HAZARD :- Is there a better definition? & Impact of Not accounting for buildings!

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***Abstract**:*

The basic derivation of “Flood Hazard” is based on the determination of “Hydraulic Hazard” and the assessment of various factors as defined in Appendix L of the Floodplain Development Manual 2005. The primary determinant being related to the momentum of the flow or, “Velocity x Depth”. Further it is common in flood studies of urban areas to utilise methods by which the residential areas within the urban area is set at a very high roughness value in an attempt to account for the influence of obstacles to the flow such as buildings and fences. What impact does this have on identifying VxD and Hazard? This paper explores the impact of not specifically accounting for the presence of these obstacles and also explores potential methods to derive a parametric equation that may provide a better scope and range for identifying a more quantitative method of differentiating Hazard. This paper has in effect two parts. Part one describes a proposed new definition of Hydraulic Hazard. Part two uses the technique to investigate and report on the inadequacies in the current practice of adopting a high roughness value to attempt to model the impact of obstacles in an urban environment.

1.0 INTRODUCTION

Identifying “Hazard” is a major component of flood studies and floodplain risk management studies. The evolution of defining what hazard is should be focussed on attempting to derive a method that is simple to apply yet provides the greatest scope and flexibility in differentiating (or delineating) the extent and severity of a hazardous condition. Howells, McLuckie, Low & Avery (2004) provide a reasonable discussion on the evolution of “hazard” in the context of flooding. Further there is some discussion on the limited delineation provided by adopting the current recommended methods as described in the NSW Floodplain Development Manual 2005 (FPDM2005). Current practice in effect limits the delineation of “hazard” to one of two possible categories:

1. Low Hazard
2. High Hazard

(Note there is a band sometimes referred to as intermediate or medium hazard.)

However this limited delineation is extremely limiting in the information in can convey.

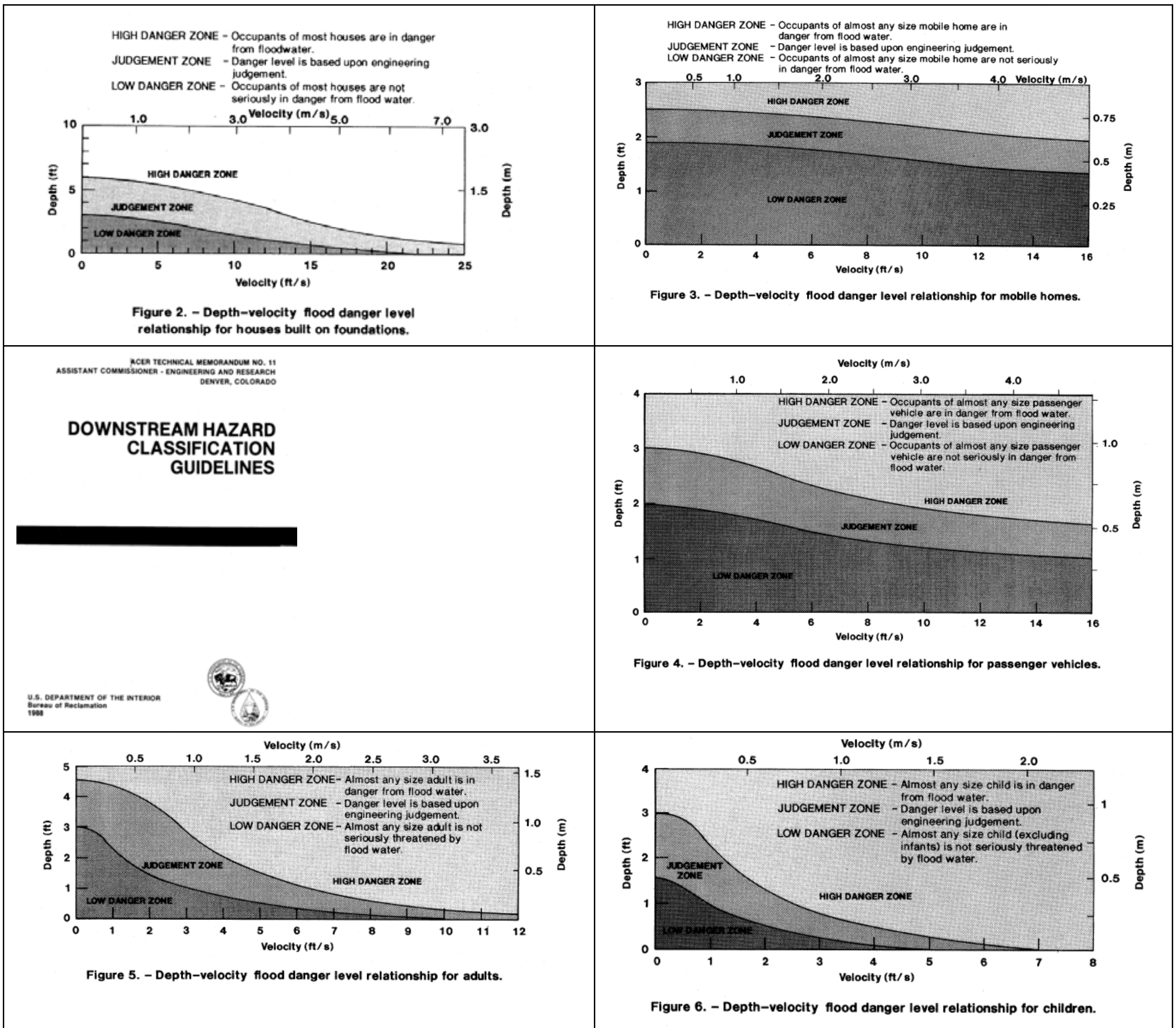
2.0 IDENTIFYING HAZARD

In the US Trieste (1988), provides a methodology whereby a series of hazard curves derived from Velocity and Depth information is additionally related to items at risk of the hazard. The specific items include:

1. Houses built on Foundation
2. Mobile Homes
3. Passenger Vehicles
4. Adults
5. Children

A series of 2 curves provide delineation of 3 zones for each of the 5 items (Figs. 1 – 5). This method is based on work by Black (1975), Ruh-Ming (1984) and David (1987).
More info from: https://www.nwo.usace.army.mil/nfpc/fpbib/ace10.htm

He also mentions that duration of exposure to hazard (as well as several other factors) should be accounted for, in determining hazard within the judgement zones. The hazard classification outlined by Trieste deals only with lives in jeopardy as opposed to “estimated loss of life”.



