DISCUSSION ON 2D OVERLAND MODELLING APPROACHES

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ABSTRACT

With advances in technology, 2D modelling has been increasingly used to determine flood risks in Auckland and to predict overland flow paths in urban areas with greater confidence than the previous 1D modelling approaches.

There are a range of challenges in developing a 2D model that need to be considered. One of these challenges is how to represent the buildings, kerbs and other features. It often depends on the complexity of the study, the software and hardware capabilities.

During the previous 1D Flood Hazard Mapping studies undertaken for Auckland City buildings, kerbs and other obstructions weren't needed to be represented in fine detail in order to represent the flood risks encountered. In more detailed 1D/2D studies AECOM used a fine 2D mesh and with this, the need to represent roads, buildings and other obstruction in finer detail was required. This paper outlines the various methodologies that can be applied to modelling buildings, kerbs and fences within a 2D model using project examples.

This paper will look at the lessons learned whilst developing the models. It will also outline the advantages and disadvantages of the different methodologies.

KEYWORDS

Hydraulic Modelling, Two Dimensional Model, One Dimensional Model, Flood Hazard Mapping

PRESENTER PROFILE

Nadia is a senior member of the AECOM team with thirteen years experience in hydraulic engineering. She has worked extensively on a variety of hydraulic modelling studies, specialising in drainage and river modelling.

1 Introduction

Two dimensional (2D) models have been widely used for coastal and river modelling, but recently have been increasingly used to predict flood hazards within the urban environment. Urbanisation changes the flow regimes of overland flooding with flood occurring on impermeable surfaces and obstructions affecting natural flow. The challenges of urban 2D flood modelling encountered are to take these obstructions, such as buildings, kerbs, fences etc into consideration when analyzing the surface flows. This paper describes some of the approaches AECOM has applied with recent flood hazard mapping projects and describes the advantages and disadvantages of the various approaches.

Highly urbanised areas have certain challenges such as:

- Increased level of topographical detail
- Complexity of terrain, i.e. roads, kerbs and inlets
- Network of inlets and pipes
- Engineered or natural open channels
- Stormwater management structures such as ponds, stopbanks, pumps and off line storage
- The ability to predict the route of floodwaters in urban areas is important and has property and financial implications

Figure 1: Property flooding

All these challenges will need to be taken into consideration when modelling extreme floods in a highly urbanised environment. This paper describes the lessons learned from the recent 2D modelling and the coupled 1D/2D modelling AECOM has completed for representation of obstructions, buildings and inlets. All of these are highly dependent on the digital terrain model in terms of accuracy and also the grid size that is chosen for the studies. The examples used in this paper are part of an Auckland City-wide flood hazard mapping (FHM) study which has been undertaken by AECOM on behalf of Metrowater and Auckland City

Council, as well as subsequent studies of the catchments of Kohimarama, Oakley, Meola and the Auckland Central Business District (CBD).

Figure 2 : Example of wall creating an obstruction in natural floodplain

2 The Terrain

An accurate set of Light Detection and Ranging (LiDAR) data and aerial photography was collected for the Auckland region initially in 2006 and recently in 2010. This new data provides the opportunity to model urban flood risk assessment with finer detail and to develop higher quality 2D hydraulic models.

2.1 Generation of DTM

There are numerous activities required to set up a 2D hydraulic model. The generation of the 2D grid to define the 2D hydraulic model is the first step in the 2D hydraulic model build process. The process generally followed by AECOM for the recent 2D studies follows the method described by Figure 3.

