50th Annual Floodplain Management Authorities Conference
2060, What Will Your Flood Legacy Be?
Gosford, Central Coast, 23rd - 26th February 2010

PROCEDURES FOR FLOODWAY DEFINITION
IS THERE A UNIFORM APPROACH?

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Abstract: The Floodplain Development Manual [1] provides a clear but broad definition of a floodway. However, for various reasons, it does not provide specific procedures for identifying floodways or for defining their extent. The procedures are left to practitioners and Floodplain Risk Management Committees to determine with reference to the particular floodplain being considered. As a result, the outcomes can be subjective and can lead to conjecture due to the legal implications of land being classified as a floodway.

Over the last decade, there has been considerable advancement in the tools used to simulate flood behavior. Accessibility to improved and more detailed topographic data has also occurred, as has the capacity to more rigorously interrogate flood characteristics derived from computer modelling using this data. In particular, the increasing use of this data in 2D hydrodynamic models has allowed more meaningful representation of flood flow across floodplains.

A range of data-sets such as depth, velocity, velocity-depth product, distribution of flow and unit stream power, can now be readily exported from flood models. This data can be combined with reliable topographic data to facilitate the hydraulic categorization of floodplains, including the identification of floodways. At the same time, the modelling tools can be more easily adapted to test the impact of floodplain encroachment and confirm initial estimates of floodway areas.

This paper explores the procedures that can be employed to identify floodways and discusses the possibility of employing a uniform approach.

Keywords: hydraulic categorization, floodway, flood storage, afflux, geomorphology

1. INTRODUCTION

Floodways are those areas of a floodplain where a significant discharge of water occurs during floods [2]. They are often aligned with naturally defined channels and are areas that if only partially blocked, would cause a significant redistribution of flood flow, or a significant increase in flood level. By definition floodways are areas of high flow conveyance and can typically be identified by areas of high flow velocity.

The blocking of floodways typically results in significant impacts on flood characteristics such as increases in predicted peak flood level and changes in flow velocities. Therefore, it is important to define floodways in floodplain risk management so that areas where development is undesirable can be identified.

Although no formal criteria are currently available, some “rules of thumb” have been presented as procedures for the delineation of floodway areas. For example, quantitative approaches were outlined in the 1986 version of the Floodplain Development Manual. These quantitative approaches suggested that the floodway zone can be defined by:

- determining the extent of encroachment that will cause a maximum change in water surface elevation of no more than 100 mm;
- determining areas where the velocity / depth product is greater than 1; and/or
- by the extent of the 20 year recurrence flood.

These approaches are all relevant but potentially ignore the significance of discharge and the impact of hydraulic controls and geomorphic features on floodwater movement.

In 2004 Howells et al [4] considered the potential for a "one size fits all" approach to hydraulic categorisation for flood studies. The question was posed as to whether a standardised and detailed definition of a floodway could be determined to aid in preparing hydraulic category mapping. Howells acknowledged that it is possible that floodways could be a function of velocity-depth product and velocity, but that rigorous testing would be required to confirm any correlation. In the absence of rigorous testing, Howells determined that no one size fits all approach could be applied to define floodways for all types of floodplains.

In 2007, Rigby [5] also raised this issue, highlighting that there is no known and universally agreed modelling procedure for the determination of the floodway and flood fringe boundaries. Notwithstanding, Rigby rightly emphasised that there is a clear need to establish a procedure for delineation of floodways. This procedure does not necessarily need to be a strict mathematically derived outcome or a direct output from a flood model, but it does need to be more rigorous in order to avoid different interpretations between practitioners and different outcomes for similar types of floodplains.

The aim of this paper is to present the results of work that has been carried out since 2007 for flood study projects where efforts have been made to more rigorously determine floodway corridors.

2. ALTERNATIVE METHODS FOR FLOODWAY DEFINITION

2.1 Encroachment Assessment Techniques

Procedures for the determination of floodway extents using modelling tools are not new. Determination of the floodway zone based on identification of the extent of encroachment that will cause a maximum change in water surface elevation of no more than 100 mm has been applied since the 1980s using one dimensional modelling tools such as HEC-RAS (*formerly as HEC-2*) and MIKE-11. In fact, HEC-RAS incorporates an encroachment optimisation routine that allows the modeller to determine the extent to which the floodplain can be blocked to generate a specified increase in peak flood level. However, the reliability of this approach has always been questionable due to the steady state nature of the analysis.

