TwoD (runoff) or not TwoD (runoff) – that is the question

Author & Presenter:
Richard Allitt BSc FICE CEng CEnv – Director – Richard Allitt Associates Ltd
Tel: 01444 401840 email: richard.allitt@raaltd.co.uk

Introduction

There have been long held aspirations for urban drainage models to provide a better representation of the runoff from the different surface conditions found in a catchment. These aspirations have revolved around whether the modelling should be undertaken in 1D or in 2D as there are advantages in both approaches.

This paper will review the ways in which runoff can be simulated and will examine the benefits and pitfalls of using 2D runoff in a model either exclusively or in conjunction with conventional 1D runoff. This will be presented partly as a case study based on a model created for a London Borough as an update for the Environment Agency's surface water flood risk mapping.

Contributing Areas

Contributing areas have always been the cornerstone of conventional 1D modelling. The definition of contributing areas is a labour intensive activity which relies on the skill of the Modeller to define correctly. The use of Lidar data has advanced this activity considerably but there is always a certain degree of conflict in whether the areas should be allocated to the upstream or the downstream manhole; there are valid arguments both ways.

Because the drawing of contributing areas (if done properly) is the single most labour intensive and expensive task in any model building exercise many people (with very mixed results) have attempted ways of automating the definition of the contributing areas.

The runoff surfaces within each contributing area have to be individually digitised or generated from mapping, coded and then used in the 'Area Take Off' process to become numerical values in various fields of the contributing area data.

The biggest drawback with the use of contributing areas is that the runoff from all surfaces is routed directly and immediately into the manhole which the contributing area is assigned to; this becomes quite unrealistic when there are large permeable areas such as gardens around each house. It is possible to partially overcome this problem by reducing the extent of the contributing area and allowing 2D runoff of large garden areas; this process however is even more time consuming.

2D Runoff

The advances in computer hardware and software now make modelling of runoff in 2D for the whole of a study area a very real possibility. It will always be slower than just a 1D model but when there is a need for some 2D overland flood flow routing there is very little difference in simulation times.

When considering using 2D runoff for the whole of a study area it is important to define the purpose of the model as the approach will be tailored differently for different purposes.

2D Runoff for Pluvial (surface water) Runoff Models

For these types of models there are two distinct versions; those without any sewers modelled and those where the sewers are modelled. The conventional approach for the model versions without sewers is to make deductions from the rainfall to compensate for the effects of the sewer system – this is viewed as a short term 'work around' approach which will be phased out.

The main versions of pluvial runoff models will be those which include the surface water and combined sewers and may or may not include road gullies.

In these types of models data from Ordnance Survey MasterMap will form the basis of the modelling. This data requires a bit of work on it before commencing modelling work; the reason for this is that the MasterMap data contains far more vertices than are necessary for modelling purposes and as each vertex creates a triangle this can result in a very large number of very small triangles. The first step therefore is to undertake a combining and thinning process which can be done in any GIS program. Buildings should be combined so that small porches, extensions etc are all integrated into the main building and rows of terraced houses can be combined into a single building. A thinning process can then simplify the buildings to remove small irregularities. The resultant "Buildings" layer will then be used again later. Roads should be combined together and then thinned to create a “Roads” layer.

It is essential that there is good quality Lidar data available for the whole of the study area. To create the model there are a number of different layers which need to be created as summarised below:-

Buildings	**Mesh zones** should be created for each building which can easily and quickly be done using the ‘Buildings’ layer imported via the data import centre. The 2D meshing will create triangles within the buildings and there will be pluvial runoff from the mesh. The zone should be raised above the DTM by say 150mm to allow for the difference between ground level and internal floor level. This is sufficient to cause overland flow to pass around the buildings but when flow depths or ponding are more than 150mm there will be some flow through the building. If the threshold levels of individual properties are known the mesh zone can be reset to those levels. Plus **Infiltration zones** should be created for each building, again using the ‘Buildings’ layer, with the infiltration characteristics set to a fixed runoff of 100% or whatever other figure the Modeller wants. Plus **Roughness zones** should be imported for each building using an appropriate value for the roughness of the roof. It is recommended that different values are used for pitched roofs which are typically found on houses and flat roofs which are found on larger buildings.
Roads	**Mesh zones** should be created for each road which can easily and quickly be done using the ‘Roads’ layer imported via the data import centre. The 2D meshing will create triangles within the buildings and there will be pluvial runoff from the mesh. The zone should be raised below the DTM by say 125mm to allow for the height of the kerbs. Plus **Infiltration zones** should be created for the roads, again using the ‘Roads’ layer, with the infiltration characteristics set to a fixed runoff of 100% or whatever other figure the Modeller wants. Plus **Roughness zones** should be imported for each road using an appropriate value for the roughness of the road.
Paved Areas	**Infiltration zones** should be created for the paved areas (footpaths, driveways, car parks etc), again using MasterMap layers where relevant or digitised from other data. The infiltration characteristics should be set to a fixed runoff of 100% or whatever other figure the Modeller wants. Plus **Roughness zones** should be created for each paved area using an appropriate value for the roughness of the paved area.
Woodland	**Infiltration zones** should be created for each different type of woodland (deciduous, evergreen etc) using regions which can be extracted from MasterMap. The infiltration characteristics should be set to appropriate values for the type of woodland bearing in mind that many evergreen trees trap a lot of the rainfall. Plus **Roughness zones** should be created for each woodland area using an appropriate value for the roughness of the underlying ground surface within the woodland area.
Lakes & Ponds	**Infiltration zones** should be created for each pond or lake with the infiltration characteristics set to 100% runoff. Plus **Roughness zones** should be created for each pond or lake with a very low roughness value so that any flow across lakes or ponds is allowed to traverse quickly.
Sports Pitches or other areas of mown grass	**Infiltration zones** should be created for each sports pitch or other areas where there is relatively short mown grass. The infiltration characteristics should be set to appropriate values to reflect the characteristics of each area bearing in mind that some sports pitches might have an underlying land drainage system. Plus **Roughness zones** should be created for each sports pitch or other relevant areas with a comparatively low roughness value reflecting the characteristics of the area.

