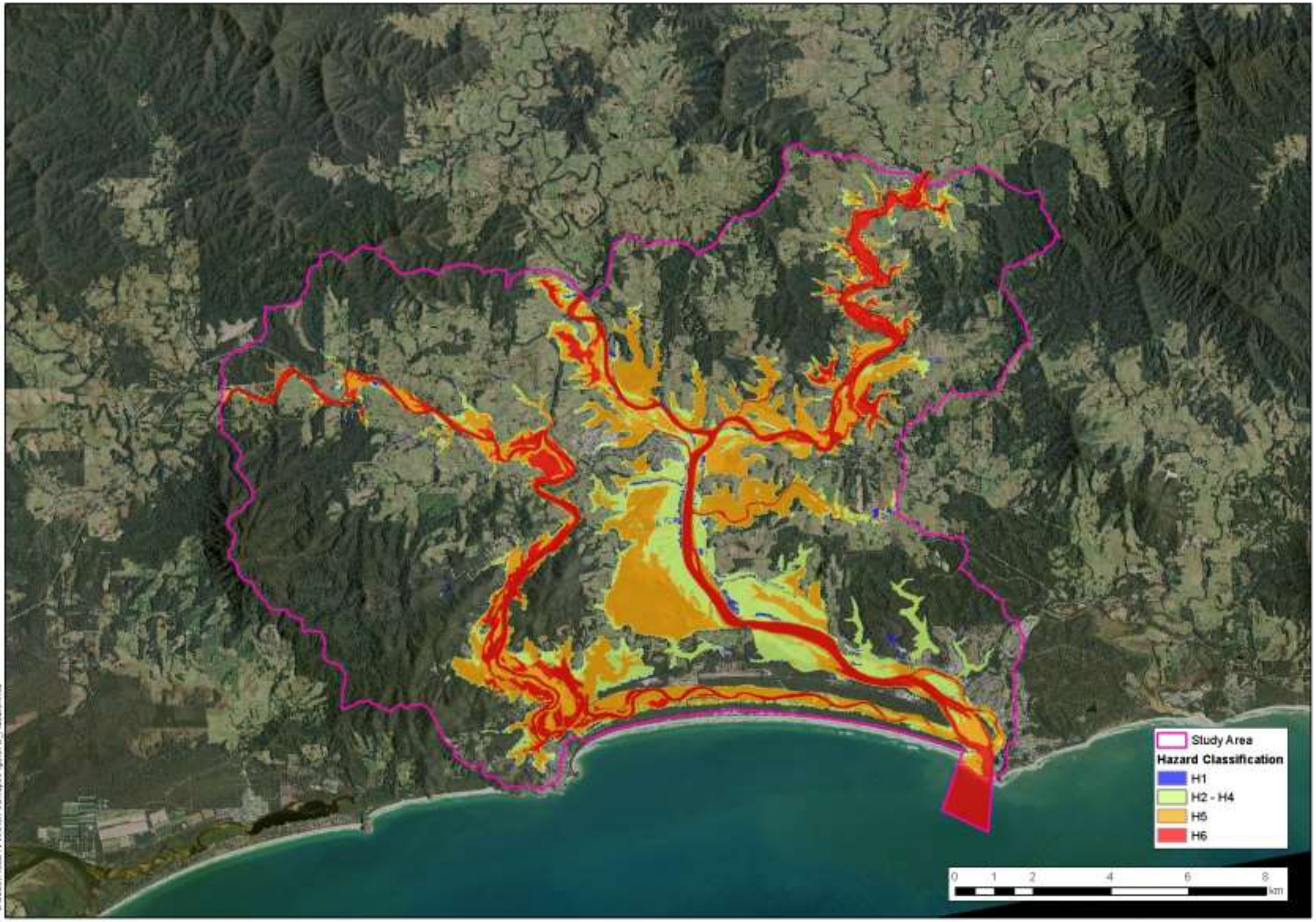


Figure A3 Flood hazards for categories H1, combined H2–H4, H5 and H6 for a broad floodplain

