ACCOUNTING FOR FUTURE DEVELOPMENTS IN LARGE SCALE 2D MODELLING – A DIFFERENT APPROACH

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ABSTRACT

Large scale 2D flood models built to support Integrated Catchment Management Plans (ICMPs) need to account for future alteration to landform as a result of development. This paper examines a new method of taking account of these changes. The Te Awa O Katapaki (TAOK) flood model, built by AECOM for Hamilton City Council with input from Beca and T&T, is presented as a case study.

LiDAR is typically used to generate surfaces for 2D flood models. This works well for existing development cases or maximum probable development cases with only minor development or earthworks proposed in the catchment.

Where major alterations to the catchment landform as a result of development are proposed, these changes may fundamentally alter downstream flows due to the creation or removal of barriers to flow; alteration to catchment storage; or smoothing of previously undulating catchments. Traditionally these changes are simulated through increased curve numbers and roughness values and in some cases, where these are available at the time of modelling, future development surfaces are integrated into the LiDAR surface. This can be impractical or introduce errors where a large number of different developments are proposed within the modelled catchment.

For the TAOK flood model, the approach of adding future development surfaces was initially taken. Due to challenges related to integration of development surfaces into the model, supplementary 1D modelling was carried out in HEC-HMS for those areas with proposed developments. Hydrographs from the HEC-HMS model were then substituted into the 2D model in order to provide a second, simpler and more adaptable, assessment of downstream flows and flooding. This provided a useful and more conservative assessment of flood risk, and allowed Hamilton City Council to make level of service decisions on upstream infrastructure based on a more robust flood assessment. This paper discusses Hamilton City Council and AECOM's experience using this approach.

KEYWORDS

Flood Modelling Stormwater Integrated Catchment Management Plan

PRESENTER PROFILE

Matthew Lillis is a project engineer for Hamilton City Council. He leads Council projects including flood models, strategic stormwater infrastructure, Council's pipe and pump station renewal programme and the Borman Road extension. Matthew previously worked for PDP in Auckland and Christchurch, and enjoys trail running in his spare time.

Chris Hardy is a consulting engineer with 18 years' experience in the planning and design of water, stormwater and wastewater systems, particularly on networks and pump stations. Chris has led the Water Team at AECOM's Hamilton office for the past six years with focus on Hamilton and the surrounding regions.

1 INTRODUCTION

Integrated Catchment Management Plans (ICMPs) are produced by Hamilton City Council (Council) to provide a strategic framework for managing three waters infrastructure with emphasis on stormwater. Large scale 2D flood models are developed to support ICMPs. These models are used as decision making tools which allow development and mitigation scenarios to be tested, and different policies or projects pursued in response to model results. Council carries out most flood modelling in catchments experiencing rapid growth. This is because these areas represent the best opportunity for corrective action to be taken if modelling indicates a likelihood of flooding in major storm events.

Development of greenfield sites often requires earthworks which change the catchment landform. These changes may alter flows downstream of developments due to the creation or removal of barriers to flow; alterations to catchment storage; or flattening of previously undulating catchments.

Future changes to landform are usually simulated by increasing the runoff coefficients and roughness values in the developing area. This approach does not account for changes to landform due to bulk earthworks. As a result, models can show flooding in the developing area within hollows, depressions and drains, while in real life these will be filled in (in some places) by development earthworks. This unrealistic flooding may also artificially attenuate and slow flows. As a result, the model may be unable to confirm that development won't cause downstream flooding.

Another approach to this terrain problem is to superimpose design surfaces onto the LiDAR in the model to create a "future" surface. This can resolve both issues and is viable in smaller sub-catchment models. For full catchment scale models, this can be expensive and involves integrating surfaces from multiple developments. Design surfaces may not reflect what is eventually built, and the interface between design surfaces and LiDAR may be unrealistic.

The two approaches discussed above can be useful for developing a broad understanding of the likely impacts of development. However both approaches have limitations, and neither makes any attempt to understand the impact of stormwater attenuation devices on flooding.

The subject of this paper is a different approach to this problem. This is to remove rainfall runoff from the 2D model for the developing area and replace this with a hydrograph generated in a simple 1D hydrological model. This does not allow for flood maps of the area being modelled in 1D to be produced. However, it can be an effective and inexpensive way of ensuring the model estimates flows downstream of this area with a useful level of accuracy and conservativeness.

Using a 1D model also allows for the effects of stormwater attenuation devices to be modelled, and various sensitivities tested, in a time efficient way. This gives more confidence when determining the appropriate level of service that should be applied when designing stormwater attenuation devices in the catchment.

