Hydraulic Categorisation of the Floodplain – Why and How

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Abstract:
Recognition of different hydraulic categories of flow on a floodplain has been an important feature of floodplain management for several decades. In New South Wales, the Floodplain Development Manual (FPDM, 2005) recognises three such zones: ‘floodway’, ‘flood storage’ and ‘flood fringe’. While the conditions these zones represent are easily understood from a qualitative viewpoint, modelling and mapping their extents is far from straightforward, particularly when flooding is strongly two-dimensional in character and/or no watercourse is present in the area of inundation. This paper explores why hydraulic categorisation is of value in floodplain management and reviews the various means by which these zones have been mapped in past studies, both in Australia and overseas. Other possible approaches are then explored and commented upon. The Authors conclude that a full technical solution to hydraulic categorisation is not yet within our grasp and that subjectivity in the approaches adopted to date has created and continues to create serious non-uniformity in the planning and floodplain management process that urgently needs to be addressed through interactive collaboration between government and industry.

1. INTRODUCTION
Categorising flood flow on the basis of its hydraulic characteristics is now a common component of most flood studies, both in Australia and overseas. This has been driven largely by a desire to be able to identify those areas of the floodplain where development could adversely impact flood behaviour.

The concept of a floodway in particular is far from new and has been part of the vocabulary of those interested in flooding and its impact on landforms for over a century. Despite the general long term use of the word, ‘floodway’ only appeared as a term of relevance to flood studies in New South Wales with the publication of the first edition of the Floodplain Development Manual (FPDM) in 1986. Notably, only minor changes have occurred in the definition of a ‘floodway’ since the manual was first published.

The current (2005) version of the FPDM defines a ‘floodway’ as;
‘... those areas where a significant volume of water flows during floods and are often aligned with obvious natural channels. They are areas that, even if only partially blocked, would cause a significant increase in flood levels and/or a significant redistribution of flood flow, which may in turn adversely affect other areas. They are often, but not necessarily, areas with deeper flow or areas where higher velocities occur’.

While many countries have split the hydraulic categorisation of the floodplain into a ‘floodplain’ and a residual ‘flood fringe’, the FPDM adds a further zone in which loss of storage (due to filling or levee protection) could significantly increase downstream discharges and therefore adversely impact downstream flood levels.

The FPDM (2005) defines a ‘flood storage area’ as:
‘…those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. If the capacity of a flood storage area is substantially reduced by, for example, the construction of levees or by landfill, flood levels in nearby areas may rise and the peak discharge downstream may be increased. Substantial reduction of the capacity of a flood storage area can also cause a significant redistribution of flood flows.’

And a ‘flood fringe area’ as:
‘…the remaining area of land affected by flooding, after floodway and flood storage areas have been defined. Development in flood fringe areas would not have any significant effect on the pattern of flood flows and/or flood levels. In determining appropriate hydraulic categories, it is important that the cumulative impact of progressive development be evaluated, particularly with respect to floodway and flood storage areas. Whilst the impact of individual developments may be small, the cumulative effect of the ultimate development of the area can be significant and may result in unacceptable increases in flood levels and flood velocities elsewhere in the floodplain.”

It is important to understand that these zones are based on the hydraulic characteristics of flood flow in so far as they relate to the above definitions and have little relationship to the zones reflecting flood hazard or risk.

While the above definitions are easy to understand from a conceptual viewpoint, they present a major challenge in regard to their quantification. These challenges have substantially increased in recent years with the addition of urban areas into the New South Wales flood study program and the growth of two dimensional (2D) hydrodynamic modelling. 2D models have greatly improved our understanding of flood behaviour generally and have permitted modelling to extend into areas that could not sensibly be modelled with a 1D model. Urban areas where watercourses have been filled and built over are a case in point, frequently encountered when modelling older urban areas. In such areas, conventional 1D based categorisation procedures such as those proposed by FEMA(2007) simply can not be used.

The following two figures, showing the VxD flow patterns through a natural valley junction and through a fully urbanised area, highlight the challenges hydraulic categorisation poses in such areas. In both figures multiple branching and converging high flow paths are present, with high flow paths often developing locally to disappear a little further downstream. Even with an agreed numerical procedure for delineating areas meeting the criteria for a ‘floodway’, it is difficult to understand how a floodway boundary could be mapped, without some manual intervention to ‘clean up’ pockets of discontinuous mapping.

