WOULD YOU LIKE FREEBOARD WITH THAT?

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ABSTRACT

For flooding assessments, it is common to see the addition of a freeboard allowance to account for uncertainties and other effects above a calculated water level. A uniform freeboard allowance is often globally applied, even when the magnitude of these uncertainties and presence or absence of other effects can easily be shown to vary significantly.

In this paper variation of model uncertainty is compared to freeboard offsets that are commonly applied across New Zealand. Multiple modelling scenarios have been used to investigate the sensitivity of outputs. The use of fuzzy maps is demonstrated to show how these can support a more detailed assessment of the freeboard - risk relationship.

This approach is compared with current practice across New Zealand and the pros and cons discussed. The implications of freeboard choices are considered in the context of urban flooding, river stop banks and coastal flooding situations.

KEYWORDS

Freeboard, Flooding, Modelling, Risk, Uncertainty

PRESENTER PROFILE

Ian is currently a 3-waters infrastructure planning engineer with Tasman District Council. Over his 25-year career in Australia and New Zealand he has developed a keen interest in the management of droughts and floods. He is now exploring our standard of responses to the challenging world we face.

1 INTRODUCTION

For flooding assessments, it is common to see the addition of a freeboard allowance to account for uncertainties and other effects above a calculated water level. A uniform freeboard allowance is often globally applied, even when the magnitudes of these uncertainties and presence or absence of other effects can easily be shown to vary significantly. However, there is a lack of guidance in the Building Code and NZS 4404:2010 the *Land Development and Subdivision Infrastructure* standard on the applicability of appropriate site-specific and/or variable freeboards. This paper therefore provides some suggested approaches.

The variation of model uncertainty is compared to freeboard offsets that are commonly applied across New Zealand. Multiple modelling scenarios have been run to investigate the sensitivity of outputs. The use of fuzzy maps is demonstrated to show how these can support a more detailed assessment of the freeboard - risk relationship.

This approach is compared with current practice across New Zealand and the pros and cons discussed. The implications of freeboard additions are considered in the context of urban flooding, river stop banks and coastal flooding situations.

The aim of the paper is to assist the search for improved approaches in line with the direction sought by recent publications from the Insurance Council of New Zealand (ICNZ, 2014) and the Ministry for the Environment (MfE 2015).

2 WHY HAVE FREEBOARD?

Freeboard acts as a safety net as part of the art of stormwater management in an uncertain world. This section briefly discusses different aspects that contribute to the need to have a freeboard allowance.

2.1 UNCERTAINTY

There is significant uncertainty in the modeling processes due to natural processes such as the starting or antecedent moisture content of the ground and the actual pattern of the rainfall. Both of these can have a significant effect on the runoff and hence flooding potential. Uncertainty in model results is often not quantified, yet the freeboard allowance applied is expected to cover this.

2.2 ERRORS

Technology errors can occur in modelling results due to inaccuracies in the LiDAR or other survey, the software that translates the ground levels to a surface or the modeling software that generates the flood height. Naturally, human errors in the modelling process can also be present.

Given that ground elevation data is frequently taken from LiDAR surveys, the accuracy of the LiDAR survey is fundamental in the accuracy of the final output. LiDAR terrain data is often used with above-ground features stripped out, and in areas where this has occurred the interpolated ground elevations may be prone to error.

2.3 LOCALISED BACKUP

Where flowing water impacts a structure or other obstruction, a localised increase in water levels can occur. This can be enough to cause structural damage or flow diversion.

Photograph 1: Localised flow backup

2.4 WAVES

Waves can occur due to pressure changes in a watercourse eg tidal bore or roll waves, wind or vehicles. In urban situations vehicles are the most likely source and the Building Verification Method E1/VM1 Clause 4.3.1 requires a 0.5m freeboard for residential properties when a pond of 100mm depth extends from a common vehicle area to the dwelling (BC, 2009).

2.5 SYSTEM CHANGES

Climate variability is an obvious source of system change however this should be allowed for in rainfall estimates in line with current government advice (NIWA 2009). Changes in the system performance due to development, system deterioration or maintenance activities can accumulate slowly and lead to unexpected problems. Others such as earthquake damage can happen very quickly and cause ongoing issues.

However, system changes are often difficult to foresee, but in any system change there is a reliance on the resultant effects never being worse as time progresses. As such, allowance for system changes in setting a freeboard may be irrelevant in many cases.

