The Next Generation in SWMP Modelling

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Abstract

Recent legislation and recommendations from the Pitt Review (2008) have led to the implementation of Surface Water Management Plans (SWMPs) by Lead Local Flood Authorities. The Surface Water Management Plans aim to provide an understanding of all flooding mechanisms within an urban catchment including; pluvial, fluvial, sewer and groundwater. This has in part lead to dramatic advancements in modelling programs and techniques. Key among these is the need for flooding to be modelled in 2D, and the ability to model point and linear coupling in one program.

This paper will cast light on some of the techniques which it is believed are part of the next generation of modelling. It will then suggest a methodical approach to identifying flood alleviation solutions as part of SWMPs and discuss these in relation to the benefits of using next generation models. Finally it will demonstrate how this approach can be used to ensure transparent and comprehensible results.

Keywords
SWMP, hydraulic modelling, 1D-2D coupling, integrated modelling

1. Introduction

In 2004 the governments' flood and coastal erosion risk management strategy; "Making Space for Water" (Defra, 2004) sought to produce an integrated approach to managing flood risk effectively. As part of this programme 15 pilot studies were undertaken to examine various aspects of Integrated Urban Drainage (IUD). These pilot studies examined data sharing issues, modelling approaches, approaches to flood risk assessment and options to mitigate surface water flooding. The IUD Pilot Studies directly contributed to the development of the Surface Water Management Plans (SWMPs) which were implemented following recommendations from the Pitt Review (Pitt, 2008). Although each study is individual and defined through a partnership of Lead Local Flood Authorities and their corresponding stakeholders, they are principally concerned with managing surface water flooding from 4 key mechanisms; pluvial, fluvial, groundwater and sewers.

The scope of the SWMPs has led to considerable advances in computational modelling, predominantly due to the need to model both surface water and sewer systems in an integrated manner, allowing point (at manholes) and linear (along riverbanks) 1D-2D coupling between the 1D and 2D domains in the same model. This has led to a requirement for modellers to have a broader knowledge encompassing both sewer and river modelling techniques.

2. Model Build

There are 5 key elements to consider when building a model for an SWMP; rivers, bridges, culverts, sewers and the 2D mesh. While there are a variety of different software programs available to do this, each in their own way, the principles and approaches are similar in all of them.

2.1. Rivers

To enable computational efficiencies river reaches are generally modelled in 1D. Ideally there would be surveyed cross-sections available at intervals which are used to build up the reaches; however for many watercourses these are unavailable and when they are available they are often too widely spaced to adequately represent the sinuosity of the watercourses, especially in urban catchments. The consequence of this is that, without further work the modelled reaches would frequently cross buildings which then jeopardises the creation of the 2D mesh.

It is therefore usually necessary to increase the number of cross-sections by conducting further surveys, inferring the levels from a DTM or by interpolating between surveyed cross-sections. These techniques have their advantages and disadvantages, and there is no right or wrong way of doing this so a degree of common sense is needed to determine when each technique should be used. However in general it is fair to assume that if there are surveyed cross-sections available then interpolation between them should be carried out to increase the sinuosity of the river reach. The exception to this is where a watercourse passes through urban areas and the profile changes regularly. In these circumstances it may be more appropriate to either undertake additional surveys or to infer the extra cross-sections from the DTM. If the latter approach is taken it is important to remember that in some areas the DTM may not be accurate due to resampling in highly vegetated or built up areas.

2.2. Bridges and Culverts

When modelling, the only way to decide whether a bridge or a culvert is needed is by looking at the DTM; if the deck has not been filtered out of the DTM then the structure can be modelled as either a culvert or a bridge (figure 2.1a). However if the DTM has been filtered and the deck level cut out then it can only be modelled as a bridge (figure 2.1b).