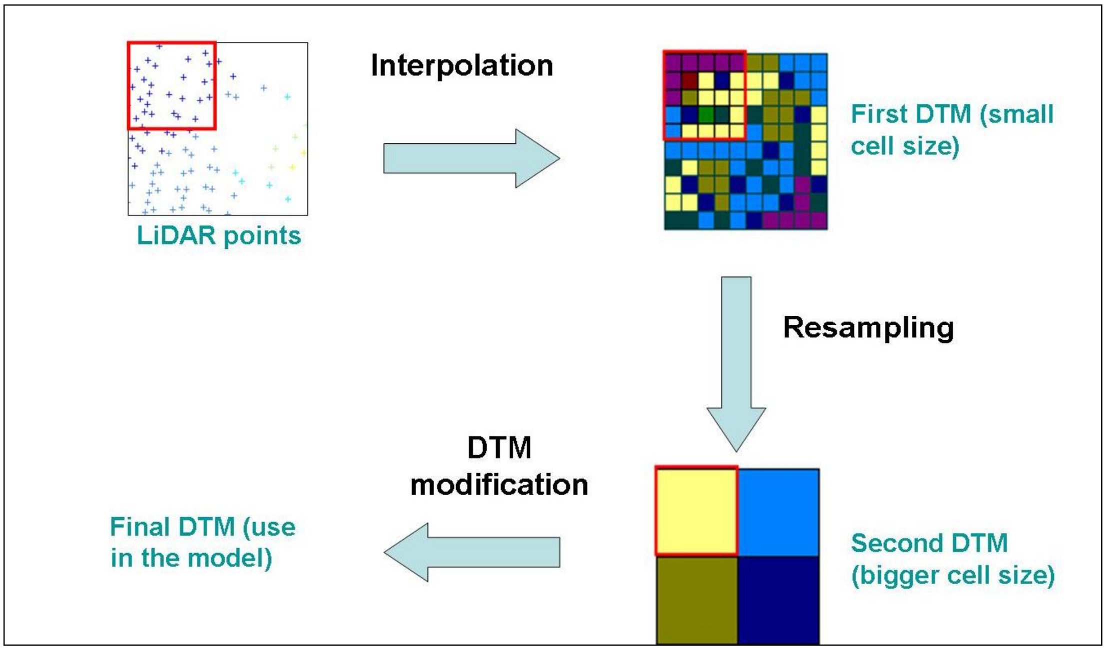

Figure 3: Transformation of LIDAR Point Data into a 2D Model DTM

DTM's can generally be built as a grid structure, irregular triangulated networks (TIN) or based on contours. It is crucial for the modeller to understand the accuracy of the digital terrain model (DTM) that is used for the model build. It is therefore recommended that DTM's are verified with surveys. For the studies AECOM completed, the site surveys and site visits in the catchments were used to complement the topographical information from the LiDAR data. The surveying gives a localised but very accurate indication on the topography whereas the LiDAR data gives a view of the catchment but with a lower accuracy in some types of ground cover (heavily vegetated areas). Figure 4 presents examples of the LiDAR contour data and the point data on Waiheke Island.

LIDAR 0.5m Contour and Aerial Photography

LIDAR Points and Aerial Photography

Figure 4 : LIDAR and Aerial Photography Sample Data

As can be seen in Figure 3, the first DTM which has been created from the LiDAR elevation points is re-sampled to a different grid size for importing into the 2D model. The model grid size is selected according to the study requirements. The resolution of the grid directly influences the duration of the model simulation (run time) and the accuracy of the results. Therefore, the grid resolution should be selected to enable a reasonable run time and an appropriate topographical accuracy. The 2D models involve very complex calculations and the run time for a single rainfall event can easily reach up to 4 days or more if a very high resolution grid size is used. Once the grid has been imported into the model, the DTM is checked against the survey and site observations and then corrected accordingly.

There are several ways of creating the DTM for the bathymetry which the 2D software uses. Within ARCGIS there are several methods which can be utilised. The grid can also be generated within MIKE Zero, if using DHI Mike software. If the Infoworks software is used, there are also methods provided to generate a suitable mesh.

For whichever method is used there also may be a loss of resolution from the original LiDAR Data when creating the mesh for the 2D model. It is important to check the bathymetry (Mike21) or the ground model mesh (Infoworks) against the LiDAR and survey points to see whether the approximation is acceptable.

2.2 Lessons Learned

The following lessons are learned from the flood hazard studies completed:

- In the Auckland Central Business District (CBD) FHM AECOM found that the LiDAR data differed from the bathymetry due to approximation in the GIS TIN creation methodology. This influenced the direction of the overland flow path. It is important to check the bathymetry against the LiDAR to see whether the approximation is acceptable.
- During the development of the DTM, smoothing of kerb and channel and other potential important features within the DTM will often occur.
- Other features such as verandahs and dense vegetation will block the LiDAR and may create a wrong interpolation in the DTM. This may alter the flow path and surface storage volumes. These areas will need to be checked and potentially corrected.

3 Representations of Buildings

For flood hazard mapping in urban areas, it needs to be considered if buildings and roads need to be represented in the grid as these could have significant effects on the overland flow paths. In previous flood hazard mapping for Auckland Council, the buildings have been represented by increasing the roughness to allow flow to go through the building. In situations where it is known that the buildings will cause an obstruction to the overland flow path, such as buildings constructed by concrete blocks for example, the buildings have been “blocked” out (such as in CBD). The appropriate method to represent the buildings would need to be defined during the model schematisation process. Physical site inspection of flow paths and drainage structures should be undertaken and photographic evidence of all important features should be collected and checked to ensure good alignment with the 2D model grid. Figure 5 and Figure 6 are examples where the buildings are within an overland flow path or a flooding area and would need to be represented within the 2D representation. The different methods which have been used in the flood hazard mapping projects are described in this section.

Figure 5: Example of a flooded house

Figure 6: Example of flooding within a house

3.1 Increasing Roughness

Stormwater pipes can pass through properties and if surcharged to ground level the surface flow can flow through gardens and around buildings. These buildings may then become considered to be at “risk of flooding”. It is therefore crucial during the model schematisation process to consider if buildings and roads need to be represented in the 2D grid as these could have significant effect on the overland flow paths.