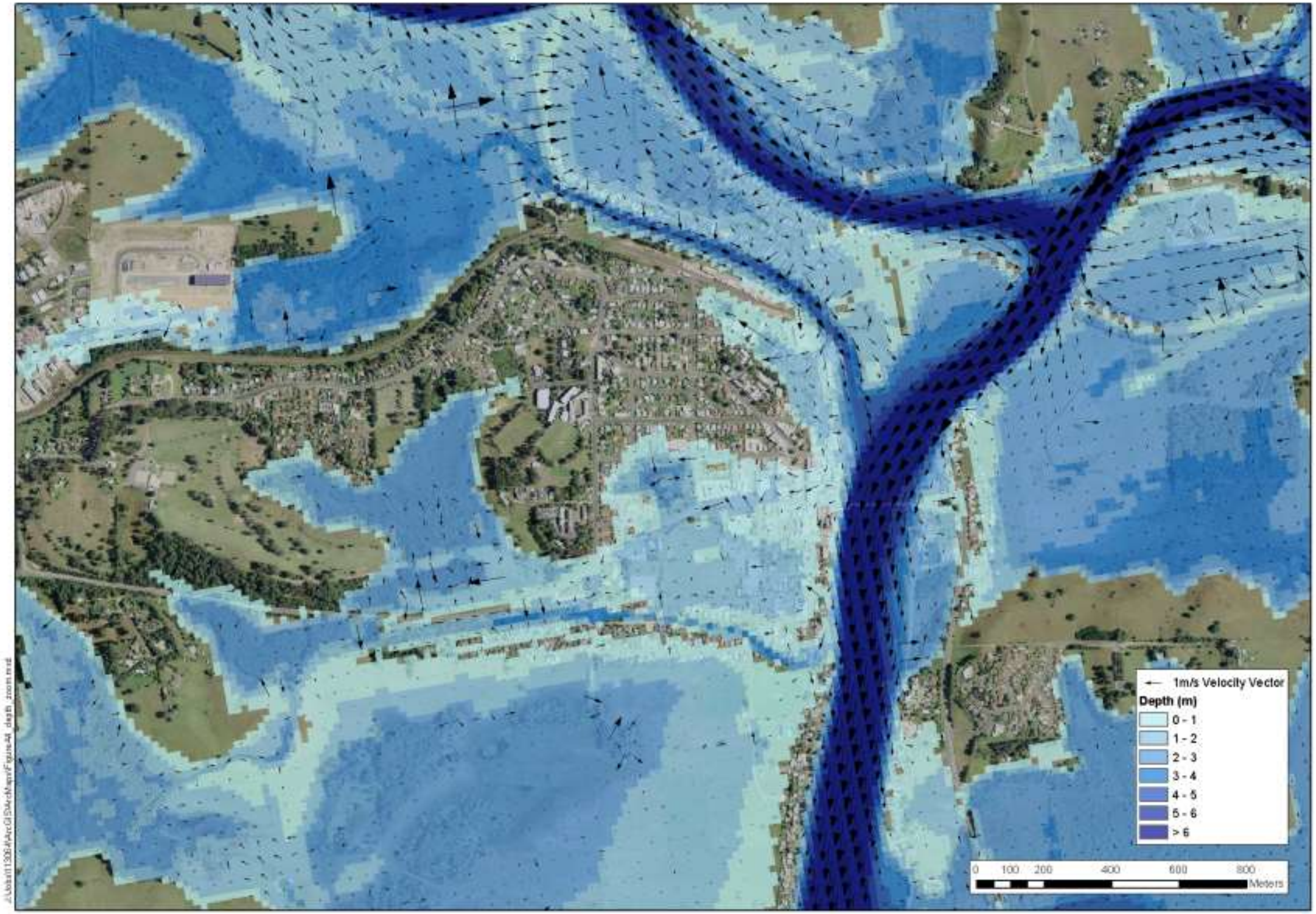


Figure A4 **Velocity vectors and flood depths within a more localised area of floodplain**