As a means of testing this, a section of Ropes Creek in western Sydney was analysed using both a HEC-RAS model and a two-dimensional flood model. The encroachment optimisation routine within HEC-RAS was used to define the maximum floodplain encroachment that would result in no more than a 100 mm increase in peak 100 year recurrence flood level along a reach of Ropes Creek extending from Erskine Park downstream to the M4 Motorway.

A two-dimensional flood model of the same reach of Ropes Creek was developed using the RMA-2 software package. RMA-2 is a fully two dimensional finite element model developed by Resource Management Associates of the USA and Prof. Ian King of the University of NSW. It has been used as the modelling tool for flood studies on the bigger river systems such as the Hastings, Camden Haven, Hunter, Moruya, Manning, Richmond and Shoalhaven Rivers, as well as for smaller systems such as Turallo Creek (*Bungendore*) and South Creek (*western Sydney*).

The RMA-2 flood model for the test section of Ropes Creek was modified to reflect two separate encroachment "methods" that mirrored the encroachment established using HEC-RAS. Each "method" involved either full or partial blockage of land outside the floodway extent that had been determined using HEC-RAS. This "blockage" was achieved by either artificially increasing model element roughnesses in areas outside of the encroachment extent or artificially filling the land to above the predicted peak 100 year ARI flood level.

Two new and separate RMA-2 flood models were developed; one for each of the two encroachment test methods.

The models are referred to as:

- Method 1 – which involved floodplain "blockage" by applying roughness values of 0.20 to all areas outside the HEC-RAS defined floodway corridor.
- Method 2 – which involved floodplain "blockage" by artificial filling of all areas outside the HEC-RAS defined floodway corridor to a level above the predicted peak 100 year ARI flood level; i.e., by up to 3 metres.

The following sections outline the results of flood simulations that were undertaken for each method.

Method 1 – Encroachment Modelled by Increasing Floodplain Roughness to 0.2

Method 1 was modelled by increasing the roughness of all elements outside of the HEC-RAS defined floodway corridor to an artificial roughness value of 0.2. A roughness value of 0.2 is considered to represent a significant "blockage" in a two-dimensional flood model.

In that regard, it is generally not appropriate to make a direct comparison between 'textbook' Manning's 'n' values and roughness parameters applied in two-dimensional flood models such as those developed using RMA-2. This is because the 'textbook' Manning's 'n' values have been derived empirically using normal depth calculation procedures where the adopted value of 'n' considers the hydraulic roughness of the river or floodplain, but does not account for flood storage or energy losses around bends and increased turbulence around flow obstructions.

In contrast, the algorithms within the RMA-2 flood model consider each of these items individually. For example, roughness is considered via the roughness parameter nominated for individual model elements, turbulence via eddy viscosity coefficients and energy losses around bends are accounted for by the two-dimensional representation of the planform geometry of the stream.

Because of this, the roughness parameters adopted within the RMA-2 flood model are generally lower than 'textbook' Manning's 'n' values.

Experience gained in the application of RMA-2 across a range of river and floodplain systems indicates that a roughness value of 0.2 is equivalent to dense vegetation. Therefore, Method 1 is not expected to prevent the passage of flows in areas outside of the floodway corridor, but will significantly reduce the proportion of the flow carried in these areas. As a result, those areas assigned a roughness parameter of 0.2 could be considered to effectively equate to flood fringe or flood storage areas.

The model that was developed for Method 1 was used to simulate the design 100 year ARI flood along Ropes Creek. The results were interrogated and compared against peak flood levels generated for the 100 year ARI flood for existing conditions; i.e., for the base case. Both data-sets were used to develop flood level difference mapping which was then used to assist in the comparison. This effectively creates a contour map of the post-encroachment 'affluxes' and allows easy determination of the impact of encroachment of the floodway on peak flood levels.