The process is further complicated by the fact that these figures only highlight flow paths in an event of one particular Average Recurrence Interval (ARI). Determination
of the ‘floodway’ for planning purposes requires delineation of floodways across the full spectrum of ARIs and the consolidation of these individual ‘floodways’ into one ‘regulatory floodway’. As the event ARI changes, these individual ‘floodways’ can change markedly, making it difficult to develop a non subjective procedure for their consolidation.

No deliberate procedures are provided in the FPDM for hydraulic categorisation of the floodplain during an individual event, nor is there a procedure for the consolidation of the various ‘event floodways’ into a ‘regulatory floodway’. This has forced those modellers that have attempted to map these zones to develop their own, one off, categorisation procedures typically based on simplified procedures only relevant to a specific study. Given the direct impact of hydraulic categorisation on development controls, such a subjective and non-replicable basis for categorisation is not, in the Author’s view, an acceptable situation.

To explore the matter further, this paper documents the Authors’ efforts to investigate the procedures flood modellers in New South Wales have used to quantify and map hydraulic categorisation in past studies, and reviews possible options for improving the quality and reproducibility of such procedures in the future.

2. CURRENT PRACTICE

2.1. Categorisation Guidelines

2.1.1 FPDM 2005

Current practice in New South Wales flows from the guidelines presented in the first FPDM published in 1986. There has been little change in the definition and intended application of hydraulic categorisation procedures over the intervening two decades.

In Sec 2.4 pp7 of the FPDM(205), the manual states that;
The flood study also determines hydraulic and hazard categories within the floodplain for the potential range of floods and land use scenarios in order to consider cumulative affects. The FPDM recognises three hydraulic categories (floodways, flood storage and flood fringe) and two hazard categories (high and low), as described in Appendix L.’

Appendix H3 of the FPDM reinforces the need for such categorisation stating that; ‘The following major elements need to be considered in the preparation of a management plan, where relevant. These elements are derived through the data collection and studies as part of the management process: …Hydraulic Categories.’

Appendix L3 of the FPDMI defines these hydraulic categories as;
- floodways;
- flood storage areas; and
- flood fringe areas

The definitions presented in the introduction to this paper were extracted from this appendix. Guidelines for the delineation and mapping of these categories are presented in Appendix L4 where the FPDM states;

‘In all but the simplest flow situations, the results of a flood study will be required to determine hydraulic categories. A flood study involves a detailed hydraulic analysis of flood behaviour for a range of flood severities up to the PMF, and generally involves the use of numerical or physical models (see Appendix F). A flood study provides details of peak depths and velocities across the floodplain, the pattern and timing of flooding, etc.

It is impossible to provide explicitly quantitative criteria for defining floodways and flood storage areas, as the significance of such areas is site specific. The following guidelines, although general, are given to assist in the delineation of flooding and flood storage areas:

Floodways are areas conveying a significant proportion of the flood flow and where partial blocking will adversely affect flood behaviour to a significant and unacceptable extent. It is essential that this be investigated across the full range of potential floods as the definition of the floodway is one of the critical steps in the floodplain risk management process.

Flood storage areas – are those areas outside floodways which, if completely filled with solid material, would cause peak flood levels to increase anywhere by more than 0.1 m and/or would cause the peak discharge anywhere downstream to increase by more than 10%. Areas being tested by the above criteria should be treated as contiguous entities, having regard for topography and location within the overall flood-prone area. They must not be separated or considered in a piecemeal fashion.’

2.1.2 SCARM 2000

The Standing Committee for Agriculture and Resource Management of the Agriculture and Resource Management Council of Australia and New Zealand
formed a national floodplain management working group in 1998 to ‘consider best practice principles and guidelines for the management of the risks associated with flooding across the floodplains of Australia.’ Their recommendations were published two years later SCARM (2000).

The SCARM report states that ‘Floodway and Flood Fringe areas are to be determined for various flood events in the Flood Study’ (refer Sec 3.3.2, App I and J). No guidance is however provided on how these areas are to be delineated or used in Floodplain Management.

2.1.3 FEMA (USA)

The Federal Emergency Management Authority (FEMA) of the USA has maintained a quite effective over-arching control of flood studies prepared in the USA for over two decades. While each state has implemented local requirements for flood studies within their state, their requirements are based on the FEMA guidelines. Guidelines for several states may be downloaded from their web sites. (e.g., Indiana Department of Natural Resources (2002), Arizona Department of Water Resources (1996)).

A ‘Regulatory Floodway’ as defined by FEMA (2007) is “…. the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flow without cumulatively increasing the water surface elevation by more than a designated height’.