2.6 OVER-DESIGN SITUATIONS

Over-design situations mainly relate to rainfall in excess of the design rainfall. However, system blockage leading to unplanned flow routes is the other major cause of problems. For example, photograph 2 shows a pipe blocked in a 20% AEP storm event in Richmond in February 2016. Figure 1 shows an excerpt from an Australian rainfall and runoff publication suggesting contingency design thinking for such situations.

Photograph 2: Blocked Culvert Inlet

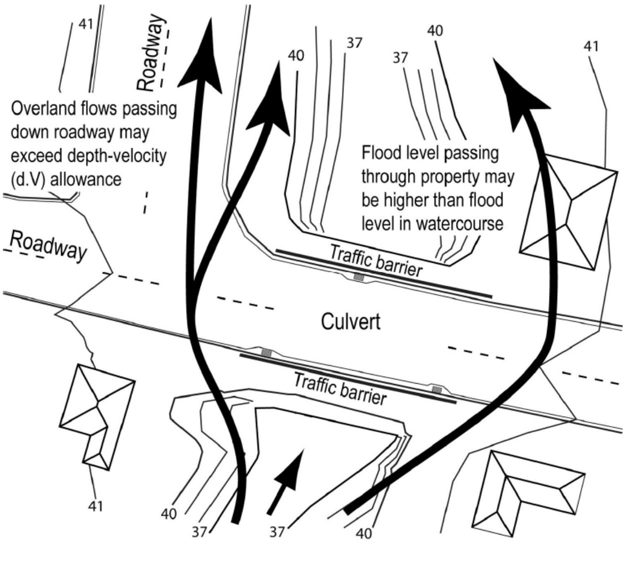

Figure 1: Blocked culvert potential flowpaths (AR&R, 2013)

3 URBAN FLOODING

Urban flooding can be related to Coastal Inundation (Section 4) or River Stop Banks (Section 5). However, this section focuses on flooding within urban areas from rainfall within or directly uphill of the urban catchment. The two key types of flood hazard relate to ponding and flowpaths and these have different characteristics that influence considerations of appropriate freeboard.

3.1 PONDING FLOODING

Ponding freeboard may be due to the presence of a naturally low lying area or a temporary or permanent man-made barrier. Potential ponding depth may be either limited by the physical features or the total rainfall that can gather in the catchment. Hence each hollow and sub-catchment has a different potential flood height hazard. Given the trend towards slab-on-ground residential construction, the risk of internal flood damage in new suburbs can be much higher than for older areas with traditional pile construction. However, as some ponding areas can hold significant volumes, simply assuming that the pond is full for formal planning processes can be too conservative. Hence the pond level to base the freeboard on is best derived from a detailed level of protection setting process as was discussed at last year's conference (McComb, 2015).

3.2 FLOWPATH FLOODING

Flowpath flooding may be the result of a blocked or overloaded channel or inlet as shown in Figure 1, or may just be caused by small localised flows on their way to an obvious channel. Relatively small catchment areas can lead to flooding of buildings when diverted and/or concentrated towards a vulnerable structure. Figure 2 shows an example of small flowpath modeling in Richmond. The kerb and channel flowlines can easily be seen as can places where the flows are expected to leave the road and travel through private sections.

If obstructions are placed across such flowpaths, then localised flood levels may be raised. In many cases, a regulatory authority has little control over placement of obstructions in such flow paths, and application of a freeboard allowance is important to ensure the required level of protection is able to be met.