Figs. 1-5 Hazard methodology by Trieste (1988)

This methodology would presumably be reflected in the creation of 5 separate maps for each of the types of items exposed to hazard.
It should be noted that although this methodology was developed in 1988, they are still current practice in the US as stated by Harrington (2003).

2.1 FPDM 2005 Approach

By comparison the FPDM2005 method also provides two lines that create three zones of hazard (Fig 6&7). However there is only one family of lines to cover all cases. The FPDM has in some ways extended the range of differentiation by utilising "Hydraulic Categorisation". But what is the underlying value in these categories? This question is not the subject of this paper however further discussion can be found in the paper by Rigby & Roso (2008) {this conference}. So in effect we have 6 categories that appear to have no underlying parametric approach to differentiate them. This is a situation that the author feels should be avoided at all costs, as it has the potential to become too subjective rather than definitive.

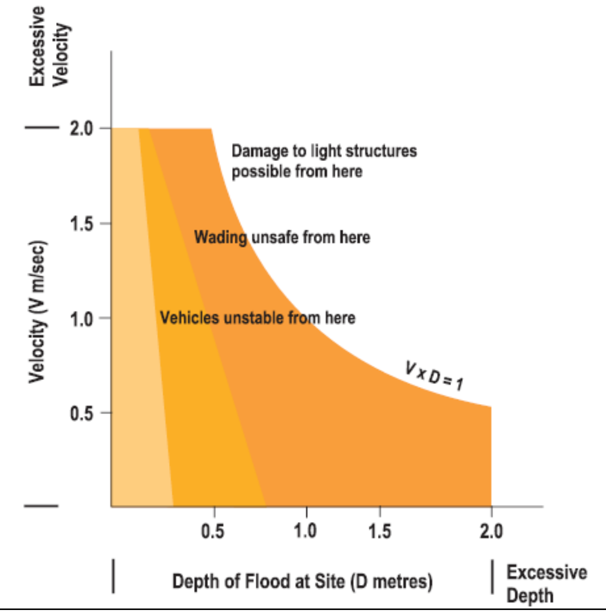


Fig. 6. FPDM Fig. L1

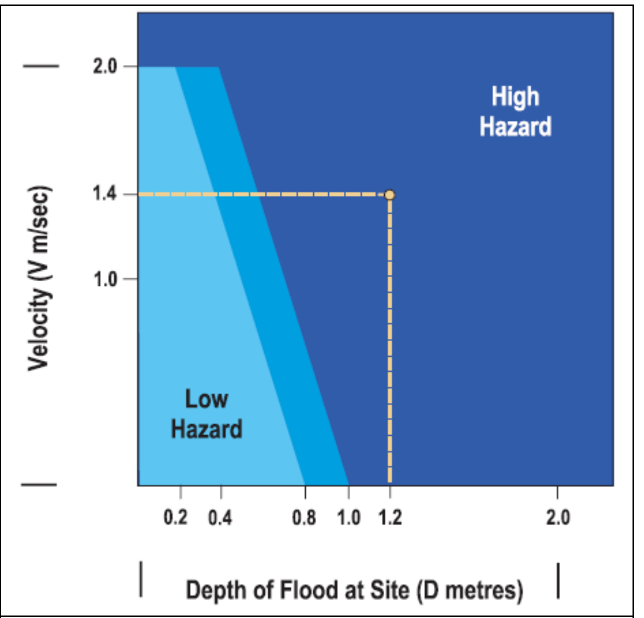


Fig. 7. FPDM Fig. L2

From the Fig. L2 in the FPDM2005 it is clear that the simplistic relation that defines the differentiating line between Low Hazard and higher Hazard is:

Approximate equations that make up the FPDM plots are as follows:

A. For Fig. L1:

1. Vehicles unstable from here:

Depth = Velocity x (-.092) +0.3155 (For Velocity 0 -2m/s) **Eqn. 1**

2. Wading Unsafe From here:

Depth = Velocity x (-.092) +0.3155 (For Velocity 0 -2m/s) **Eqn. 2**

3. Damage to light structures possible from here:

Depth = 1 / Velocity (For Velocity 0 – 2m/s) **Eqn. 3**

B. For Fig. L2:

1. Low Hazard Below this Line:

Depth = Velocityx(-0.3) + 0.8 (For Velocity in the Range 0 - 2m/s) Eqn. 4

2. High Hazard above this Line

Depth = Velocity x (-0.3) + 1.0 (For Velocity in the Range 0 - 2m/s) Eqn. 5

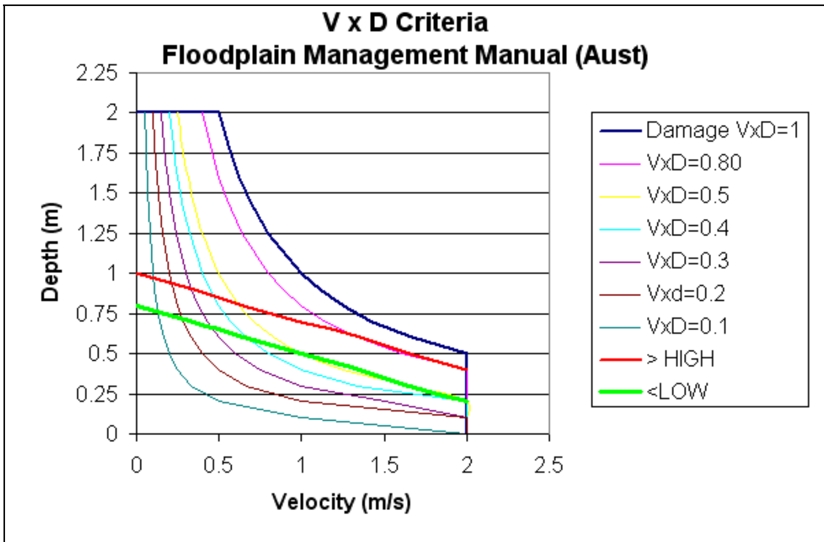
These relationships are relatively easy to use to colour a 2 dimensional computational domain to produce a hazard map. But what does it mean, what does it represent and how useful is it, and how can this usefulness be extended?

By plotting these lines over plots of Velocity x Depth, you can get a bit of a “feel” for what these lines represent.

The fact that the line identifying areas that are deemed low hazard, has a range of VxD values from 0.18 to around 0.53 shows that the line is actually not strongly related to VxD. Similarly the line that represent that an area is deemed high hazard has a range from 0.23 to 0.83 once again not at all strongly related to VxD.

It would appear that these lines were derived by simply connecting 2 points on a graph and do not have a relationship with the underlying intrinsic value of VxD.

This can be seen in Fig. 8.



The current lines that delineate Hazard do not reflect any particular value of VxD, the underlying plotted data.

	Velocity x Depth	
	L -Int	Int - H
Min	0.18	0.23
Max	0.53	0.83
Mean	0.46	0.74
Aver	0.42	0.65
Range	0.35	0.60

Fig. 8. VxD and the FPDM Hazard Lines.

So why then relate Hazard to VxD?
Velocity x Depth, does not identify Depth with minimal velocity as being hazardous. Is that why the two straight lines evolved in the FPDM plots? : - To effectively cut off the influence of velocity over depth at high depths and low velocities?

If this is the case, potentially there is a better derivation that will lead to the newly defined hazard having a relationship with the underlying plotted data. So, what style of parametric equation can be plotted to provide better insight into a value for Hazard? It is clear that more research is required to identify what potential for damage exists for a range of Depths and Velocities that exists on the floodplain.

3.0 A new Alternative Approach to Hazard Definition

The answer to the question (is there a better relationship to define hazard?) may be reflected in analysing the Trieste plots.

The first outstanding difference is that the FPDM HAZARD lines are straight lines, whilst the Trieste plots are curves. What is influencing the shape of the curve? Secondly the vertical axis is depth rather than velocity, so in effect they are more like the FPDM plots rotated through 90 degrees (Fig. 9 &10).

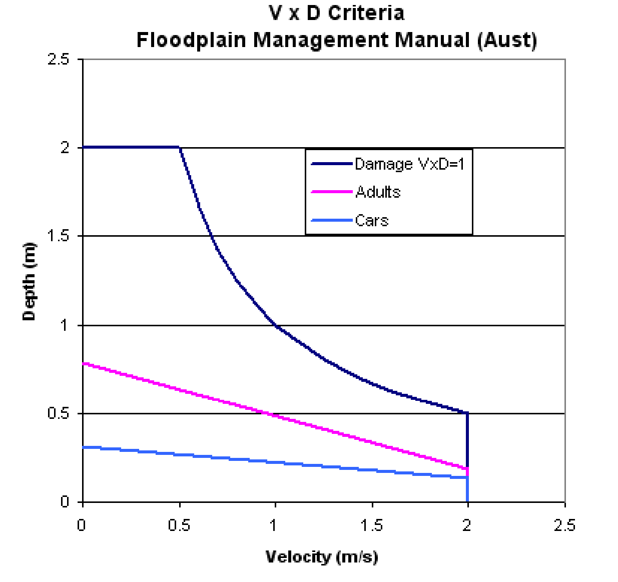


Fig. 9 FPDM L1 Rotated 90 degrees

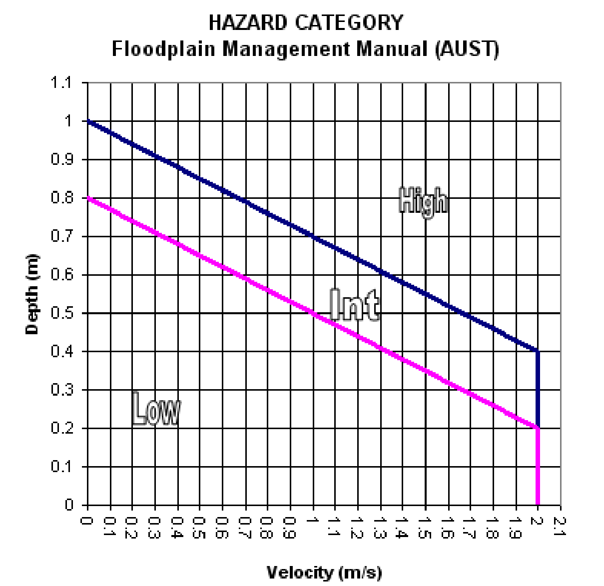


Fig. 10 FPDM L2 Rotated 90 degrees

The curves are essentially almost (half) a bell shape. The classic form of a bell shape form of equation is the equation for a solitary wave, which is a hyperbolic cosine equation. However potentially it is even simpler.