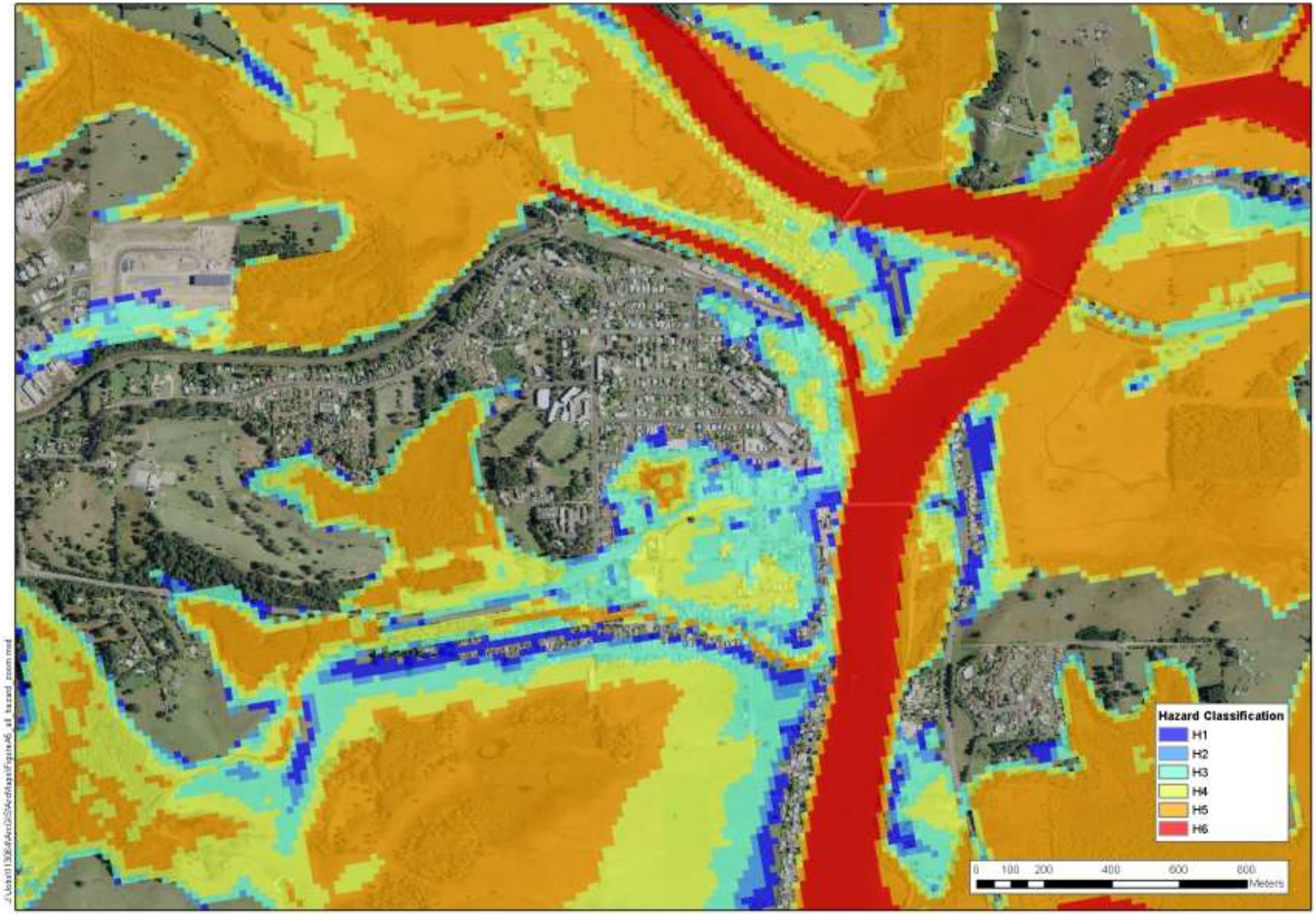


Figure A5 **Flood hazards for categories H1–H6 for a more localised area of floodplain**