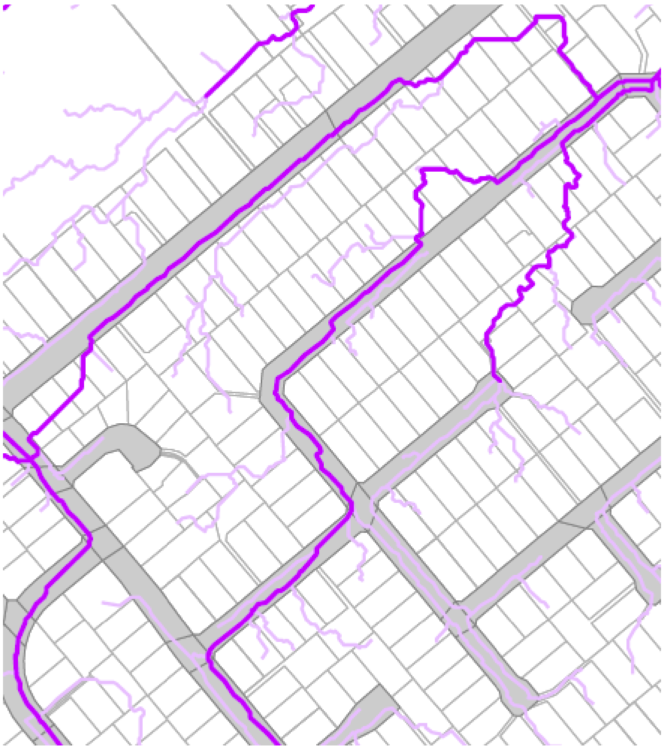

Figure 2: Modelled small secondary flowpaths in Richmond

3.3 BUILDING CODE

The Building Code does specifically address freeboard but in a limited way as discussed below. There is also an inconsistency in approach with NZS4404:2010 (SNZ, 2010) in that the latter approaches freeboard to the underside of the floor and the Building Code to the finished floor level. The combination of these documents results in national-level freeboard guidance that is partial and inflexible considering the range of reasons to have freeboard as discussed throughout this paper.

Building Code Clause E1 'Surface Water' is the most relevant section and specifically Performance E1.3.2 which requires protection of Residential and Communal buildings from surface water inundation in the 2% or 50-year event. Clause E2 'External Moisture' also has freeboard linkages.

Surface water is a defined term in the Building Code as: *All naturally occurring water, other than sub-surface water, which results from rainfall on the site or water flowing onto the site, including that flowing from a drain, stream, river, lake or sea*.

The associated Compliance Document and Verification Method/Acceptable Solution documents (VM/AS) require freeboard of 100 to 500mm in limited circumstances as summarised in Table 1.

Table 1: Building Freeboard Provisions

Clause	**Freeboard Amount**	**Notes**
E1/VM1 4.3.1	500mm above water level	Where *surface water* has a depth of at least 100mm and extends to a road or a common carpark
	150mm above water level	All other cases
E1/AS1 1.0 and 2.0	150mm above reference level	150mm above surrounding ground AND 150mm above the road crown or 150mm above the lowest point on the site boundary - only applicable to sites free from flood history, not located in a low lying area or adjacent to a watercourse or in a secondary flow path.
E2/AS1 9.3.1	100mm above paving level	Masonry veneer construction
	150mm above un paved ground level	Masonry veneer construction
	150mm above paving level	Other claddings construction
	225mm above un paved ground level	Other claddings construction

(MBIE 2015)

3.4 CURRENT NZ COUNCIL DESIGN REQUIREMENTS

Table 2 summarises some current Council design and freeboard requirements in New Zealand.

Table 2: Council Design Freeboard Provisions

LGA	Component	Design/LOS	Freeboard
Auckland (AC, 2015)	Primary Secondary	10% AEP 1% AEP	150-300-500mm depending on secondary flow threshold of 2m^3/sec rate and activity vulnerability[1].
Christchurch (CCC, 2013)	Primary Secondary	20% AEP 2% AEP	400mm 300mm
Hamilton (HCC, 2013)	Residential Industrial Commercial Secondary flow	2 year ARI 1-hour storm 5 y ARI 1 hr storm 10 y ARI 1 hr storm 100 y ARI TOC storm	500mm (200mm)[2] 300mm 300mm
Kapiti Coast (KCDC, 2012)	All urban areas	10% AEP Primary and 1% AEP secondary	Varies with locality 0.3-1.0m
Nelson (2016[3])	Residential Industrial Commercial Major communal facilities	6.67% AEP (1 in 15 year ARI)	500mm (200mm)[2] 300mm 300mm 600mm (supply of electricity, telecommunications water supply and wastewater
Tasman	New systems	10, 15 or 20 year ARI primary and 100 years ARI secondary[4]	As for Nelson
Tauranga (TCC 2014)	Greenfields development Infill and brownfield (re) development	10 year ARI primary and 50 year ARI secondary Based on above plus public safety	As per NZS 4404:2010
Wellington (WCC 2012, Capacity 2015)	Residential Industrial (I) Commercial (C)	10% AEP primary 1% AEP for residential and communal building floors 10% AEP primary 2% AEP for C & I floors.	500mm (200mm)[6] for secondary 300mm above open channels for primary

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[1] Vulnerable activities under the PUAP (2013) are similar to the Building Code E1 residential and communal buildings.

[2] 200mm for non-habitable outbuildings – all adopted from NZS4404:2010 or an alternative calculation to potentially allow a lower freeboard if sufficient data exists (similar to Table 3).