An investigation was undertaken to attempt to formulate an expression that could reflect the shape of Trieste plots and provide a close representation of the FPDM lines, with a singular value. That is that the definition of hazard could be related to a value directly related to a single expression.

After many and various expression were tested, the following seemed to provide some merit:

HAZARD = Depth + Velocity^2 x Depth ie: ($D + V^2 x D$) **Equation 6.**

By plotting this parametric equation of directly derived values it can be seen that in fact potentially, now a single line provides a transition over the previous two lines in the FPDM plot. Further, conveniently the underlying parametric value of this line is 1.

So that 1 now represents the differentiation between Low and High Hazard. In addition it appears that a value of 2 is closely aligned with the current VxD=1 (deemed potentially damaging to light structures) Figs. 11 & 12. Possibly other values higher than 2 may relate to damage to other structures? In deed the current limit for vehicles is well represented by a constant value of 0.4 and the current limit for wading for an adult is also reasonably well represented by the new HAZARD function with a constant value of 0.75 Figs. 11 & 12.

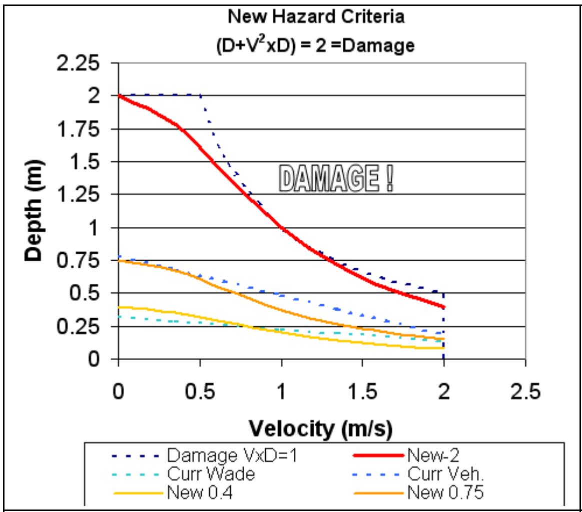


Fig. 11. Note the current hydraulic criteria are well depicted at values of 0.4, 0.75 and 2.0

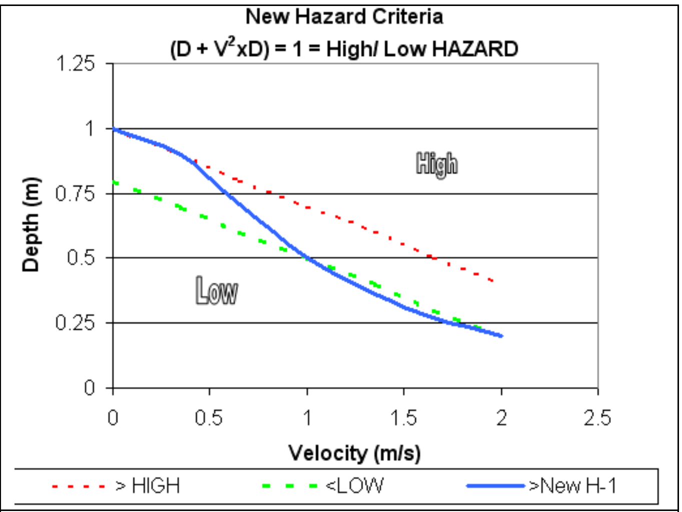


Fig. 12. Line between Low Hazard and High hazard is set at the New function value = 1

Now that there is a parametric relationship that relates directly to Hazard, 2 dimensional plots of this expression can provide significant insight into the source of hazard. For instance a graded (shaded) colour plot of the new expression over the floodplain will show how hazard propagates and moves throughout the floodplain. In fact further to that the time of arrival and the duration of the new hazard values at various locations potentially provide much greater insight into RISK.

Further, animations of this parameter if utilised will provide an amazing amount of insight in the evolution of hazard during an event. It should be noted that there appears to be a serious data gap in determining what values of VxD present what amount of hazard. However regardless of whether or not a situation is quite clearly hazardous, it seems that there are always people willing to RISK the HAZARD.

Fig. 13. Note regardless of the obvious evidence of HAZARD, some people can't help but over expose them selves to RISK

4.0 Influence of Obstacles on HAZARD Flood behaviour

It has been shown that although VxD, (momentum) provides some useful insight into flood behaviour, it fails to adequately identify hazard, particularly in deep, slow moving floodwater.

A common approach in 2-Dimensional flood modelling of urban environments is to artificially adopt a very high Manning's roughness (of up to 1.0). The aim of this is to some how account for the influence of major obstacles in the flood plain in urban areas, such as houses. However knowing that Q =V*A, and also knowing that more energy is required to accelerate flow if it needs to be squeezed between buildings, it is obvious that this approach has the potential to both underestimate the velocity between (and down stream of) buildings and underestimate the depth in front of buildings as the total energy is forced to increase to drive the flow between the buildings.
Therefore as both Velocity and Depth may actually be higher it is therefore also obvious that the resulting hazard (VxD) may also be considerable higher.
This potentially results in many areas being identified as low hazard when in fact they could be substantially highly hazardous areas.