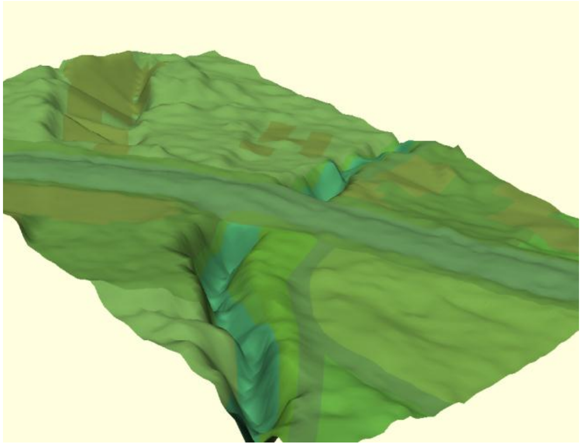

Figure 2.1a – DTM with deck left in (2.1a). This can be modelled as either a bridge or a culvert.

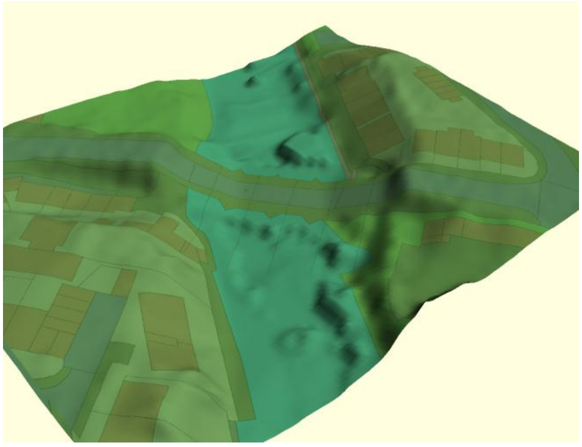

Figure 2.1b – DTM which has had the deck filtered out. This can only be modelled as a bridge.

The next generation of modelling handles bridges and culverts in slightly different ways. The bridges are modelled with a 1D flow through the opening, when the flows in the upstream river reach become high enough that they can overtop the deck level and are then modelled in 1D over the deck and back into the downstream river reach. As a result there is no interaction between flows through or over the bridge structure and the surrounding mesh. In comparison, when it is possible to model a structure as a culvert the mesh can be continued over the structure, which not only allows overland flows to cross the structure but also allows high level flows in the upstream river reach to spill over the bank and onto the mesh.

2.2.1. Bridges

There are 5 key physical features which have to be included when modelling bridges; the shape, height, length, skew and deck level. Of particular importance is the deck level as this is the height at which water in the upstream river reach can spill over the top of the bridge as a 1D flow and continue back into the reach downstream of the bridge structure.

Where a bridge has a parapet attention needs to be paid to the type and level of it to identify whether the modelled deck level should be at parapet level rather than the actual deck level. The reason for this becomes apparent when the deck level is lower than the bank level and the bank level is lower than the parapet. If this is the case when the parapet height is modelled flooding will occur over the banks rather than the deck.

Also important are the more subjective features which can also have an effect on the conveyance of water through a structure, but which cannot be easily surveyed. These include the roughness of the river bed and the length of the expansion and contraction zones.

A reasonable assumption of the roughness of a bridge structure can be made by assessing the bed roughness and barrel roughness and the vegetation type. It is particularly important to consider this where more than just the river bed is contained within the bridge (e.g. if a footpath is also contained within it) as this could have an effect on the conveyance of floodwater through the structure. The roughness of the channel is generally interpolated through the bridge structure from the upstream cross-section to the downstream cross-section (sections 3 to 2 in figure 2.2).

Modelling the length of the expansion and contraction zones is particularly subjective, especially if it is not possible to conduct field investigations during high flows. In the past, tables have been used which help to define these lengths (HEC, 1995). Figure 2.2 (HEC, 2002) shows the relationship between the expansion and contraction zones and the bridge structure which has previously been used.