[3] Proposed for new Land Development Manual

[4] Tasman District Council has approved different standards being 10 year ARI for most new residential areas and 20 year ARI for most town centre areas, however for Richmond a 15 year ARI standard is proposed to apply for new works as part of a joint Land Development Manual with Nelson City. Refer also footnote 2

[6] 200mm for non-habitable outbuildings – a mix of NZS4404:2010 and E1 standards is evident in the detail.

3.5 REDUCED FREEBOARD FOR LOW HAZARD AREAS

As suggested by the limitations imposed on the 150mm freeboard requirement in Clause 1.0 of E1/AS1 there are situations where it is reasonable to design for low flood heights. Where modelling exists to support the analysis, an approach that some Councils are using is to consider the appropriate freeboard to building platform or ground level based on the catchment area, depth and velocity. Table 3 provides an example. Note: This approach would need to be tailored to each Council area based on local rainfall and runoff characteristics.

Table 3: Suggested 1% AEP Freeboard to Ground Level for Habitable Dwellings and Communal Buildings in Low Hazard Areas

This type of table may be used where Council has appropriate hazard modelling data. The required freeboard is the highest value determined from columns A-C.

A: Catchment Area		**B: Ponding Depth**		**C: Flow Velocity**	
(ha)	**Freeboard (mm)**	**(mm)**	**Freeboard (mm)**	**(m/s)**	**Freeboard * (mm)**
0.25<	0	<100	0	<0.5	0
0.25-0.5	25	100-249	150#	0.5-.99	150
1	50	250-499	350#	1.0-1.49	250
2	75	500+	500	1.5-1.99	350
3	100	# on site rather than adjacent to building - if touching building then note a 500 mm minimum freeboard to FFL as per Building Code Compliance Document E1/VM1		2+	500
Above 3ha add 25mm per ha until 500mm				* Freeboard assumes vertical walls, for ramps specific design is required.	

4 COASTAL FLOODING

The potential for coastal inundation is driven by a range of factors including tides, wave runup, wave setup, inverse barometric effect, beach profile, coastal structures, wind, erosion, coincidental fluvial flooding, tsunami, land mass movements and sea level rise. These are heavily influenced by the specific local environment.

The building code protection from surface water includes protection from the sea however currently little specific information is available to assist. Further guidance is expected within the next year following the report highlighting the coastal issues by the Parliamentary Commissioner from the Environment (PCE, 2015).

5 RIVER STOP BANKS

Apart from reducing the risk of over topping on bends and from wave action, adequate freeboard for stop banks can allow for a range of changing circumstances, including bed aggradation.

The influence of freeboard on river stop banks is a significant design consideration with regard to the consequent total land take and project cost. However, the risk associated with simply adopting a standard design without consideration of the implications of overtopping has been well discussed by Throssell et al in their 2015 conference paper *Floor Levels Above The 2% Flood Event – Are They High Enough*? In this case a Kaiapoi subdivision developer was convinced that adopting a higher than required design standard was justified in the residual risk reduction and hence site sales.

The typical freeboard allowance for stopbanks in New Zealand is 2-3 feet (~600-900mm) above the highest known flood or the Q50 flow. Bridge structures often use the 900mm standard to allow for trees to pass under structures and it has been observed that railway bridges have even greater margins. (PC, 2016).

Other risk factors for stopbanks performance include lateral erosion, piping and saturation failure. Once stop banks are installed, complacency can reduce hazard awareness and lead to increased development or investment on "protected" land. Hence adopting a suitable freeboard for key assets behind stopbanks is prudent to avoid excessive damage in the event of failure or overtopping.

This supports our position that adopting appropriate freeboards should involve a detailed assessment of the relevant factors for each situation.

6 TESTING THE UNCERTAINTIES WITH FUZZY MAPPING

6.1 RULE OF THUMB

An often quoted "rule of thumb" for freeboard requirement is to "double the flow" and the increase in resultant flood level can be taken as the required freeboard.

While this approach appears to be an oversimplification, it does illustrate one major factor in hydraulic performance uncertainty. This is that in certain areas, a small degree of uncertainty in hydrological input can translate to a large difference in resulting flood level, and vice versa.

For example, in an incised channel that is subject to flash flooding, a very large (and rapid) change in flood level occurs in response to a rainfall burst in the catchment. Conversely, in a large, open flood ponding zone, the response to a rainfall burst is far smaller. It makes little sense, in these cases, to apply the same freeboard allowance to both.

