Flood Hazard Report
Flood Hazard Report

Prepared for
Hamilton City Council

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<th>Definition</th>
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<tr>
<td>FHM</td>
<td>Flood Hazard Modelling</td>
</tr>
<tr>
<td>City Wide FHM</td>
<td>City Wide Flood Hazard Modelling</td>
</tr>
<tr>
<td>CRS</td>
<td>Cross-section</td>
</tr>
<tr>
<td>1D</td>
<td>One-dimensional</td>
</tr>
<tr>
<td>2D</td>
<td>Two-dimensional</td>
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<tr>
<td>HD</td>
<td>Hydrodynamic</td>
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<tr>
<td>LiDAR</td>
<td>Light Detection and Ranging</td>
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<tr>
<td>RFA</td>
<td>Rapid Flood Assessment (high level flood assessment)</td>
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Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ARI</td>
<td>Annual Recurrence Interval (Return period of storm events)</td>
</tr>
<tr>
<td>DHI</td>
<td>DHI, formerly Danish hydraulics Institute</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
</tr>
<tr>
<td>HTML</td>
<td>Hyper Text Meta Language</td>
</tr>
<tr>
<td>HCC</td>
<td>Hamilton City Council</td>
</tr>
<tr>
<td>Mike Urban</td>
<td>DHI software used for pipes and catchments</td>
</tr>
<tr>
<td>Mike11</td>
<td>DHI software for streams</td>
</tr>
<tr>
<td>Mike21</td>
<td>DHI software mainly for overland flow</td>
</tr>
<tr>
<td>Mike Flood</td>
<td>DHI software that links all the software above together</td>
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Executive Summary

Background

In 2010 Hamilton City Council (HCC) embarked on a programme to develop computer models to represent the behaviour and performance of their wastewater, water supply and stormwater networks, excluding treatment plants. The project was known as the Hamilton City Three Waters Modelling Programme.

The Hamilton City Three Waters Modelling Programme was awarded to the AECOM team, consisting of AECOM, AWT, DHI and Watershed with the contract commencing in September 2010. The project was broken into three phases being:

Phase 1
- Develop calibrated trunk water supply and wastewater models from field monitoring, flow gauges and asset data. The models were used to understand existing and future system performance issues at a strategic level.
- Undertake Flood Hazard Model (FHM) scoping based on a rapid flood assessment approach and then from that agree the level of detailed modelling to develop FHM outputs for the future fully developed 100yr rainfall event with climate change.
- Support any Catchment Management Planning work and stormwater flow gauging as necessary.

Phase 2
- Develop a calibrated all pipe water supply model from additional field test data. The model will be used to understand existing and future system performance issues in more detail.
- Develop calibrated wastewater network model based on short and long term flow gauge data. The model will be focussed on historic problem areas, growth areas and the results from the system performance outputs from Phase 1.
- Support any Catchment Management Planning work and stormwater flow gauging as necessary.

Phase 3
- Provide support to HCC regarding any ongoing model queries and updates.

This report focuses on the Phase 1 stormwater works.

Stormwater Flood Hazard Mapping Objectives

The objective of this work was to understand the existing flooding issues within the Hamilton City Council (HCC) catchments from both a strategic high level and also in more detail in selected areas.

Stormwater Deliverables

The stormwater deliverables were:
- Stormwater models for the 100yr extreme event plus climate change based on the Rapid Flood Assessment (RFA) and the more detailed modelling discussed below.
- A GIS layer showing the hazard classification results for the complete City based on a slightly amended Waikato Regional Council (WRC) Regional Policy Statement (RPS) matrix dated 2012.
- An improved GIS layer for use by Hamilton City staff that allows them to understand for each grid cell (either 5m or 2m square) the data source and confidence, maximum water depth and associated velocity, maximum water velocity and associated depth, and depth times velocity.
- Flood Hazard Mapping Report (this report)

High Level Methodology

A methodology was developed to define the extent and likely impact of extreme 100yr event flooding within the City.

AECOM proposed using a nested storm approach for the 100yr annual recurrence interval (ARI) plus climate change event. This approach used all of the 100yr storm durations and intensities from the Hamilton City Development Manual. The nested storm approach provided the critical duration, rainfall intensity and peak flow...
for all locations for the 6, 12 and 24 hour duration storms. Appendix A provides more detail on the nested storm approach.

A three (3) phase approach was adopted for the stormwater modelling programme with each phase building on the work of the previous phase. The phases adopted were:

- Flood Hazard Scoping
- Detailed Flood Hazard Modelling
- Catchment Management Planning

A Rapid Flood Assessment (RFA) approach was undertaken in the Flood Hazard Scoping phase. The purpose of the RFA was to provide a high level understanding of areas that may flood in a significant storm event to enable prioritisation of areas for more Detailed Flood Hazard Modelling. The RFA did not include the primary stormwater network in the model (apart from road culverts greater than 900mm) and assumed that all ground acts like an impervious surface i.e. all rainfall becomes surface runoff. The RFA was completed using a 5m grid over the complete City along with a 2m grid and all road culverts in two localised areas to compare the RFA methods and results.

The information from the RFA was used to prioritise areas of the city for more Detailed Flood Hazard modelling based on the number of properties at risk and the cost for completing the more detailed modelling. This more detailed modelling was undertaken over approximately 11% of the total Hamilton City area as shown in Figure ES1 below.

**Figure ES1 Model Extent**

The final phase of the stormwater modelling journey is the development of Catchment Management Plans (CMPs) for the entire city. HCC have allocated around $3.4M over the next 10 years in the Long Term Planning (LTP) programme for completion of CMPs.
While development of the CMPs is outside the scope of the HCC 3 Waters Modelling programme, it is intended that the more detailed stormwater model will be used to support the development of the CMPs.

**Modelling results and risk classification scores**

The 5m RFA / 2m RFA and more detailed FHM results were used to develop a hazard classification based on a slightly amended Waikato Regional Council matrix of Depth (D) against Velocity (V) – see Section 3.4 for more details. The hierarchy of data confidence used for each cell was based on the more detailed modelling being highest, the 2m RFA being next and finally the 5m RFA results. Thus if more detailed modelling results were available they were used to categorise the cell risk category, and if not then the 2m RFA results followed finally by the 5m RFA results.

The hazard classifications are no hazard (<100mm deep), low, medium and high based on an amended Waikato Regional Council matrix.

The maximum velocity and depth, along with the depth times velocity (D x V) results were used to establish the greatest risk category (low to high) and the greatest risk category was then applied to that cell.

For the Waikato River the model results from the Waikato Regional Council (WRC) 100yr water level profile and hazard classification were used based on the water depths alone. There were no velocity results provided by the WRC for the Waikato River.

**GIS deliverables**

The model results were delivered in raster format to allow for incorporation into the Hamilton City GIS system. The results were compiled into one (1) layer of GIS data.

Each grid cell within the supplied GIS file shows the data confidence of the cell as well as the risk matrix score. For overlapping cells (2m cell size over 5m cell size) then the higher confidence data was used for that cell (e.g. more detailed over 5m RFA or 2m RFA over 5m RFA).

AECOM also provided GIS information for each cell that shows:
- Source of data and level of confidence (e.g. 5m RFA = low confidence, 2m RFA = low to medium confidence and detailed FHM = medium to high confidence)
- Maximum depth (D) and associated velocity (V)
- Maximum velocity (V) and associated depth (D)
- Greatest value of depth multiplied by velocity (D x V)
- Hazard classification (based on greatest value of either V, D or D x V)

**Key Findings**

The outputs from the modelling have varying levels of confidence. This is primarily due to the amount of detail in each model. In this regard, the following should be noted:
- The 5m RFA results have the least confidence and generally provide the upper extreme of the flood potential. This is due to only road culverts greater than 900mm diameter being included, the primary pipe system (pipes and catchpits) not being allowed for and 100% rainfall becoming runoff.
- The 2m RFA results are the next in level of confidence and slightly better than the 5m RFA results. This is due to all road culverts being included in the models thus allowing for flow to be passed forward. With the culverts in the model the most upstream impacts should be reduced.
- The more Detailed FHM modelling provides a medium to high level of confidence in the model outputs. This is due to all road culverts and primary pipe system being used, and minor losses to ground being taken into account. The catchments completed in this work were Waitawhirihiri Stream, Mangakotukutuku Stream, Hamilton East, Callum Brae and Hamilton CBD.

**Key Assumptions and Limitations**

The following are the key assumptions and limitations. Further details are available in Section 2.0.
- Rainfall has been taken from the Hamilton City Development Manual depth – duration - frequency tables assuming climate change effects. AECOM created nested 6, 12 and 24hr duration storms from this data.
- The climate change effects assumed in the Hamilton City Development Manual allow a medium range average temperature increase of 2.08 degrees Celsius by 2090.
- The LiDAR data supplied by Hamilton City used to develop the terrain that formed the model ground surface base is assumed to be correct. It is noted that Hamilton City has identified issues with the LiDAR data in the Rotokauri area.
- The roughness of the surface model has been averaged over the whole catchment.
- The primary drainage network capacity is not reported at this stage.
- The 6 hour duration was used for the Flood Hazard Mapping (FHM) work as this exceeds the maximum flow time in all Hamilton City catchments.
- The existing scenario impervious coverage has been utilised for the Detailed Flood Hazard Mapping.
- Catchpits are assumed to have a maximum inletting capacity of 25 l/s.
- In-letting to the network is regulated according to the number of catchpits located within the catchment with a minimum regulation of 100 l/s.
- Manhole levels have been set to the terrain model level to ensure that all couplings operate correctly.
- Rural boundary conditions were developed for the Mangakotukutuku Streams and Waitawhirihiri Stream models based on pervious upstream catchments.
- The kinematic wave rainfall runoff model used is suitable for Flood Hazard Mapping as losses are negligible during extreme rainfall events. If the model is to be used for long time series or low rainfall events the hydrology and model set-up should be reviewed.

With future land use scenario runs and lower return period events the following could be analysed using the models with minor modification:

- Better understand the future infrastructure requirements to cater for growth
- Identify deficiencies in the existing primary drainage system
- Hydro-economic assessment to understand the financial impact of flooding
- Habitable floors at risk counts to assist in risk management
1.0 Introduction

1.1 Background

In 2010 Hamilton City Council (HCC) embarked on a programme to develop computer models to represent the behaviour and performance of their wastewater, water supply and stormwater networks. The project is known as the HCC Three Waters Modelling Programme and excludes the specific modelling of the water supply and wastewater treatment plants.

The Three Waters Modelling Programme was awarded to the AECOM team, consisting of AECOM, AWT, DHI and Watershed with the contract commencing in September 2010. The project was broken into three (3) phases being:

Phase 1
- Develop calibrated trunk water supply and wastewater models from field monitoring, flow gauges and asset data. The models will be used to understand any existing and future system performance issues at a high level.
- Undertake Flood Hazard Model (FHM) scoping based on a rapid flood assessment approach and then from that agree the level of detailed modelling to develop FHM outputs for the future fully developed 100yr rainfall event with climate change.
- Support any Catchment Management Planning work and stormwater flow gauging as necessary.

Phase 2
- Develop a calibrated all pipe water supply model from additional field test data. The model will be used to understand any existing and future system performance issues in more detail.
- Develop calibrated wastewater network models (5) based on short and long term flow gauge data. These models will be focussed on historic problem areas and the results from the system performance results from Phase 1 and will not cover the City in detail but rather be focussed.
- Support any Catchment Management Planning work and flow gauging as necessary.

Phase 3
- Provide support to HCC regarding any ongoing model queries and updates.

1.2 Stormwater Objectives

The objective of FHM is to develop an understanding of the flooding issues within a catchment based on the available information and analysis performed. FHM will assist Hamilton City Council to:
- Identify the hazard by understanding the flood extent, flood depths and the hazard classification
- To assist in resolving flooding issues through Catchment Management Plans

1.3 General modelling Deliverables

The outputs from these models will provide a City wide coverage of the expected flood hazards. The flood hazards that have been identified and mapped have differing levels of confidence depending on the modelling method (further details on the level of confidence can be found in Section 3.6).

Key points to note with regard to the project are as follows:
- The 5m RFA is a high level assessment of the likely areas of flooding and was intended to identify areas that required further detailed modelling studies. The 5m RFA has the lowest confidence level.
- The 2m RFA was used to compare the 5m RFA results in 2 areas only. It has a slightly higher confidence than the 5m RFA but lower than the detailed FHM models.
- The detailed models have been developed for specific isolated areas as shown in Figure1 below.
- The modelling outputs will be used in the District Plan but confidence in outputs needs to be clearly noted.

This report outlines the work completed in this project in terms of the modelling processes followed, the outputs and impacts for the simulated 100yr ARI storm event with climate change.
2.0 Assumptions and Limitations

The following assumptions and limitations apply to the flood hazard modelling results provided as deliverables. These assumptions and limitations should be read by Hamilton City staff using the results.

2.1 Hydrology

- Rainfall has been taken from the HCC Development manual depth/duration/frequency tables assuming climate change effects and AECOM created nested storms from these tables (refer Appendix B AECOM letter dated 18 November 2010).
- The climate change effects assumed in the HCC Development manual are detailed in a report prepared by NIWA (NIWA Client Report WLG2008-010) and provides for an IPCC medium range average temperature increase of 2.08 degrees Celsius by 2090.
- Design hyetographs have been developed to ensure peak flow and volume are replicated at any point within the model extent. A nested storm contains peaks for all durations and therefore, in theory, generates 1 in
100yr storm flows when applied uniformly across a range of sub-catchments with varying times of concentration.
- The 6 hour duration storm has been used for the Flood Hazard Mapping (FHM) work.
- In order to provide an appropriate boundary condition at the Waikato River, the 1998 flood event has been used as the 100yr event water level. This approach is consistent with Waikato Regional Councils determination of water levels for design purposes.
- The hydrology was undertaken using Model B. This is suitable for Flood Hazard Mapping as losses are negligible during extreme rainfall events. If the model is to be used for long time series or low rainfall events the hydrology should be reviewed along with the model configuration and losses.

2.2 LiDAR and Terrain Development

- The LiDAR data supplied by HCC has been used to develop the terrain that formed the base for the model. This data is assumed to be correct and no adjustments have been made other than those required to stabilise the model at the inlet and outlets of critical culverts.
- The FHM uses a 2 x 2m grid with the level of the grid cell the average of the LiDAR points within the cell.
- Water level was defined by adding together the ground level and the water depth at the relevant grid cell. The ground level is determined from the interpolation of the LiDAR DTM points and is therefore subject to inaccuracies (inaccuracies in the elevation of the LiDAR points and in the data processing to create the DTM). This is particularly true wherever the LiDAR DTM point density is sparse or in heavily vegetated areas. In such cases, it is assumed that the flood extent and the water depth give a good approximation of the flood risk even if the ground level is not accurate.
- In urban areas the LiDAR data is stated to have an accuracy of about ± 0.25m with a 95% confidence interval. This relates to the spheroid height; additional error is introduced when the geodic height model is applied. As a result of the water level variability, the lateral extent of flood hazards may vary significantly from that shown.
- The actual range of uncertainty as a result of the combined effect of LiDAR and other possible errors and inaccuracies will in some situations be in excess of 0.5 metres. Asset planners, consent planners and designers should take appropriate care in using the results and should apply a freeboard allowance that is appropriate for the situation, taking into account these limitations, assumptions and uncertainties including the compounding effects of uncertainties in the rainfall model.

2.3 Land-use

- The existing scenario impervious coverage has been utilised for the Detailed Flood Hazard Mapping.
- The impervious and pervious coverage for the future scenario is taken from the District Plan allowances for each land use type should that be utilised for the future model scenarios.
- The roughness of the surface model has been averaged over the whole catchment. A Manning’s ‘M’ value of 32 has been determined to represent surface roughness over the catchment. For more detailed modelling this needs to be reviewed to better represent reality.