The FEMA procedure for delineation of a ‘Regulatory Floodway’ involves modelling the progressive encroachment of development on the left and right floodplains until the flood surface is surcharged by no more than an acceptable amount (normally 1ft (300mm) but varies between states). This is a 1D oriented procedure designed to be used with hydraulic models such as HEC-RAS where specialised routines are provided to simplify the encroachment modelling process. Details of the use of this procedure with HEC-RAS are covered in a guideline prepared by FEMA (2007). FEMA has not addressed to date, the delineation of floodways in areas of two dimensional flow. There is however work being undertaken in this area by researchers such as Norman, Nelson and Zundel (2001).

2.2. Past Studies

To provide an understanding of how hydraulic categorisation has been handled in past studies in New South Wales, a sample of 45 Flood and Floodplain Management Studies, accessible by the Authors and published in the past decade, were reviewed. These studies were somewhat biased toward the central and south coast of New South Wales, but given the number of studies reviewed and range of Consultants involved, should provide reliable conclusions in respect to the matters investigated.

Of the 45 Flood and Floodplain Risk Management Studies reviewed;

36 - neither discussed or attempted hydraulic categorisation of the floodplain.
2 - attempted partial categorisation (typically floodway but not flood storage areas)
4 - attempted categorisation of all three hydraulic zones
3 - studies have not yet been finalised. Being current they may yet include some form of hydraulic categorisation.
In summary, the procedures included in those studies where full or partial categorisation was attempted, involved one of the following four methods;

**Table 1: Summary of Hydraulic Categorisation Methods Used in NSW**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
<th>Comment</th>
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| A      | - Delineation of a ‘Regulatory Floodway’ by equating the floodway boundary to the extent of a 20yrARI event  
- Delineation of the ‘Regulatory Flood Storage’ area based on the 100Yr ARI event by equating the flood storage area to the area between the 20Yr and 100Yr flood extents  
- Delineation of the ‘Regulatory Flood Fringe’ area by setting it to be all land between the 100Yr and PMF flood extents | As this procedure skips consideration of the underlying categorisation objectives, it can not be considered a full implementation of the FPDM guidelines. It is however reproducible and does provide a form of hydraulic categorisation for planning purposes. |
| B      | - Delineation of a Floodway for each of the events in the full spectrum by:  
o) Taking the bank to bank width as a minimum floodway width  
o) And including areas where V*D > 0.25 m²/sec and V > 0.25m/sec  
o) And including areas where V> 1m/sec  
- Delineation of Flood Storage areas for each of the events by:  
o) Including areas not in the floodway but flowing at a depth > 0.2m  
- Delineation of the Flood Fringe by setting to be any inundated area not part of either of the above areas. | It is noted that the value of 0.2m used in Method B for Flood Storage delineation was study specific, based on a subjective assessment of the average depth of 10% of the total flow. No procedure was however provided for the consolidation of the individual event zones into a unique hydraulic categorisation zones as required for regulatory purposes. This procedure also cannot be considered a ‘full’ implementation of the FPDM guidelines. |
| C      | - Delineation of the ‘Regulatory Floodway’ based on the 100Yr ARI event by  
o) Including visible flow channels  
o) Including areas of high hazard flow  
o) Including areas of overland flow > 1m³/sec/M | This also is clearly only a partial implementation of the FPDM guidelines. |
| D      | - Delineation of the ‘Regulatory Floodway’ using the flow behaviour of the 100Yr ARI flood event as a guide;  
o) with subjective consideration of the pattern of flood conveyance  
o) with subjective consideration of the floodplain width  
o) and including areas where the 100Yr ARI flood depth is > 0.5m  
- Delineating the ‘Regulatory Flood Fringe’ as being the area beyond the regulatory floodway up to the flood extent. | This also is clearly only a partial implementation of the FPDM guidelines. |

As is readily apparent from the small number of studies in which any form of hydraulic categorisation was undertaken and the widely different approaches adopted where categorisation was attempted, the present FPDM hydraulic categorisation guidelines can not be considered effective, and given the significance to regulatory controls, to be in urgent need of review.
3. DO WE NEED HYDRAULIC CATEGORISATION

3.1. Generally

Before attempting to develop more useable and consistent guidelines for hydraulic categorisation it is relevant to consider the more strategic question of whether hydraulic categorisation should be retained (at all) in the NSW Floodplain Development Manual.

Given the complexity of hydraulic categorisation and its limited application in past studies, there must exist an option to drop hydraulic categorisation and manage the floodplain on a hazard/risk basis. Depending on how the floodway is actually quantified, the floodway could be quite well correlated with the zone of high hazard flow, which could in many circumstances act as an alias for the floodway.