In many cases, particularly with flood levels derived from hydraulic models where inputs come from hydrological models, it is not possible to apply the "double the flow" algorithm because the input variable to the whole computation is rainfall and not flow. However, it is possible to increase input rainfall depths to test sensitivity in results to such a change, and thereby calculate the catchment response sensitivity and hence freeboard requirement.

6.2 CHANGE TO INPUTS

A common source of uncertainty in design flood level is driven by our understanding of the likely effects of climate change with time. While industry guidance is frequently quoted and referenced on the topic, a skeptical designer may seek to develop an independent understanding of how a specific catchment may respond to changes in climatic conditions.

In Figure 6.1 an example of a flood depth output from a hydrological and hydraulic modelling exercise is presented. In this only predicted flood depths in excess of 100mm have been plotted. Two specific areas of interest have been highlighted – areas A and B. Area A is at the head of a small sub-catchment, and the modelling analysis has revealed formation of some channel flow, initially at shallow depth, which drains towards a more major collector channel. Ground slope in this area is relatively mild, getting steeper with distance downstream.

Area B contains a part of a major river system, which has a large and steep upstream contributing catchment area. Land use in the upper catchment is mainly forestry and pasture, with some reasonably significant areas of native bush. The major river channel is relatively steep and incised, and is likely to respond rapidly to intense rainfall.

The effects of climate change in this area, these being limited to an increase in predicted rainfall intensity and depth (with changes in vegetation neglected) were simulated. The resulting flood depths are shown in Figure 6.2 in red, underlying the data plotted in Figure 6.1. In Figure 6.2 wherever a red colour is visible it is indicative of an enlarged flood extent as a direct result of the change in design rainfall applied.

In Area A no change is visible, in spite of the change in rainfall. However, in Area B an overflow path from the major river channel is identified that was not shown in the original flood depth map. These two figures and the two areas identified within them are indicative of the sensitivity in predicted flood depth to input parameters – in this case, input rainfall. It could be argued that a larger freeboard allowance should consequently be made for Area B than for Area A.