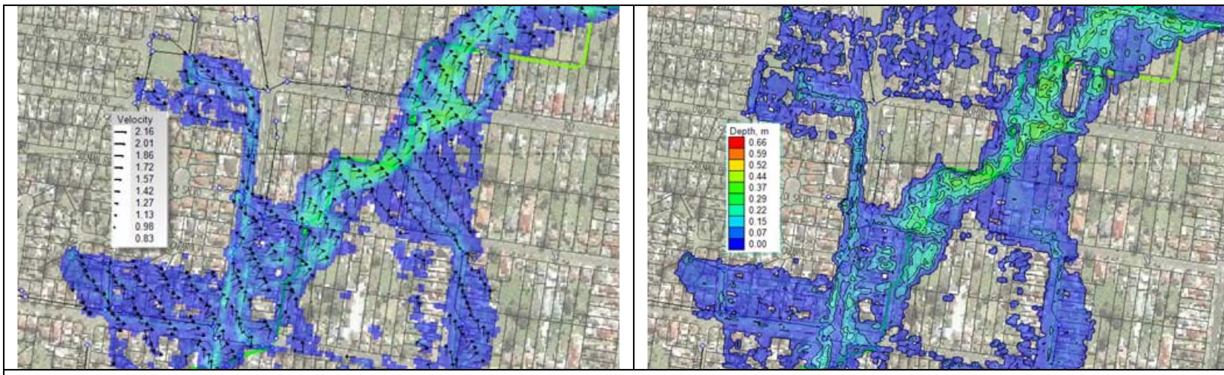


Fig. 14. Typical approach of modelling urban environment

This paper investigate this by comparing an analysis of the same urban area modelled in two ways:

1. As is commonly done by providing artificially higher Manning's n
2. Deliberately including the houses in the topography, to model the effect

Further this section of the paper also utilises the new method described above to provide a much more flexible range of delineation of hazard in these two scenarios, the aim being to highlight the danger of the most common practice.

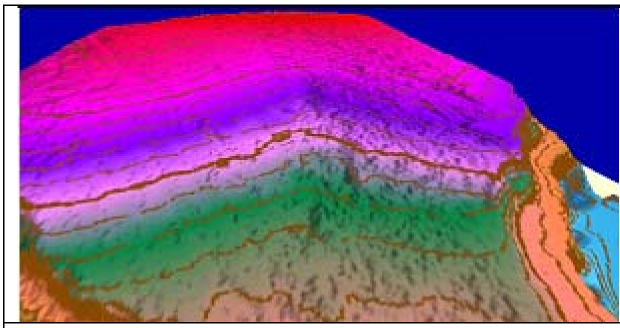


Fig. 15. General Terrain to be modelled

Fig. 16. Terrain with Houses and Draped Air Photo

The following images show precisely the difference in the terrain being modelled. The base terrain is identical, except that one includes structures (buildings).

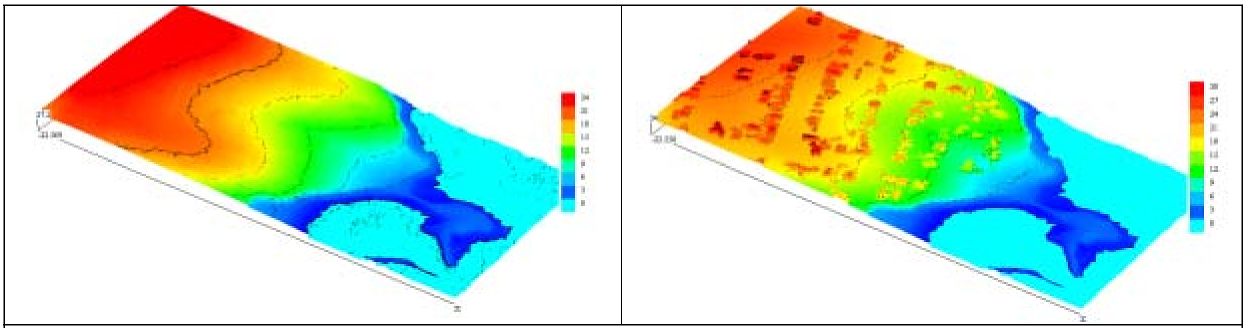


Fig. 17, Comparison of Terrain Models. Note Flow is from Left to Right.

The aim of the exercise is to show the potential influence and impact of not accounting for these obstacles as obstacles.
This was done by modelling three scenarios:

1. Terrain only with a normal Manning's n (n = 0.04)
2. Terrain with artificially raised Manning's n (n = 1.00)
3. Terrain with normal Manning's n but with obstacles present.

It must be stated that the approach was to simply adopt the ALS data as is with no refinement, to create a very fine 0.5m DEM. In some instances the underlying ALS almost fully blocked some smaller flow paths. In the future it may be worth considering placing more regular shaped obstacles on the terrain, to investigate the impact even more precisely. The model used for this analysis was the ANUGA model. It is an unstructured Grid, Finite Volume model. Its particular strength is in being able to easily handle shocks and sudden transition from sub to super critical flow.

5.0 RESULTS of ANALYSIS:

The results provide some startling insight. The influence of increasing Manning's n does provide in some areas a similar estimate of the extent of inundation, as the floodwaters are forced to disperse due to the high roughness. However the velocity is artificially very much reduced over the whole domain. In addition storage effects are not accounted for as well: - leaving the down stream area of inundation much wider than reality. Similarly the maximum depth is quite similar, although it is occurring over a much greater area. The example where the buildings are specifically accounted for shows that the buildings form dams with spillways between them. This results in raised water levels upstream of the buildings and high velocity plumes between them.

FLOW DEPTH COMPARISON:
The overview of flow depth shows that the raised Manning value over estimates depth generally and underestimates velocity. The case with buildings included clearly forms a dam effect. See Figs. 20 – 22.