However these were based on old 1D models which include the floodplain in each cross-section, rather than the 1D channel, 2D floodplain now being separately modelled. As a result these tables and diagrams should be used with caution

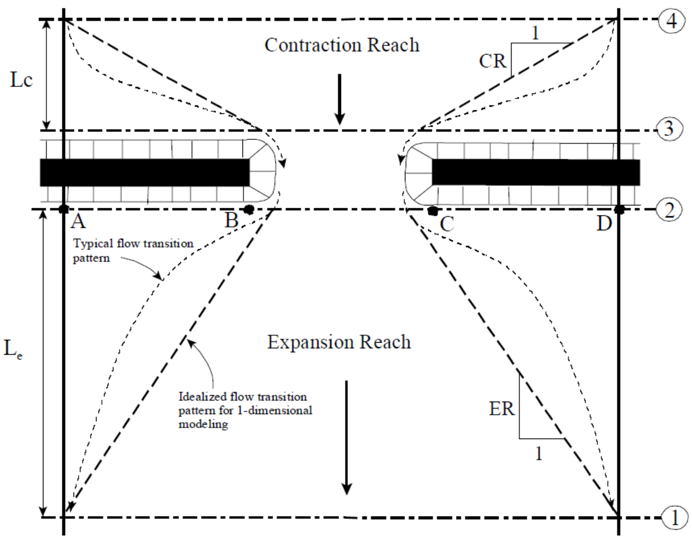

Figure 2.2 – Contraction and Expansion reaches through a bridge structure from HEC-RAS Hydraulic Reference Manual (2002).

When next generation modelling is used there is no interaction between the 1D bridge structure and the 2D mesh. This includes the expansion and contraction zones and so perhaps more important now is to consider the impact that the length of these may have upon overbank flows.

2.2.2. Culverts

There are 3 principle processes which cause energy losses in structures such as culverts, these occur as the flow travels into, through and out of the structure (figure 2.3). In order to model these, the culvert shape, headwall type and upstream and downstream inverts need to be known.

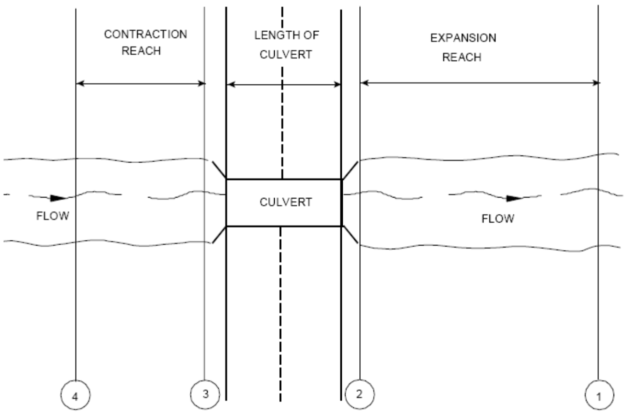

Figure 2.3 – Contraction and Expansion reaches through a culvert structure from HEC-RAS Hydraulic Reference Manual (2002).

Next generation of programs generally treat culverts as a separate entity from bridges, interpreting the contraction reach as an inlet to the culvert and the expansion reach as a culvert outlet. This method has the benefit, of allowing the mesh to cover the culvert. As a result of this overland flow routes can pass over the structure.

As the inlet and outlet are modelled as 1D connections from the river reach to the culvert with no defined length there is no implication ascribed to the length of them. As a result these should be made, within reason as short as possible to reduce the impact of loss of interaction between the river reach and mesh.

It is important that the connection between a culvert and the inlet and outlet is either modelled as a sealed manhole or a break-node to prevent instabilities arising.

2.3. Sewers

Sewers are generally brought into the SWMP model from another source and can then be incorporated into the river reaches to allow interactions to take place, for example, where an outfall discharges into a river the two would be linked together allowing the storm sewer system to back up and possibly flood if the river level rose above the outfall invert level.

2.4. 2D Mesh

There are two ways of bringing the DTM into a model, dependant on the software being used. The first method is a square mesh element where a regular grid is overlaid across the model. If this method is being used the river channels are generally 'carved' out of the mesh after it has been created. Buildings can generally be represented in one of three ways; increased roughness, blocking out of elements completely or partially blocking out elements (Syme, 2008).

In contrast, next generation modelling usually uses an irregular triangular mesh which is built into the model from a DTM after the systems have been created. As a result these can be created to exactly match elements in the model such as a river reach or building. In addition to this break-lines can be introduced to force triangles to abut along a specified boundary, for example at the top and bottom of slopes. This reduces the inaccuracies between the mesh and physical elevation (Allitt, 2009).