2.4 Model Setup and Boundary Conditions

- Catchpits are assumed to have a maximum inletting capacity of 25l/s
- Catchpits are free flowing and unimpeded (i.e. no blockages)
- All culverts included in the model are free flowing and unimpeded
- In-letting to the network is regulated according to the number of catchpits located within the catchment (i.e. total number of catchpits multiplied by 25l/s) with a minimum regulation of 100l/s.
- All other manholes are coupled to the 2D terrain using the default urban linkage. This linkage allows flow in both directions between the terrain and network up to a maximum of 100l/s.
- The manhole levels have been set to the terrain model level to ensure that all couplings operate correctly.
- Rural boundary conditions were required for the Mangakotukutuk u and Waitawhiwhiri models. These were developed by utilising 5m RFA results to calibrate the fully impervious scenario using the Unit Hydrograph method for M11 rainfall runoff. These calibrated catchments were subsequently updated with pervious catchment parameters. This produced realistic runoff hydrographs for utilising in the model run.
2.5 Reporting
- In order to represent the extent of possible flooding within the water course extent the full width of the Mike 11 water course between the bank markers is shown in hazard maps. If work is required within this area a more accurate understanding of the flood extent can be extracted from the model results.
- The primary drainage network is not reported at this stage. If an understanding of the capacity of the primary drainage network is required this can be extracted from the original result files.
- Further details regarding the RFA model development are included in Appendix D and should be referenced in any consideration of areas outside those areas covered by detailed FHM areas.

3.0 Methodology

3.1 Overview
The modelling project was undertaken in two phases, being the
- Rapid Flood Assessment (RFA), and
- Detailed FHM

The rainfall used was the 100yr event with climate change.

The methodologies used to produce the flood hazard results vary between the two phases and they each have a confidence level associated with the results. Further details of the confidence to expect from the results are discussed further in Section 3.6.

This section discussed the methodologies used to develop each model, the primary hydrological assumptions, and the flood hazard classification process.

3.1.1 Model Runs
Table 1 outlines the model runs undertaken during the project. These model runs are required to understand the network during extreme event rainfall:

<table>
<thead>
<tr>
<th>Project Phase</th>
<th>Return Period (ARI)</th>
<th>Land-use Scenario</th>
<th>Climate Change</th>
<th>Storm Duration</th>
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<tr>
<td>Rapid Flood Hazard Mapping</td>
<td>100yr</td>
<td>MPD</td>
<td>✓</td>
<td>6hr, 12hr, 24hr</td>
</tr>
<tr>
<td>Detailed Flood Hazard Mapping</td>
<td>100yr</td>
<td>MPD</td>
<td>✓</td>
<td>6hr</td>
</tr>
</tbody>
</table>

3.1.2 Deliverables
The deliverables have been split into two (2) components:

Deliverable 1 – District Plan inputs
AECOM supplied a single GIS layer showing the hazard classification for each cell. This information is to be used in the draft District Plan consultation process and therefore the confidence of the data needs to be clearly identified.

The GIS layer was made up of results from the detailed FHM, 2m and 5m RFA in that order of priority and data confidence. This means that in some areas as the grid cells do not match exactly there is an over or underlap of the cells. Data supplied was:
- Polygon shape file with hazard classification, including data source and confidence. The darker the cell colour reflects the greater data confidence. The colours for the hazard classification are low = green, medium = orange and high = red. This is shown in Figure 2 below with the 3 sources of data confidence.
- Geo-database including results and MXD files with symbolised results for viewing
- Instructions for use
Deliverable 2 – Hamilton City viewer information

As requested by Hamilton City AECOM will be supplying a single GIS layer of the following information:

- Source of data and level of confidence (e.g. 5m RFA = low confidence, 2m RFA = low to medium confidence and detailed FHM = medium to high confidence)
- Maximum depth (D) and associated velocity (V)
- Maximum velocity (V) and associated depth (D)
- Greatest value of depth multiplied by velocity (D x V)
- Hazard classification (based on greatest value of either V, D or D x V)

This GIS layer can then be accessed by Hamilton City staff to obtain the results needed. The aim is for the data to be able to be accessed through the Hamilton City GIS viewer.

3.2 Rapid Flood Assessment (RFA) Mapping

The RFA was undertaken to provide a high level understanding of the potential flooding hazards across the City. The RFA approach provides a conservative estimate of flooding as it assumes that all of the pipes and catchpits are fully blocked and that any rain that falls on the land becomes runoff (i.e. no losses).

A ground surface digital terrain model (DTM) of the entire catchment area (including the expanded Hamilton City boundary) was developed using the LiDAR data. This DTM provides a ground surface profile where any water that lands on the surface will flow where it would naturally. The software requires a grid size to be selected and in this case a 5m grid was used. The 5m grid essentially provides a 5m x 5m level surface with the grid level based on the average of all of the LiDAR points within that grid.

The proposal at tender stage had not allowed for pipes, catchpits or culverts in the RFA. After further discussions with Hamilton City it was agreed that culverts with openings larger than 900mm would be included in the model. This was considered appropriate on the basis that any culvert less than 900mm in diameter has a high risk of blockage during the 100yr extreme rainfall event when debris can be washed down to the culvert inlet.
During the model build phase it was established that not all culverts greater than 900mm had asset data. Overall there were field surveys of 41 critical culverts to ensure they were correctly represented in the model. The critical culverts were added to the ground surface model ready for the rainfall.

The 100yr plus climate change rainfall profile was developed from the Hamilton City Development Manual such that all of the rainfall intensity and durations were incorporated into one rainfall event covering 6, 12 or 24hr duration storms. The methodology and reasoning is discussed further in Appendix A.

In areas where there is no outlet drain modelled the results are sensitive to the storm duration. Consequently, any depressions or low lying land areas (with no culvert outlets) will flood to a greater extent for the longer duration storm. Based on industry standards a 24hr duration storm was recommended and accepted as the longest duration storm to be used for stormwater modelling.

The 100yr plus climate change rainfall was applied to the ground surface model (DTM) for the 6, 12 and 24 hour duration storms.

The result files were processed in accordance with the 2D hazard classification methodology as discussed in Section 3.5 and the results provided as a raster output for inclusion in Hamilton City Councils GIS system.

These results were discussed with the HCC Operations staff and there was agreement that the results reflected. The specific limitations of the 5m RFA results are as follows, refer to Section 2 for a comprehensive list of limitations and assumptions:

- All surfaces are considered impervious i.e. no losses are accounted for due to using rain on grid hydrology
- No primary drainage is represented except critical culverts, therefore, flood locations and extents may vary due to surcharging manholes etc.
- Critical culverts are considered to have a diameter greater than 900mm. Culverts with diameters less than 900mm are considered prone to blockage and have not been represented in the RFA model.

## 3.3 Flood Hazard Mapping

### 3.3.1 Introduction

Following the City Wide FHM modelling, areas that show significant areas of high risk flood hazards were identified and developed into detailed models. Key attributes of the detailed models are as follows:

- The hydrological analysis was undertaken using the Model B kinematic wave approach. This provides a robust assessment of rainfall losses and runoff.
- The primary drainage network was incorporated into the model
- In-letting into the primary network was calculated on the number of catchpits in the sub-catchment multiplied by 25l/s with a minimum of 100l/s.
- The terrain grid has been refined from the City Wide FHM to 2m x 2m grid.

The results from these models have been processed for hazards in accordance with section 3.4 and converted to vector files as required by Hamilton City Council.

Further details of each detailed model and the results can be found in Sections 5.0 to 7.0.

### 3.3.2 Flood Hazard Mapping Software

The software platforms used for Hamilton City were as follows:

- **Mike Urban**: Pipe network and soakage representation and Hydrology. The Mike urban is used for the hydrology as it is more accurate as the hydrological losses are better represented.
- **Mike11**: Open Channel
- **Mike21**: Floodplain, Surface flooding
- **Mike Flood**: final 1D-2D coupled model.

## 3.4 Hazard Classification

### 3.4.1 Background

Surface flooding, as well as overland flow with unsafe depths and/or velocities were identified and agreed with Hamilton City as shown in Table 2 and Figure 3 below. The Flood Hazard Mapping (FHM) programme identifies
areas with the potential to cause damage according to chosen criteria. These criteria considered the following aspects:
- Flooding of private or public property and floor levels
- Overland flow occurring to such a depth and/or velocity as to pose a possible safety hazard to vehicles and pedestrians.

3.4.2 2D Hazard Classification Methodology

High risk flood zones mean that land is subject to flooding during the 100yr ARI event; and during such an event:
- The depth of flood waters exceeds one (1) metre;
- The speed of flood waters exceeds two (2) metres/second; or
- The flood depth multiplied by the flood speed exceeds one (1).

The outputs from the model can be used for the following applications:
- FHM Mapping
- Hamilton City GIS layer for internal and public information, although the confidence in the outputs needs to be taken into account
- Land Information Memorandums (LIM’s)

It is therefore necessary to ensure that outputs sufficiently fulfil the requirements of all applications while maintaining consistency in presentation and extractable information.

3.4.3 Hazard Classification Methodology

To determine the hazard classification as described in Table 2 below, the velocity and depth for each grid is used at each time step during the simulation to determine the hazard classification at the given time step. The depth/velocity criteria for each hazard classification are shown in Figure 3 below. The hazard is classified with one of the following values:

Table 2 Hazard Classification Category

<table>
<thead>
<tr>
<th>Hazard Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>High Risk Zone</td>
</tr>
<tr>
<td>2</td>
<td>Medium Hazard</td>
</tr>
<tr>
<td>1</td>
<td>Low Hazard</td>
</tr>
<tr>
<td>0</td>
<td>No Hazard</td>
</tr>
</tbody>
</table>

The maximum value during the simulation for each grid cell is extracted from the result file and used to determine the hazard classification. This method evaluates the hazard classification at each time step and determines the maximum / worst case hazard. The maximum value for V, D and D x V then produces the hazard classification for that cell.

These classifications are then used for the raster output showing the colour scheme for each grid cell based on the model results.
The hazard classification is used to produce digital GIS raster shape files showing ponding and overland flow hazards.

### 3.5 Model Validation

#### 3.5.1 Historical Events

Operational knowledge and records are a valuable source of information for the modeller. Stormwater flooding issues have been confirmed with the operational staff and this has provided confidence in the 5m RFA high level outputs, even though the confidence is considered to be low.

### 3.6 Model Results – Level of Confidence

In order to quantify the level of confidence in the different types of model results a detailed comparison has been undertaken. The comparison was undertaken between the 5m City Wide FHM results, the 2m detailed model results and the 2m additional City Wide FHM models. Details of this process are located in Appendix B, however, the key findings of this task are as follows:

- The 5m RFA results are the lowest confidence. This is due to upper parts of catchments with culverts smaller than 900mm not allowing for the flow to be passed forward, even partially. This has the potential to reduce downstream impacts. These results can be used to identify where potential hazards are likely to occur. Further work to establish accurate flood levels should be carried out on a case by case basis.

- The 2m RFA results are the next in level of confidence and provide a more refined flood extent than the 5m results. This is due to all culverts being included in the models thus allowing for flow to be passed forward. Including the culverts should reduce the most upstream impacts, however, without the primary pipe system (pipes and catchpits) in the model and 100% rainfall runoff the flooding impacts will still be conservative.

- The local detailed modelling (FHM) provides the highest level of confidence in the model outputs. This is due to catchments being loaded to the pipe system thus utilising that capacity, losses to ground being taken into account and all culverts in place.
4.0 Capacity of the Existing Primary Pipe System

The capacity of the existing pipe network throughout the detailed models is generally exceeded. Many of the pipes within the network surcharge as result of insufficient primary drainage capacity. This is expected due to the high return period of the storm (100yr with climate change) whereas the pipe may have only been designed to between a 2 and 10yr return period storm.

In order to appropriately assess the system performance the design level of service event could be run through the model at a later stage. This would provide valuable operational information about stress points within the network and inform the development of a capital works programme going forward. It should be noted that to undertake the system performance work the model will need to be modified to allow for more appropriate in-letting into the primary system (be it pipe or stream), losses allowed for and greater catchment and pipe detail.

5.0 Waitawhiriwhiri Stream Catchment

5.1 Introduction

The Waitawhiriwhiri Stream catchment is predominantly residential with low levels of industry and commercial activity compared to other urban catchments. The catchment was predominantly constructed during the 1970’s.

Due to the large rural catchment upstream of Waitawhiriwhiri Stream there are significant flooding issues in the Dinsdale suburb. Due to these high flows the railway culvert has become a hydraulic control point within the stream. Future developments of the rural catchment could incorporate additional attenuation in order to alleviate flooding as a result of this hydraulic control and to control the flows to no greater than the existing scenario.

5.2 Overview of Study Area

5.2.1 Catchment

Area: 2,045 Ha

Catchment: Waitawhiriwhiri

5.2.2 Location

Figure 1 shows the location of the catchment in the context of Hamilton City.

5.2.3 Relationship To Nearby Catchments

The Waitawhiriwhiri Catchment is located in the south west of Hamilton City. It is bounded by the Mangakotukutuku Stream to the east, Waikato River to the north and Whatawhata to the west.

The receiving environment for this catchment is the Waikato River and there are a number of other catchments that also impact on the same receiving environment.

5.3 Catchment Description

The Waitawhiriwhiri catchment has an area of approximately 2,045 ha. The impervious percentage within the Hamilton boundary (62% existing development (ED)) is similar to that of most urban areas; however the impervious percentage over the entire catchment is much lower due to its large area of upstream farmland.

Overall the catchment is moderately flat within the urbanised areas with an overall drop in elevation of 75m from the upper part to the Waikato River over a distance of 2,500m. The stormwater pipe system covers approximately 70% of the catchment with the remaining 30% drained via farm channels.

The catchment predominantly drains via Waitawhiriwhiri Stream, with tributary creeks, farm drains and pipe reticulated areas all feed into this stream. Several culverts are located along the entire length of the watercourse.

Waitawhiriwhiri stream is predominantly a uniform, engineered channel throughout; gradients within the channel generally range from flat to moderately steep.

The geology of the catchment is predominantly clay loam and peaty loam.
There are sections of this catchment which are currently not part of the existing HCC boundary, these areas are predominantly undeveloped farm land, however there is potential for further development here to increase overall imperviousness. Details of the land use in the area of Waitawhiriwhiri catchment that is currently within the Hamilton City Council Boundary are shown in Table 4.

**Table 4 Land Use in Waitawhiriwhiri Stream Catchment**

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Services</td>
<td>4%</td>
</tr>
<tr>
<td>Residential</td>
<td>52%</td>
</tr>
<tr>
<td>Future Urban</td>
<td>9%</td>
</tr>
<tr>
<td>Roads</td>
<td>11%</td>
</tr>
<tr>
<td>Industrial</td>
<td>14%</td>
</tr>
<tr>
<td>Recreation</td>
<td>9%</td>
</tr>
<tr>
<td>Suburban Centre</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

The existing imperviousness (2011) in the Waitawhiriwhiri catchment is 58% of the total area.

A summary of the main network components in the study area is shown in Table 5 below.

**Table 5 Summary of Modelled Existing Stormwater Network**

<table>
<thead>
<tr>
<th>Item</th>
<th>Stormwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Modelled Asset Pipes and Culverts</td>
<td>813</td>
</tr>
<tr>
<td>Total Length of Modelled Asset Pipes</td>
<td>53,168m</td>
</tr>
<tr>
<td>Number of Modelled Asset Manholes</td>
<td>900</td>
</tr>
<tr>
<td>Number of Pump Stations</td>
<td>0</td>
</tr>
<tr>
<td>Watercourse length</td>
<td>7,092m</td>
</tr>
</tbody>
</table>

### 5.4 Model Schematisation

The model schematisation for the Waitawhiriwhiri catchment can be seen below in Figure 4.
The areas that have been modelled in detail were determined using the City wide FHM results. The areas where flooding was predicted to be high hazard were connected to a detailed pipe network. This model representation most accurately reflects the whole drainage system.

The sub-catchment areas in the detailed model areas were limited to 0.5-2Ha. For areas where there are no flood risks the model sub-catchments have been increased in size generally in the range of 2 to 5 Ha.

5.5 Results

With the exception of some isolated capacity constraints, the Waitawhirihiri Stream appears to have sufficient capacity to convey the 100yr ARI event flood flows. The main hydraulic controls along this watercourse appear to be located where road culverts are located (e.g. Dinsdale Road roundabout).