This paper discusses the experiences of Council and AECOM trialling the approach described above for the Te Awa O Katapaki (TAOK) flood model, which was developed to support the TAOK ICMP. Results from using this approach informed a Council decision to require stormwater attenuation devices to be sized to attenuate the 1% Annual Exceedance Probability (AEP) storm event in parts of catchment.

2 TE AWA O KATAPAKI MODEL BUILD

2.1 MODEL PURPOSE

In 2013, Hamilton City Council engaged AECOM to produce a 2D flood model to support the TAOK ICMP. The extent of the model is shown in Figure 1.

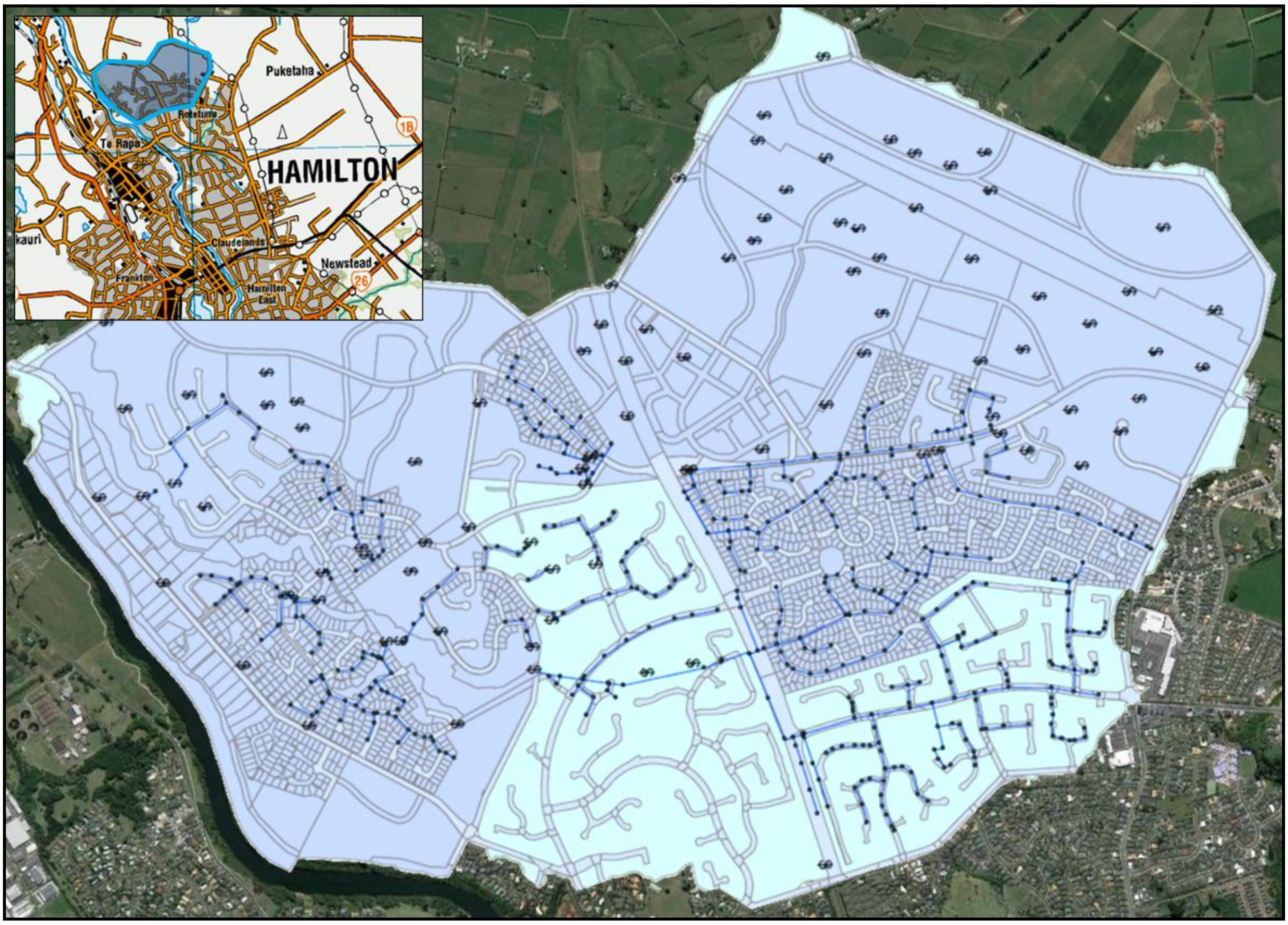

Figure 1: TAOK Model Extent

The TAOK model was built to serve two main functions:

1. To provide flood hazard maps for public consultation.
2. To support ICMP decision making.

One of the key decision-making objectives of modelling was informing in what areas stormwater attenuation devices should, and should not, be designed to attenuate the 1% AEP storm event to mitigate the risk of downstream flooding.