Increasing roughness is a method generally used for representing the flow around or through the building. It is often favoured for blocking out buildings as with applying roughness the storage effects of the water in the building is taken into account. This method is generally applied to buildings such as timber structures, where it is known that water can enter.

When representing roughness, a spatially distributed roughness map may be used to reflect different resistance to surface flow based on the land use. This may be significant in the urban flood studies as there is a large difference in conveyance between impervious and pervious areas. Varying the roughness is also considered to work well when the resolution of the 2D model is coarse and a bigger cell size is chosen. In the studies AECOM has completed, it has been found that low values of roughness do not have enough influence on the flow path through buildings. Figure 7 and Figure 8 show examples of model runs completed for different roughness scenarios. The roughness has been altered for three key areas: the roads, the pervious areas and the buildings. The different shades of blue show varying water depth, the arrows show the velocity and direction of the flow. It can be seen from the figures that altering the roughness did not significantly change the flow path or the depth of the water.

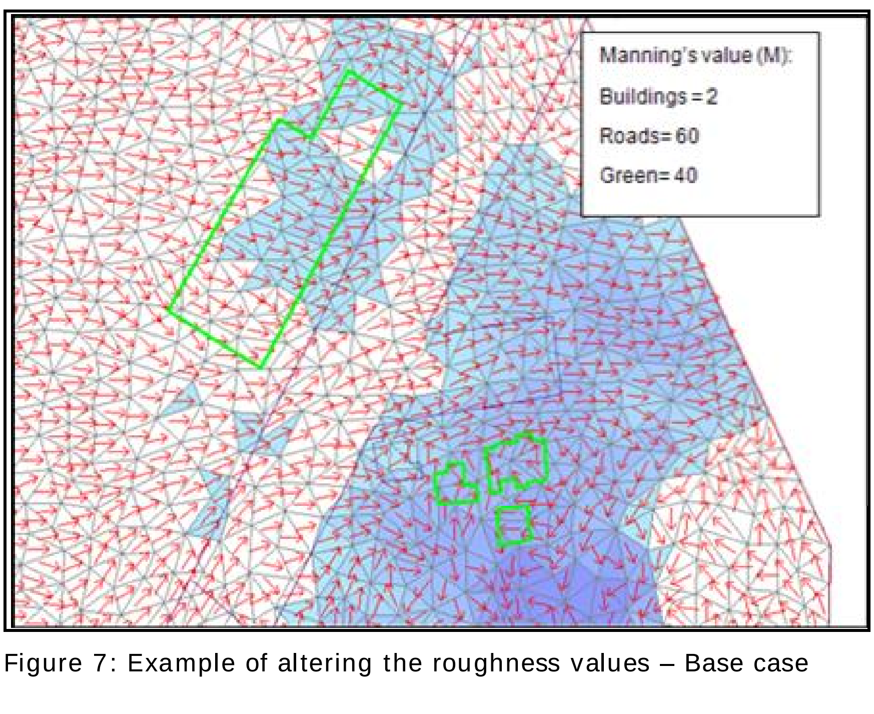

Figure 7: Example of altering the roughness values – Base case

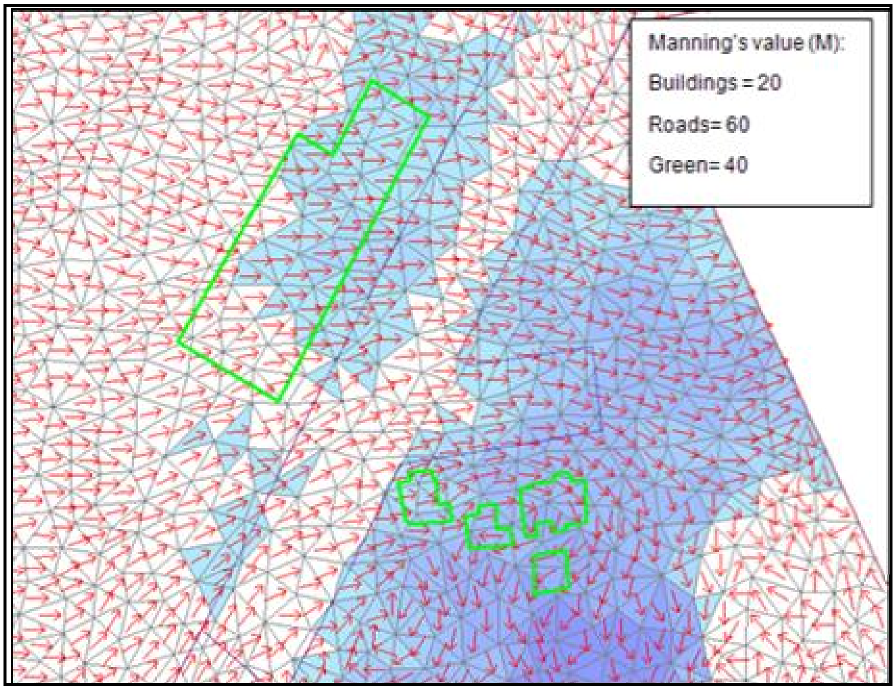

Figure 8: Example of altering the roughness values – Building (20)