Due to the large areas of flat terrain extensive surface flooding is expected to occur with surface flows accumulating in low points, predominantly within the road reserve. Typically the flooding in these areas will be minor to moderate flooding with isolated areas of high hazards. Areas that are particularly susceptible to this are the Nawton, Dinsdale and Frankton suburbs.
6.0 Mangakotukutuku Stream Catchment

6.1 Introduction

The Mangakotukutuku stream begins in the countryside to the south of Hamilton and flows to the north, through the southern suburbs of Glenview and Fitzroy, before discharging into the Waikato River.

The stream is made up of three main branches that flow through most of the major parks in the catchment, before meeting at Sanford Park in the north of the catchment.

6.2 Overview of Study Area

6.2.1 Catchment

Catchment Name: Mangakotukutuku
Catchment Area: 2,961 Ha

6.2.2 Location

Figure 1 shows the location of the catchment in the context of Hamilton City. Figure 5 shows a general layout of the Mangakotukutuku catchment. The receiving environment for this catchment is the Waikato River and there are a number of other catchments that also impact on the same receiving environment.

Figure 5 Schematisation of the Mangakotukutuku Catchment
6.2.3 Relationship to Nearby Catchments

The Mangakotukutuku catchment is located in the southern region of Hamilton. It is bounded by Hamilton East and Hillcrest to the northeast, and Waitawhiriwhiri to the northwest.

6.3 Catchment Description

The Mangakotukutuku catchment has an area of approximately 2,961 ha. The impervious percentage within the Hamilton boundary (36% ED) is similar to that of most urban areas; however the impervious percentage (12% ED) over the entire catchment is much lower due to the vast farmland areas in the south-west of the catchment.

Overall the catchment is moderately flat within the urbanised areas with an overall drop in elevation of approximately 63m from the eastern edge of the catchment to the Waikato River over a distance of 3,600m. The stormwater pipe system covers approximately 21% of the catchment with the remaining 79% drained via farm channels.

The catchment is predominantly drained via the Mangakotukutuku Stream, tributary creeks, farm drains and pipe reticulated areas that feed into the stream. Several culverts are located along the entire length of the watercourse.

Mangakotukutuku Stream is predominantly a uniform channel throughout, with dense vegetation coverage in most areas.

The geology of the catchment is predominantly a mixture of clay loam, silt loam and sandy loam of the Horotiu, Kainui and Te Kowhai series.

Approximately 64% of the Mangakotukutuku catchment is currently outside the existing Hamilton City boundary. This area is predominantly undeveloped, however there is potential for further development to increase the overall imperviousness. Details of the land use in the Mangakotukutuku catchment within the Hamilton City Boundary are shown in Table 6.

Table 6 Land Use in the Mangakotukutuku Catchment

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community Facilities</td>
<td>2%</td>
</tr>
<tr>
<td>Future Urban</td>
<td>46%</td>
</tr>
<tr>
<td>Industrial</td>
<td>1%</td>
</tr>
<tr>
<td>Recreation</td>
<td>7%</td>
</tr>
<tr>
<td>Residential</td>
<td>32%</td>
</tr>
<tr>
<td>Roads</td>
<td>11%</td>
</tr>
<tr>
<td>Suburban Centre</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100%</td>
</tr>
</tbody>
</table>

The existing imperviousness (2011) in the Mangakotukutuku catchment is 36% of the total area.

A summary of the main network components in the study area is shown in Table 7 below.

Table 7 Summary of Modelled Existing Stormwater Network

<table>
<thead>
<tr>
<th>Item</th>
<th>Stormwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Modelled Asset Pipes and Culverts</td>
<td>180</td>
</tr>
<tr>
<td>Total Length of Modelled Asset Pipes</td>
<td>9,765 m</td>
</tr>
<tr>
<td>Number of Modelled Asset Manholes</td>
<td>157</td>
</tr>
<tr>
<td>Number of Pump Stations</td>
<td>0</td>
</tr>
<tr>
<td>Watercourse length</td>
<td>9,753 m</td>
</tr>
</tbody>
</table>
6.4 Model Schematisation

A zoomed-in view of the catchment can be seen in Figure 6 below.

Figure 6: Schematisation of the Mangakotukutuku Catchment (Zoomed)

6.5 Results

The Ohaupo Road culvert capacity is insufficient to convey the 100yr ARI event with climate change effects. As a consequence significant flooding is predicted to occur upstream of these culverts resulting in private property flooding and potentially habitable floor flooding.

Due to the flat terrain throughout Deanwell, extensive surface flooding is predicted to occur. This flooding will be exacerbated by insufficient primary drainage capacity required to drain storm flows from low areas. As a result extensive surface property flooding is predicted to occur with some isolated high hazards. As most of the road reserves are slightly lower than the private properties the worst flooding is expected to occur within the road reserves with the deeper flooding encroaching into private property.

7.0 Hamilton East Catchment

7.1 Introduction

The Hamilton East catchment is predominantly residential with low levels of industry and commercial activity compared to other urban catchments. The catchment was predominantly constructed during the 1970’s.
7.2 Overview of Catchment

7.2.1 Catchment

Area: 466 Ha
Catchment: Hamilton East

7.2.2 Location

Figure 1 shows the location of the catchment in the context of Hamilton City. Figure 7 on the following page shows a general layout of the Hamilton East Catchment.

7.2.3 Relationship To Nearby Catchments

The Hamilton East catchment is located in east Hamilton. It is bounded by the Hillcrest to the east, Waikato River to the south and Fairfield to the west.

The receiving environment for this catchment is the Waikato River and there are a number of other catchments that also impact on the same receiving environment.

7.3 Catchment Description

The Hamilton East catchment has an area of approximately 466 ha and is characterised by large, flat flooding areas. The impervious percentage within the Hamilton boundary (48% ED) is similar to that of most urban areas.

Overall the catchment is very flat within the urbanised areas with an overall drop in elevation of 63m from the upper part to the sea over a distance of 2,700m.

The catchment drains via two stormwater drains which discharges directly into the Waikato.

The catchment is predominantly developed however there is potential for further development to increase overall imperviousness. Details of the land use in the Hamilton East catchment are shown in Table 8.

### Table 8 Land Use in the Hamilton East Catchment

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>5%</td>
</tr>
<tr>
<td>Residential</td>
<td>53%</td>
</tr>
<tr>
<td>Future Urban</td>
<td>15%</td>
</tr>
<tr>
<td>Roads</td>
<td>16%</td>
</tr>
<tr>
<td>Industrial</td>
<td>2%</td>
</tr>
<tr>
<td>Recreation</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

The existing imperviousness (2011) in the Hamilton East catchment is 43% of the total area.

A summary of the main network components in the study area is shown in Table 9 below.

### Table 9 Summary of Modelled Existing Stormwater Network

<table>
<thead>
<tr>
<th>Item</th>
<th>Stormwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Modelled Asset Pipes and Culverts</td>
<td>370</td>
</tr>
<tr>
<td>Total Length of Modelled Asset Pipes</td>
<td>24,330</td>
</tr>
<tr>
<td>Number of Modelled Asset Manholes</td>
<td>336</td>
</tr>
<tr>
<td>Number of Pump Stations</td>
<td>0</td>
</tr>
</tbody>
</table>
7.4 Model Schematisation

The model schematisation for the Hamilton East catchment can be seen in Figure 7 below.

Figure 7 Hamilton East Model Schematisation
8.0 References

Hickey et al. 2001
Appendix A

Design Storm Hyetograph
Development of the nested hyetographs for HCC 3 Waters Modelling

**Background**

There is currently no approach outlined in the Hamilton City Development Manual other than Rational Method for calculating peak flows.

In order to predict storm flows and volumes for the Flood Hazard Mapping project AECOM agreed an approach (AECOM letter dated 18 November 2010) to develop three (3) hyetographs to represent the 100yr plus climate change storm events for the 6, 12 and 24hr.

**Methodology**

AECOM utilised the Ruakura rainfall depth including climate change from the HCC Development Manual October 2010 and the distribution of rainfall intensities and durations is based on the Chicago Storm profile. This is commonly accepted in NZ as appropriate as there are no historically recorded extreme events.

The shortest time to reach an inlet into the primary system has been taken as 10 minutes (based on ARC TP108). Thus the HCC 5 minute information has not been used to develop the hyetographs.

The information used to develop the 3 hyetographs is shown in the table below.

<table>
<thead>
<tr>
<th>Duration (mm)</th>
<th>10mins</th>
<th>20mins</th>
<th>30mins</th>
<th>60mins</th>
<th>2hours</th>
<th>6hours</th>
<th>12hours</th>
<th>24hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (mm)</td>
<td>25</td>
<td>39</td>
<td>49</td>
<td>68</td>
<td>81</td>
<td>104</td>
<td>131</td>
<td>163</td>
</tr>
</tbody>
</table>

All of the storms are assumed to start at midnight (0:00 hrs) and the peak intensity will be in the middle of the storm duration (i.e. 6hr storm peak intensity is 3:00am, 12hr storm peak intensity is 6:00am etc). The method used to develop each hyetograph is discussed below.

**6hr storm**

The storm will run from midnight (12pm) to 6am overall.

10min rainfall depth

To develop the hyetograph utilise the peak intensity area first (10minute) which gives a rainfall depth of 25mm. This will become the centre of the hyetograph.

Rainfall intensity = depth / time in hours = 25 / (10/60) = 150mm/hr. This intensity will occur 5minutes either side of the 3hr time interval (i.e. 2:55am to 3:05am). HCC shows the intensity as 152mm/hr which means the depth is slightly greater but within the realms of accuracy for modelling.

20min rainfall depth

Then move to the intensity either side of the central peak intensity. This will add 10minutes to the hyetograph (5 minutes either side). Total depth = 39mm of rain therefore there is 39mm – 25mm = 14mm of rain that fell in that 10 minute period. HCC shows the average rainfall intensity over this 20minute period which will be relatively the same for this methodology. The only difference is in the rounding of the rainfall depth which will slightly change the rainfall intensity.

Rainfall intensity = depth / time in hours = 14 / (10/60) = 84mm/hr. This intensity will then be for the period 2:50 to 2:55am and 3:05 to 3:10am which equates to an overall time of 20minutes.

30min rainfall depth

Then move to the next intensity period. This will add another 10minutes to the hyetograph (5 minutes either side). Total depth = 49mm of rain therefore there is 49mm – 39mm = 10mm of rain that fell in that 10 minute period.

Rainfall intensity = depth / time in hours = 10 / (10/60) = 60mm/hr. This intensity will then be for the period 2:45 to 2:50am and 3:10 to 3:15am.
60min rainfall depth
Then move to the next intensity period. This will add another 30 minutes to the hyetograph (15 minutes either side). Total depth = 68mm of rain therefore there is 68mm – 49mm = 19mm of rain that fell in that 30 minute period.

Rainfall intensity = depth / time in hours = 19 / (30/60) = \( 38 \text{mm/hr} \). This intensity will then be for the period 2:30 to 2:45am and 3:15 to 3:30am.

2hr rainfall depth
This will add another 1 hr to the hyetograph (30 minutes either side). Total depth = 81mm of rain therefore there is 81mm – 68mm = 13mm of rain that fell in that 1hr period.

Rainfall intensity = depth / time in hours = 13 / 1 = \( 13 \text{mm/hr} \). This intensity will then be for the period 2:00 to 2:30am and 3:30 to 4:00am.

6hr rainfall depth
This will add another 4hrs to the hyetograph (2hrs either side). Total depth = 104mm of rain therefore there is 104mm – 81m = 23mm of rain that fell in that 2hr period.

Rainfall intensity = depth / time in hours = 23 / 4 = \( 5.75 \text{mm/hr} \). This intensity will then be for the period 0:00 to 2:00am and 4:00 to 6:00am. This then gives a total hyetograph covering 6hours of rainfall.

12hr storm
The storm will run from midnight (12pm) to 12am (noon) overall with peak intensity around 6am. The storm will use the 6hr storm as the central core and then add 3hrs either side of it.

12hr rainfall depth
Total depth = 131mm of rain therefore there is 131mm – 104m = 27mm of rain that fell in that 2hr period.

Rainfall intensity = depth / time in hours = 27 / 6 = \( 4.5 \text{mm/hr} \). This intensity will then be for the period 0:00 to 3:00am and 9:00 to 12:00am. This then gives a total hyetograph covering 12hours of rainfall.

24hr storm
The storm will run from midnight (12pm) to 12pm (midnight) overall with peak intensity around 12am. The storm will use the 12hr storm as the central core and then add 6hrs either side of it.

24hr rainfall depth
Total depth = 163mm of rain therefore there is 163mm – 131mm = 32mm of rain that fell in that 12hr period.

Rainfall intensity = depth / time in hours = 32 / 12 = \( 2.66 \text{mm/hr} \). This intensity will then be for the period 0:00 to 6:00am and 6:00 to 12:00pm. This then gives a total hyetograph covering 24hours of rainfall.
### Ruakura Rainfall Intensity (mm/hr) incorporating climate change

<table>
<thead>
<tr>
<th>ARI</th>
<th>5m</th>
<th>10m</th>
<th>20m</th>
<th>30m</th>
<th>60m</th>
<th>2h</th>
<th>6h</th>
<th>12h</th>
<th>24h</th>
<th>48h</th>
<th>72h</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>93</td>
<td>71</td>
<td>51</td>
<td>40</td>
<td>27</td>
<td>16</td>
<td>8</td>
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<td>5</td>
<td>116</td>
<td>93</td>
<td>68</td>
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<td>10</td>
<td>7</td>
<td>4</td>
<td>2</td>
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</tr>
<tr>
<td>10</td>
<td>133</td>
<td>107</td>
<td>80</td>
<td>66</td>
<td>45</td>
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<td>12</td>
<td>8</td>
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</tr>
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<td>50</td>
<td>172</td>
<td>139</td>
<td>106</td>
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<td>37</td>
<td>16</td>
<td>10</td>
<td>6</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>185</td>
<td>152</td>
<td>117</td>
<td>99</td>
<td>68</td>
<td>41</td>
<td>17</td>
<td>11</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

This data prepared by NIWA (NIWA Client Report WLG2008-010) provides for an IPCC medium range average temperature increase of 2.08 degrees Celsius by 2090.

### Ruakura Rainfall Depth (mm) incorporating climate change

<table>
<thead>
<tr>
<th>ARI</th>
<th>5m</th>
<th>10m</th>
<th>20m</th>
<th>30m</th>
<th>60m</th>
<th>2h</th>
<th>6h</th>
<th>12h</th>
<th>24h</th>
<th>48h</th>
<th>72h</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8</td>
<td>12</td>
<td>17</td>
<td>20</td>
<td>27</td>
<td>33</td>
<td>47</td>
<td>60</td>
<td>72</td>
<td>85</td>
<td>91</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>16</td>
<td>23</td>
<td>28</td>
<td>37</td>
<td>45</td>
<td>62</td>
<td>79</td>
<td>95</td>
<td>114</td>
<td>121</td>
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<td>10</td>
<td>11</td>
<td>18</td>
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<td>33</td>
<td>45</td>
<td>54</td>
<td>72</td>
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The above Climate Change adjusted rainfall statistics are derived from the following statistical data which represents an analysis of annual maximum rainfall intensities of the Ruakura rainfall gauge for the period 1947 to 2006. Data for ARI s 20, 30, and 75 years is also available.

### Ruakura Rainfall Intensity (mm/hr)

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Version: October 2010
100 year ARI Design Storms with Climate Change

6hr nested storm    Total rainfall depth (mm)  104

Derived from

Hamilton City Development Manual
Volume 2 : Design Guide
Part 4 – Stormwater Drainage
Section 4.6.3 Rainfall

Ruakura Rainfall Depth (mm) incorporating climate change

This data prepared by NIWA (NIWA Client Report WLG2008-010) provides for an IPCC medium range average temperature increase of 2.08 degrees Celsius by 2090.