Unfortunately an equivalent approach for delineation of flood storage areas is not available, as these areas are not at all correlated with hazard or risk zones. This information would therefore be lost. It should however be recognised that none of the studies reviewed attempted quantification of the storage zone on anything like a serious hydrodynamic basis.

While dropping hydraulic categorisation would substantially simplify the study mapping process and eliminate an area of significant confusion and potential litigation, this would, in the Authors’ view, be a significant backward step as the identification of land that is important to flood storage (and should not be filled) would be lost. Not withstanding the difficulties in developing a relevant and reproducible hydraulic categorisation procedure, retention of hydraulic categorisation remains therefore, the Authors’ preferred option.

Options for developing such procedures are explored further in the following sections of this paper.

4. HYDRAULIC CATEGORISATION OPTIONS

4.1. Generally

Options available for hydraulic categorisation range between:

- Simplistic relationships based on readily available model outputs The Keep It Simple Stupid (KISS) approach
- Semi-quantifyable modelling approaches based on surrogate parameters such as velocity and depth
- Full hydrodynamic modeling based on quantified categorization objectives

It is also clear that to be of value, any hydraulic categorization procedure that is now put forward must be able to seamlessly handle both 1D and 2D flood datasets. This conclusion effectively rules out the FEMA procedure as an option.


4.2. Floodway Categorisation Options

4.2.1 The KISS Approach

One possible approach is that of Method A where the extents of a flood of intermediate ARI (eg 20 Yr), is chosen to represent the ‘regulatory floodway’. This has considerable short term merit as it provides replicable planning boundaries and could be implemented immediately. It is also a dataset created in the normal process of a flood study, involving minimal additional modelling time and cost. Its greatest weakness is that it does little to identify floodways that might develop in other locations at higher flow and may overestimate the floodway extent where the floodplain flow is shallow and of low velocity.

4.2.2 Conveyance Based Approaches

A floodway by any definition is an area of relatively high flow. As such, conveyance seems a logical starting place for its definition. While velocity and depth can be indicators of flow, the product of velocity and depth (VxD m$^2$/sec) most strongly identifies the distribution of flow rate across a floodplain. VxD may also be expressed as m$^3$/sec per metre width, that is discharge per unit width of a cross section or floodplain. Using VxD as a guide to flow rate, it is then possible to derive a VxD level at and below which the contribution to total flow in a particular event is not significant. Such a boundary could then be used to identify a ‘floodway’ in an individual event and by overlaying individual floodways for the event spectrum, a ‘regulatory floodway’.

This is the approach adopted, in part, in Methods B, C and D. The limitations of this approach are mostly associated with the subjective choice of the VxD flow rate threshold for the event ‘floodway’ and the subjective determination of the extents of the ‘regulatory floodway’. Notwithstanding these limitations, an approach based on conveyance does seem the most likely candidate for delineation of the ‘regulatory floodway’.

4.3. Flood Storage Categorisation Options

Categorisation of ‘regulatory flood storage’ areas on a floodplain is not a common process in other parts of the world. There is therefore little guidance beyond that of the FPDM as to how such categorisation might be achieved. It is important to note that the impact of lost flood storage on discharge and flood levels is a hydrodynamic consideration, whereas the extents of a ‘regulatory floodway’ and the PMF flood extents (outer edge of the ‘flood fringe’) can mostly be assessed on a static modelling basis. This adds additional complexity to the delineation of flood storage areas that is not necessarily present in delineation of ‘floodway’ or ‘flood fringe’ areas. While a FEMA style approach could be applied to a 1D hydrodynamic model to quantify the impact of flood storage being lost on the floodplain, such a process does not translate easily into 2D. The 2D process is further complicated by the fact that there is often no obvious single floodway which might be used as a hub for lateral encroachment modelling. This problem is readily apparent in Figures 1 and 2.
4.3.1 The KISS Approach

The KISS approach of Method A establishes ‘regulatory flood storage’ areas as all land between the extents of a flood of intermediate ARI (as used to delineate the regulatory floodway’ and the extents of the ‘designated’ flood’. This approach clearly has the benefit of simplicity and reproducibility but will in most circumstances be a relatively poor indicator of land that could impact flood behaviour if filled. The subjectivity and complexity of more technically relevant approaches are however, as indicated in discussion on other options, not without their problems as well. Such an approach should therefore be given serious consideration as an interim option.