Both methods of meshing require an element size to be chosen. It is particularly important for this to be appropriate to the type of model being used as a twofold increase in mesh element size results in a fourfold increase in the number of elements. As a result an appropriate element area for an intermediate (Type II) model would be around 100m^2 while for a detailed (Type III) model this may be reduced to around 20m^2. However it is now possible, using an irregular triangular mesh, to create 'mesh zones' which allow the user to define areas where there could be larger or smaller mesh elements. This allows less important areas of the model to be modelled at a lower resolution. As a result it is important to think about where micro or macro features may be needed. For example where conveyance is the main flood driver micro features are more important as walls, kerbs and fences will have a significant effect on the flood route. However where ponding is the main driver these features are less likely to be needed. These mesh zones can also be used to raise or lower parts of the mesh to represent roads or kerbs for example and so are a valuable tool, especially when micro features are needed to be modelled.

3. Using the Model for Optioneering

3.1. SWMM Pyramid

The Surface Water Management Measures (SWMM) Pyramid has been designed and developed by Richard Allitt Associates Ltd. as a conceptual way to increase the ease by which the process of optioneering can be conducted during the options phase of the SWMP (figure 3.1). Importantly this tool has been developed through experience during the optioneering phase and so gives a structured approach, which allows users to consider all the possible significant styles of flood defence and mitigation and identify the most cost effective range of solutions suitable for each catchment. It supplies an easy to use step by step process which is transparent and easily understood by multiple stakeholders.

It is structured so the top level (flow reduction) is the widest scale of the options and is most likely to achieve the greatest benefit across a catchment resulting in the lowest risk. Progression down the pyramid leads to smaller scale solutions which are likely to benefit fewer properties.

A logical progression can be followed downwards through flow reduction, diversion, storage, conveyance, exceedance and finally to protection with the options at each step being considered. If it is possible to solve the flooding issues at the first level then there is no need to progress, however more often than not a combination of a number of the schemes may be needed, in which case flow reduction options should be considered first, then diversion and so on. Equally if a scheme cannot be solved using an option this should be discounted and the next option down should be considered.

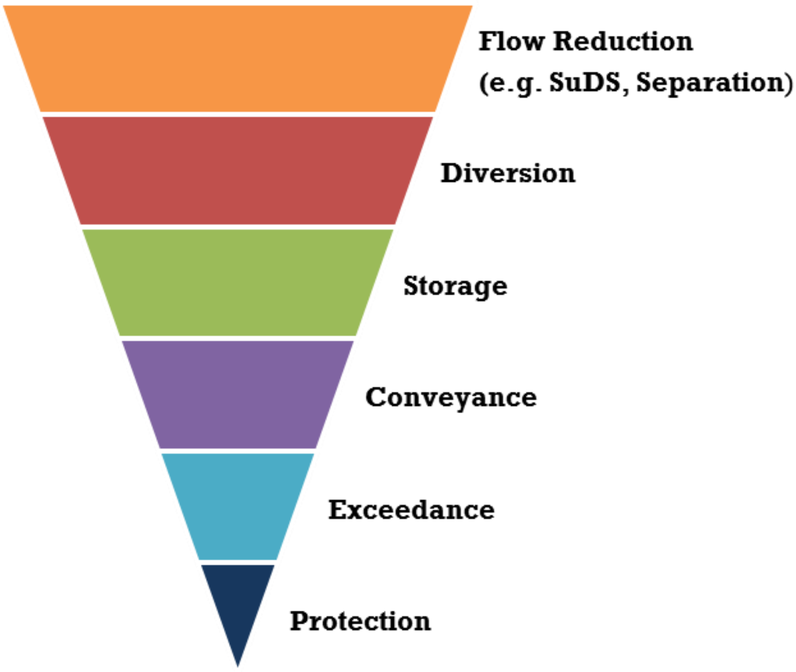

Figure 3.1 – SWMM Pyramid, developed by Richard Allitt Associates as a tool to make the consideration of flood defence and mitigation strategies transparent and understandable.