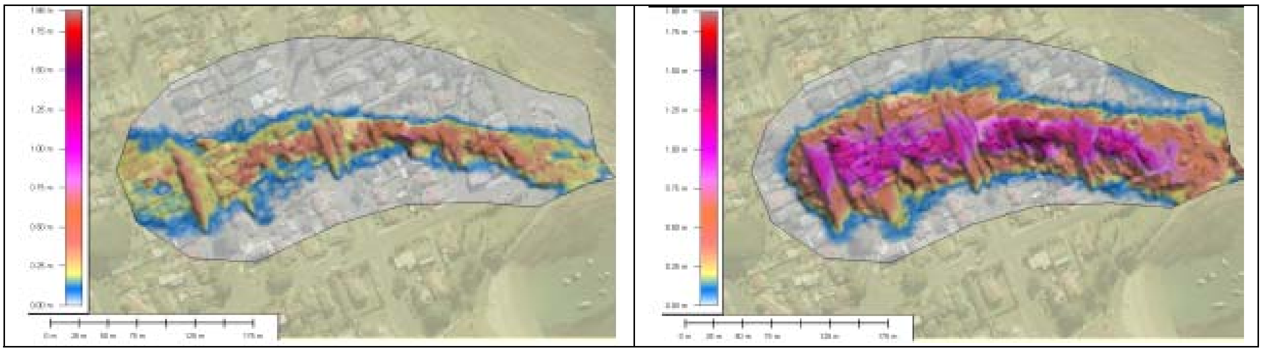


Fig 18. n = 0.04, Max Depth = 0.833m	Fig. 19 n = 1.00 Max D = 1.64m

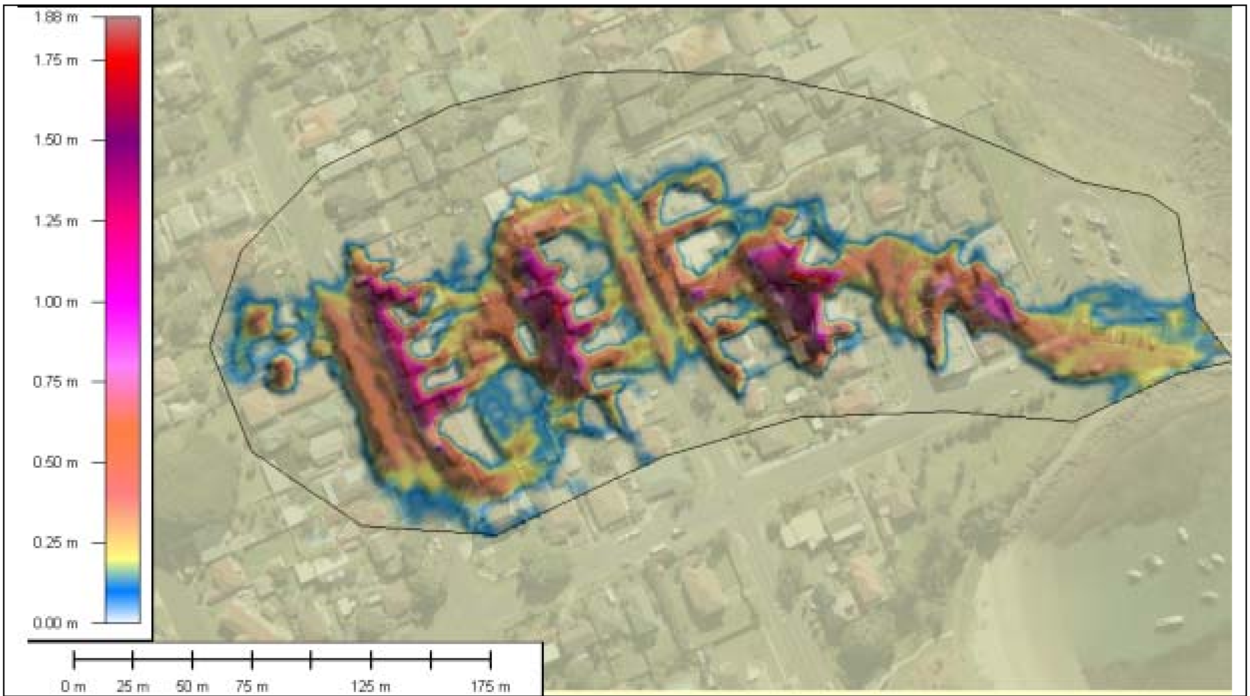


Fig. 20. Houses present (Note Damming effect of Houses) Max Depth = 1.884m

VELOCITY x DEPTH COMPARISON:

The VxD product shows that the raised Manning's scenario has a much lower VxD even though the Depth is higher than the "Normal" roughness case.

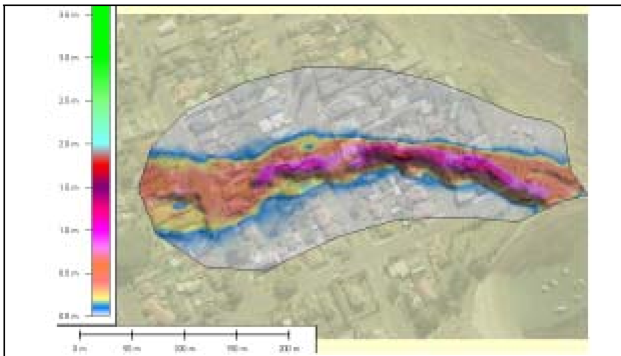


Fig.21. VxD, Max Haz = 1.754

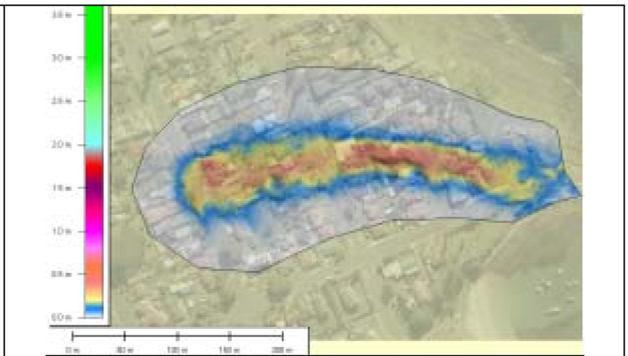


Fig. 22. VxD, Max Haz = 0.534

Once again the case where the buildings are included shows that the VxD is upto twice as high as the "Normal" case and up to 7 times higher than the raised Manning case. This is now starting to highlight the impact of the high velocity plumes, and general higher velocity, whilst also showing the influence of depths ~ 1.0m deep.