The impact of the "blockage" scenario achieved by Method 1 on peak 100 year recurrence flood levels within Ropes Creek test reach is shown in **Figure 1**. This indicates that "blockage" afforded by increasing the floodplain roughness leads to increases in peak 100 year recurrence flood levels along the full length of the test reach adjacent to Erskine Park. This is expected, but the magnitude of the increases is significant and is for most parts, greater than 100 mm.

As shown in **Figure 1**, areas shaded red correspond to flooded areas where the "blockage" scenario results in increases in peak 100 year recurrence flood level of greater than 110 mm. Areas shown white indicate increases of 90 to 110 mm, and areas shaded blue indicate increases of less than 90 mm.

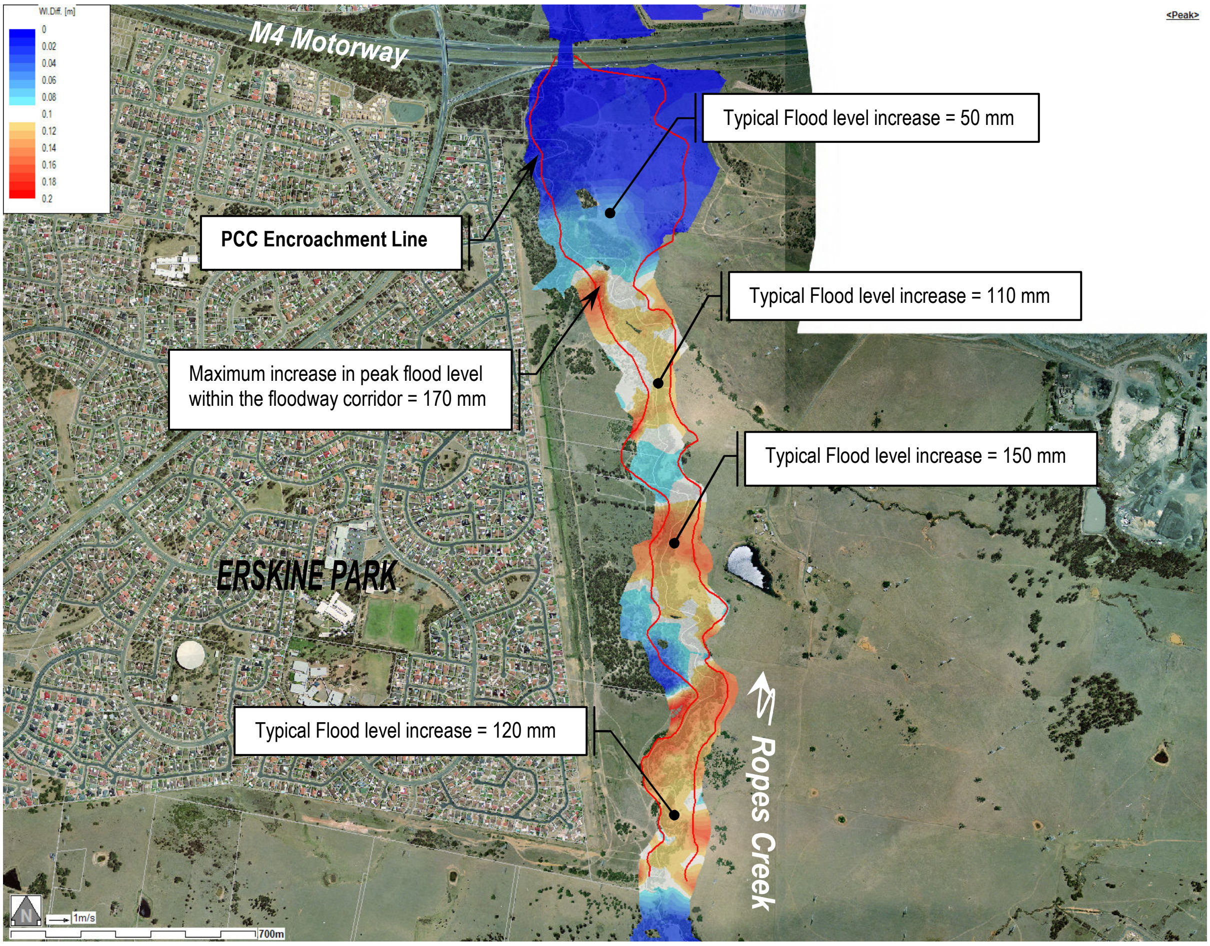

Figure 1 Increases in Peak 100 Year ARI flood level for Encroachment Based on Increased Roughness