3.2 Porous Buildings

One method of considering overland flow through buildings is by modelling buildings as “porous”. This methodology is applicable to Infoworks 2D. The 2D elements representing the buildings are partially blocked by applying a certain percentage to a parameter called “porosity”. A value of 0% means the building is impervious (non-porous), whereas at the other extreme a value of 100% means the building is fully porous (e.g. this may be a building on poles with no base walls). Figure 9 below shows model results where the buildings have been represented with different porosity values:

- Concrete building has Porosity applied as 0%
- Timber buildings has Porosity applied as 8%

It can be seen in Figure 9 that the buildings which have a porosity set to 0% do not have any flow within the building. The timber buildings (Porosity set to 8%) do have some grade of permeability and applying the porosity factor does allow the flow to pass through the building.

Applying different ranges of porosity to the building footprint allows the modeller to control the overland flow through or around a building and it is therefore recommended. It is however important that the modeller applies a sense-check to the parameters applied and confirms the assumptions on site.

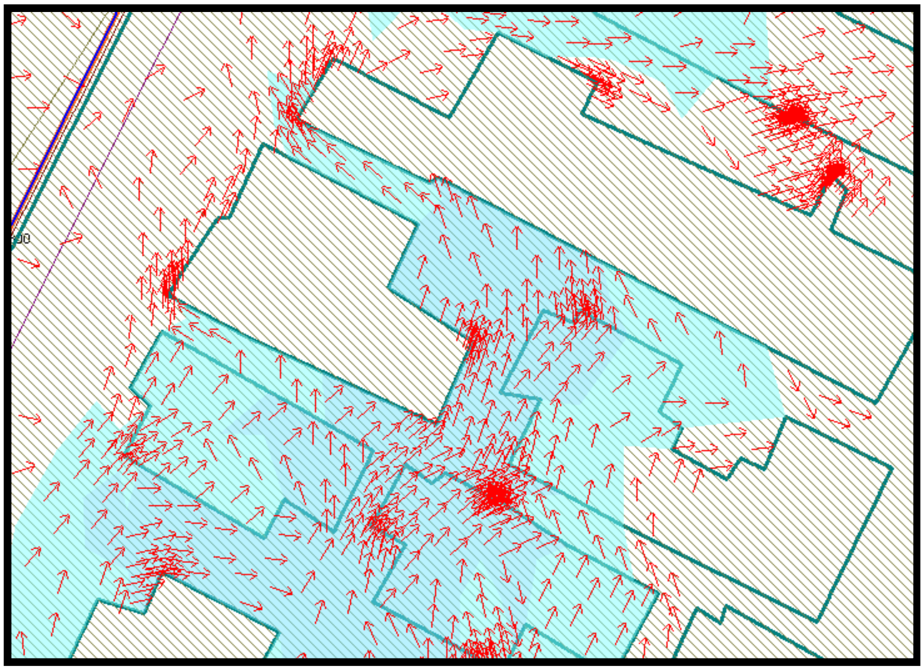

Figure 9: Example of porosity applied in the model

3.3 Blocking out Buildings

The blocking out of 2D elements to represent buildings is commonly used. This methodology is applicable to the DHI Mike21 software. In Infoworks CS it is possible to model the buildings as a “void”. This achieves similar results as providing a building with no porosity (i.e. completely impermeable).

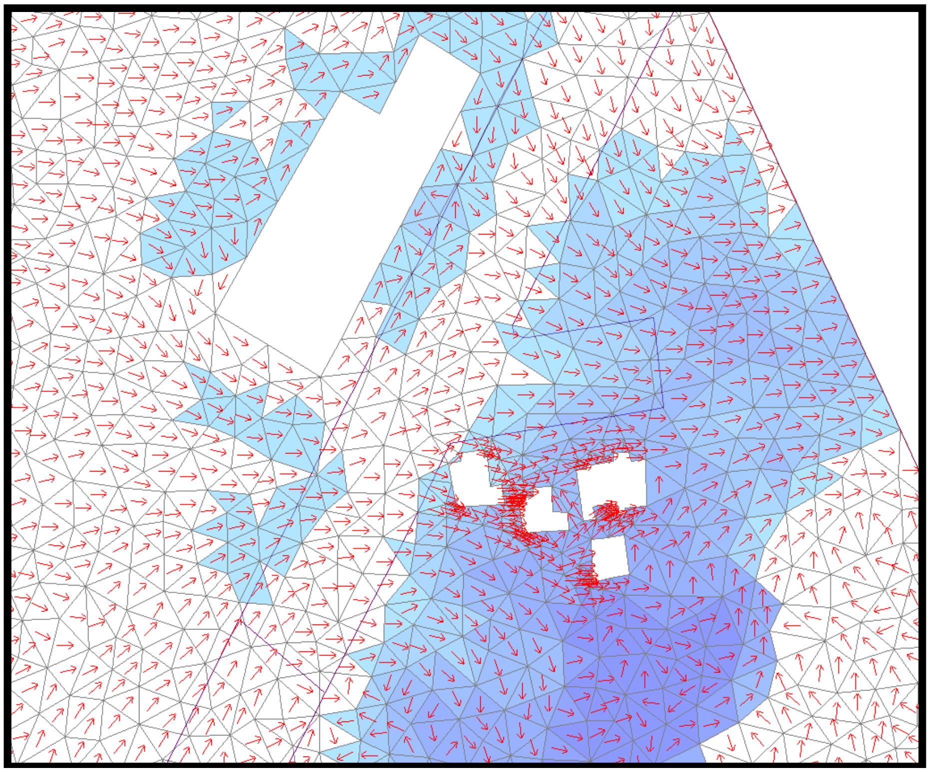

Figure 10: Example of modelling a building as a void/blocked out

Blocking out of buildings has been used especially in commercial areas. Where the building is clearly designed or protected to not let any water enter the building, this may be the better representation of the overland flow. However, buildings are not strictly completely protected and water can still seep through openings. It was found in the Auckland Central Business District (CBD) flood study that for buildings which have underground car basements, water could enter and therefore the representation was not completely accurate. Also, the water ponds around the building in the model and the model may overestimate the flood depth at the building interface.

Residential buildings are also often built on concrete block bases that displace a specific volume of water. This could be represented by blocking out the cells within the building foot print to the actual floor level. In extreme storm events, which are mostly used for the flood hazard modelling, the flood level will normally inundate at least some floors above the concrete block bases. A decision therefore needs to be made by the modeller at the model schematisation process whether to model the residential building as blocked, porous or only applying a roughness.

Figure 11: Example of building with concrete wall

In the CBD flood project it was found that by using the “rain on grid” hydrology, volume was lost due to blocking out buildings. This volume of water needed to be re-introduced back into the model. This was achieved by allowing for the runoff of roof catchments to drain directly into the network.

Another option of “blocking out” the building is to modify the ground model or DTM to allow no flow to enter the building. The ground model is artificially raised to a height above the flood level to ensure that the overland flow will go around the building. Figure 12 is an example of this approach.

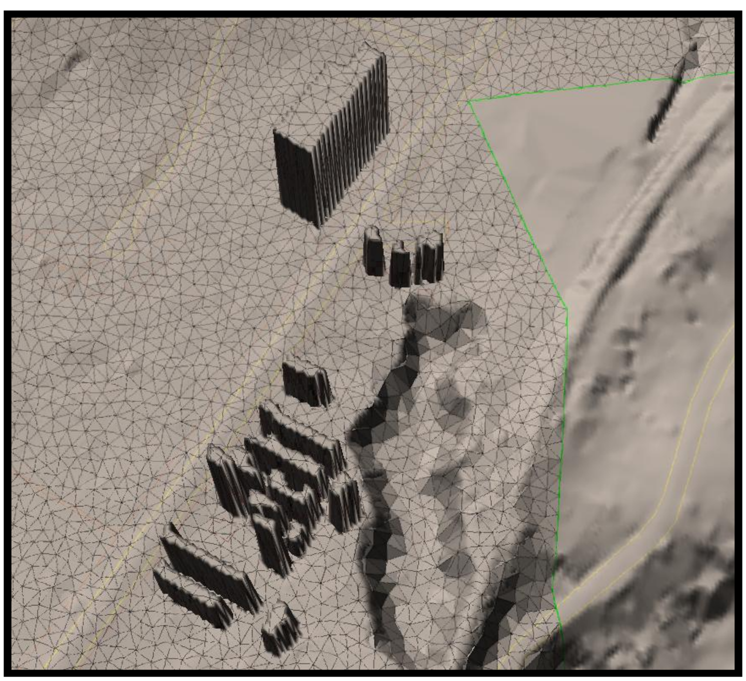

Figure 12: Example of modifying the bathymetry

3.4 Raising the sides of the building

Another methodology of representing the obstruction of a building to the overland flow path is raising the sides of the building within the grid. This methodology may be useful to allow overland flow into the building but not out, if three walls of the building are raised and one left open. This could be a representation when underground parking garages receive overland flow. An advantage of this methodology is that the storage volume of the surface water within the building is taken into consideration. However, in order to apply this methodology successfully the grid sizes need to be small enough to allow for raising the walls within the bathymetry.