2.2 MODEL BUILD

The 2D model was built using MIKE Flood software. A standard Council modelling methodology had not been established at the time of modelling, and the methodology for TAOK was developed and agreed between AECOM and Council. This is documented in AECOM's model build report (Hardy & Vajlikova 2017).

2.3 APPROACH TO MODELLING DEVELOPING AREAS

Development had occurred between the model LiDAR being flown in 2008 and the model build commencing in 2013. Modifications were therefore made to the LiDAR surface and model reticulation to bring the model up to the 2013 baseline for the Existing Development (ED) scenario. This process used development earthworks designs and surveys available at the time. In addition, runoff coefficients and roughness values were generally set to match development as it stood in 2013.

In the Maximum Probable Development (MPD) scenario, modifications were made to the LiDAR surface and reticulation network to represent all future developments where designs could be obtained. Runoff coefficients and roughness values were set to recognise District Plan zoning at the time.

Figure 2 shows part of the 2D model MPD output within the developing area.

Figure 2: MPD 1% AEP Flood map produced from the original 2D model.

3 INITIAL PEER REVIEW

Beca were engaged by Council to peer review the TAOK model. Beca's review (Tuck & Law, 2017) raised issues with the model which limited its usefulness as a decision-making tool.

Key issues raised in the report and during peer review meetings which are relevant to this paper are summarised below:

1. The existing development scenario was not clearly defined. It had a 2008 baseline with modifications to bring it roughly in line with development by 2013.

2. Modifications to LiDAR in both ED and MPD scenarios resulted in anomalies where surfaces supplied by developers did not integrate well with LiDAR. In some cases this created additional unrealistic storage or disconnected overland flow paths.

3. The MPD stormwater reticulation network was not completely represented. This reduced the usefulness of the model and created potentially unrealistic attenuation in the upper catchment.

4. No allowance was made for the effects of constructed attenuation devices.

5. The maximum imperviousness allowed in the District plan had changed in some locations since the model build, which left it out of date.

Because of these limitations, the flood extents in the ED and MPD models in the upper catchment do not reflect actual likely flooding. This can be seen in anomalies particularly in the top right corner of Figure 2.

In addition, the presence of unrealistic storage in the upper catchment meant that downstream flows were artificially attenuated. This meant that the model couldn't confirm that development wouldn't cause flooding of downstream areas (in particular habitable floors). If such flooding was identified, it would trigger a requirement for new upstream developments to attenuate the 1% AEP event.

4 USING A 1D MODEL TO REPRESENT DEVELOPING AREAS

Resolving the issues raised in the peer review within the 2D model would have required substantial time and modelling resources which were not available. Some issues such as accounting for stormwater attenuation would have remained unresolved even with this additional work. The MPD scenario earthworks designs would also still continue to change as development plans progressed.

Council therefore decided to try using 1D hydrological catchment modelling in HEC-HMS to model developing areas. HEC-HMS modelling of the same area was being carried out at the time by Tonkin & Taylor (T&T) for another Council project. Minimal additional work was required to ensure this modelling was suited for both purposes. This is discussed in Section 4.1 below.

Council also modified one of the 1D model output hydrographs to simulate attenuation of the 1% AEP storm event, as discussed in Section 4.2 below.

The T&T hydrographs and the attenuated hydrograph developed by Council were inputted into the 2D model to determine effects of attenuation, as discussed in Section 4.3 below. All rainfall runoff was removed from the 2D model for the equivalent areas.

4.1 HEC HMS MODELLING

Modelling of the developing catchment in 1D was carried out by T&T (Toang & Quilter 2017) as part of the Lake Magellan Optimisation Project. The location of Lake Magellan is shown in Figure 3. Only the part of the T&T modelling used in the TAOK model is discussed below.

T&T modelled sub-catchments H, I, L, M, and N (shown in Figure 3) in HEC–HMS for the ED (without climate change) and MPD (with climate change) scenarios. For the purposes of this modelling, sub-catchments M and N were treated as a single sub-catchment and their hydrographs summed together.