Notably, areas of greatest increase in peak level appear to occur outside the HEC-RAS defined floodway corridor; that is, in flooded areas where an increased roughness parameter has been applied. This is due to decreases in velocity caused by the artificial roughening of model elements.

Method 2 – Blockage Modelled by Artificial Filling of Areas Outside Floodway

Method 2 was modelled by raising the terrain within the HEC-RAS defined encroachment extent to a level above the predicted peak 100 year recurrence flood level. For the test section of Ropes Creek, this corresponded to an increase in terrain elevations of up to 3 metres.

Accordingly, Method 2 assumes that no flow travels through areas of the floodplain outside the HEC-RAS defined floodway corridor. Unlike Method 1, the corresponding increases in peak flood level occur as a result of the loss of flood storage and the associated conversion of the "lost" flood storage to conveyance. This results in a combination of increased flood levels and/or increased flow velocities.

Flood level difference mapping was generated to assess the impact of the encroachment associated with Method 2 on peak 100 year recurrence flood levels along the test reach of Ropes Creek. This difference mapping is presented as **Figure 2** and indicates that flood level increases are predicted to occur along the full length of the test section.

However, as shown in **Figure 2**, a greater proportion of the test reach experiences increases in peak flood level of less than 100 mm; compare the greater extent of blue shaded areas in **Figure 2** to blue shade areas in **Figure 1**. For most of the test reach, Method 2 results in increases in peak 100 year recurrence flood level of less than 90 mm (*refer* **Figure 2**).