TwoD (runoff) or not TwoD (runoff) – that is the question

The infiltration characteristics of the whole of the 2D zone can be set for the whole zone and is only over-ridden when an infiltration zone is used. There are a number of options available for defining the infiltration characteristics; the simplest is just to use a fixed runoff equivalent to the SPRHOST value for the catchment taken from FEH. A more sophisticated approach is to use the 'Horton' runoff model which gives varying runoff depending on the rainfall intensity, the degree of saturation of the ground and the soil conditions.

The above description may give the impression that creating the model is a lengthy process but in actual fact once the process is understood it is a very rapid process.

2D Runoff for Integrated Catchment Models

For integrated catchment models where all of the sewers are modelled and in some instances where the individual road gullies are also modelled. For these types of models it is ideal for a differentiation to be made between those areas which are directly drained and those which are not.

The principle difference between the approach taken for this type of model and a pluvial runoff model is the treatment of the buildings. The buildings are generally the only significant areas which are directly drained (roads will be discussed later) and these can either drain to foul/combined sewers or the surface water sewers. The 'Buildings' layer can be used to create contributing areas which are used instead of the infiltration/mesh/roughness zones discussed above; where the building drains to the surface water sewer it may be necessary to create two contributing areas (one for the foul and one for the storm) covering the same area. The 'Buildings' data can easily be imported and an area attribute created in the GIS program can be used to populate the roof area data. The contributing areas are created by importing the 'Buildings' layer and it is a relatively easy matter to allocate the contributing area to the nearest node of the correct system type; there is no problem with having several contributing areas allocated to the same node.

With this type of model the buildings can either be cut out from the 2D mesh as voids or they can still be defined with a raised mesh zone.

Roads can either be modelled as 1D contributing areas or as 2D runoff areas. There are no significantly advantages in taking the 1D approach as the roads need to be set up with mesh zones and roughness zones anyway in order to be able to adequately model overland flow. Experience has shown that improved modelling can result if the road gullies are modelled with suitable head-discharge characteristics applied to both the road gullies and to manholes.

Case Study

The approach described above for a pluvial runoff model has been successfully used for a study for one of the London Boroughs. The remit for this model was to create the model so that the results from it could be used for the latest generation of surface water flood risk maps for the Environment Agency.

The study area was generally drained on a separate basis and all surface water sewers and watercourse culverts greater than 225mm diameter were included in the model. In several locations it was found that modelling of the 225mm diameter sewers was also required to avoid long lengths of roads without any sewers. Road gullies were not modelled but the manholes were modelled with the 2D flood type which proved to be adequate for collecting the runoff off the roads and routing the flow into the sewers.

The study area was 3,250ha of which 1,900ha can best be described as dense residential development. There is extensive parkland and woodland within the study area, two significant watercourses and 4 ponds / lakes.

Conclusion

I have found from my experience of 2D modelling that the governing factor is not the size of the study area but is the number of triangles in the 2D mesh. Whilst there is no absolute limit I have found that in practical terms it is best to limit the size of the model to no more than 4 million triangles. This limit is what makes the 'thinning' of the MasterMap data so important as without the 'thinning' the 4 million limit is quickly used up.

I have also found that using the 'terrain sensitive meshing' facility is very useful as setting a relatively small vertical increment between triangles is a better way of creating appropriate triangle sizes. The triangle sizes for mesh zones for buildings and zones frequently requires a bit of trial and error to get to appropriate values.

I consider that the use of direct runoff 2D modelling is an established procedure which is improved if the sewer network can also be modelled. I also consider that direct runoff 2D modelling is now feasible for integrated catchment models for most Drainage Area Plan type models and there are considerable cost and time advantages in doing so.

It will be a matter for individual Water & Sewerage Companies as to whether they want to continue with modelling their own assets in isolation from the highway drainage systems and pluvial runoff. I consider there would be significant advantages for Water & Sewerage Companies if they followed a fully integrated approach as amongst other things it would readily identify whether or not flooding was due to other causes such as inadequate highway drainage. A recent study I have done in a different area identified that the root cause of flooding was an inadequate number of road gullies; as soon as additional road gullies were added to the model the flooding problems were resolved.

In answer to the original question "*2D (runoff) or not 2D (runoff) – that is the question*" I consider that we are now at a stage where people's aspirations for 2D runoff modelling have been met, 2D runoff modelling is feasible and above all it is cost effective.