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### 100 year ARI Design Storms with Climate Change

**12hr Nested Storm**  
**Total rainfall depth (mm)**  
131

Derived from  
Hamilton City Development Manual  
Volume 2 : Design Guide  
Part 4 – Stormwater Drainage  
Section 4.6.3 Rainfall  

**Ruakura Rainfall Depth (mm) incorporating climate change**

*This data prepared by NIWA (NIWA Client Report WLG2008-010) provides for an IPCC medium range average temperature increase of 2.08 degrees Celsius by 2090.*

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100 year ARI Design Storms with Climate Change

24hr Nested Storm  Total rainfall depth (mm)  163

Derived from

Hamilton City Development Manual
Volume 2 : Design Guide
Part 4 – Stormwater Drainage
Section 4.6.3 Rainfall
Ruakura Rainfall Depth (mm) incorporating climate change

This data prepared by NIWA (NIWA Client Report WLG2008-010) provides for an IPCC medium range average temperature increase of 2.08 degrees Celsius by 2090.

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Appendix B

Level of Confidence Study
1.0 Introduction and Summary

Purpose

The purpose of this level of confidence study is:

1. to quantify the difference between the 5m RFA results and the detailed FHM to understand the RFA accuracy, and
2. to also compare the 5m RFA and a 2m RFA in two distinct areas.

Overall these comparisons will provide an understanding of the accuracy of the 5m RFA model in terms of overland flow direction and flood extents.

Background

The Rapid Flood Assessment (RFA) undertaken in the Stormwater Modelling programme used a 5m grid with no primary drainage except for culverts with diameters greater than 900mm.

The intention of the outputs from this phase was to provide an indication of where the detailed Flood Hazard Mapping (FHM) work would be focussed.

The grid size of a two-dimensional model is generally selected according to the specific requirements of the project. Since the resolution of the grid can directly influence the duration of the model simulation and the accuracy of the results, time constraints and accuracy requirements are also taken into account when selecting the grid size.

Once the grid size is chosen, LiDAR points are used to create the catchment digital terrain model (DTM). The DTM consists of a series of square grid cells and is used in both the hydraulic calculation by the two-dimensional model and during the flood mapping to help identify the extents of significant flooding areas.

For the stormwater flood hazard work there was two (2) grid sizes used:
- 5m for the Rapid Flood Assessment (RFA) work to understand where further detailed FHM was needed.
- 2m for RFA and detailed FHM work.

In order to more fully understand and quantify the differences in the flood extents produced by 5m RFA grid and 2m grids, analysis was undertaken and discussed further in the following sections.

This exercise has shown that there are some distinct limitations with each of the models that have been developed. These limitations are mainly centred on the location and extent of peak flooding. As a result of this exercise it is possible that there are some hazard areas that have not been identified during the 5m RFA process. In addition, there are some areas that have been over predicted due to the primary drainage network not being incorporated into the model. The key points identified through this analysis are as follows:

- Flooding is reduced in flood plains when the primary drainage network is incorporated; however, by not including the primary drainage network a worst case scenario is understood.
- Upstream flood areas in the 5m RFA will be over predicted due to the smaller culverts (<900mm) not being included.
- The regions where the 2m grid predicts flow that is not seen in the 5m grid are generally overland flow paths rather than ponding areas.
- The 5m RFA model failed to predict backwater at some culverts. This was identified in the Mangakotukotuku catchment; however, this may occur in other areas where the primary drainage does not have the opportunity to drain land locked areas to the watercourse.
- The 5m flood plains are under predicted in some cases.

1.1 Methodology

Two sets of analysis were undertaken as part of this study.

- 5m RFA results compared to the 2m detailed FHM outputs
- 5m RFA results compared to the 2m RFA results
The 2m and 5m grid model results for 6 hour simulation were compared by looking at the flood extents for each grid size, and identifying areas of difference. A depth comparison was also undertaken which calculated the difference in maximum depths by subtracting the 2m raster from the 5m raster. The following sections will discuss the results of the study in more detail.

### 2.0 5m RFA compared to the 2m detailed FHM results

This section discusses the comparison between the 2m detailed model results and the 5m RFA results for the three detailed FHM catchments, being Hamilton East, Waitawhiririhiri and Mangakotukutuku.

Figure 1 Location of Phase 1b Catchments
2.1 Hamilton East

Figure 2 and Figure 3 show the difference in flood extents between the 5m RFA and 2m detailed models results. Observations from these maps follow:

- Location of ponding areas and overland flow paths are consistent across both models.
- Main difference is around flood extents of ponding areas. 5m RFA flood extent is larger in majority of areas except for the open watercourse between Grey St and Te Aroha Street, where flood extent is bigger in the 2m detailed model.
- Area bounded by Knighton Road, Silverdale Road and Hillcrest Road has no flood extent in the 2m detailed model as the sub-catchment has been lumped and loaded downstream.

Figure 2 5m Flood Extent Larger than 2m Flood Extent

![Figure 2](image1)

Figure 3 2m Flood Extent Larger than 5m Flood Extent

![Figure 3](image2)
Figure 4 shows the difference in maximum depth between the 5m grid and 2m grid results for the Hamilton East catchment. The comparison shows that the difference in depth is more evident in ponding areas. The 2m detailed model has less depth than the 5m model for most of the catchment except for the watercourse between Grey Street and Te Aroha Street, where the 2m depth is deeper than the 5m. This is expected as the flood flows have been conveyed to the water course raster than ponding in the low areas.

The results of this comparison are consistent with what should be expected when the primary drainage network is incorporated into the model and the hydrology is carried out with infiltration losses taken into account.

2.2 Waitawhiriwhiri Catchment

Figure 5 and Figure 6 show the difference in flood extents between the 5m grid and detailed models results. Observations from these maps follow:

- Location of ponding areas and overland flow paths are consistent across both models.
- Main difference is around flood extents of ponding areas. 5m flood extent is larger in majority of areas. This is expected due to the primary drainage network not being included in the 5m RFA model.
- Area bounded by Tuhikaramea Road in the southwest corner of the catchment has no flood extent in the 2m detailed model.

Figure 7 shows the difference in maximum depth between the 5m grid and 2m grid results for the Waitawhiriwhiri catchment. The difference in depth is more evident in ponding areas where the 5m grid results are deeper than the 2m results. Again, this is expected due to the primary drainage network and hydrological refinements. It should be noted that the rural boundary condition to the south of Waitawhiriwhiri catchment was decreased significantly from the 5m RFA model due to the pervious ground conditions.
Figure 5  5m Flood Extent Larger than 2m Flood Extent

Figure 6  2m Flood Extent Larger than 5m Flood Extent
2.3 Mangakotukutuku Catchment

Figure 8 and Figure 9 show the difference in flood extents between the 5m grid and detailed models results for the Mangakotukutuku catchment. Observations from these maps follow:

- Location of ponding areas and overland flow paths are generally consistent across both models.
- Main difference is around flood extents of ponding areas. 5m flood extent is larger in majority of areas.
- Two (2) ponding areas shown to the south in Figure 9 did not exist in the 5m grid model.
- The northern culvert along Ohaupo Road experiences significantly more flooding in the 2m detailed model. This is expected due to the inclusion of the primary drainage network.

Figure 10 shows the difference in maximum depth between the 5m grid and 2m grid results for the Mangakotukutuku catchment. The difference in depth is more evident in ponding areas where the 5m grid results are deeper than the 2m results. Again, flood depths at the culverts have been exacerbated in the 2m detailed models due to the primary drainage network draining the catchment to the water courses.
Figure 8  5m Flood Extent Larger than 2m Flood Extent

Figure 9  2m Flood Extent Larger than 5m Flood Extent
Figure 10  5m Maximum Depth minus 2m Maximum Depth

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<td>&gt; 1.00</td>
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3.0 5m RFA compared to the 2m RFA results

Two (2) localised 2m RFA models were developed in the Kirikiriroa and part Rototuna catchments. These models were built on the same basis as the 5m RFA model with the following changes:

- 2m instead of 5m grids,
- did not utilise multi-cell overland solver, and
- incorporated all the road culverts.

The two areas selected are shown in Figure 11 below.

The following report sections will compare the 5m and 2m RFA model results for these two (2) catchments:

Figure 11 Location of Localised Models
3.1 Kirikiriroa Catchment

Figure 12 and Figure 13 shows the difference in flood extents between the 5m and 2m RFA Kirikiriroa model results. Observations from these maps are:

- Location of ponding areas and overland flow paths are consistent across both models
- For the majority of the catchment, the 2m RFA flood extent is greater than the 5m RFA flood extent.
- Figure 12 shows that in a small section of the catchment to the North that consists of the creek section between Gordon Road and Wairere Drive, and the adjacent roads; Millbrook Place and Ellsworth Place, the 5m grid model flood extent is larger. This is likely to have occurred due to the hydraulic conditions around the culverts in this area.

It should be noted that the area to the east of this catchment does not have 5m RFA results as the catchment flows were loaded at the HCC boundary.

Figure 14 shows the difference in maximum depth between the 5m and 2m RFA results. This figure shows considerable variability with regard to water levels in the watercourses. Typically the overland flow paths have been accurately predicted, however, the magnitude of these is variable due to the upstream culverts being in (2m RFA) or out (5m RFA) of the models.
Figure 13 2m Flood Extent Larger than 5m Flood Extent

Figure 14 5m Maximum Depth minus 2m Maximum Depth
3.2 Rototuna Catchment

The Rototuna catchment differs from the Kirikiriroa catchment in the topography. Rototuna is a large flat area while Kirikiriroa is a catchment with large significant watercourses traversing it. As a result the findings in this catchment are considerably different. Figure 15 and Figure 16 show the difference in flood extents between the 5m and 2m RFA model results. Observations from these maps follow:

- Location of ponding areas and overland flow paths are consistent across both models
- In majority of the catchment, the 2m RFA model flood extent is larger than the 5m grid model flood extent.

Figure 17 shows the difference in maximum depth between the 5m and 2m RFA results. Four (4) major ponding areas show up to 200mm reduction in depth in the 2m RFA model, these areas consist of:

- Callum Brae Drive.
- Area between Endeavour Avenue and Resolution Drive.
- Area between Kay Road and Sylvester Road.
- Area between Kay Road and the SH1 Motorway.

The remaining ponding areas show an increase in depth of up to 100mm in the 2m grid model.

Figure 15 5m Extent Larger than 2m Flood Extent
Figure 16 2m Flood Extent Larger than 5m Flood Extent

Figure 17 5m Maximum Depth Minus 2m Maximum Depth
4.0 Conclusions

This exercise has shown that there are some distinct limitations with each of the models that have been developed. These limitations are mainly centred on the location and extent of peak flooding. As a result of this exercise it is possible that there are some hazard areas that have not been identified during the 5m RFA process. In addition, there are some areas that have been over predicted due to the primary drainage network not being incorporated into the model. The key points identified through this analysis are as follows:

- Flooding is reduced in flood plains when the primary drainage network is incorporated; however, by not including the primary drainage network a worst case scenario is understood.
- The regions where the 2m RFA predicts flow that is not seen in the 5m grid are generally overland flow paths rather than ponding areas.
- The 5m RFA model failed to predict backwater at some culverts. This was identified in the Mangakotukotu catchment however this may occur in other areas where the primary drainage does not have the opportunity to drain land locked areas to the water course.
- The 5m flood plains are under predicted in some cases and this could result in some areas not being identified as high risk.
Appendix C

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1.0 Catchment Model Build Details

1.1 Waitawhiriwhiri

Model Development

Following the RFA process the Waitawhiriwhiri catchment was determined to have sufficient potential flood hazards to advance into detailed flood hazard modelling. In order to increase the level of confidence in the flood hazard results, the Waitawhiriwhiri model was developed as an integrated 1D-2D coupled model.

The catchment is bisected by a significant watercourse, namely the Waitawhiriwhiri Stream. In order to accurately assess the flood levels within the stream and the flow conditions around the culverts the stream was developed in Mike 11 software.

Due to the significant areas of flat residential areas a ground surface terrain model was developed in Mike 21 software. This model has the ability to objectively and accurately represent overland flow and flooding extents.

The pipe network was truncated in order to convey flows from areas that are not at risk of flooding to the areas where flooding was predicted to occur. In areas where flooding is predicted by the RFA the whole stormwater network was incorporated into the model. The primary drainage network was modelled in Mike Urban and connected to the stream (Mike 11) and the Mike 21 overland model via Mike Flood.

The catchment contains a fully separated public wastewater reticulation. Due to the high intensity of the storm events considered during the FHM model runs the losses to the wastewater system are considered to be negligible and therefore losses to the wastewater system have not been allowed for.

Model Components

The hydrological and hydraulic models were built during the Model Development Phase for the stormwater system. Details of the model software and model build methodology can be found in Stormwater Network Model Build Guidance Manual (AECOM 2011) attached.

The main model components are summarised in Table 1 below.

Table 1 Summary of Modelled Component

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The DHI Mike Urban and Mike 11 hydrological model was used to determine stormwater runoff.

Table 2 shows a summary of the software used to model the Oakley DMA.

Table 2 Software used for Waitawhiriwhiri FHM

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Data Collection

Data collected includes LiDAR, digital terrain model (DTM), aerial photography, asset data, survey and cross-sections.

LiDAR points were used to create the catchment DTM. The DTM consists of 2m square grid cells and is used both in the hydraulic calculation by the two dimensional model and during the flood mapping to help identify the extent of significant flooding areas.

During the RFA phase of the project an extensive culvert survey was undertaken in order to determine critical asset data about the key culverts throughout the City. During the development of his model 7 of the critical culverts were utilised.

A topographical survey was undertaken in September 2011. This survey was required in order to accurately represent the stream in Mike 11. During this survey a total of 11 cross-sections were surveyed and the results were used to update the model.

Manhole inspections and lid level surveys were also completed in September 2011.

Before the commencement of flood hazard mapping for Waitawhirihiri, a preliminary walkover of the catchment was conducted in August 2011. Subsequent site visits were undertaken at later stages throughout the modelling process to confirm extents of significant overland flow paths and flooding areas.

1.2 Mangakotukutuku

Model Development

The Mangakotukutuku model has been developed as an integrated 1D/2D coupled model with an associated watercourse model.

The catchment contains a fully separated public wastewater reticulation system. Due to the high intensity of the storm events considered during the FHM model runs the losses to the wastewater system are considered to be minimal; therefore an integrated wastewater/stormwater model was not considered critical to FHM results.

The hydrological and hydraulic models were built during the model development phase for the stormwater system. The main model components are summarised in Table 3 below.

<table>
<thead>
<tr>
<th>Input Type</th>
<th>Component Type</th>
<th>Number of Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Model (SW)</td>
<td>Number of MIKE 21 grid cells</td>
<td>1,889,176</td>
</tr>
<tr>
<td></td>
<td>Number of MIKE 11 branches</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Number of MIKE FLOOD Lateral link</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Number of MIKE FLOOD Urban link</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>Number of MIKE FLOOD River/Urban link</td>
<td>15</td>
</tr>
<tr>
<td>Hydrological Model</td>
<td>Number of MIKE Urban Sub-Areas</td>
<td>98</td>
</tr>
<tr>
<td></td>
<td>Number of MIKE 11 Sub-Areas</td>
<td>41</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>139</td>
</tr>
</tbody>
</table>

The DHI MIKE Urban and MIKE 11 hydrological model was used to determine stormwater runoff. The wastewater hydrological component was not modelled specifically for the Mangakotukutuku catchment as the wastewater system has been separated.

A coupled MIKE FLOOD model was used to determine stormwater flow processes. One dimensional and two dimensional models are run in a single and coupled simulation. In the Mangakotukutuku catchment the two dimensional model (MIKE 21) has been chosen to represent overland flow and MIKE 11 was chosen to represent open channel flow. Pipes and culverts are represented in the one dimensional model (MIKE Urban).
Table 4 shows a summary of the software used to model the Mangakotukutuku catchment.

Table 4 Software Used for Mangakotukutuku Model

<table>
<thead>
<tr>
<th>Software Name</th>
<th>Software Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHI Mike Flood, Mike 21, Urban and 11</td>
<td>2011 with Service Pack 4</td>
</tr>
</tbody>
</table>

### 1.3 Hamilton East

**Model Development**

This is the first time a model for the Hamilton East catchment is being developed. The Hamilton East model will be developed as an integrated 1D/2D coupled model.