3.5 Representation of Basements

Infoworks CS can represent Buildings with basements as:

- Porous walls and1D/2D storage nodes with a weir at ground level. This allows the flow to enter the building through the porous walls and flow into the storage node (basement) until the water level rises to a level where it would flow out of the basement again. This transfer of flow to the 2d bathymetry from the storage node would be through the weir.

- Another option may be to burn the building footprint into the ground model to reflect the depression of the basement. The building footprint in the DTM would also have porous walls applied to it. Once the water level rises within the basement to the level where it would flow out of the building again, an overland flow will develop on the 2D surface and flow through the porous walls.

The disadvantages of the two above listed methodologies is that it is time consuming to set up in the model if there are a large number of basements within the catchment.

3.6 Lessons Learned

The following lessons were learned from the flood hazard case studies:

- Varying the Manning's roughness did not seem to provide a significant difference in water depth or flow path. This may be due to the grid size used in the FHM studies and only a limited number of cells occupying a building were available to effectively change the velocity. This may be different in cases where a smaller grid size is chosen or the building is reasonably long in the direction of the water flow. It may have less impact on areas with high slope and therefore high velocity.

- The cell size in relation to the building is important. Especially for overland flow paths between buildings. The modeller needs to verify the flows around the building on site.

- Blocking out of building proved to be useful in the studies where it has been applied. However, when using the "rain on grid" hydrology, care needs to be taken for the lost storage and rainfall.

- Blocking out of buildings proved to provide graphically and visually a more realistic solution in highly commercial areas.

4 Representation of Roads and Kerbs

During the development of the DTM the flow path definition expected from the kerb and channels may be lost. This loss of resolution can have significant implications on the surface flows as road reserves are typically designed to convey secondary overland flow within the kerb and channel. There are several ways to address this issue:

- Firstly, for a triangular mesh, the software generally has a tool which can manually create break lines (or they can be imported from GIS data) that force the edges of the triangles of the 2D mesh to form along the edges of the break lines, and therefore will effectively create a kerb. This methodology is supposed to route the flow along the break lines, however, AECOM found that these break lines do not always operate to the same extent that an actual kerb line would. Also, driveways are not generally represented well.
- Another option would be to model kerbs as very short walls (setting the wall height as 0.125m) and therefore force the flows along the road.
- The third option would be to "burn" in the road by decreasing the elevation of all the cells within the road by a specified amount (such as 0.125 to represent the kerb height).
- Lastly, the road could be represented with a smooth Manning's resistance in order to help route the flow down the road.

It is noted that none of the options are ideal. It is therefore important for the modeller to check during the model schematisation process which representation would best suit the catchment. Putting in break lines directs most flow down the road; however AECOM found occasions where the water would get high enough to still pass over the "kerb" and driveways weren't necessarily represented. The disadvantage of lowering the road ("burning" the road in) means that the centre of the road could be lower than the LiDAR point. The volume of overland flow therefore could be overestimated. The disadvantage of putting in short walls is that if a flooding manhole is located on the foot path, the water is trapped on the wrong side of the kerb and cannot flow towards the road. For all options outlined above, it is necessary that the modeller confirms on site whether the flow of the water would pass over the kerb into the properties or actually pass down the road.

Figure 13 shows an example where the overland flow would enter the property at the driveway. The model may not necessarily represent this if the representation of the road within the model is lowered within the DTM or if a wall is set up at the foot path.

Figure 13: Example of driveway allowing flow into the property

Another example of the representation of the overland flow path along the roads is a project where the modelled overland flow proved to be excessive and the flow topped the kerb in the model and entered properties. These properties would have come up as “at Risk of Flooding”. However, during the QA/QC of the model and the site visit, it was evident that overland flow would actually flow along the road carriageway and not flow into the properties. This was confirmed with residents in the area. It was found, that during the 2D model build, when using the break lines to represent the kerbs, the kerb height got lost for a short section of the road. Only this short section along the road needed to be rectified within the model. Small walls were added along the entire road to route the water along the road carriageway.

From the examples outlined above, it can be seen that it is crucial for the modeller to go out on site and convince themselves that the model results are reasonable.

The following recommendations are made from the lessons learned in the model build of the FHM studies when representing kerbs:

- Check the overland flow by doing site specific assessments and allow for the extra detail in the areas where it is needed.
- Ensure that the resolution between the LiDAR and the road are not completely lost.
- Solutions to adjust the kerb might not be suitable for the entire model, or the entire road. It might only be a short section.
- A sensitivity analyses is recommended to determine the best option for representing the reality

5 Configuration of transfer of flow in the coupled 1D/2D model

5.1 Background to coupling options

For the DHI Mike Flood software the 1D/2D coupling is coupled via a discharge coefficient. MIKE URBAN nodes enable exchange of flow between the 1D primary network and the 2D surface by connecting one or more cells in MIKE 21 to a manhole, a basin, a weir or a pump in MIKE URBAN. Flow into the pipe network from overland flow can be specified as weir flow, orifice flow or by an exponential function. A maximum allowable flow can be specified to transfer water from the 1D to the 2D and vice versa. This is illustrated in Figure 14.