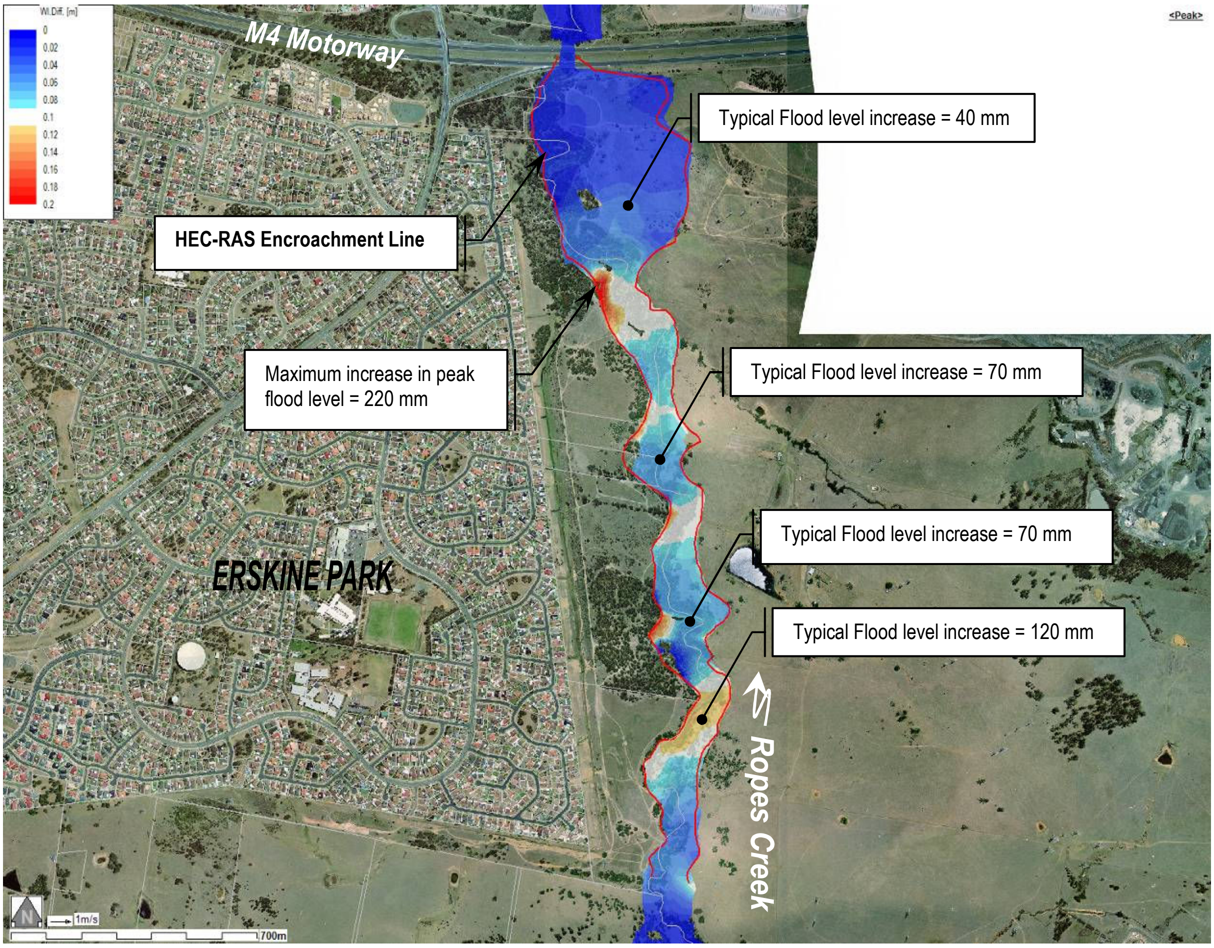

Figure 2 **Increases in Peak 100 Year ARI flood level for Encroachment Based on Complete Blockage**

However, the findings from testing this conclusion using the RMA-2 flood model indicate that flood level increases of greater than 100 mm could be expected if the same encroachment was applied within the RMA-2 model. As outlined above, increases of greater than 100 mm occur irrespective of how the encroachment is modelled; i.e., either via Method 1 or Method 2.

This suggests that the HEC-RAS encroachment optimisation routine underestimates the extent of the floodway corridor in some areas of the test reach.

Conclusion

The increases in peak flood level derived using Methods 1 and 2 (*refer* **Figures 1** *and* **2** *respectively*) suggest that Method 1 will generate flood level increases that are higher than for Method 2. Furthermore, additional increases are also observed in areas outside the encroachment extent due to Method 1 not employing a complete blockage (*refer* **Figure 1**).

The results for Method 2 suggest that the HEC-RAS encroachment optimisation routine underestimates the floodway extents (*refer* **Figure 2**). Therefore, it could be concluded that the encroachment optimisation routine in HEC-RAS is not a reliable tool for defining floodway corridors. In that regard, the HEC-RAS optimisation routine does not account for:

(i) local features along the edge of the floodplain which influence flow velocity in a two-dimensional context;

(ii) areas where depth dominates the velocity-depth product; and,

(iii) areas where backwater flooding occurs.

This is considered to be the major limitation of the HEC-RAS encroachment optimisation routine as it does not account for the impact that a loss of flood storage may have on the increases in peak flood level that are determined from the analysis. That is, there is a proportion of the increase in peak flood level due to the encroachment that occurs as a result of the loss of flood storage and not as a result of the extension of the encroachment into a floodway corridor.

Despite this shortcoming, the HEC-RAS encroachment optimisation routine does provide a reasonable initial estimate in circumstances where flood storage is not significant; that is, in river and creek systems with relatively one-dimensional flood characteristics.

2.2 Velocity-Depth Product Techniques

The Floodplain Development Manual and relevant Floodplain Risk Management Guidelines do not recommend the use of velocity-depth product as a means of identifying floodways. It is argued that this approach limits floodways to areas of relatively high velocity and depth, and doesn’t strictly adhere to the broad definition of floodways being areas that discharge a significant proportion of the flow during a flood.

However, in its simplest form, the velocity-depth product is a measure of the unit flow per metre width and therefore can be correlated to flow. Hence, if used with caution and combined with consideration of velocity, the velocity-depth product can be a good indicator of floodway extent.

Recognition of this led to consideration of an approach that could use velocity-depth product as a means of determining floodway extents. This approach involves making an initial appraisal of “floodway extent” based on a comparison of contours of various values of velocity-depth product. The extents associated with different values of velocity-depth product are plotted onto the floodplain in question and analysed to establish whether some “threshold” exists. The concept of determining a “threshold” was based on identifying if a sudden expansion in “floodway extent” can be correlated to a step in velocity-depth product. If such a step can be identified, it may be that the associated velocity-depth product is a threshold value for the floodplain in question and could be an indicator of floodway extent.

It should be noted that this approach would still require some sort of blockage assessment to confirm that the velocity-depth product is a suitable delineator of floodway extent.

This approach was applied to a short reach of the floodplain of Turallo Creek at Bungendore. An initial appraisal of the extent of the 100 year recurrence floodway was made based on a comparison of velocity-depth product values of 0.5, 0.8 and 1 m^2/s. It should be noted that areas with a v x d of 0.5 m^2/s or less cover more floodplain area than those with a v x d of 1.0 m^2/s. That is, if a v x d of 0.5 m^2/s were adopted as the extent of the floodway zone, it would be more restrictive than if a v x d of 1.0 m^2/s was adopted.

As a “first pass”, each of the three velocity-depth product values were plotted relative to each other for the 100 year ARI flood. This data was analysed and it was established that a large expansion of the velocity-depth contours occurred with the step from 1.0 to 0.8 m^2/s. This suggests that a threshold exists between these values and that the extent of the floodway could correspond to the extent of the area defined by a v x d of between 1.0 and 0.8 m^2/s.

Further analysis showed that the greatest increase in the extent of the corridor defined by contours of v x d occurred over the “step” from v x d of 0.9 to 0.8 m^2/s. Accordingly, it was concluded that contours of v x d of 0.9 m^2/s appeared to define an initial estimate of the floodway extent.

Additional investigations were undertaken to assess the potential impact of partial blockage of this initial floodway extent. It was assumed that if the impact of partial blockage was found to be significant (*say in the order of 100 mm*), then it could be concluded that the initial floodway corridor represented by a velocity-depth product of 0.9 m^2/s was reasonable.

The results of the analysis for the test reach at Bungendore showed that partial blockage of the floodplain would lead to significant increases in upstream flood levels. As a result, it was concluded that a velocity-depth product of 0.9 m^2/s provided a reasonable initial estimate of the 100 year ARI floodway extent.

3. DISCUSSION

3.1 Importance of Floodplain Type

The analysis discussed in the preceding sections highlights the difficulties associated with selecting an appropriate methodology for determining floodway extent. It also highlights the importance of different floodplain types. The examples presented above involve reaches of creek systems that are relatively one-dimensional. They have limited off-channel storages and flood flow is generally distributed parallel to stream direction.

In contrast, the floodplains of the larger coastal rivers typically have well defined estuarine backwater areas which serve as significant flood storages. Similar could be said of many of the rivers of western NSW, which are often characterised by effluents that connect the main channel to enormous off-channel storages.

Hence, it is difficult to apply the encroachment approach referred to above in these much larger systems. In such systems, modellers are presented with a dilemma of how to simulate blockage without effectively removing the flood storage and skewing the impact.

Similarly, the application of a velocity-depth product approach has limitations in the larger floodplains where the velocity-depth product is dominated by depth. A rudimentary application of the velocity-depth approach where large storage areas exist could lead to these areas being identified as floodways when in fact they are not. This of course can be overcome by considering flow velocity in tandem with velocity-depth product, but this serves to introduce another parameter in the process which can complicate such an assessment.

It is also important to acknowledge that in circumstances where flood storage is removed during floodway testing, albeit not intentionally, the resulting flood level increases will be ‘skewed’ and therefore are not independently reflective of the floodway alone. An example which highlights the difficulty of adopting a single methodology for simulating a floodway ‘blockage’ is discussed below. The scenario is for the same test section of Ropes Creek and therefore is primarily relevant to a one dimensional creek system.