In reality many schemes will need more than one of the solutions, for example it is likely that a diversion would be needed to route flows to storage. However experience from multiple case studies has shown that there are strong similarities in the hierarchy with which the possible alternative SWMM's should be investigated.

Importantly all of these solutions can be modelled in the same programme if a next generation model is used. This allows the interaction between different solutions to be investigated and also dramatically enhances the cost-benefit comparison of all the options.

3.1.1. Flow Reduction

The first preference is to establish whether the flows can be reduced. This can be carried out at a catchment wide scale, for example reducing flows through the disconnection of roofs via water butts, rain gardens and green roofs and the addition of SUDS to large paved areas. Many of these solutions have the benefit of being simple and cheap as well as very effective at reducing the volume of water transferred into sewer and river systems.

These solutions can be easily modelled by altering the characteristics of different contributing surfaces.

3.1.2. Diversion

Following on from reduction the next option is to divert flows away from high risk areas. For this to be an appropriate option the flows can only be diverted to an area which can safely accommodate them. Diversions can often be used in conjunction with storage solutions to take flows away from at risk areas and then hold them back until the water levels have subsided enough for the water to be returned to a watercourse safely, without the risk of causing further flooding. As a result, this is often considered at the same time as storage as many of the issues relating to storage need to be taken into account at the same time. It is also generally only applicable where pluvial runoff from rural outskirts into urban areas is a substantial problem.

Further channels can be added to the model to represent diversion routes.

3.1.3. Storage

The next preference is storage. This is a particularly cost effective way of reducing the flows through an area at risk of flooding; however there are a number of important factors to consider. Firstly the size of the storage and embankment height needed should be calculated and the visual impact of a large storage area also needs to be considered. It is important to think about this in terms of whether it exceeds the criteria for a reservoir which is currently 25,000m^3; however this is currently being re-evaluated and is likely to be decreased to 10,000m^3.

Suitable locations for storage areas can usually be found in fields or parkland and can either be within or upstream of urban areas. They can be modelled at the optioneering phase in one of two ways. The simpler choice is to model permeable walls which hold the water back, however these are unrepresentative of the final outcome so the other option is to alter the DTM to better reflect the shape of the embankments.

3.1.4. Conveyance

Conveyance options usually involve either upsizing the sewers or increasing the capacity of the watercourses. These methods help to reduce the time it takes for the flow to pass through the catchment. However it is important when modelling these to consider the issues which may be caused downstream of the catchment and ensure that enough area downstream is modelled to ensure there are no adverse impacts as a result of increasing the conveyance.

Again these can be easily modelled. Watercourse capacity can be easily increased by altering existing channels in the model.

3.1.5. Exceedance

The penultimate solution is exceedance. This makes use of overland flood pathways to convey water which has already flooded in designated areas and help to direct it either back into a watercourse further downstream or via storage.

While exceedance is a useful option it should not be considered before the above options as it is only applicable once flooding has occurred. This generally involves enhancing existing overland pathways to make them formal exceedance routes, for example along roads. Part of this process could involve increasing kerb heights and profiling of roads to ensure that flows are contained within the pathway. The pathways will generally lead to temporary storage where the water can be held until it is safe to release it back into the watercourse.

When exceedance is chosen as an option, attention needs to be paid to the threshold levels of nearby properties to ensure that these are not put at greater risk. It is also important to ensure that emergency routes do not coincide with the chosen pathways.

Exceedance routes can be modelled using mesh zones to 'cut' into the mesh resulting in a shallow channel along which water can flow in 2D. Alternatively it is also possible to use mesh zones to raise the kerb levels.

3.1.6. Protection

The final SWMM option is protection, this is conducted at a property level and generally only individual properties or a small group benefit. An example of this would be fitting flood gates to the front of a property. Due to the scale of these schemes this is a particularly expensive solution with respect to the cost per property.

While some protection measures cannot be directly modelled, such as air-brick covers. The modelling results can inform the design criteria for all of these measures. For example information on the depth and duration of flooding around a property can be useful when these features are being planned. For other protection measures such as flood gates a porous wall can again be designed in the model to represent the ultimate solution.

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