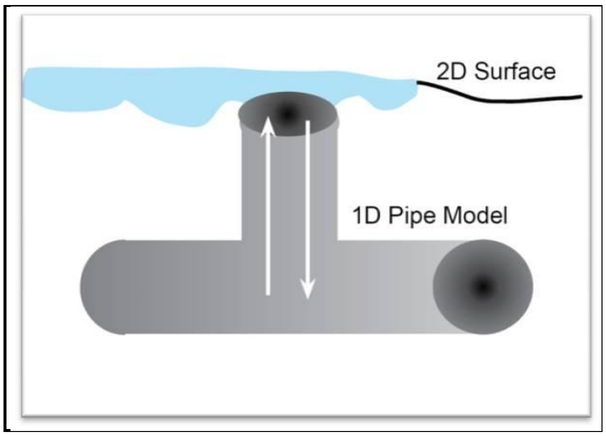

Figure 14: 1D/2D coupling

5.2 Cesspit Modelling

With the additional advances of the 2D modelling and the 1D/2D coupling options, the inletting of surface runoff through cesspits has been made possible. This has an advantage of indicating to the Client whether the overland flow can enter the primary network through the existing inletting provided in the catchment. Generally, the inletting capacity in the coupled 1D/2D model will determine how much flow can enter or also leave the system. Applying only one value of inletting capacity assumes that the flow can enter the primary system the same as that which leaves it once the system is full and surcharges. This is a limitation in the model setup.

The modeller generally needs to assess what the coupling limitation needs to be set to.

Figure 15: Example of Cesspit

During the schematisation process of the Auckland CBD it was decided to provide further detail to the 1D/2D model coupling. As it was understood by AECOM that the flooding in the catchment is due to insufficient inletting and not pipe capacity it was decided to represent the inletting capacity with cesspits in the model. The model was configured so that:

- Coupling occurred at 9 cells closest to the actual cesspit (taken from the GIS) to allow flow into the primary system. This coupling representation is illustrated in Figure 16.
- The number of cesspits in the catchment was assessed and an inletting capacity of 25 l/s per cesspit was assumed to transfer flow into the primary network.

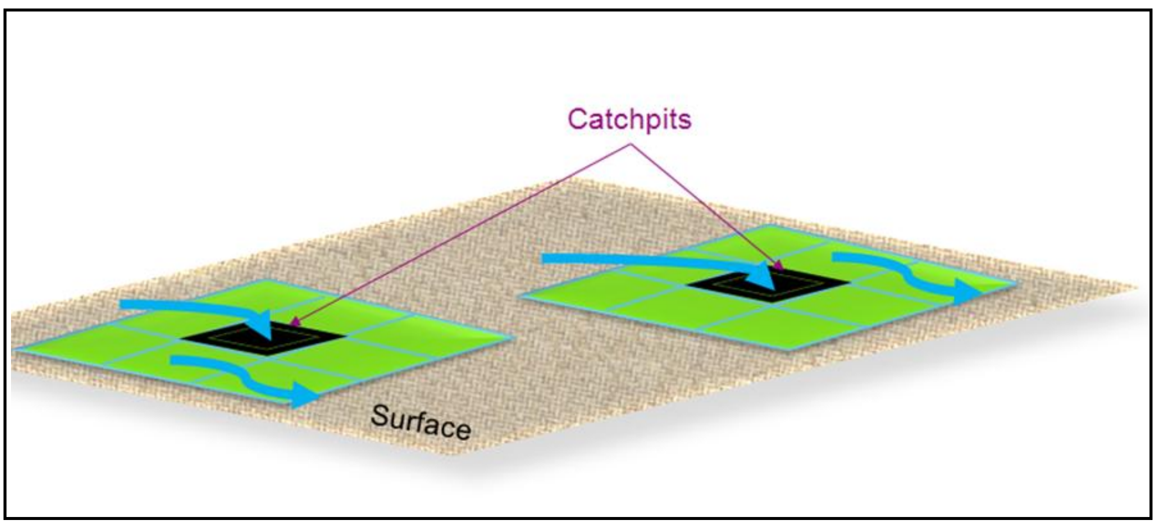

Figure 16: Example of multiple cell coupling

5.3 Weir coupling

Weir couplings can be used in the DHI MIKE FLOOD model to convey water surcharging from the 1D pipe network onto the surface. If flows from the 1D surface to the 2D surface is configured with a weir, then flow is one directional, i.e. the flow only flows into the 2D model and not back into the primary network.

For the CBD FHM it was decided to use the weir coupling to restrict flow to one direction and to provide unrestricted capacity of surcharging (see Figure 17). Weirs were added to all the MIKE URBAN model nodes except for the dummy nodes, basin and outlets. These weirs were then coupled to the grid cells in MIKE 21 corresponding to the MIKE URBAN node location using the 'urban link – weir to inlet link type'. This provided a mechanism for representing a pipe network that could surcharge to the terrain. This schematisation gave a good indication if the primary network has insufficient capacity or whether the catchpit inletting capacity is insufficient.

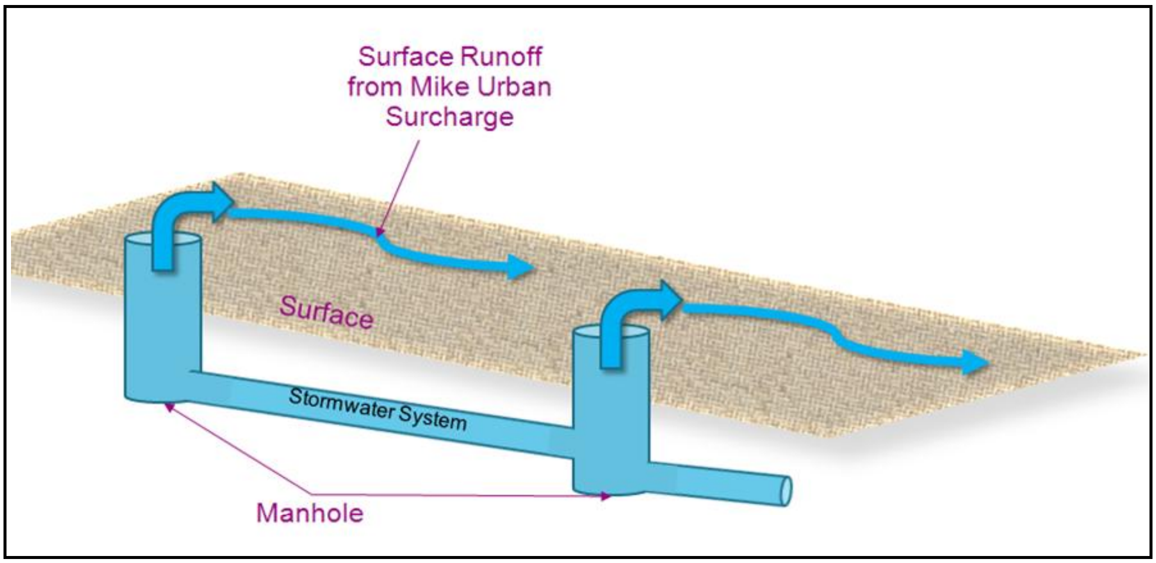

Figure 17: restricting flow to one direction

5.4 Lesson Learned

The following lessons were learned during the model build:

- Where multiple cells are coupled to MIKE URBAN the highest Mike21 cell was used as the default MIKE URBAN lid level. This was over written in the model to force the MIKE URBAN lid level to be the default level. Initially, the model believed that the water from the highest cell was considered as a hydraulic head and therefore was generating water. Also, once the pipe surcharged, it would surcharge through all 9 coupling cells which may not be the reality.

- It was found that the cesspit location provided in the GIS file was not always the lowest point in the model DTM and therefore surface flow would still bypass the coupling node
- The location of the coupling was not necessarily the place in the primary network where the network would surcharge.
- The runoff hydrograph and the capability of the inletting into the primary network needed to be manually checked to ensure that the results were reasonable. This proved to be very time consuming.
- The huge amount of weirs created instabilities within the model. It also proved to be time-consuming.
- Having multiple different inletting set-ups created a very complex model with long simulation times.
- The most valuable lesson learned is that for flood hazard mapping a simpler model might prove sufficient to indicate the flood areas which are at risk and then a smaller “cut-down” model with additional detail may be more useful for the detailed flood analyses and option analyses.

6 Recommendation and Conclusion

It can be seen from the examples illustrated in this paper, that there is a range of options available for the modeller for representing buildings, kerbs and cesspit inletting in the 2D models. As 2D models are becoming finer and the modelling which is been undertaken is becoming more detailed, attention will need to be provided to the detailed modelling of these obstructions in order to accurately reflect the surface flows. It is important for the modeller to understand the impact the obstructions will have on where the flow would go.

The most valuable lesson of the flood studies undertaken is that it is crucial for the modeller to determine from actual site-inspection which modelling schematisation is suitable and then verify the overland flow once it is modelled.

It is recommended, that further research and testing is needed to provide guidance to the modeller on recommending suitable methods which will reflect the actual flooding. It is also recommended that the modeller does sensitivity analyses in order to determine the suitable model schematisation and time and cost in the project is allowed for to enable this.

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