4.3.2 Minimal Depth Based

A somewhat more deliberate approach could be to evolve a simplified relationship between the magnitude of flood storage lost and its impact on flood behaviour, with flood depth. Using such a relationship, flood depth could then be used as an indicator of the depth below which storage lost is not significant and below which filling would therefore have minimal impact on dynamic flood behaviour. This is the basic approach adopted in Methods B and C.

4.3.3 Hydrodynamic Analysis Based

In the general (1 and 2D) case, it is technically possible to fill the area between the floodway boundary and flood extents boundary and progressively move the inner boundary of the fill outward (on diminishing VxD contours) until the increase in discharge or afflux resulting from this filling drops below the specified limit. As with the ‘floodway’ definition the various event specific flood storage areas then need to be consolidated into one ‘regulatory flood storage’ area. As these areas will certainly change with event ARI it is difficult to see how a process other than a subjective overlay could then be used to map the ‘regulatory flood storage’ areas.

There are also spatial considerations whereby filling in some parts of a floodplain may be more beneficial (from viewpoints other than flooding) than in others. Identification of these areas and their integration into modelling requires considerable engineering judgement and would be difficult to replicate or automate at this time.

Given the remaining subjectivity of this process and considerable increase in modelling time and cost to achieve a result, categorisation specific hydrodynamic modelling is not, in the Authors’ view, a practicable option for delineation of ‘regulatory flood storage’ areas at this time. Future advances in flood modelling may however make such a process feasible.

4.4. Flood Fringe Areas

The ‘regulatory flood fringe’ is simply that land that falls within the area of inundation in a PMF event, that is neither part of the ‘regulatory floodway’ or ‘regulatory flood storage’ area. As such there is no problem mapping this area as long as the other areas have been mapped
5. MOVING FORWARD

The reviewed studies confirm that hydraulic categorisation is a process that is being skipped in most Flood Studies in New South Wales. Consideration of options for such categorization makes clear however that a fully compliant, technically competent and reproducible procedure for categorization is, in the Author’s view, beyond our capabilities at this time. If hydraulic categorization is to be retained (and used in NSW flood studies), a compromise solution is needed now. Being a compromise, such a solution ought not, in the Author’s view be the individual responsibility of Consultants. The establishment of an agreed and reproducible procedure must involve all parties involved in the floodplain management process. It is, in addition, important that any procedure under serious consideration be tested across a range of catchments and modellers to confirm and provide confidence in its ability to produce sensible results that can be replicated by others.

6. TAKE HOME MESSAGES

- There is a problem with the lack of reproducible procedures for the hydraulic categorisation of a floodplain in the current FPDM (2005).

- Hydraulic Categorisation can provide valuable information on areas in which
  o no development should occur (Floodways)
  o no filling should occur (Flood Storage Areas)
  o development would be minimally impacted by flooding (Fringe Areas)

- Despite being a requirement of the FPDM, only a limited number of Flood Studies or Floodplain Management Studies undertaken in NSW in the last ten years have attempted hydraulic categorisation of the floodplain.

- Where studies have tried to address hydraulic categorisation, the procedures adopted have varied and have been undertaken in a relatively simplified and subjective manner. It is highly unlikely that another Consultant would arrive at the same categorisation boundaries, opening the door to potential litigation.

- As the hydraulic categorisation of a floodplain can provide information not obtainable by other means, it should be retained in the FPDM. Technically relevant, practicable and reproducible approaches for quantification of hydraulic categorisation are however necessary and need to be incorporated into the FPDM. Any procedure adopted should apply equally to 1D and 2D models.

- Given the considerable complexity and time/cost in developing a broadly applicable and reproducible hydraulic categorisation procedure – a KISS based approach, such as that outlined in Method A, should be given serious consideration, as an interim solution.

- Resolution of an acceptable compromise procedure for hydraulic categorisation is not, in the Authors’ view, a task for individual Consultants. Agreement in respect to acceptable procedures can only occur with the full
support of the DECC in an environment of cooperation with those Councils active in floodplain management and those Consultants undertaking Flood Studies in NSW. It is important that any procedure under serious consideration be tested across a range of catchments and modellers to confirm and provide confidence in its ability to produce sensible results that can be replicated by others.

- If we are to retain and pursue the delineation and mapping of hydraulic categories of land in our flood studies, more deliberate procedures are urgently required now.

7. REFERENCES

Arizona Department of Water Resources – Flood Mitigation Section (1996) Requirements for Floodplain and Floodway Delineation in Riverine Environments, State Standard 2-96


Indiana Department of Natural Resources – Division of Water (2002) General Guidelines for the Hydrologic-Hydraulic Assessment of Floodplains in Indiana