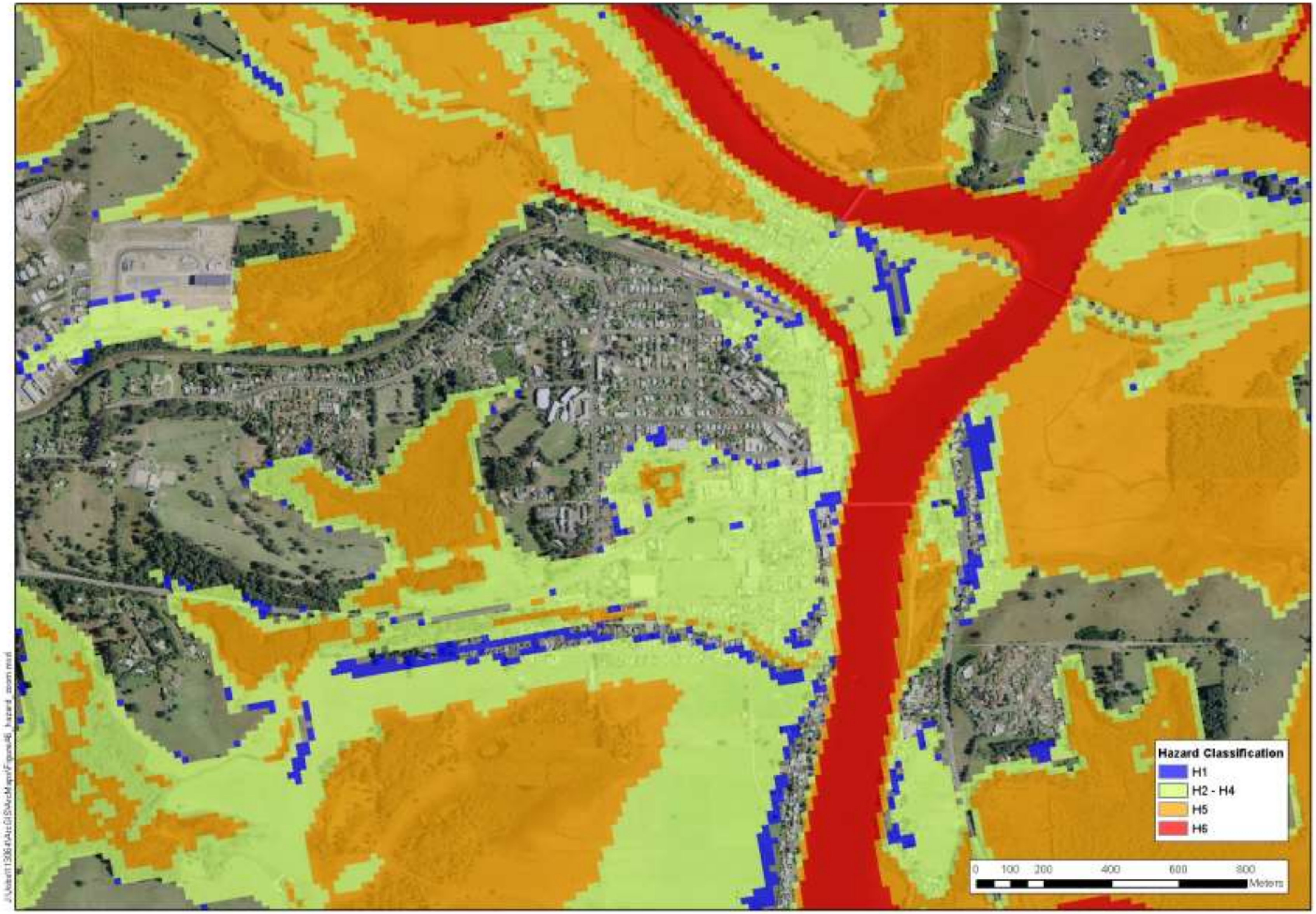


Figure A6 Flood hazards for categories H1, combined H2–H4, H5 and H6 for a more localised area of floodplain

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