3.2 Preferred Approach

As a result, it appears that despite the availability of more complex modelling tools and data-sets that better define floodplain topography, the assessment of floodways remains the domain of experienced practitioners with the skills to holistically evaluate the physical features of the floodplain and all available hydraulic / flood modelling outputs. The process should involve an iterative approach that considers:

- section averaged velocity in the planning level flood at both the peak and on the rising limb of the hydrograph;
- maximum velocity-depth product for the planning level flood;
- topographic and geomorphic features along the floodplain;
- hydraulic controls such as structures that cause backwater effects; and,
- the results of hydraulic analysis and / or flood modelling that incorporates a blockage scenario similar to that outlined above for Method 2.

As a means of considering this preferred approach, each of the bullet points listed above was used to refine the HEC-RAS defined floodway corridor determined above for the test section of Ropes Creek.

The refined floodway corridor was therefore derived manually and is shown in **Figure 3** superimposed in yellow over air photography. The HEC-RAS derived floodway corridor is shown in red for comparison purposes.

As a means of testing this approach, the RMA-2 flood model was used to simulate the encroachment associated with the refined floodway corridor shown in **Figure 3**. The increases in peak flood level are shown in the figure and indicate that for most of the test section, the associated encroachment will not lead to flood level increases of greater than 100 mm.

The only exception to this is in the area at the downstream end of the test reach where the increase in peak flood level is considered to be due to the loss of flood storage associated with the back-up of floodwater upstream from the M4 Motorway crossing.

In this regard, the results of the analysis indicate that the following parameters would characterise the extent of the floodway along the test section of Ropes Creek:

- v x d = 0.5 m^2/s; and,
- section averaged velocity > 0.5 m/s.

Notably, these parameters are different to those determined for a one-dimensional section of Turallo Creek at Bungendore.