The catchment contains a fully separated public wastewater reticulation. Due to the high intensity of the storm events considered during the FHM model runs, the losses to the wastewater system are considered to be minimal; therefore an integrated wastewater/stormwater model was not considered critical to FHM results.

**Model Components**

The hydrological and hydraulic models were built during the Model Development Phase for the stormwater system. Details of the model software and model build methodology can be found in Stormwater Network Model Build Guidance Manual (AECOM 2011).

The main model components are summarised in Table 5 below.

Table 5 Summary of Model Components

<table>
<thead>
<tr>
<th>Input Type</th>
<th>Component Type</th>
<th>Number of Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Model (SW)</td>
<td>Number of MIKE 21 grid cells</td>
<td>1,687,824</td>
</tr>
<tr>
<td></td>
<td>Number of MIKE FLOOD Urban link</td>
<td>367</td>
</tr>
<tr>
<td>Hydrological Model</td>
<td>Number of MIKE Urban Sub-Areas</td>
<td>196</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>196</td>
</tr>
</tbody>
</table>

The DHI MIKE Urban and MIKE 11 hydrological model was used to determine stormwater runoff. The wastewater hydrological component was not modelled specifically for the Hamilton East catchment as the wastewater system is separate.

A coupled MIKE FLOOD model was used to determine stormwater flow processes. One dimensional and two dimensional models are run in a single and coupled simulation. In the Hamilton East catchment the two dimensional model (MIKE 21) has been chosen to represent overland flow and MIKE 11 was chosen to represent open channel flow. Pipes and culverts are represented in the one dimensional model (MIKE Urban).

Table 6 shows a summary of the software used to model the Hamilton East catchment.

Table 6 Software Used for Hamilton East FHM

<table>
<thead>
<tr>
<th>Software Name</th>
<th>Software Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHI MIKE FLOOD, 21, 11 and Urban</td>
<td>Version 2011, Service Pack 4</td>
</tr>
</tbody>
</table>
2.0 Model Build – 2D Model Mike21

2.1 Introduction

The surface flooding will be represented in the 2D Mike21 model. The following section provides some general guidance on the parameters to be set during the model development. The parameter setup is separated into basic parameters and hydrodynamic (HD) parameters:

The basic parameters that need to be set up for the Mike 21 calculations are:
- Model simulation
- Bathymetry
- Simulation Period
- Boundary
- Source and Sink
- Mass Budget
- Flood and Dry

The HD parameters that need to be set up for the Mike 21 calculations are:
- Initial Surface elevation
- Boundary
- Source and Sink
- Eddy Viscosity
- Resistance
- Wave Radiation
- Wind Conditions
- Structures.

The parameters used in the flood hazard modelling are described below.

2.2 Model Simulation

The simulation chosen can be
- Hydrodynamic only, i.e. the HD module alone
- Hydrodynamic and Advection-Dispersion, i.e. the HD and AD modules
- Hydrodynamic and Mud Transport, i.e. the HD, AD and MT modules
- Hydrodynamic and ECO Lab, i.e. the HD, AD and ECO Lab modules

For the Hamilton FHM the HD will only need to be selected. If the bathymetry is located significantly above mean sea level it is recommended to enable 'High precision calculation' for the HD calculations. Otherwise rounding errors may become an issue. The Mike21 manual (DHI, 2009) will have further information if this is needed.

2.3 Bathymetry

When preparing the grid for the modelling, the following steps are important:
- Check that topography of the linear features such as roads and railways have not been lost or degraded during the interpolation process required to develop both the terrain and bathymetry. Manual editing may be required to fix the problem areas.
- For open channel flow paths not modelled in 1D, flow path connectivity should be enforced by removing bridges and culvert obstructions where appropriate (i.e. where blockages are deemed unlikely).
- Physical site inspection of drainage structures should be undertaken and photographic evidence of all important features should be collected and checked to ensure good alignment with 2D model grid.

When preparing the bathymetry for the modelling, the appropriate grid spacing and extent need to be considered. The number of “active” cells in 2D model and their size are the main factors determining the time required to run MIKE FLOOD simulation. The grid resolution for urban flooding (detailed) should be between 1 and 5 m. In the recent flood studies a grid size of 2m seemed to provide the necessary detail required for urban flooding. In order to reduce the simulation time, it is recommended to reduce the number of active cells by setting the elevation to “true land” for the cells that will never be subject to flooding.

If kerb lines are available the modeller needs to determine whether the road profile needs to be burned into the bathymetry or not. In flat areas the model could show the overland flow into properties if the road is not burnt into the bathymetry whereas in reality the kerbs would align the flow down the road. Overland flow should always be interrogated against site visit or street view to see whether the overland flow path is correct. For the HCC FHM work the kerb lines are not available at this stage but can be developed from the RGBi Impervious Area take-off work being completed for the Wastewater Modelling.

Where there is an open channel modelled in Mike11, the DTM would need blocking out cells under open channels where the models would be coupled to avoid double counting of the volume. As a rule of thumb, all channels wider than 2 grid cells should be blocked out.

The Coriolis forcing should be deactivated for MIKE FLOOD simulations as the effects are negligible for relatively small modelling extent found in MIKE FLOOD studies. Use of this parameter slows down the simulation.

2.4 Simulation Period

The simulation period chosen should correspond to the simulation period chosen for the Mike11 calculations. Generally the design storms used are 6, 12 or 24 hour nested storms in 5 minute interval rainfall. The time step specified in Mike21 over rides time steps specified in both Mike 11 and Mike Urban. AECOM will be running the 6, 12 and 24 hr ARI storms and the results discussed with HCC. For the Flood Hazard Map Scoping it must be accepted that were culverts are omitted from the model the greater flooding will occur upstream for longer duration storms due to increasing volumes of rainfall. For the final detailed model areas as the 6hr storm produces the peak flow rate it has been used to provide appropriate results and also minimise simulation times.

2.5 Boundaries

In the Guidelines for Stormwater Modelling using Mike Flood DHI recommend the following:

The boundaries should be located so as to minimise the impact of boundary effects such as ‘artificial’ backwater from outflow (downstream) and jetting of flows at inflow (upstream) boundary. For the inland model domains, this can be simplified by raising the cells at the edge of the domain to the ‘true land’ level. This is also called ‘closing the boundary’. It is important that the extent of the grid is large enough to accommodate maximum flood extent, i.e. the flood waters should not touch the boundary. If this cannot be achieved, sink points can be added to allow water to leave the domain if it is fair to assume that the water will not return into the modelling area. There are other methods of controlling the flow at the boundary (e.g. structure links), but the detailed elaboration on those is outside the scope of this document.

2.6 Initial Water Level

Initial water surface elevation (i.e. initial condition) should be set to realistic water levels at the beginning of the simulation and matched with the 2D boundary conditions. Most commonly, the bathymetry grid setting the initial water level to be same as the ground surface elevation. If the modelling area has an open boundary, initial conditions should be set to match boundary conditions used. Any depressions that are assumed to be filled at the commencement of the simulation can be incorporated into the initial water level file. This is done by using the bathymetry file as a base and selecting the extent of the depression and set the value to the required water level.

2.7 Source and Sink

Source and sinks provide a mechanism within the Mike21 model setup where a point source or a point sink of a specified magnitude can be inserted in the model. A velocity and direction is required for a point source to ensure flows leave the source point without causing instabilities.
2.8 Eddy Viscosity

For overland flow conditions it is unlikely that eddy viscosity will have a major effect on model predictions as friction will dominate in most cases. However, for flow in and around structures, the value of eddy viscosity can have a significant effect. The most recommended eddy viscosity formulation for MIKE FLOOD is “flux based” constant. Other choices available in the model setup are shown to be more prone to numerical instability in surface flooding applications. The following rule of thumb formula can be used for the value:

\[
\text{Constant Eddy} = 0.02 \, dx \, dy/dt \, [m^2/s]
\]

2.9 Resistance

When representing roughness, two options are available. These include using a catchment wide average roughness or 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 paved (e.g. roads, driveways) and unpaved areas (parks, reserves).

District plan coverage’s will be used to determine the roughness for private properties and open spaces. Open watercourses will be site specific based on construction type and coverage. The road reserve parcels will be used to determine the area for the road roughness. The road reserve roughness calculation will be based on the average percentage of impervious vs pervious. A list of proposed roughness values is shown in Table 7 below.

<table>
<thead>
<tr>
<th>Coverage Type</th>
<th>Manning’s n</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential Pervious</td>
<td>0.035</td>
<td>Typically pervious areas of residential properties are short grass with tree coverage</td>
</tr>
<tr>
<td>Residential Impervious</td>
<td>0.014</td>
<td>Typically driveways and paved areas will be broom finished or paving blocks</td>
</tr>
<tr>
<td>Commercial Pervious</td>
<td>0.035</td>
<td>Pervious areas consist or mainly gardens with high roughness</td>
</tr>
<tr>
<td>Commercial Impervious</td>
<td>0.013</td>
<td>Typically car parks are smooth texture asphalt pavement</td>
</tr>
<tr>
<td>Road Reserve Pervious</td>
<td>0.030</td>
<td>Pervious areas in road reserves are typically short grass with some tree cover</td>
</tr>
<tr>
<td>Road Reserve Impervious</td>
<td>0.015</td>
<td>Roads are constructed with rough asphalt pavement and concrete gutter</td>
</tr>
<tr>
<td>Open Spaces</td>
<td>0.030</td>
<td>Pervious areas in open spaces are typically medium grass with some tree cover</td>
</tr>
<tr>
<td>Bush cover</td>
<td>0.110</td>
<td>Dense bush cover, low velocity flows</td>
</tr>
<tr>
<td>Open Watercourses – concrete lined</td>
<td>0.013-0.020</td>
<td>Refer to ODOP Hydraulic Manual Appendix A for specific values</td>
</tr>
<tr>
<td>Open Watercourses – Naturally formed</td>
<td>0.033-0.150</td>
<td></td>
</tr>
</tbody>
</table>

Although the roughness can be used to stabilize MIKE FLOOD runs, care must be taken to stay within the realistic range of values applicable to the domain.

For the detailed model areas the average catchment wide roughness approach was used.

2.10 Flooding and Drying depth

Another important parameter in MIKE21 setup is flooding and drying. This feature of the 2D engine governs the status of a cell as active. The cell will not become active in the simulation until the water level in it exceeds the flooding value. Similarly, when the water level in a cell drops below the drying value, the cell will cease to be active. The flooding and drying values should be kept small to avoid problem with positive mass balance, i.e. water generated by the engine trying to prevent water depth in cells dropping below zero. The appropriate values for surface flooding are 0.003m for flooding and 0.002m for drying.
3.0 Model Build – 1D Model – Mike11

3.1 Introduction

Open channel flow will be modelled in Mike11 to more accurately represent flow and water levels in critical water courses. The extent of the open channels to be represented in Mike 11 should be considered in conjunction with the Client to ensure a balance between accurate representation and model build time is achieved.

Consideration should be given the following:
- Flood extent vicinity to properties with habitable floors
- Can the water course be appropriately represented in the Mike 21 bathymetry
- Are there culverts that create hydraulic controls within the watercourse

3.2 Cross Section Markers

As per the *Guidelines for Stormwater Modelling using Mike Flood* (DHI, 2010) the most significant difference in preparing the MIKE 11 model for MIKE FLOOD compared to stand alone MIKE 11 HD model, is in the way the cross sections markers are positioned. When a MIKE 11 model is coupled with 2D model in MIKE FLOOD, in most cases it is better to leave the floodplains in MIKE 21. To achieve this, the markers 1 and 3 need to be positioned to define the main channel only. Marker 1 defines the left bank, where the water will spill from the main channel into the left floodplain and marker 3 designates the right bank, where the water will spill form the 1D Mike11 model to the 2D Mike21 floodplain. Marker 2 is required to define the lowest point in the watercourse.

3.3 Dx Value

Another factor to keep in mind is the maximum dx value, i.e. the maximum distance between two adjacent water level computation points. As h-points are fundamental in linking, the dx value should relate to the grid spacing. Preferably, the resolution should be the same in the Mike21 and the Mike11 models, and not more than 3 grid cells in flat areas. Note that h computational point is inserted by the computational engine at each cross section location and the maximum dx value will be enforced between cross-sections.

3.4 Boundary Condition

While there are no special requirements for lateral links, it is necessary to specify a dummy water level boundary (in MIKE11 boundary file) for each standard or structure link point. The location of the boundary condition is used as a parameter in setting up the link. The value assigned is not important as it will be overridden during the simulation by the calculated value.

3.5 HD Parameter File

The creek flooding is represented in the maps by enabling the “Maps” option in MIKE 11 HD parameter file. This enables the integration of MIKE 21 and MIKE 11 results into a single 2-dimensional result file (.dfs2). The MIKE 11 user manual gives step-by-step instructions in how to use this feature.

The modeller needs to determine an initial water level that corresponds to the water level of the open channel flow.

All the parameters in the HD file are set with default values when initially created. The modeler should ensure all values are reviewed to ensure appropriate values are used in all parameter fields. Refer to the DHI user manual for further details for each parameter.

4.0 Model Build – 1D Model – Mike Urban

4.1 Introduction

Mike Urban shall be used for all the network modelling. Any outstanding data or low confidence asset data needs to be identified and reported back to Hamilton City. Survey and manhole lid inspection recommendations might
be necessary and identified during the model build process. Asset data is compiled from survey, as-built drawings, previous models and GIS datasets.

### 4.2 Data Collection, Model Settings and Status Flagging

This phase of the project is crucial to overall success of the program. Wherever, appropriate the data must be referenced and stored within the Hamilton City Council (HCC) GIS system.

There are 3 key elements that comprise the initial model calibration stage:

- Preparation of the hydraulic model - settings of initial values for the calibration
- Preparation of hydrological catchments – settings of initial values for calibration
- Initial analysis of flow survey and monitoring data

#### 4.2.1 Status Flagging

It is important to track the status of both records as well as individual attributes during the model building process and model calibration in order to ensure the source and reliability of the individual attributes can be known. MIKE URBAN has status fields on both record level as well as on attribute level. A default list of status codes is provided with MIKE URBAN but the list is user configurable and the Domain Editor dialog is shown in Figure 1 below.

**Figure 1 Domain editor for status codes in Mike urban**

<table>
<thead>
<tr>
<th>Code</th>
<th>Coded Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Model</td>
</tr>
<tr>
<td>2</td>
<td>GIS</td>
</tr>
<tr>
<td>3</td>
<td>Imported</td>
</tr>
<tr>
<td>4</td>
<td>Inserted</td>
</tr>
<tr>
<td>5</td>
<td>Modified</td>
</tr>
<tr>
<td>6</td>
<td>Calibrated</td>
</tr>
<tr>
<td>7</td>
<td>Verified</td>
</tr>
<tr>
<td>8</td>
<td>Error</td>
</tr>
<tr>
<td>9</td>
<td>Unknown</td>
</tr>
<tr>
<td>10</td>
<td>Other</td>
</tr>
</tbody>
</table>
4.2.2 List of HCC Status Codes

Table 8 List of status codes to be used in model building process

<table>
<thead>
<tr>
<th>Code</th>
<th>Code Text</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GIS Initial Supply 20101015</td>
</tr>
<tr>
<td>101</td>
<td>GIS Update YYYYMMDD</td>
</tr>
<tr>
<td>102</td>
<td>GIS Update YYYYMMDD</td>
</tr>
<tr>
<td>103</td>
<td>GIS Update YYYYMMDD</td>
</tr>
<tr>
<td>2</td>
<td>Initial Supply from HANSEN YYYYMMDD</td>
</tr>
<tr>
<td>201</td>
<td>Updated from HANSEN YYYYMMDD</td>
</tr>
<tr>
<td>202</td>
<td>Updated from HANSEN YYYYMMDD</td>
</tr>
<tr>
<td>203</td>
<td>Updated from HANSEN YYYYMMDD</td>
</tr>
<tr>
<td>3</td>
<td>Manual Interpolation</td>
</tr>
<tr>
<td>4</td>
<td>Mike Urban Interpolation</td>
</tr>
<tr>
<td>5</td>
<td>Inferred-Needs to be checked</td>
</tr>
<tr>
<td>6</td>
<td>Updated from As-builts</td>
</tr>
<tr>
<td>7</td>
<td>Updated from ACAD</td>
</tr>
<tr>
<td>8</td>
<td>Updated from Survey</td>
</tr>
<tr>
<td>9</td>
<td>Updated from Inspections Sheets</td>
</tr>
<tr>
<td>10</td>
<td>Updated from Mike 21 Existing Bathymetry</td>
</tr>
</tbody>
</table>

Other Status codes can be added to the list in consultation with HCC.