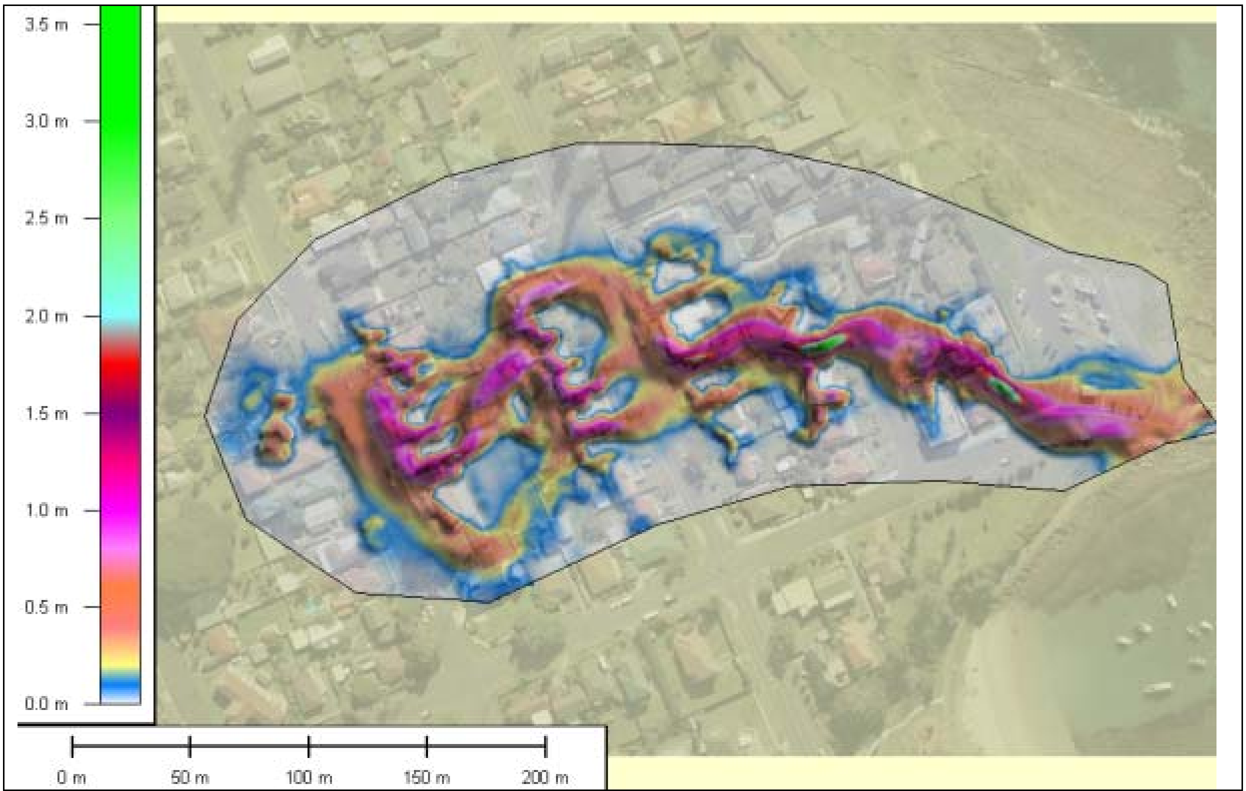


Fig. 23. VxD, Max Hazard = 3.641 (Note the flow being deflected)

NEW HAZARD DEFINITION COMPARISON:
By defining HAZARD as shown in Equation 6 above, this single equation will delineate areas of LOW: HIGH hazard as those below and above 1.0. In addition it will provide a greater range of values to aid interpret behaviour and separate the nature of hazard. Finally it has an intrinsic mechanism to honour the apparent hazard of deep water even if it is moving relatively slowly.

Mapping of this is through a simple SINGLE equation can be easily applied and automated. The results clearly show that the common practice of adopting a raised roughness leads to a significant underestimation of hazard in the urban environment.

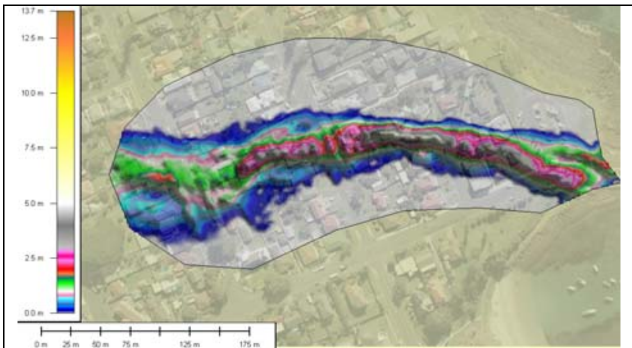


Fig. 24. New Hazard, Max Haz = 5.403

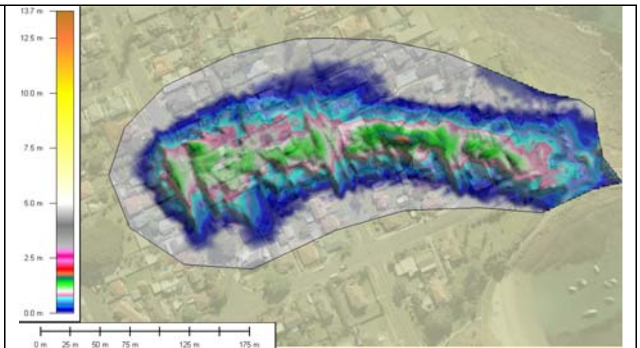


Fig. 25. New Hazard Max Haz = 1.807

The parametric equation shows that the influence of building is to increase hazard very substantially as indicated by values above 3.0 and up to 13.0 between buildings. This is potentially damaging to dwellings and shows to what extent the adopted practice of using a raised roughness misrepresents hazard. What about fence I hear!