Outflow hydrographs were produced for all sub-catchments for ED and MPD scenarios.

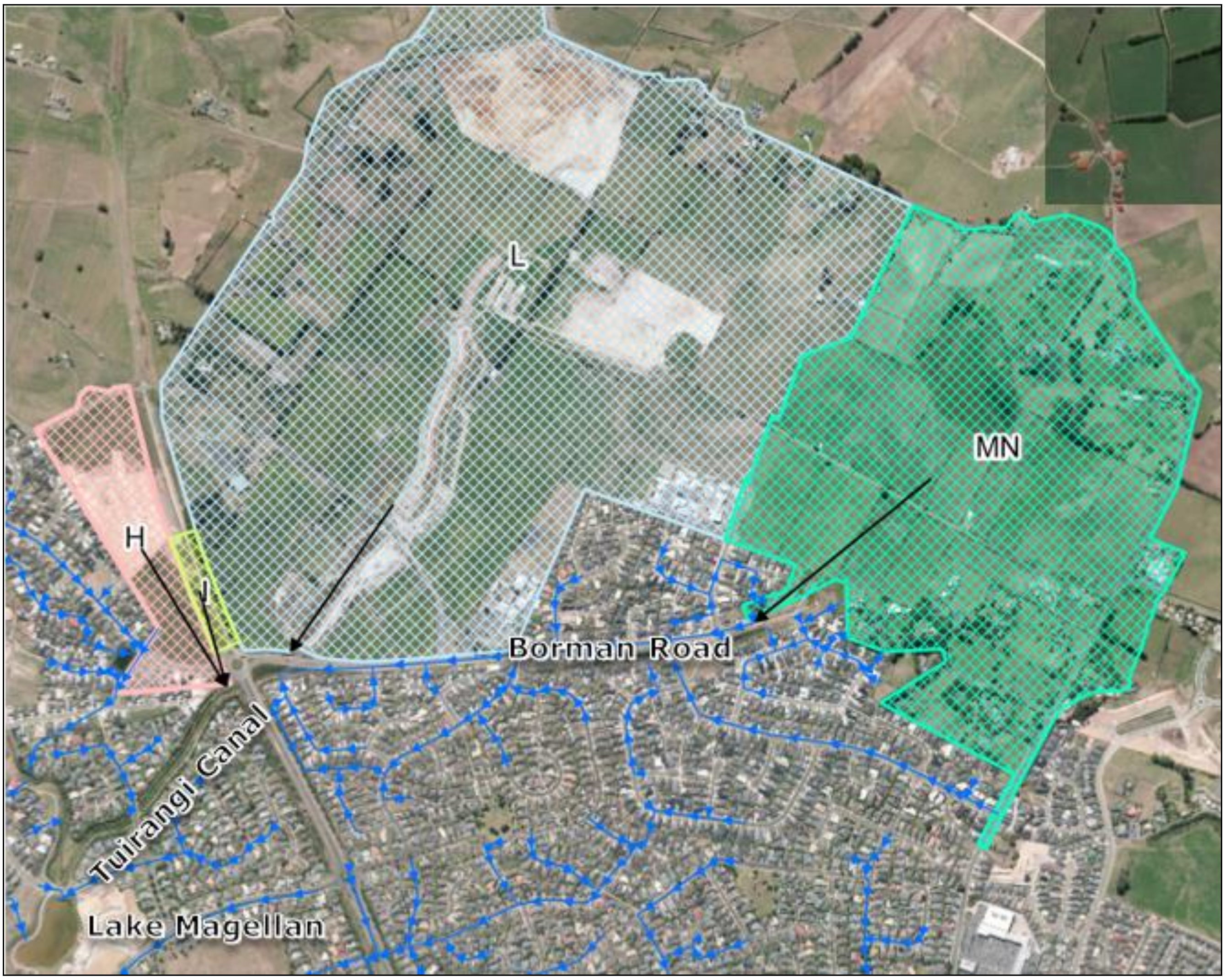

Figure 3: HEC – HMS Sub-catchments and key features

4.2 MODELLING ATTENUATION DEVICES

Based on the HEC-HMS modelling, it was anticipated that in the 1% AEP storm event, flooding was likely in the vicinity of Borman Road directly downstream of sub-catchment MN (Figure 3). It was also anticipated that this flooding might be mitigated if the 1% AEP storm event was attenuated in this sub-catchment.