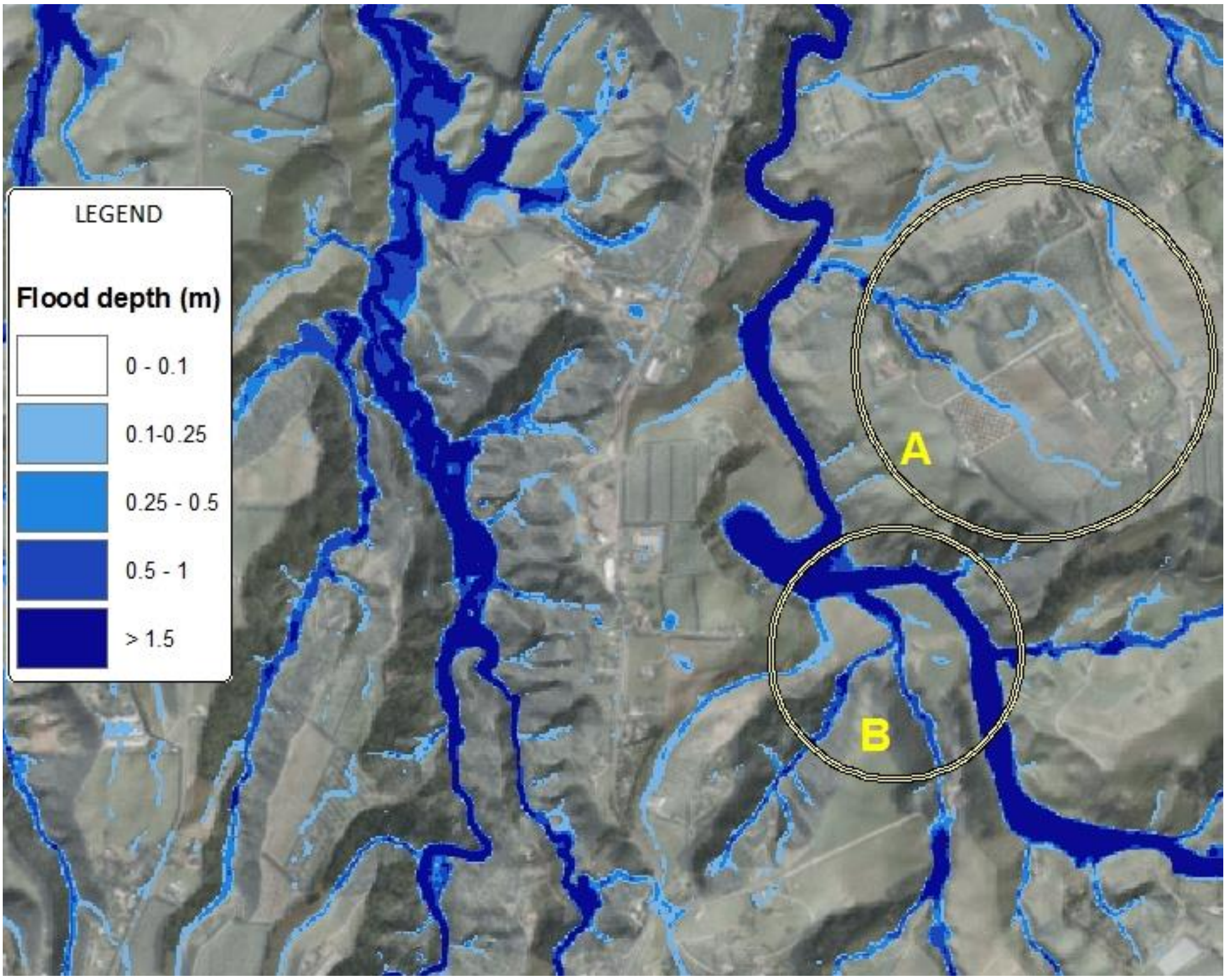

Figure 6.1: Flood depth map

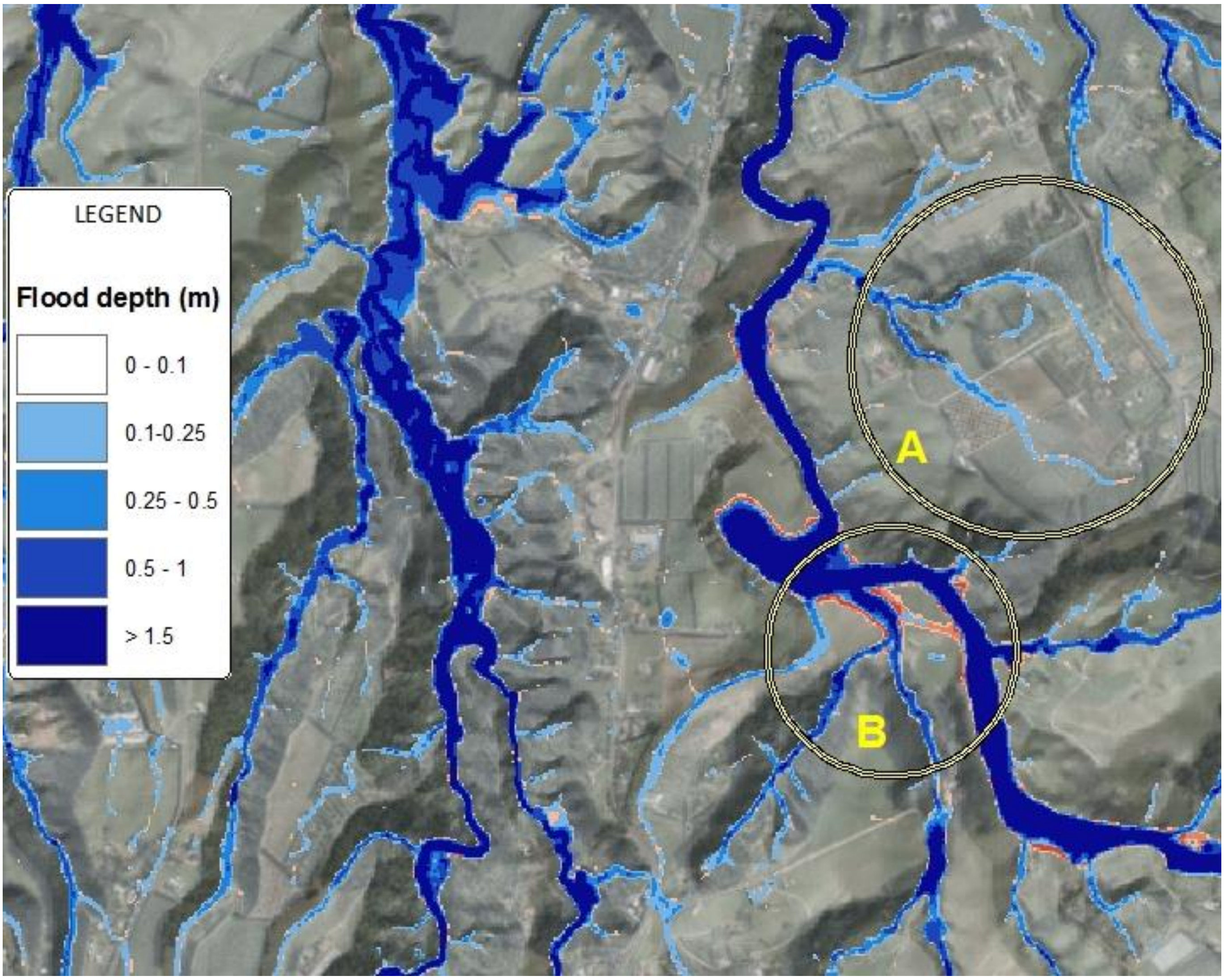

Figure 6.2: Flood depth map for changed rainfall

6.3 MODEL UNCERTAINTY

Uncertainty in model results is controlled by many factors, of which the most significant are probably the following:

- Uncertainty in source data (eg LiDAR)
- Hydrological parameters (rainfall spatial distribution, antecedent conditions, etc)
- Hydraulic controls (eg roughness).

The degree to which these factors affect the ultimate results, which are usually maximum flood depths over the simulation period in response to a design rainfall, can easily be tested. Previous work on the accuracy of LiDAR data and its effect on model results has been undertaken and referenced separately.

For the purpose of illustration, the model used for the results shown in Figure 6.1 and in Figure 6.2 was re-run using the following sensitivity analysis:

- Initial rainfall loss plus and minus 10%
- Ultimate infiltration loss plus and minus 10%
- Manning n roughness plus and minus 10%
- Percentage impervious area plus and minus 10%

The results from these runs were aggregated into a *fuzzy map*, as shown in Figure 6.3. This essentially represents model results confidence, and was done for the rainfall that was used to prepare Figure 6.1 only (i.e. not the adjusted rainfall).

Immediately visible from this *fuzzy map* is that confidence in the model results is low in some of the potentially flood-prone areas in Area A, while it remains high throughout most of Area B. Using these sensitivity results it is possible to quantify the model confidence based on the range of results obtained for sensitivity variables considered. Tailored further investigation can then be undertaken that will support setting appropriate (variable) local freeboards.