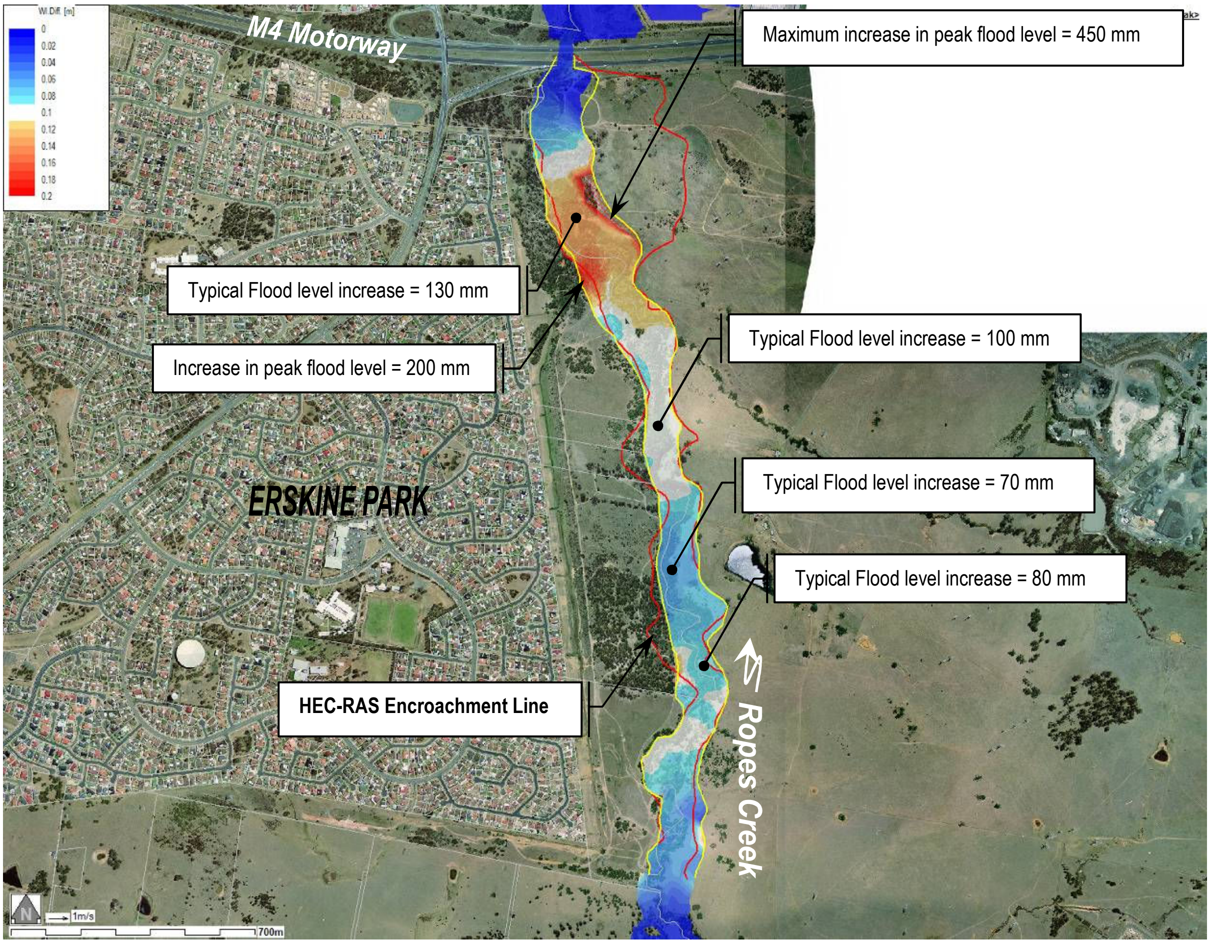

Figure 3 Increases in Peak 100 Year ARI flood level for Refined Floodway Definition based on Preferred Approach and Simulation of Encroachment by Complete Blockage

4. CONCLUSIONS

Investigations for a range of floodplains indicate that the encroachment optimisation routine in one-dimensional flood modelling tools such as HEC-RAS are generally suitable for determining a “first pass” assessment of the extent of a floodway corridor. Similarly, velocity-depth product procedures can be employed to identify an initial estimate of the floodway corridor.

However, it is clear that these techniques only serve to provide an initial estimate of the potential floodway corridor and that manual refinement is necessary. This refinement exercise should seek to make changes to the corridor based on a combination of:

(i) consideration of local topographic features along the alignment of the preliminary floodway corridor;

(ii) air photo interpretation to identify critical geomorphic characteristics of the floodplain that may indicate the alignment and extent of floodway corridors;

(iii) consideration of the potential impact of hydraulic controls such as bridges and culverted embankments that lead to substantial backwater effects;

(iv) assessment of velocity-depth product and velocity estimates from modelling under existing conditions; that is, no blockage; and,

(v) an assessment of the predicted increases in peak flood level as derived from modelling of the preliminary floodway corridor assuming full blockage of the encroachment area.

Once a refined floodway corridor is determined, it is recommended that it be modelled under a scenario whereby all areas outside the corridor are “blocked” at a global scale, and that the results of the modelling be analysed to confirm that the impacts are not significant.

5. FUTURE DIRECTIONS

Although a “one size fits all approach” is not apparent, it does appear that a uniform methodology could be developed for floodway definition. While it is recognised that this methodology will always involve an iterative assessment, it is apparent that the steps in this iterative assessment process need to be better defined.

This issue is of particular interest in the context of the impact of climate change on flood characteristics in coastal river systems. Much discussion occurs on the impact of sea level rise and increased rainfall intensity on peak flood levels, but perhaps the more important issue for planning is the impact on our current estimates of floodway extent.

6. TAKE HOME MESSAGE

Floodway definition is a complex and iterative process that requires specialist input from practitioners with skills in interpreting flood data and floodplain geomorphology, and in understanding the importance of hydraulic controls. Although flood modelling tools can assist to help characterise floodways, there remains no definitive flood modelling procedure that can be applied to automate the process of generating floodway extents.

A range of outputs such as velocity-depth product can be used to establish an initial estimate of floodway extent, but these outputs require testing and subsequent interpretation in order to define a reliable floodway extent. This interpretation must rely on consideration of both hydraulic characteristics and physical features that influence the way floodwaters move through a floodplain.

Perhaps the most significant advancement in flood engineering that has assisted practitioners with the determination of floodways is the availability of LiDAR or ALS data which can be used with aerial photography to isolate areas of flood storage and flood fringe and allow more realistic identification of floodway areas.

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