4.2.3 List of Records and Attributes Requiring Status

The following attributes are required by HCC to have a status code assigned.

Nodes
- Ground Level (all types of nodes; manholes, basins, outlets and storage nodes)
- Invert Level (all types of nodes; manholes, basins, outlets and storage nodes)
- Diameter (all manholes)
- Head loss parameters (all manholes)

Links
- Upstream Level (all types of links)
- Downstream Level (all types of links)
- Diameter (all links with shape circular)
- Width (all links with shape rectangular)
- Height (all links with shape rectangular)
- Material (all types of links)

4.2.4 Model Version

It is important that the calibration is performed on a model version that represents the sewer network at the time of the monitoring period. For this reason it is important that the status codes are always used in the model and HCC GIS.
4.2.5 Naming Convention

Consistent naming convention should be undertaken to enable a link between the stormwater model and GIS and/or HANSEN data.

Recommended naming convention for Nodes and Pipes and Canals are in Table 4 and Table 5 below:

Table 9 Naming convention for nodes

<table>
<thead>
<tr>
<th>GIS/HANSEN ID</th>
<th>Mike Urban ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPKEY</td>
<td>Asset ID</td>
</tr>
<tr>
<td>UNIT ID</td>
<td>Node ID (MUID - Mike Urban ID)</td>
</tr>
<tr>
<td>ASSET</td>
<td>Description</td>
</tr>
</tbody>
</table>

Table 10 Naming convention for pipes and canals

<table>
<thead>
<tr>
<th>GIS/HANSEN ID</th>
<th>Mike Urban ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPKEY</td>
<td>Asset ID</td>
</tr>
<tr>
<td>COMPKEY</td>
<td>Link ID (MUID - Mike Urban ID)</td>
</tr>
<tr>
<td>TYPE</td>
<td>Description</td>
</tr>
</tbody>
</table>

Note: In the case of merging pipes for whatever reason, GIS/HANSEN compkeys for merged pipes should be added into Mike Urban Asset ID separated by "-". The same applies for Mike Urban Link ID as well.

4.3 Hydraulic

The purpose of a detailed calibrated MIKE URBAN model is to enable HCC to understand the relationship between problems in the system and the hydraulics of the stormwater system.

The project has two phases.

Phase 1 consists of two sub-phases being 1a and 1b:

- Phase 1a – FHM Scoping will provide an understanding of potential flood areas using a rapid flood assessment approach.
- Phase 1b - the 100yr ARI Flood Hazard Map outputs will be produced using more detailed modelling for the prioritizes areas based on results of Phase 1s RFA. Coupled 1D (mike Urban and M11) and 2D (Mike 21) will be used for Phase 1b modelling.

4.3.1 Pipe Network

The primary pipe stormwater is that part of the system which takes the regular flows. The primary piped system comprises of a series of manholes and pipes, open channels and other ancillary structures which drain the catchment.

All asset data used in the model must be reviewed, checked and verified for the purposes of assessing its suitability for model build. Drainage infrastructure data required for model build are outlined:

Manhole Data

Typical manhole (node) data needed to build a hydraulic model are:

- Manhole ID – as outlined in the naming convention section.
- Coordinates (Easting, Northing)
- Manhole diameter
- Manhole invert level
- Manhole ground level (lid level)
- Benching (if present)
- Physically sealed
- Spill level (if present)

**Pipe Data**

Typical pipe data needed to build a hydraulic model are:

- Pipe ID – as outlined in the naming convention section.
- Upstream manhole ID
- Downstream manhole ID
- Pipe diameter (or other sizing parameter)
- Pipe upstream invert level
- Pipe downstream invert level
- Pipe material (roughness)
- Rising main (or not)
- Pipe length (especially for rising mains)

Only pipes equal to or greater than 300mm diameter will be modelled in the areas agreed with Hamilton City that detailed modelling is necessary.

All manholes connected to the modelled pipes shall be included in the model system data. Manhole diameters shall be cross-referenced with the diameter of connected pipes to ensure that physical connectivity is possible. The invert level of the manhole shall be cross-referenced with pipe inverts to check on connectivity.

Pipes shall be checked for invert levels lower than ground levels. Negative slope pipe shall also be identified and inverts checked and updated where appropriate.

Relatively short pipes which are not hydraulically significant shall be identified in order to improve model robustness. Short pipes shall be solved either by removal of intermediate manholes or by extending the pipe lengths. If pipes are removed or merged with other pipes, IDs must be provided and originally ID should be stored in Asset Name. The MIKE URBAN Simplification Wizard tool will be used for this purpose.

The primary system model shall be based on the assumption that all pipes, culvert inlets and outlets are capable of achieving their respective discharge capacities and are unaffected by partial or total blockage but may be affected by pipe condition and sediment.

**Pipe Condition** - The condition of the pipe can have a significant impact on the roughness of the pipe. Pipe condition data (e.g. from CCTV surveys) should be used where available to determine the roughness of pipes.

**Sediment Level Data** - Sediments may reduce the cross-sectional flow area of the pipes and also increase roughness. Sediment depth data (e.g. from CCTV, flow survey reports, or from operational records) should be incorporated where available.

### 4.3.2 Open Channels

**Open Channel Data**

Open channels include natural or manmade drainage paths usually as part of the stormwater primary system, but also include overland flow paths mainly from the stormwater system but also from the wastewater system. In many respects the modelling of open channels is similar to the modelling of the pipe network. Some of the key issues regarding open channel modelling are discussed in this section to highlight differences between the two systems. For the flood hazard mapping for HCC the open channels will generally be represented with Mike11 or may be represented within the Bathymetry.

Section data must be surveyed or inferred from topographical data to an adequate accuracy. Typical open channel data needed to build a hydraulic model are:

- Section ID – must be unique.
- Upstream node ID
- Downstream node ID
- Chainage (if using topography feature)
- Cross-section (x-z pairs for an open channel)
- Channel roughness

**Linkage from 1D to 2D model**

Surcharging manholes shall be modelled primarily using the 1D – 2D coupling method.

**Weirs**

A weir represents the overflows from the network. A weir is defined with location and discharge point (To Node). The location can be any node in the system. The discharge point can be any node in the system except an outlet. If the discharge point field is left blank, then the weir is discharging out of the system. The flow can go both ways across the weir except if the discharge point is left blank, then the discharged water is not returning into the simulation.

In a situation where one way flow is required between a Mike Urban node and M21 a weir can be defined. In this case the “from node” is the Mike Urban node and the “to node” is the left blank. In Mike Flood the coupling is defined as a weir to Mike 21 coupling. In this case the flow will transfer in one direction only i.e. from the node to the M21 bathymetry. For a detailed description on this type of setup refer the DHI user manual.

For the weir the following must be specified:

- Weir Type (Weir Formula or Q-H)
- Invert level
- Flow angle (Side (0°) or perpendicular (90°))
- Weir coefficient (Weir Formula)
- Operation Mode (Optional)
- Flap (Optional - A non-return valve can be set at the weir to prevent flow discharging in the opposite direction of the definition (Location / To Node)).

The weir type shall be defined and the definition depends on the actual weir. It is optional to model the flow across the weir using weir formula or based it on a Q-H relation.

Invert level must be set and represents the crest level of the weir.

The angle of the weir must be set and can either be perpendicular to the flow direction (orthogonal, 90°) or parallel to the flow direction defined as a side weir (0°).

The weir coefficient used in MOUSE is the $C_h$ coefficient. Weir coefficients are often found in the literature as $C_d$ and $C_w$ coefficients. The weir coefficient must be set and depends on the actual constructed weir. For more details refer to Ref 3.

**Orifices**

An orifice is an opening of any shape allowing water passage between otherwise separated parts of the network. Usually an orifice represents a flow restriction. As with weir, the orifice represents a function between two nodes. MIKE URBAN supports any shape of orifice and for rectangular shapes controllable gates can be added. An orifice cannot be connected to an outlet.

Basically there are four flow regimes covered by the orifices in MIKE URBAN.

- Free overflow
- Submerged overflow
- Free underflow
- Submerged underflow

For the orifice following must be specified:

- Orifice Type (Circular, CRS, or Rectangular)
- Geometry depending on orifice type
- Invert level
- Discharge coefficient
- Operation Mode (optional)
- Flap (Optional - A non-return valve can be set at the orifice to prevent flow discharging in the opposite direction of the definition (Location/Discharge Point)).

The orifice type shall be defined and the geometry depends on the actual orifice type. Invert level must be set and represents the invert of the orifice. The discharge coefficient must be specified and depends on the actual orifice. Default orifice coefficients are supplied with MIKE URBAN. Specific orifice coefficients can be found in the literature. For more details please also refer to Ref 3.

4.3.3 Basins and Other Storage Areas

Storage areas shall be modelled as a structure with inlet and outlet arrangements modelled appropriately.

The geometry of the basins shall be provided in the model as H, A_c, A_s data. The A_c represents the cross sectional area of the flow and the A_s the horizontal area at a given level. For the actual computation in the MOUSE engine only the H and A_s values are used.

The characteristics of the filling and emptying may need control rules (RTC) to be implemented.

Typical basin data needed to build a hydraulic model are:
- Basin ID – as outlined in the naming convention section.
- Coordinates (Easting, Northing)
- Representative Level – Area (storage) relationship
- Representative Level – Area (cross-sectional) relationship
- Outlet invert, size and entrance shape.
- Basin ground level
- Overflow level and dimension

4.3.4 Syphons (inverted)

Siphons shall be modelled explicitly using a pressurised pipe which allows the correct calculation of pipe velocities and losses. The full length of the siphon including down pipes shall be included, so that head losses are calculated correctly. Additional head losses for bends, bell mouths etc. shall be derived from standards provided by the manufacturer. It is understood at this stage that there are no syphons in the Hamilton City Stormwater network.

4.3.5 Other Structures

Other complex existing structures e.g. in the stormwater system shall be modelled using best judgement and schematisation in consultation with HCC.

4.3.6 Outlets

Outlets are locations at the boundary of the model i.e. where it enters a network part which is outside the modelled catchment area. In a Mike Flood model an outlet can be coupled to M21 and M11 to ensure continuity of flow through the model.

The outlet shall be modelled according to the current downstream conditions at the outlet boundary. Outlets can be modelled as free outlet and submerged outlet. A tidal boundary curve can be attached to the outlet in order to model time varying water level in the recipient water body (e.g. at overflows). If a non-return valve exists at the outlet, it should be included in the model and assigned to the outfall pipe. Only one pipe can be connected to an outlet in MIKE URBAN.
4.3.7 Manhole Cover Type

There are three ways in which manholes / system nodes can be defined to accurately reflect the system behaviour when the water level reaches the ground surface:

- Spilling - This is the where it is assumed that any water which breaches the ground level at a manhole, escapes the system. MIKE URBAN also allows a parameter which specifies a level of pressure head which must be exceeded above the ground level before the manhole starts spilling.

- Sealed – This is used to represent nodes in a rising main network and locked manhole covers. The HGL can exceed the ground level without water escaping the system.

- Normal - Typical option for combined or storm water systems, where excess flow is stored in a notional storage area above the ground level and is returned to the sewer when capacity is available.

A cover type of all modelled manholes shall be set to “normal”, which is required to allow linkage between 1D and 2D model.

Only normal cover should be used for manholes, except for the pressurised parts of the pipe network or where there is knowledge of sealed manholes and nodes should be sealed and not coupled for these cases. Unlike in standalone MIKE URBAN modelling, spilling nodes should be avoided as their use leads to loss of water out of MIKE FLOOD model.

4.3.8 Ground Level

One of the important aspects of coupling MIKE URBAN model is agreement of ground levels between MIKE 21 and nodes in MIKE URBAN. There is a tool in MIKE URBAN that generates a level differences map. Any disagreement between the levels (which are often found) can be resolved by MIKE FLOOD, based on several parameters in Dhiapp.ini file. MIKE FLOOD can be configured to use MIKE 21 level as the correct and change the ground level in the coupled node accordingly when the difference is below the value assigned for MM21_ALLOWEDGROUNDLEVELDIFFERENCE (set M21_AS_GROUNDLEVEL = 1). Use of this parameter should be considered carefully as it can cause problems with MIKE URBAN network integrity (check profile in MIKE View to see pipes being above the top of manholes, refer to Figure 2). Manually correct any major ground level differences (e.g. of more than 10 cm) between DTM and linked nodes. This may involve both editing elevations in the grid and adjusting the ground levels in MIKE URBAN, depending on the data quality and local considerations.

4.3.9 Dhiapp.ini File

According to the Guidelines for Stormwater Modelling using Mike Flood there are several other aspects that need to be considered when MIKE URBAN model is used in MIKE FLOOD, coupled with MIKE 21. They are covered under the ‘MOUSE – MIKE 21 PARAMETERS’ heading in Dhiapp.ini file (see Figure 2). It is common to leave the default values in place.

Figure 2 Mike Flood related coupling parameters in MIKE Urban Dhiapp.ini file
In addition, it is recommended to increase the RESERVOIRHEIGHT to prevent artificial storage being formed above the manhole, which could lead to double counting the storage for manholes located in depressions.

**Figure 3** Error in Mike Urban network caused by using automated ground level alignment (coupling parameter M21_AS_GROUNDLEVEL=1 forcing the manhole to align with DEM

### 4.3.10 Manhole Head Loss

Head losses are calculated at manholes in MIKE URBAN. The MOUSE engine calculates following losses at the manhole:

- Inlet expansion loss
- Direction or bend loss
- Drop loss
- Outlet pipe contraction loss

The head loss formulation in MIKE URBAN is flexible and different head loss formulations can be combined into individual Head Loss IDs. A Head Loss ID is basically made up by

- Method
- Effective Node Area
- Loss Coefficient
- Max Loss Limits

#### Method

The Method represents the ‘Classic’, ‘Mean Energy Approach’ and ‘No Head Losses’.

- ‘Classic’ corresponds to the MOUSE head loss options, Round Edged, Sharp Edged. The inlet expansion loss is included in this equation. The different option uses the same equation, but different energy loss coefficients.
- ‘Mean Energy Approach’ does not include inlet expansion loss. It assumes that the energy level in the manhole is the same as in the inlet pipe. This means that the inlet expansion loss is ignored and the outlet losses are applied across the manhole.

- ‘No Head Losses’ is provides the option of applying no head losses at all. This option shall be used when connecting open cross sections, fictitious nodes i.e. underground connection of pipes. The volume of these nodes is still included so the diameter of the node should be considered carefully.

**Effective Node Area**

The effective area is used when applied to manholes with one ingoing pipe and one out going pipe. The calculation of the inlet and the outlet contraction loss involves the cross sectional area of the manhole. There is two options either the flow expands into the full cross sectional area of the manhole or passes through the manhole as a type of submerged jet. The submerged jet implementation is only valid for one ingoing pipe and one out going pipe. If the option with submerged jet is applied to manholes with more than one ingoing pipe or outgoing pipe, then the full cross sectional area of the manhole shall be used.

**Loss Coefficient (Km, Contraction HLC or Total HLC)**

The loss coefficient is applied to the calculation of the head loss at the outlet of the manhole. These factors do not influence the calculation of the inlet expansion loss.

- Km
- Contraction HLC
- Total HLC

The Km value is only used in the calculation of the outlet contraction loss. Km is an intermediate head loss coefficient and is scaled by the velocity in the manhole and in the outlet pipe.

The Contraction HLC is only used in the calculation of the outlet contraction loss but is not scaled by the velocity in the manhole and outlet pipe. Using the Contraction HLC effectively fixes the value of the outlet contraction loss coefficient.

The Total HLC not only overrides the outlet contraction loss coefficient, but it also overwrites the calculation of the bend loss coefficient and the drop loss coefficient.