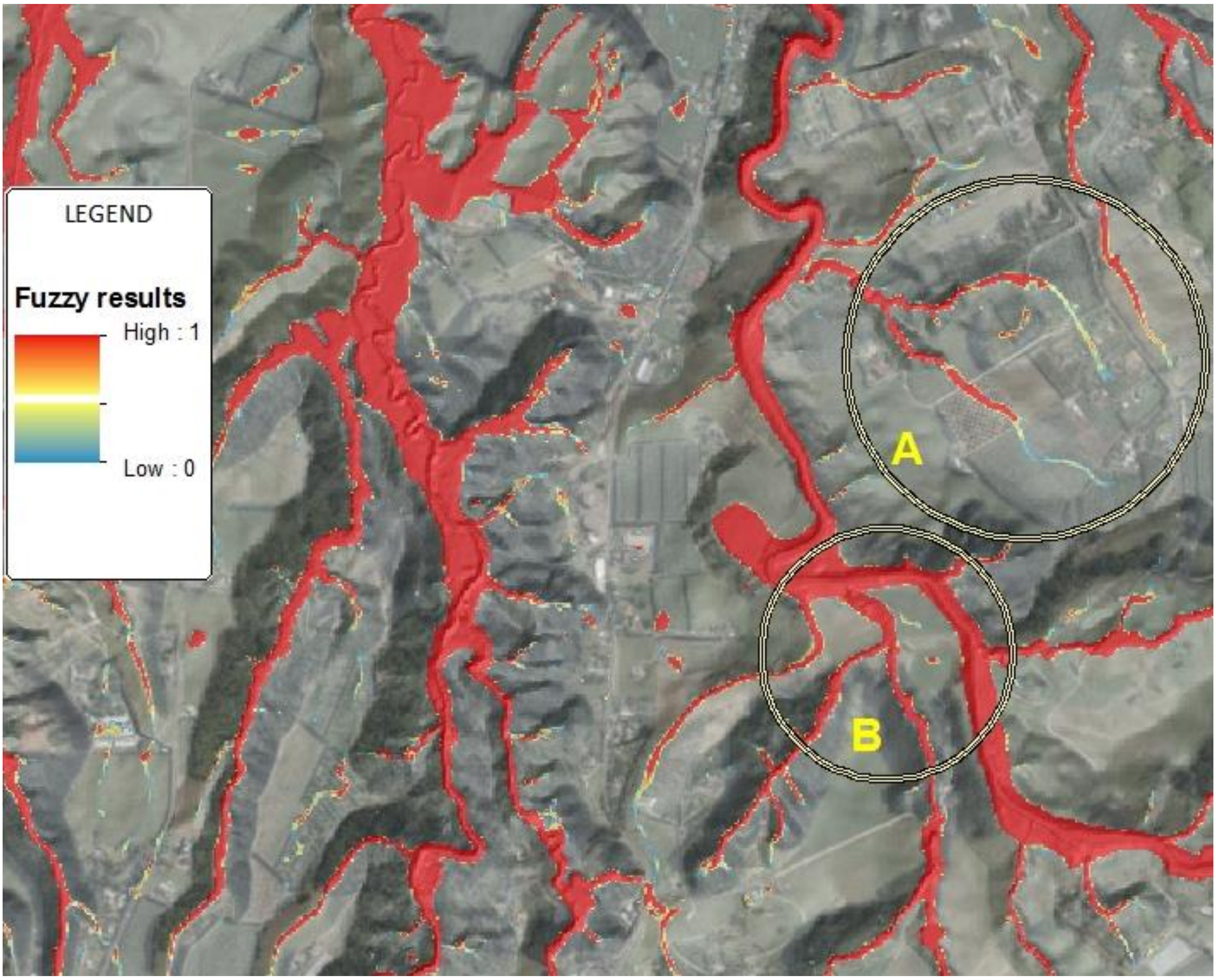

Figure 6.3: Fuzzy map for model confidence

7 APPLICATION

The ability to move beyond standard uniform freeboards as per NZS 4404 or Table 1 is generally based on having robust data from a well-constructed model. Hence the ability to apply an approach as outlined in Table 3 or fuzzy mapping depends on the availability of a suitable model.

Constructing the model knowing that it will or could be used for setting variable freeboards in a regulatory or practical sense will focus the modelers mind on the required input data and accuracy requirements.

Whether this additional work is appropriate to each local situation will depend on the use and the potential value at risk. Table 4 summarises the Pros and Cons of the freeboard setting approaches discussed.

Table 4: Comparison of Pros and Cons of freeboard setting approaches

Approach	**Pros**	**Cons**
Apply fixed freeboard based on NZS4404:2010.	Aligns with most recent national guidance. Well known standard used by engineering staff. Easy to apply for new subdivisions	Needs to be adopted into District Plans to give sufficient weight in Council processes. Lacks flexibility to deal with a variety of situations and potentially leaves some properties at risk.
Rely on Building Code freeboard provisions.	Simple to apply, low data requirements. Has regulatory weight and significant industry awareness	Only applies to some situations and hence leaves some properties at risk. Is based on 2% rather than the more conservative 1% flood level.
Apply locally derived (and potentially variable) freeboard	Can account for relevant influences. More accurate reflection of hazard and reduces residual risk. Can signal better areas for development.	Higher data requirements Need to embed results in Council planning process to provide regulatory weight. Potentially more open to challenge

8 CONCLUSIONS

This paper has explored a range of aspects relating to flooding and freeboard in the urban, rural and coastal environments. Due to the ranges of uncertainty that must accompany any flooding level calculation, the inclusion of freeboard is always a prudent move to minimise property damage. However, we have demonstrated that, rather than adopting simplistic standard freeboards, setting variable offset levels that are appropriate to the circumstances is justified to better reflect localised risks.

By considering the key factors that control flooding potential in each area, an appropriate freeboard allowance can be set. Good quality modelling is a key requirement to assist setting appropriate local freeboards. The minimum details to consider are:

- Rainfall intensity
- Catchment size, shape and responsiveness
- Ponding, secondary flow, coastal or river flooding
- The impact of over design scenarios.

Checking the sources or error and the sensitivity of inputs allows testing of the model and the implications of inaccuracies. The fuzzy mapping approach allows a sensitivity analysis to be visually displayed to support an improved understanding of the variances that could occur for each catchment. Further investigation can then be undertaken that will support setting appropriate (variable) local freeboards.

These techniques are suggested to support the resilience of our communities in an uncertain environment.

ACKNOWLEDGEMENTS

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Fuzzy mapping by Tonkin and Taylor staff

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