T&T's HEC-HMS model did not simulate stormwater attenuation devices. Council therefore carried out a theoretical routing in Microsoft Excel to simulate the effect of attenuating the 1% AEP storm event to the predevelopment peak flow rate (Lillis, 2017).

The following assumptions were made in the simulation:

1. A basin with an outlet designed to attenuate flows from a 1% AEP storm event to predevelopment levels reasonably represents a basin or wetland designed for other purposes as well as attenuating the 1% AEP storm event.

2. The discharge rate from a basin decreases at a rate directly proportional to the volume of water stored within the basin. This is due to reduced hydraulic head on the outlet.

3. A single basin placed at the bottom of a sub-catchment reasonably approximates the effect of having multiple basins throughout a sub-catchment.

4. Although Council requires attenuation of the 1% AEP storm event to 80% of predevelopment peak flow rates, it was considered conservative to assume that the peak flow rate was only attenuated to 100% of the predevelopment peak flow rate.

The simulation produced the attenuated hydrograph shown in Figure 4. The peak flow rate is reduced by a factor of about three. The overall runoff volume is conserved as the area under the inflow and outflow lines is the same.

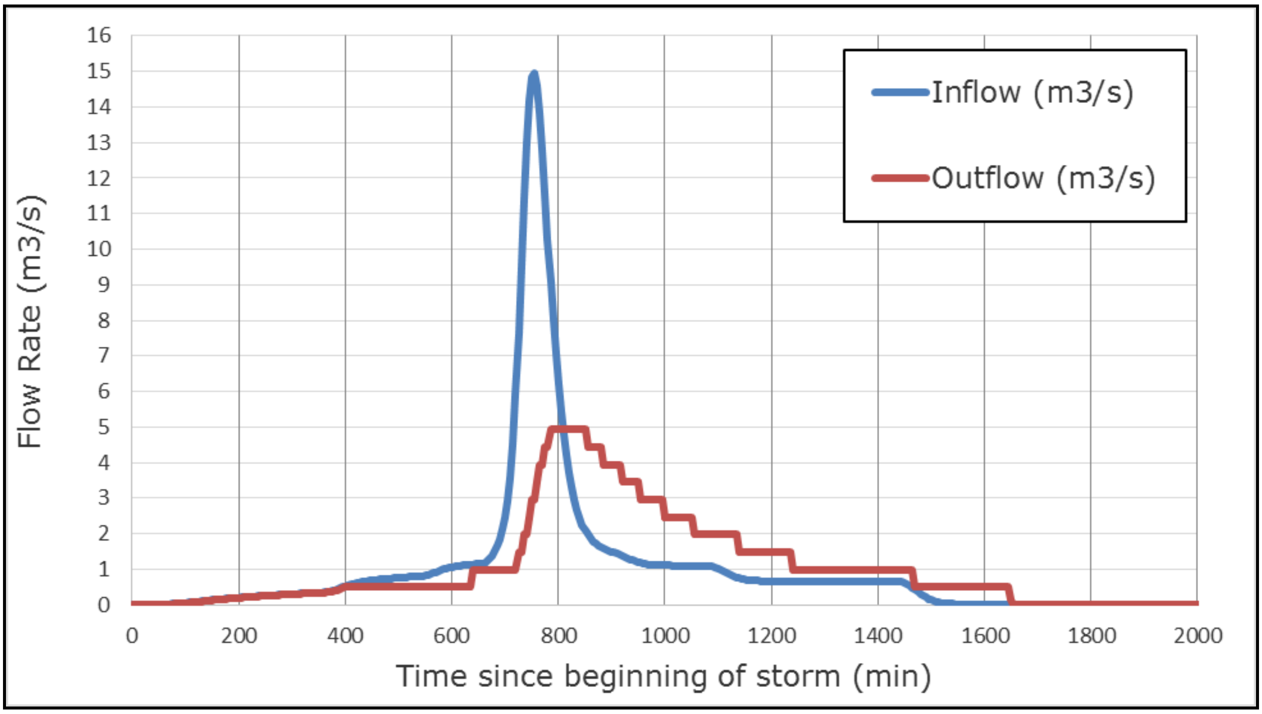

Figure 4: Inflow vs Outflow, 1% AEP Basin

4.3 INTEGRATION INTO THE 2D MODEL

Three different 1% AEP scenarios were run in the 2D model. The scenarios used 1D and 2D modelling to represent the developing and developed areas respectively. All scenarios replaced rainfall runoff in the 2D model for sub-catchments H, I, L, and MN with hydrographs produced in HEC-HMS and inserted at points shown in Figure 3. The scenarios each used different hydrographs as follows:

1. ED Scenario – used ED hydrographs with no allowance for climate change.

2. MPD Unattenuated Scenario – used MPD hydrographs.

3. MPD Attenuated Scenario – used the same hydrographs as MPD Unattenuated scenario except for sub-catchment MN which used the attenuated hydrograph from Figure 4 instead.

Results of the three scenarios are shown in Figure 5, Figure 6 and Figure 7 respectively. The maps provide an overview of the impact of flood control and show that a significant reduction in flooding is achieved in comparison to the unattenuated MPD case.

Figure 5: ED Flood Map

Figure 6: MPD Unattenuated Flood Map

Figure 7: MPD Attenuated Flood Map

The key information gained from the new modelling assessment was:

1. Without attenuation, Figure 6 shows that in the 1% AEP event, flood levels within the Tuirangi Canal downstream of Borman Road would not cause flooding of habitable floors, and no blanket requirement for attenuation of the 1% AEP event should be required on that basis.

2. If attenuation of the 1% AEP event is not provided, Figure 6 shows substantial flooding is likely on Borman Road and adjacent streets.

3. If attenuation of the 1% AEP storm event is provided for sub-catchment MN, this may substantially reduce flood risk on Borman Road and adjacent streets as shown in Figure 7. It also appears to reduce flows to the extent that they can be conveyed by the stormwater reticulation under Borman Road without requiring an overland flow path down the road.

Based on this modelling, it was decided by Council that an ICMP approach of attenuating the 1% AEP storm event in sub-catchment MN would be pursued.

5 FINAL PEER REVIEW

Following the completion of the revised modelling, a second peer review was carried out by Beca. The peer review concluded that the model was fit for purpose, including the purpose to "determine whether not attenuating the 1% AEP event in the upper catchment will result in a significant increase in flood hazard". Limitations to the model are discussed in Section 6.

6 LIMITATIONS

Limitations were acknowledged in AECOMs model report and Beca's final peer review. Some key limitations were:

1. MPD flood maps of the developing area within sub-catchments H, I, L and MN could not be produced, as hydrographs were inputted downstream of these areas. It is noted that MPD flood maps do not usually accurately represent developed areas in any case, for the reasons described in this paper.

2. HEC-HMS is likely to produce more conservative results than MIKE.

3. There was disagreement on the correct time of concentration to use in the HEC-HMS model. A sensitivity check was carried out which determined that applying different times of concentration would not substantially alter the conclusions drawn from the model.

4. The combined 1D - 2D model ouputs were limited to use as a decision-making tool, rather than producing maps for identifying flood hazard areas in detail.

5. Modelling of storage in attenuation devices was coarse, and separate modelling still needs to be carried out to size individual attenuation devices.

Due to these limitations, flood maps produced using this methodology should not be used to determine whether any individual property is at risk of flood in a 1% AEP storm event.

They should rather be considered a useful tool for assessing the impact of attenuation at a macro level.

7 CONCLUSIONS

Large scale 2D flood models are often built to understand the potential impacts of development. Areas undergoing development may be modelled by altering rainfall runoff factors and roughness values. They may also be modelled in further detail by stitching in developed design surfaces. Both approaches have limitations. The latter approach is potentially more accurate but more expensive and prone to error. Both approaches can be used to recommend stormwater controls. However, neither will show whether these controls are likely to achieve their objectives.

The TAOK model explored a different approach - using a 1D model to simulate rainfall runoff from developing areas, modelling attenuation in Microsoft Excel, and then using the resulting hydrographs as inputs to the 2D model.

This was successful, and the method had the following benefits:

1. It could provide a baseline ED model for a defined date and development extent without reliance on LiDAR from that exact date.

2. It was fast and cost effective compared to manipulating a full 2D model.

3. A range of options could be quickly tested within the 1D model.

4. Simple representation of attenuation devices was possible, which is much complicated in 2D.

5. Sensitivities of different parameters such as time of concentration can be quickly tested without long model run times.

6. The comparison between ED, MPD Unattenuated and MPD Attenuated scenarios provided sufficient basis for setting ICMP requirements.

Based on the results of the model, it was determined that the benefits of providing attenuation of the 1% AEP storm event upstream of Borman Road, to reduce flood risk, were sufficient to justify requiring it of developers. Prior to this modelling exercise, Council did not have sufficient information to justify or understand the impact of that decision. Council are now looking at using a similar approach in other catchments within Hamilton.

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