**Max Loss Limits**

It is optional to apply the upper limit of the maximum head loss and it can be applied to any head loss combination. There is two options available either based on the flow depth or the velocity on the outlet pipe.

**Recommendations**

For Straight-Through manholes (0°-30° deviation angle at manhole) the head loss should initially be set to

- Method: Mean Energy Approach
- Coefficient: Km = 0.25 (Mike Urban default value)

For manholes with bends greater than approx. 30° or manholes with multiple number of inlet pipes use following settings:

- Method: ‘Classic’ (Round or Sharp edged type in MOUSE)
- Coefficient: Km = 0.5 (Mike Urban default value)

For manholes with special hydraulic setup then the settings below can used. This setting will overwrite the head loss calculated by MOUSE engine to the head loss provided:

- Method: Mean Energy Approach
- Coefficient: Total HLC
- Loss Value: Should be based on engineering judgement, engineering tables from the literature.

The head loss settings recommended above is initial settings. The settings shall be verified as part of the calibration.
4.3.11 Non Return Valves

Non return valves are modelled as a flow control within a link in the MOUSE model system. MIKE URBAN allows for the inclusion of valves within rising mains. All installed flaps, non-return valves must be modelled.

4.3.12 Pipe Roughness

Pipe roughness shall initially be determined based upon the material type assigned to each pipe in HCC GIS. MIKE URBAN allows the use of Manning’s ‘n’, Colebrook-White or Hazen-Williams Roughness formulas.

For gravity pipes Manning roughness equation shall be used and default values provided in MIKE URBAN shall be used based on the pipe material.

Table 11  Pipe Roughness values

<table>
<thead>
<tr>
<th>Code</th>
<th>Pipe Material</th>
<th>Manning’s n-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>ASBESTOS CEMENT</td>
<td>0.011</td>
</tr>
<tr>
<td>ACM</td>
<td>MDPE IN ASBESTOS CEMENT DUCT</td>
<td>0.013</td>
</tr>
<tr>
<td>ACUPVC</td>
<td>UPVC IN ASBESTOS CEMENT DUCT</td>
<td>0.011</td>
</tr>
<tr>
<td>ALK</td>
<td>ALKATHENE:LDPE OR HDPE</td>
<td>0.013</td>
</tr>
<tr>
<td>ALU</td>
<td>ALUFLO (ALUMINIUM PIPE)</td>
<td>0.025</td>
</tr>
<tr>
<td>CI</td>
<td>CAST IRON</td>
<td>0.012</td>
</tr>
<tr>
<td>CICL</td>
<td>CAST IRON - CONCRETE LINED</td>
<td>0.012</td>
</tr>
<tr>
<td>CIMDPE</td>
<td>MDPE IN CAST IRON DUCT</td>
<td>0.013</td>
</tr>
<tr>
<td>CP</td>
<td>CCTV CONCRETE PRECAST</td>
<td>0.013</td>
</tr>
<tr>
<td>CU</td>
<td>COPPER</td>
<td>0.011</td>
</tr>
<tr>
<td>DICL</td>
<td>DUCTILE IRON - CONCRETE LINED</td>
<td>0.012</td>
</tr>
<tr>
<td>EW</td>
<td>EARTHENWARE,VC,CERAMIC</td>
<td>0.014</td>
</tr>
<tr>
<td>EWCP</td>
<td>EW LINED WITH CIPP RESIN</td>
<td>0.014</td>
</tr>
<tr>
<td>EWHDPE</td>
<td>HDPE IN EARTHENWARE DUCT</td>
<td>0.013</td>
</tr>
<tr>
<td>EWMDPE</td>
<td>MDPE IN EARTHENWARE DUCT</td>
<td>0.013</td>
</tr>
<tr>
<td>EWPOLY</td>
<td>EW LINED WITH FIBREGLASS RESIN</td>
<td>0.011</td>
</tr>
<tr>
<td>GALV</td>
<td>GALVANISED</td>
<td>0.016</td>
</tr>
<tr>
<td>HDPE</td>
<td>HIGH DENSITY POLYETHYLENE</td>
<td>0.013</td>
</tr>
<tr>
<td>HDUPVC</td>
<td>HEAVY DUTY UPVC</td>
<td>0.01</td>
</tr>
<tr>
<td>MDPE</td>
<td>MEDIUM DENSITY POLYETHYLENE</td>
<td>0.013</td>
</tr>
<tr>
<td>PVC</td>
<td>MODIFIED PVC</td>
<td>0.01</td>
</tr>
<tr>
<td>PVC2</td>
<td>BLUE RHINO,GENEX,METRO</td>
<td></td>
</tr>
<tr>
<td>MPVMDP</td>
<td>MDPE IN MPVC2 DUCT</td>
<td>0.013</td>
</tr>
<tr>
<td>MS</td>
<td>MANNESMANN</td>
<td></td>
</tr>
<tr>
<td>NOVA</td>
<td>FLEXIBLE PVC,PERFORATED</td>
<td></td>
</tr>
<tr>
<td>OPVC</td>
<td>UPVC</td>
<td>0.01</td>
</tr>
<tr>
<td>PPR</td>
<td>POLYPROPYLENE RIBBED PVC SN16</td>
<td>0.018</td>
</tr>
<tr>
<td>PVC-O</td>
<td>BIAXIALLY ORIENTATED PVC</td>
<td>0.01</td>
</tr>
<tr>
<td>RC</td>
<td>REINFORCED CONCRETE</td>
<td>0.013</td>
</tr>
<tr>
<td>RCCIP</td>
<td>RC LINED WITH CIPP RESIN</td>
<td>0.014</td>
</tr>
<tr>
<td>Code</td>
<td>Pipe Material</td>
<td>Manning’s n-value</td>
</tr>
<tr>
<td>----------</td>
<td>---------------------------------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>RCHDPE</td>
<td>HDPE IN CONCRETE DUCT</td>
<td>0.013</td>
</tr>
<tr>
<td>RCPOLY</td>
<td>RC LINED WITH POLYESTER RESIN</td>
<td>0.015</td>
</tr>
<tr>
<td>RCSPPVC</td>
<td>RC LINED WITH SPIRAL WOUND PVC</td>
<td>0.015</td>
</tr>
<tr>
<td>RCSRL</td>
<td>RC WITH SULPHATE RESIST LINER</td>
<td>0.015</td>
</tr>
<tr>
<td>RCUPVC</td>
<td>UPVC IN CONCRETE DUCT</td>
<td>0.01</td>
</tr>
<tr>
<td>SS</td>
<td>SPIRAL STEEL UNLINED</td>
<td>0.016</td>
</tr>
<tr>
<td>SSCL</td>
<td>SPIRAL STEEL CONCRETE LINED</td>
<td>0.013</td>
</tr>
<tr>
<td>SSUPVC</td>
<td>UPVC IN STEEL DUCT</td>
<td>0.01</td>
</tr>
<tr>
<td>U</td>
<td>UNKNOWN</td>
<td></td>
</tr>
<tr>
<td>UPVC, 1 &amp; 2</td>
<td>UPVC (UNPLASTICISED)</td>
<td>0.01</td>
</tr>
</tbody>
</table>

For pipes defined as rising main pipes, the Colebrook-White roughness may be used.

4.3.13 Computational Grid Points

The computational grid points are set automatically by the MOUSE engine. The number of grid point can be changed for specific reason and this should be discussed with HCC if required to do so.

4.3.14 Priessmann Slot Widths

The Priessmann slot width shall be set to 1cm (default) for all pipes, unless changed for a specific reason and discussed with HCC if required to do so.

5.0 Model Build – 1D Model – Mike Flood

5.1 Introduction

This section will give an overview of the link types available in MIKE FLOOD, as well as how the coupling of the Mike Flood model needs to be approached in developing Flood Hazard Mapping models for Auckland City Council. In-depth technical details for the linking options available in Mike Flood can be found in the MIKE FLOOD manual.

5.2 URBAN Links

URBAN links enable exchange of flow between urban network and the 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 allowed flow can be specified.

Discharge out of the pipe network to overland flow is considered to be weir flow, unless it is pumped. This is compatible with flow out of a manhole, provided the depths don’t get too great. Once the “receiving” ground is flooded, the submerged weir equation is applied. Orifice flow applies for depth > 0.4 x manhole diameter, and weir flow for depth < 0.25 x manhole diameter.
Flow from weirs in MIKE URBAN is one directional, i.e. the flow only flows into the MIKE 21 model and not back. This can be fixed if needed by replacing a weir with a small pipe and an outlet and couple the outlet instead. At occasions the modeller might want the overland flow to only flow into one direction; this is where a dummy weir would then be set up. This could be used in a situation where manholes are located in flow paths or flood plains. If a normal coupling is used flow can incorrectly transfer into the pipe model unless one way flow is established.

It is possible to couple a node to multiple cells if using a rectangular grid. In general, using multiple cells as opposed to coupling to only one point will enhance stability. Where multiple cells are coupled to MIKE Urban the highest Mike21 cell is used as the default Mike Urban lid level. This can be over written in the ini file to force the mike urban lid level to be the default level.

With inlet and outlet couplings, the Exponential Smoothing Factor should be set to 0.2 – 0.4. The value can be reduced further (which increases the smoothing) if the link causes instability problems. If a particularly small value of the smoothing factor is used, the modeller should be satisfied that the results are reasonable.

When MIKE URBAN is coupled in MIKE FLOOD, the amount of water let into the coupled manhole with a catchment connection is limited by the Q_{\text{max}}. The modeller needs to assess what Q_{\text{max}} will be. It is recommended to assess the number of cesspits in the catchment and assume 25 l/s per cesspit is transferred into the primary network. It may in some instances be necessary to model the catchment nodes as dummy nodes. The modeller needs to assess the runoff hydrograph and the capability of the inletting and the primary network to take the flows.

5.3 River-Urban Links

The river urban link has been designed for modelling the dynamic interaction of the river network and the collection system. River-Urban links connect MIKE URBAN and MIKE 11 models in MIKE FLOOD. Small streams and ditches modelled in MIKE 11 can be routed into a stormwater pipe system simply by linking the downstream water level boundary to the MIKE URBAN inlet node.

Outflow from a MIKE URBAN model into a river can be pumped, over a weir, or fully linked to MIKE 11 via chainage. The link is placed at the nearest cross-section. While pump and weir link allow only transfer of water from MIKE URBAN to MIKE 11, the fully linked “Outlet” or “WL Boundary” links allow reverse flow as well which makes it suitable for modelling backwater effects.

Figure 5 Mike Urban to Mike11 coupling schematic

5.4 Mike11 – Mike21 Links

Links between MIKE 11 and MIKE 21 are the most comprehensive group of links, enabling the dynamic exchange of flow between channels, streams and rivers (1D) and surface (2D).

The lateral and standard links define the movement of water both along the river and at the connection point between end of MIKE 11 model and grid cells on the surface. The structure links allow for detailed modelling of a structure within 2D domain which spans more than two grid cells (structures connecting adjacent cells can be modelled directly in Mike 21).

Figure 6 Mike11 to Mike21 coupling schematic
5.5 Standard Links

The standard links connect one or more MIKE 21 cells to the end of a MIKE 11 branch. This type of link is useful for connecting a detailed MIKE 21 grid/mesh into a broader MIKE 11 network, or to connect an internal structure (with an extent of more than a grid cell) or feature inside a MIKE 21 grid/mesh. The end of branches in MIKE 11 that connect to MIKE 21 must have a water level boundary specified. This is a dummy boundary specification for initialization purposes only and will not affect the calculated values during the simulation.

More details on how to configure standard links can be found in MIKE FLOOD User Manual.

5.6 Lateral Links

The Mike11 open channel should be laterally linked to the Mike21 surface. This link will represent the flow from the main channel into the floodplain.

Flow through the lateral link is calculated using a structure equation. Five (5) alternative types of structures are available, including weirs, tabulated discharges and a standard head-loss equation. The structure level information can be taken from MIKE 21, MIKE 11 or can be supplied in an external file.

Figure 7 Standard link types and how they work

AECOM - DHI recommend the following:
- Choose the CELLTOCELL method over the obsolete SIMPLE method. It is more flexible, more accurate and is the default choice;
- Use a dx value in MIKE11 that is similar to the grid side length;
- Lateral link weir invert level should always be higher than the cell it is connecting to;
- Very long sequences of linked cells will (depending on the size of the cells and the meandering of the branch) tend to be longer than the corresponding MIKE11 branch. Check this using the mflateral.txt file and where the match between lengths becomes unacceptable, break linked branches into smaller sections. Step-by-step guide how to use this feature can be found in MIKE FLOOD manual, under the “Lateral link height analysis heading”.
- The use of the depth tolerance makes the water quite viscous below the specified value. This slows the rapidity with which flow is transferred from MIKE 11 to MIKE 21 and vice versa, avoiding “see-sawing”. Experiment with the sensitivity of your model in initial stages of the build and try to make the depth tolerance as low as possible. This can be significant where the depth of water flowing over the lateral link weir is relatively shallow compared to the depth tolerance value. If numerical instabilities are evident in model runs when flows reverse at these links, consider raising this tolerance.
- If flow passes between channel and floodplain over a relatively wide bank covered in vegetation, pay some attention to the appropriate flow resistance (i.e. Manning’s n) to apply to the link. Make sure the roughness used in the lateral link is not too high. If the value is too high then the water levels in MIKE 11 will tend to be super elevated which, except in situations where extreme amounts of vegetation are present, is nonsensical.
- If the stop bank is the earthen or similar, allowing its invert to be taken from the MIKE 11 or MIKE 21 should be fine. However, in case of well-defined structure like side weirs constructed in concrete, more precise levels should be made available to the model by using an external ASCII file.

### 5.7 Structure Links

The structure link is used to simulate structures within the Mike21 model. For the linkage a MIKE 11 branch with upstream cross-section, structure, and downstream cross-section is linked to MIKE 21 with two links, one for each end of the structure. The link takes the flow terms from the structure in MIKE 11 and applies them directly into the momentum equations of MIKE 21. The Mike Flood Manual provides further details on the options available and how to set the link up.

### 6.0 Hydrology

#### 6.1 Rainfall – Runoff Model

The Mike Urban hydrological model is to be used in order to model the rainfall-runoff process. Currently there are four rainfall-runoff models. Each model is a split-catchment model that defines both impervious and pervious areas.

Most rainfall-runoff models consist of a loss model and a routing model. Mike urban gives the modeller the option of several rainfall-runoff models. The rainfall runoff models are summarized in Table 12 below.

<table>
<thead>
<tr>
<th>Model</th>
<th>Name</th>
<th>Loss Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>Time-Area Relationship</td>
<td>Initial plus proportional loss</td>
</tr>
<tr>
<td>Model B</td>
<td>Kinematic Approach</td>
<td>Horton Infiltration Losses</td>
</tr>
<tr>
<td>Model C</td>
<td>Linear Reservoir</td>
<td>C1:Horton Infiltration Losses and C2: Proportional Loss</td>
</tr>
<tr>
<td>UHM</td>
<td>Unit Hydrograph Method</td>
<td>Initial plus proportional loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Initial plus continuing loss</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Generalized CSC</td>
</tr>
<tr>
<td>RDI</td>
<td>Rainfall Dependant Infiltration</td>
<td>Not Applicable – RDI is a lumped conceptual model and accounts for water balance in several inter-connected conceptual storages</td>
</tr>
</tbody>
</table>

1 May 2012
The hydrological model to be used for the HCC stormwater FHM will be Model B. Due to the relatively short duration high intensity events to be simulated the Horton Infiltration model will sufficiently estimate the infiltration losses. Should a long time series need to be run for the stormwater model in the future, a revision of the hydrology will be required and the RDII component incorporated.

6.2 Rainfall utilised

AECOM recommended to Hamilton City that a nested hyetograph approach for the rainfall should be used for the 3 Waters modelling project. The hyetograph would be based on the HCC Development Manual rainfall / duration / intensity information and then hyetographs for the 6, 12 and 24 hour durations would be created.

For further information regarding the proposed rainfall method refer Appendix A.