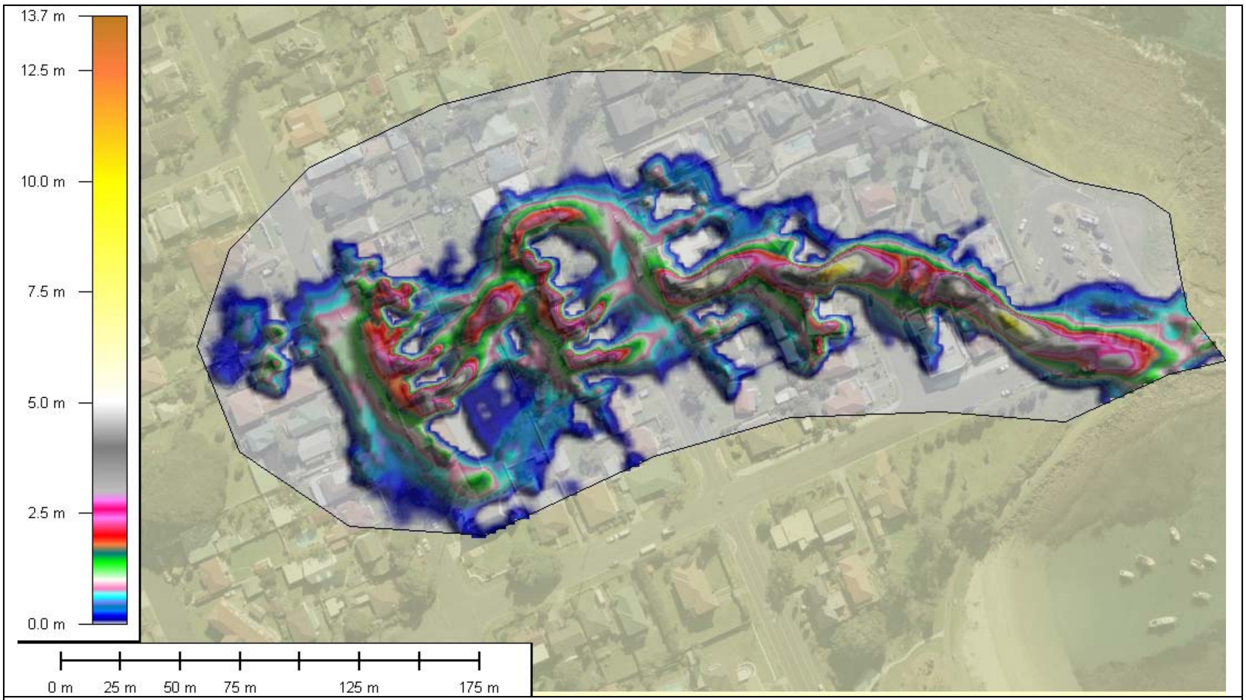


Fig. 26. New Hazard Plot Max Haz = 13.738 highlighting the misrepresentation

The accurate depiction and understanding of what constitutes a hazard and where these hazardous environments are is the ultimate goal of the role of Floodplain Risk Management. Our urban environments potential are much more hazardous then currently being depicted using our current approach. Not only is the methodology of using raised roughness underestimating the danger, the current reliance on simply Velocity and Depth leaves little scope to differentiate flood dangers.

The following image provides some very typical urban flooding scenarios, which are considerably more hazardous then what the current methods depict.

Fig. 27. Urban Flood Flow behaviour

Fig. 28. Extremely Hazardous

In extreme cases the fast flowing floodwater can lead to significant damage of buildings.

	
Fig. 29. High velocities	Fig. 30. Damage to brick building

TAKE HOME MESSAGE

- Current practice using Velocity x Depth may not be the most effective indicator of hazard.

- A parametric relationship has been derived that provides much greater insight to not only hazard, but also its behaviour and associated risk.

- Although the derived parametric expression may not be the ultimate (best) expression of hazard it is potentially much more useful and easier to apply than current methods.

- The equation derived in this paper may provide a more robust method that is easy to apply and provides a greater range of values to interpret hazard, included the convenience of delineating LOW from HIGH hazard with a value of 1.0.
-
- **HAZARD = Depth + Velocity^2 x Depth ie: ($D + V^2 x D$)**
-

- Further development of the principles outlined in this paper will not only provide a more easily applied and uniform approach, with a more sound basic principle than the current method, it will also allow the potential categorisation of the likely level of damage sustained to items at risk of exposure to floodwater with “New Hazard” greater than 1.

- The parametric equation presented provides an opportunity to define a Hazard Number in a similar fashion to the role of the Froude number. Where anything below 1 is Sub Hazard (Low Hazard) and anything above 1 is “Super Hazard” (High Hazard), indeed numbers above 1 can now also potentially be related to level of potential damage or severity.

- Common current methods of modelling urban areas with artificially elevated roughness values DO NOT accurately depict hazard in those areas. General hazard is under estimated.

ACKNOWLEDGEMENTS

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