6.3 Catchment Delineation and Load Points

The modelled catchment area must be delineated into smaller sub-catchments. Sub-catchment delineation shall take different land use layers, cadastre layers, terrain information, and location of flow monitors into account.

The catchments polygons can be created in MIKE URBAN using the graphical editing tools or delineated automatically based on either Thiessen Polygon concept or based on digital terrain model (DTM). The catchment delineation shall be done using the graphical editing tool.

Sub-catchment boundaries shall follow property boundaries, street centre lines and terrain topology. When undertaken the sub-catchment delineation location of load points must be considered.

Load points shall be defined at an appropriate manhole within the sub-catchment such that the resultant flows entering the model represent flows and surcharge levels in the system. Where feasible sub-catchment load points shall be defined at least one manhole upstream of known problem areas.

The actual geo-coding of the sub-catchments to the load point can be done graphically one by one or it can be done automatically based on the concept of nearest manhole from the centroid of the sub-catchment in MIKE URBAN.

6.4 MOUSE Runoff Model B

The concept of surface runoff computation of MOUSE Runoff Model B is founded on the kinematic wave computation. This means that the surface runoff is computed as flow in an open channel, taking the gravitational and friction forces only. The runoff amount is controlled by the various hydrological losses and the size of the actually contributing area.

The shape of the runoff hydrograph is controlled by the catchment parameters length, slope and roughness of the catchment surface. These parameters form a base for the kinematic wave computation (Manning equation).

6.4.1 Calculation of Sub-Catchments Parameters

The general catchment data must be provided. These are following:

- **ID** - an identifier string of up to 25 ASCII characters.
- **Location** - MOUSE network node identifier, defines the catchment connection point.
- **X- and Y-co-ordinates** - catchment co-ordinates used for the allocation of spatially distributed rain data. Per default, the fields are filled-in by the connection node co-ordinates. For better accuracy for larger catchments, the co-ordinates may be edited and replaced with e.g. centre point co-ordinates.
- **Catchment Area [ha]** - the total horizontal surface area of the catchment.

Model B specific data must be provided. These are following:

- **Length [m]** - conceptually, definition of the catchment shape, as the flow channel. The model assumes a prismatic flow channel with rectangular cross section. The channel bottom width is computed from catchment area and length.
- **Slope [%]** - average slope of the catchment surface, used for the runoff computation according to Manning.
- **Surface type areas [% of total area]** - fractions of the catchment surface belonging to different surface types:
  - impervious steep
  - impervious flat
  - pervious - small impermeability
  - pervious - medium impermeability
  - pervious - large impermeability

The model applies different hydrological parameters for each of the surface types. The hydrological parameters are following:
- **Wetting loss [m]** - one-off loss, accounts for wetting of the catchment surface.
- **Storage loss [m]** - one-off loss, defines the precipitation depth required for filling the depressions on the catchment surface prior to occurrence of runoff.
- **Start infiltration [m/s]** - defines the maximum rate of infiltration (Horton) for the specific surface type.
- **End infiltration [m/s]** - defines the minimum rate of infiltration (Horton) for the specific surface type.
- **Horton's Exponent** - time factor "characteristic soil parameter" [s -1]. Determines the dynamics of the infiltration capacity rate reduction over time during rainfall. The actual infiltration capacity is made dependent of time since the rainfall start only.
- **Inverse Horton's Equation [s -1]** - time factor used in the "inverse Horton's equation", defining the rate of the soil infiltration capacity recovery after a rainfall, i.e. in a drying period.
- **Manning's number [m 1/3 s -1]** - Describes roughness of the catchment surface, used in hydraulic routing of the runoff (Manning's formula).

### 6.5 Model Testing

The model should be tested prior to validation being carried out. Model testing should include an assessment of the:
- **Stability of the model results**
  - Oscillations in depth, velocity or flow time series results
  - Significant mass conservation errors (typically > 15%)
  - MIKE URBAN warnings
- **Sensibility of the model results**
  - Are the magnitudes of velocities sensible
  - Are depth of flows realistic
  - Is pump operation (number of starts, runtimes, etc. reasonable)

The model testing shall be carried out for a range of flow conditions covering those that the model is designed to be used to predict system hydraulics.
Stormwater Flood Hazard Mapping

Phase 1A Results
Stormwater Flood Hazard Mapping

Phase 1A Results

Prepared for

Hamilton City Council

Prepared by

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17 June 2011

60163957

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Prepared by: Shaun Jones
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Revision History

<table>
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<th>Details</th>
<th>Authorised</th>
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<td>For Record</td>
<td>Mike Summerhays</td>
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1.0 Introduction

AECOM are pleased to provide the Phase 1A Flood Hazard Scoping results for the stormwater programme. The results included on the enclosed DVD include the peak water depth, peak velocity and maximum hazard classification for the whole City (including the revised boundaries) in raster format for the selected storm durations. Some of the key points from phase 1A study are:

- The 2D model includes all critical culverts 900mm and over (details of the survey are also attached)
- Large areas of the City appear to be free from significant flood hazards for the rapid flood hazard mapping
- Hydrology was undertaken for a 100yr ARI event including climate change predictions using 6, 12 and 24hr duration nested storms
- The rain on grid approach was used on a 2D surface and assumes all pipe systems are blocked
- No losses are taken into account
- The 50yr flood levels (refer Table 1 50yr Levels [A]) were used in the Waikato River as a boundary condition as there is a wide discrepancy in the modelled values between 10, 50 and 100yr events.

2.0 Hazard Classification

The model results have been analysed in accordance with the process outlined in the Stormwater Network Model Build Guidance document to determine the hazard classification. This analysis has been undertaken using the water depth and velocity at each time step throughout the entire model extent, the maximum hazard at each point has then been reported according to the hazard classification agreed with Hamilton City Council.

To determine the hazard classification as described in the table below, the velocity and depth for each cell is used at each time step during the simulation to determine the hazard classification at the given time step. The depth/velocity criteria for each hazard classification are shown in the figure below. The hazard is classified with one of the following values:

<table>
<thead>
<tr>
<th>Hazard Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>High Risk Zone</td>
</tr>
<tr>
<td>4</td>
<td>Flow path Hazard</td>
</tr>
<tr>
<td>3</td>
<td>Ponding Hazard</td>
</tr>
<tr>
<td>2</td>
<td>Minor ponding and/or overland flow risk</td>
</tr>
<tr>
<td>1</td>
<td>Potential ponding or overland flow risk</td>
</tr>
<tr>
<td>0</td>
<td>No hazard</td>
</tr>
</tbody>
</table>

The maximum value during the simulation for each grid cell is extracted from the result file and used to determine the hazard classification. This method evaluates the hazard classification at each time step and determines the maximum/worst case hazard during the simulation period. These classifications are then used for the raster output showing the hazard classification value shown in the table above.

Hamilton City also requested that we provide hazard classifications raster outputs for depth and velocity independently. For these outputs AECOM will use the maximum depth or velocity for each cell during the simulation period. These values have been used to create the raster files.
The hazard classification is used to produce digital GIS raster files showing flood and overland flow hazards. It can be observed within the results, that significant hazards are located along the naturally formed watercourses. In addition, there are flat areas and basins that have potential flood hazards.

### 3.0 Storm Duration Sensitivity

As part of Phase 1A, a sensitivity analysis has been undertaken to determine the appropriate storm duration to use in Phase 1B. AECOM have provided outputs for the 6, 12 and 24hr 100yr ARI storm event results for Hamilton City to review. We are proposing to have a meeting with HCC to agree the critical duration storm to us going into Phase 1B of the stormwater work.

### 4.0 Waikato River Boundary Condition

In addition to the sensitivity analysis undertaken on the storm duration, a check of the boundary condition to be used at the Waikato River has been undertaken. Two sources for the flood levels in the Waikato have been used. The sources are as follows:

- Environment Waikato River analysis – This is a spreadsheet data source and provides 10, 50 and 100yr flood levels along the Waikato River through Hamilton (A in Table 1)
- Waikato River Mike 11 Model – This included model runs for 10 and 50yr events (B in Table 1)

Five locations along the Waikato River were selected to provide a comparison between the results. The results are shown below and highlight the difference with the predicted levels within the Waikato River. A major reason for the uncertainty is due to the control of the upstream dams. This control is not necessarily driven by flood flows and therefore flood responses in the Waikato River through Hamilton can be suppressed due to attenuation in these dams.

It should be noted that a limitation of these models are that no model build report outlining the assumptions has been provided and therefore the assumptions in the spreadsheet data source are not known. To account for the uncertainty with these levels a conservative approach has been taken. AECOM therefore decided to utilise the 50yr ARI water levels (refer Table 1 50yr Levels [A]).
Table 1  Waikato River Levels

<table>
<thead>
<tr>
<th>Location</th>
<th>10yr ARI</th>
<th></th>
<th>50yr ARI</th>
<th></th>
<th>100yr ARI</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Malcolm St</td>
<td>15.58</td>
<td>14.957 0.623</td>
<td>17.39</td>
<td>16.146 1.244</td>
<td>18.95</td>
<td>Not available</td>
</tr>
<tr>
<td>Bridge St</td>
<td>14.87</td>
<td>13.727 1.143</td>
<td>16.61</td>
<td>14.891 1.719</td>
<td>18.09</td>
<td></td>
</tr>
<tr>
<td>Ann St</td>
<td>14.29</td>
<td>13.389 0.901</td>
<td>16.03</td>
<td>14.491 1.539</td>
<td>17.48</td>
<td></td>
</tr>
<tr>
<td>Arcus St</td>
<td>13.93</td>
<td>13.356 0.574</td>
<td>15.59</td>
<td>14.481 1.109</td>
<td>17.07</td>
<td></td>
</tr>
<tr>
<td>Bree Pl</td>
<td>13.56</td>
<td>12.857 0.703</td>
<td>15.15</td>
<td>13.952 1.198</td>
<td>16.66</td>
<td></td>
</tr>
</tbody>
</table>

The implementation of this boundary condition was undertaken by creating a source point at the upstream end of the Mike 21 model in the location of the Waikato River. The magnitude of this source point was determined by calculating the difference in flow between the flow that was occurring when the LiDAR was being flown and the predicted 50yr flow rate. The difference was calculated at 5 locations within the model extent and was consistently 190m³/s, therefore a constant 190m³/s flow rate was inserted at the upstream end of the model. By inserting this flow rate of 190m³/s an initial Waikato River level has been established and is shown in Table 2 below. Note that this level corresponds well to 50yr (A) level in Table 1 above. Due to the additional inflows from the Hamilton Catchment the maximum depths increased slightly as the storm duration increased. Table 2 shows the maximum surface elevation at the 5 cross-sections for the 3 duration storm events compared to the initial surface elevation.

Table 2 Mike21 Model Boundary Condition

<table>
<thead>
<tr>
<th>Location</th>
<th>Initial Waikato River Level</th>
<th>Maximum Surface Elevation for Storm Duration (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Malcolm St</td>
<td>19.13</td>
<td>20.23</td>
</tr>
<tr>
<td>Bridge St</td>
<td>17.06</td>
<td>19.28</td>
</tr>
<tr>
<td>Ann St</td>
<td>16.31</td>
<td>18.72</td>
</tr>
<tr>
<td>Arcus St</td>
<td>15.55</td>
<td>17.50</td>
</tr>
<tr>
<td>Bree Pl</td>
<td>14.67</td>
<td>15.87</td>
</tr>
</tbody>
</table>

5.0 Assumptions and Limitations

The following assumptions and limitations apply to the results provided as deliverables from Phase 1A Flood Hazard Scoping of this project. These assumptions and limitations should be read by Hamilton City staff using the results.

- The model was undertaken using rain on grid methodology. This method assumes that the piped network is fully blocked in the 2D model. In reality, the pipe system can convey flow and may transfer flows and exacerbate flooding elsewhere. Additionally primary network may surcharge at a location and create a potential hazard not identified by the Phase 1A results.

- In order to run the model in a manageable time frame, multi-cell overland solver was utilised. This method utilises a course grid to undertake the computational part of the simulation, the calculated runoff is then distributed to a fine grid. Consequently, some of the definition that would be found in a fine mesh is lost due to the use of the course mesh. The fine mesh used was 5x5m and the course mesh was 25x25m.

- All surfaces are assumed to be fully impervious i.e. no infiltration or initial storage except natural surface depressions. It should be noted that this is typically how storm flows operate during extreme storm events where the ground is typically fully saturated.
- The LiDAR data supplied by HCC has been used to develop the terrain that formed the base for the model. This data is assumed to be correct and no adjustments have been made other than those required to stabilise the model at the inlet and outlets of critical culverts.
- Rainfall has been taken from the HCC Development manual depth/ duration/ frequency tables assuming climate change effects and AECOM created nested storms from these tables refer AECOM letter dated 23 November 2010).
- Design hyetographs have been developed to ensure peak flow and volume are replicated at any point within the model extent. A nested storm contains peaks for all durations and therefore, in theory, generates 1 in 100yr storm flows when applied uniformly across a range of sub-catchments with varying times of concentration (refer to letter dated 18 November 2010).
- In order to provide an appropriate boundary condition at the Waikato River, a check was undertaken between the water level produced when the LiDAR was flown and the 50yr water level. The difference in levels consistently equated to a flow rate of 190m$^3$/s (assuming the velocity is the same in both cases). Consequently, a source point of 190m$^3$/s was placed at the upstream end of the project extent to replicate the 50yr ARI water level in the Waikato River.
- The Flood Hazard Scoping has used a 5 x 5m grid with the level of the grid cell the average of the LiDAR points within the cell.
- Water level was defined by adding together the ground level and the water depth at the relevant grid cell. The ground level is determined from the interpolation of the LiDAR DTM points and is therefore subject to inaccuracies (inaccuracies in the elevation of the LiDAR points and in the data processing to create the DTM). This is particularly true wherever the LiDAR DTM point density is sparse or in heavily vegetated areas. In such cases, it is assumed that the flood extent and the water depth give a good approximation of the flood risk even if the ground level is not accurate.
- Larger culverts where burned into the bathymetry which means that the culvert width is 5m.
- Culverts less than 900mm in diameter have not been included in the model as based on a risk approach there is a high likelihood that they will block. Culverts 900mm and greater have been added in to model.
- In urban areas the LiDAR data is stated to have an accuracy of about ± 0.25m with a 95% confidence interval. This relates to the spheroid height; additional error is introduced when the geodic height model is applied. As a result of the water level variability the lateral extent of flood hazards may vary significantly from that shown.
- The actual range of uncertainty as a result of the combined effect of LiDAR and other possible errors and inaccuracies will in some situations be in excess of 0.5 metres. Asset planners, consent planners and designers should take appropriate care in using the results and should apply a freeboard allowance that is appropriate for the situation, taking into account these limitations, assumptions and uncertainties including the compounding effects of uncertainties in the rainfall model.
- The hydrology was undertaken using Model B. This is suitable for Flood Hazard Mapping as losses are negligible during extreme rainfall events. If the model is to be used for long time series or low rainfall events the hydrology should be reviewed.

6.0 Phase 1B Methodology

The results of this Flood Hazard Scoping provided to Hamilton City, along with discussions with Hamilton City staff, will form the basis of the decision on which areas would require detailed investigation in the detailed FHM stage. It is worthwhile to note that the historical flood complaints plotted onto the maps provided matches up well with the results from the Flood Hazard Scoping work provided to HCC (refer appendix A).

A proposed methodology is currently being developed for Phase 1B and this will be discussed with HCC at the same time as the detailed model extent.

After the desktop study is completed a better understanding of the requirements for detailed model build will be known.
Appendix A: 100yr ARI 6hr Rapid Flood Hazard Results
RAPID FLOOD HAZARD MAPPING
Hamilton City Council

Predicted Maximum Probable Development Flood Hazards

Legend:
- Hamilton City Boundary
- 100yr/6hr Hazards
- 10yr/6hr Hazards
- Protected Ponding and/or Overland Flow Risk
- Minor Ponding and/or Overland Flow Risk
- Ponding Hazard
- Flow Path Hazard
- High Risk Zone

Overview
DRAWN: Shaun Jones
DATE: 15 June 2011
PROJECT: Hamilton City Three Waters Study
PROJECT NO: 60163957 AEEW

Print Date: