2D MODELLING OF STORMWATER IN AUCKLAND CITY - LESSONS LEARNT

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ABSTRACT

Due to recent advances with hydraulic modelling packages and the availability of LIDAR (light detection and ranging) survey data, the application of two dimensional (2D) modelling techniques to better represent surface flow behaviour and flood extents in hydrodynamic models is increasing. The purpose of this paper is to contrast the methods used and results gained from flood risk assessment projects utilising one dimensional (1D) hydraulic models coupled with a 2D model component. Examples used are part of studies undertaken by AECOM on behalf of Metrowater and Auckland City Council in recent years. This paper describes the differences in processes used in the development of the models, the advantages and disadvantages of each, the instabilities encountered and the difference in the types and nature of results achieved. The lessons learned from the projects are discussed, which can be applied to future projects.

Key areas described in the paper are model conceptualisation, model development, instabilities encountered, model run times achieved, issues found and how they were dealt with, along with how results were interpreted and validated. The paper shows how each project is unique and the catchment characteristics that need to be considered when identifying the optimum modelling methodology.

KEYWORDS

Flood Hazard Mapping, hydraulic modelling, one dimensional model, two dimensional model, LIDAR, DTM.

1 INTRODUCTION

Due to recent advances with hydraulic modelling packages and the availability of LIDAR (light detection and ranging) survey data, the application of two dimensional (2D) modelling techniques to better represent surface flow behaviour and flood extents in hydrodynamic models is increasing. The purpose of this paper is to contrast the methods used and results gained from flood risk assessment projects utilising one dimensional (1D) hydraulic models coupled with a 2D model component.

Examples used are studies undertaken by AECOM on behalf of Metrowater and Auckland City Council in recent years. This paper describes the differences in processes used in the development of the models, the advantages and disadvantages of each, the instabilities encountered and the difference in the types and nature of results achieved. The lessons learned from the projects are discussed, which can be applied to future projects. The four separate studies discussed in this paper all have different catchment characteristics which are summarised in Table 1, but also described in more detail in the following sections.

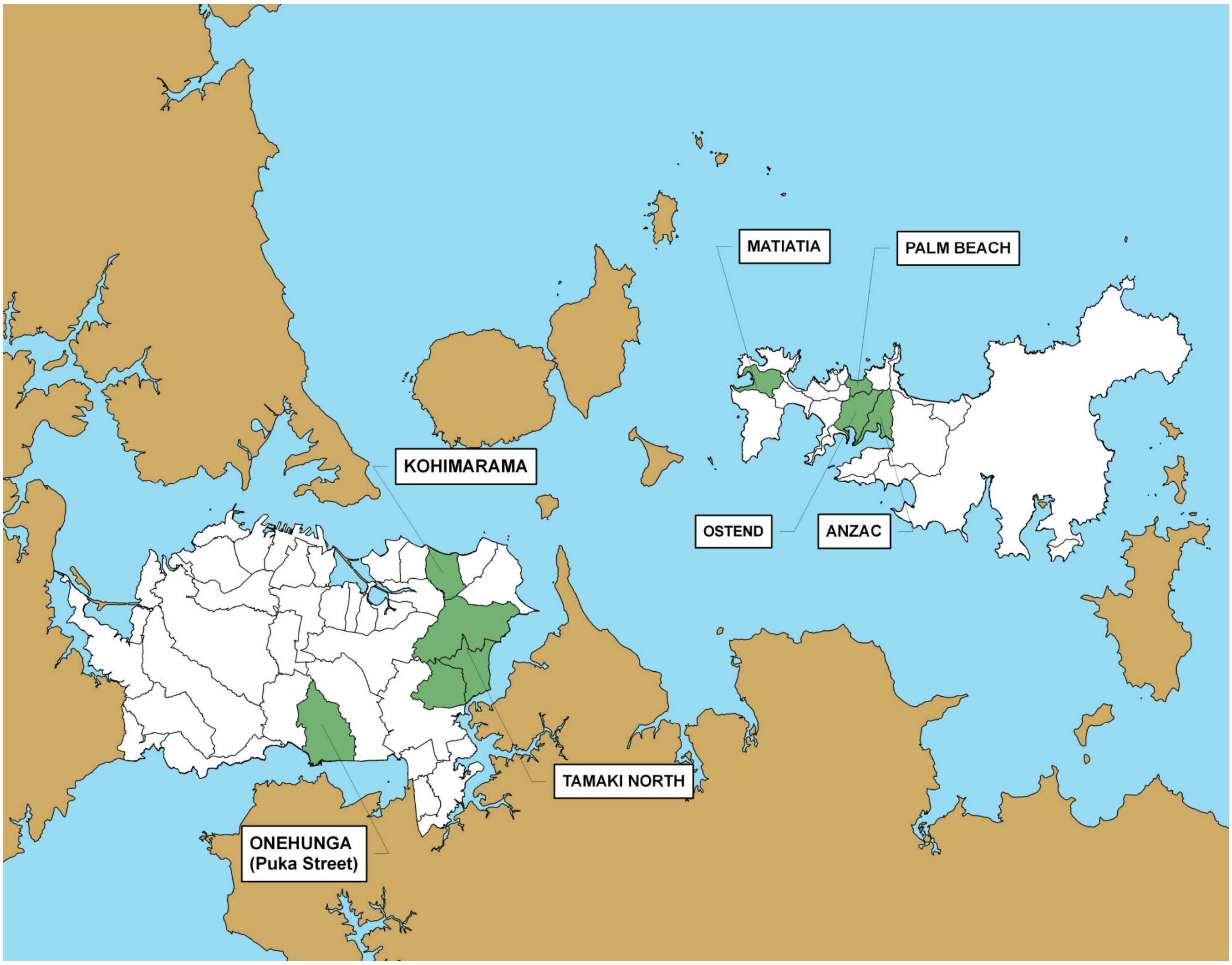
The examples used in this paper are listed in Table 1.

Table 1: List of projects used as examples in this paper

Area	Catchment name	Study Type	Modelling methodology used	Catchment Characteristics
1 a b c d	Waiheke Island catchments: Palm Beach Matiatia Anzac Ostend	Flood hazard mapping (FHM)	2D with limited 1D to represent channels; no pipe network	Low density urban areas and limited stormwater piped system. Well-defined steep valleys falling to central flat areas.
2	Kohimarama	Flood mitigation options	2D with 1D representing pipe network	Residential Undulating flat area with open channel
3	Puka Street	Soakage modelling and options analysis	2D with 1D representing soakage	Residential flat area with soakage as disposal
4	Tamaki North (includes Mt Wellington North, Glen Innes and Pt England)	Stormwater growth impact assessment	2D with 1D representing pipe network	Residential area with commercial and industrial; steep areas with low lying flat area

The location of each catchment area is shown on Figure 1.

Figure 1: Catchment Location Map



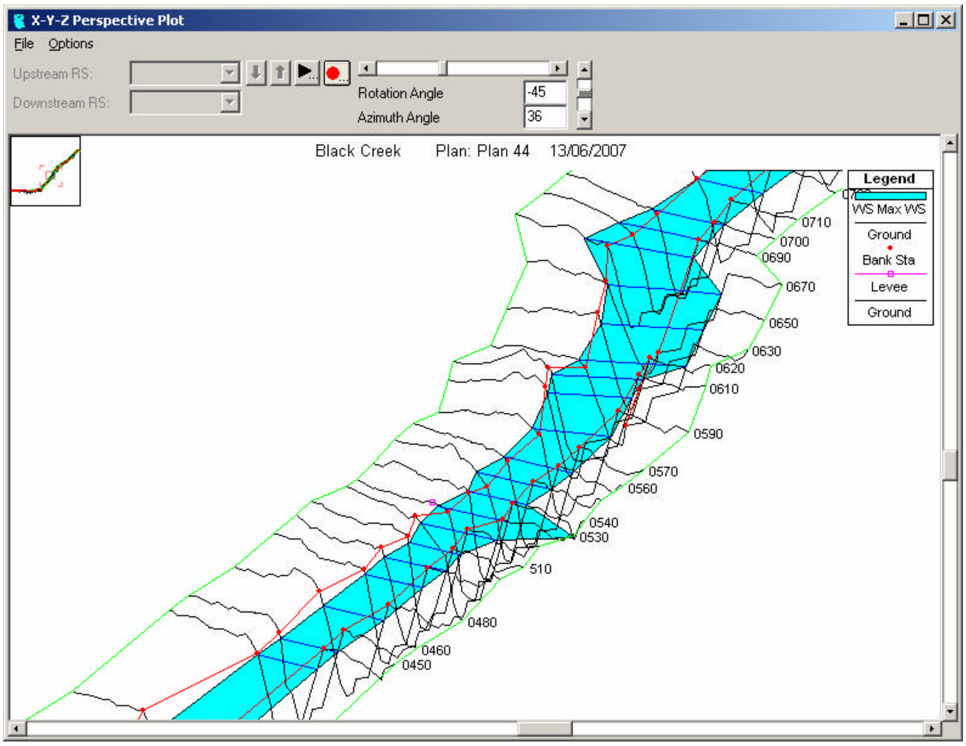
2 EXPLANATION OF MODELLING TERMS

2.1 1D FLOW MODEL

At the model conceptualisation phase it can be determined whether a 1D or 2D model is required. If the flow generally occurs only in one direction (such as a pipe or well defined stream channel) modelling in 1D will be the best tool for the study. Flood computation is done based on a water level within a defined cross section, where the cross section is perpendicular to the flow direction. The 1D flow has velocity in one direction only.

Topography is modelled by surveying cross sections perpendicular to the stream channel. The water level may breach the banks of the channel, but the flow does not generally vary from the single direction.

Figure 2: Typical flood extents shown in a 1D model



Rotation Angle -45

Azimuth Angle 36

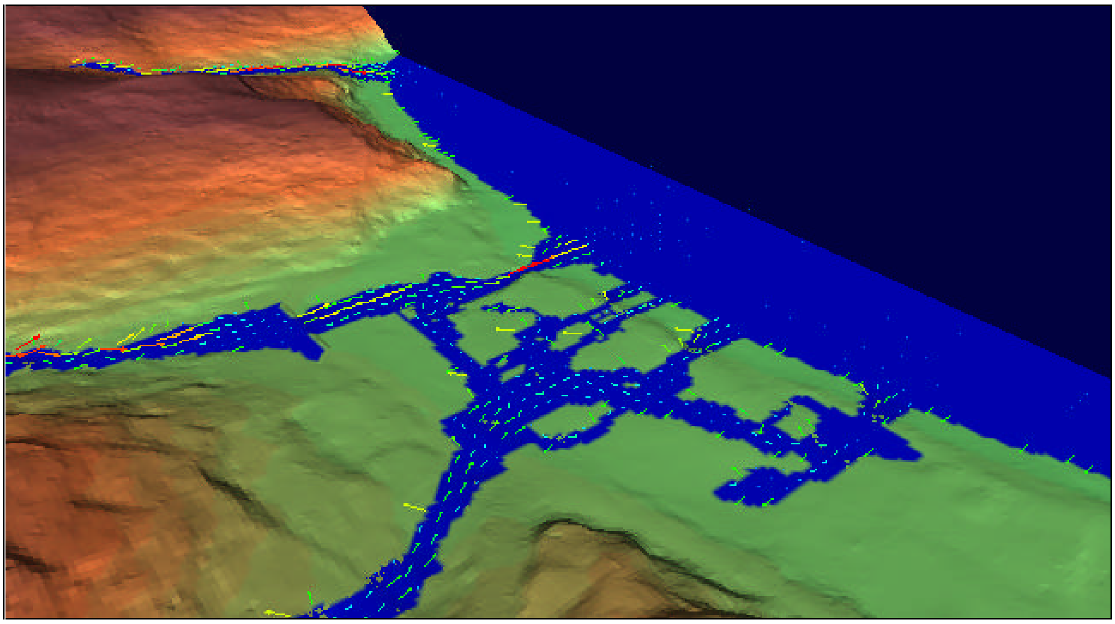
2.2 2D FLOW MODEL

It is not always necessary to model in 2D. Modelling in 2D may take more time and also more instability may occur. 2D modelling is generally considered in areas where flow can occur in two directions (such as wide, flat areas or gently undulating coastal plains).

The model is set up with grids. The topography is represented by a three dimensional regular grid. Each grid cell is defined by an x and y position and an elevation. Highly accurate and extensive topographic information is required to build the grid. Data is usually obtained via an aerial LIDAR survey.

The flood water level is defined by the depth of water in the grid cell added to the elevation of the grid cell.

Figure 3: Typical Flood extents shown from a 2D model



2.3 1D/2D COUPLED MODEL

A 1D/2D coupled model utilises the advantages of both 1D and 2D to model the catchment. The 1D model portion generally represents the model sections which have well defined 1D flow (channels, structures, steep sections etc) and the 2D represents the flat sections of the catchment. The hydrology in the studies described in this paper is represented in the 1D portion and applied as source points in the 2D.

3 BACKGROUND

The Integrated Catchment Study (ICS) was a joint project undertaken by Auckland City Council and Metrowater from 2001 to 2005. The objective of the ICS project was to develop a comprehensive understanding of the Auckland City wastewater and stormwater drainage system and receiving environments and to develop decision-making tools based on information gathered and analyses performed during the programme to enable:

- Prioritised investment decisions based on triple bottom line;
- Management decisions and planning now and in the future to 2050;
- Support for resource consent application, for Auckland City Council and Metrowater drainage discharges, to Auckland Regional Council.

The ICS project made use of a 1D software package to develop hydraulic and hydrological models of the integrated stormwater, wastewater and combined systems for most catchments within the city to achieve abovementioned objectives. These catchment models were then used for system performance, flood hazard mapping and options analysis. The ICS Modelling Framework (Metrowater, 2005) described the procedures followed for model build, calibration/validation, system performance analysis, flood hazard mapping, and options analysis and reporting. The purpose of the Modelling Framework was to ensure consistency of data requirements, quality and modelling techniques as several consultants were used to complete the modelling. It allowed all consultants working on the ICS to follow a common modelling and logging/reporting platform.

The 1D model simplified the predicted overland flow paths into pre-determined, continuous cross-sections and basins based on the modeller's observations. Standard cross-sections were used to define overland flow paths where no survey was available. Where standard cross-sections were unsuitable, field survey was undertaken and incorporated into the model. The simplified 1D representation therefore relied heavily on the modeller's judgment, therefore increasing the chances of errors.

Since the ICS model builds, 2D modelling to determine urban flooding has advanced and allowed models to be improved during subsequent studies to incorporate a 2D digital terrain model (DTM) along with a 1D pipe model. The availability of LIDAR survey data and aerial photography collected for the Auckland Region in 2006, and recent advances in hydraulic modelling software capabilities now allows the 1D representation of surface flow to be improved upon by using 2D modelling techniques. A number of stormwater models developed by AECOM for Metrowater and Auckland City since the ICS study now make use of a coupled 1D/2D model approach to enable a better representation of the surface flow and flooding in some areas.

The first project listed in Table 1, the Waiheke Island catchments (Palm Beach, Matiatia, Anzac and Ostend) form part of an Auckland City-wide flood hazard mapping (FHM) study currently being undertaken by AECOM on behalf of Metrowater and Auckland City Council. This study aims to develop FHMs for catchments not completed during the ICS. Model build and flood hazard mapping activities for these catchments have been substantially completed.

The methodology used to develop the Waiheke Island models is the subject of a paper 'Application of 2D Modelling for the Assessment of Flood Risk on an Island in Auckland City '(Arthur et al, 2008). Both Palm Beach and Matiatia were used as examples in this paper of how 2D modelling techniques are used in rural/limited urban catchments, such as Waiheke Island. Models developed for the catchments of Anzac and Ostend are both based on the same methodology.

The Kohimarama Flood Mitigation Options, and Puka Street Soakage Modelling and Options Analysis, and Tamaki North Stormwater Growth Impacts Study are studies improving using 1D models built during the ICS with 2D components added.

Table 2 summarises the objectives of the studies used as examples in this paper.

Table 2: Objectives of example studies

Item	Study	Objectives
1	Waiheke Island FHM (Palm Beach, Matiatia, Ostend, and Anzac Catchments)	• Identify flood hazards for the 10, 50, and 100 year ARI design storms using models developed for each catchment area.
2	Kohimarama Flood Mitigation Options	• Develop options for reducing habitable floor flooding in the Kohimarama Drainage Management Area (DMA) during the 50 year Annual Recurrence Interval (ARI) storm event for the Maximum Probable Development (MPD) scenario. • Model options to assess their effectiveness • Develop cost estimates for each option
3	Puka Street Soakage Modelling and Options Analysis	• Develop options for reducing habitable floor flooding in the Puka St area during the 50 year ARI storm event for the MPD scenario. • Model options to assess their effectiveness • Develop cost estimates for each option
4	Tamaki North SW Growth Impacts	• Summarise the impacts of proposed growth areas on the stormwater system in Tamaki North.

4 CATCHMENTS STUDIED

4.1 WAIHEKE ISLAND FLOOD HAZARD MAPPING

4.1.1 OBJECTIVE OF THIS STUDY

The Waiheke Flood Hazard Mapping study is part of an Auckland City wide flood hazard mapping study undertaken by AECOM on behalf of Metrowater and Auckland City. The objective of the study was to model and map flood hazards for the 10, 50 and 100 year ARI storms. These flood hazard maps are then used for identifying potential flood damage analysis hazards and problem areas, planning development and assessing resource consent applications.

4.1.2 CATCHMENT CHARACTERISTICS

Waiheke Island is located approximately 20km to the East of Central Auckland. The four Waiheke Island catchments modelled and mapped are Matiatia, Palm Beach, Ostend and Anzac. These catchments all have similar characteristics as shown below:

- All houses are equipped with rainwater collection systems.
- There is no public reticulated wastewater system for residential areas.
- There is limited stormwater piped network. The stormwater system primarily consists of open natural watercourses with short culverts under private driveways and public roads.
- There are well-defined steep valleys falling to central flat areas adjacent to outlets to the sea.
- All four catchments are located on Western Waiheke which is characterised by a series of villages containing most of the island's population, with clustered residential areas and interspersed rural land.
- All four catchments are hilly and generally small due to their closeness to the sea. The catchment areas of the four Waiheke Island catchments range from 64ha (Palm Beach) to 223ha (Ostend).

4.1.3 MODEL DEVELOPMENT

At the model conceptualisation phase, the catchments were visited to identify the nature of the catchments, historical operational information and site measurements of critical culverts. A recommendation of model methodology was set up and subsequently discussed with the client to ensure that all key areas and issues will be addressed. A 2D model coupled to a 1D model was recommended.

The models were all set up to represent the following in the 1D model:

- Steep watercourses with slopes greater than 6%
- Narrow watercourses
- Pipes and culverts

The 2D model comprised:

- Wide watercourses with slopes less than 6%
- Potential floodplains – flat or nearly flat land adjacent to a watercourse
- Ponding areas and depressions
- A roughness map was created using land zoning information.
- Representative Manning's roughness values were determined for each zone and assigned accordingly.

The software package allowed the 1D and 2D components to be dynamically linked. A paper detailing the application of 2D modelling on Waiheke Island has previously been written (Arthur et al, 2008) and discusses the methodology applied for flood hazard mapping on the Waiheke Catchments in detail.

4.1.4 RESULTS

Model results are extracted separately in the 1D and 2D modules. The results from the 1D are the water level and velocity for each time step at nodes whilst the 2D model gives the results at each grid cell.

It was concluded from this study that an integrated 1D/2D model is a valuable tool for modelling and representing flood hazards for low density urban areas with limited stormwater infrastructure. It is extremely valuable in calculating flooding in flat areas.

4.2 KOHIMARAMA FLOOD MITIGATION OPTIONS ANALYSIS

4.2.1 OBJECTIVE OF THIS STUDY

The Kohimarama catchment is located in east Auckland. Flood Hazard Mapping has been undertaken for the Kohimarama catchment during the ICS using the 1D model. During the Flood Mitigation Options Study for the Kohimarama catchment, it was noted that the flatter areas of the catchment were not well represented using a 1D model. This was particularly relevant for both the Eltham Road and Madills Farm /Melanesia Road areas as they gently undulate, thus creating topography that it was very difficult to accurately represent in a 1D model. These two areas also represented flood hazards that affected numerous habitable floors.

The objective of this study was to build a 2D model coupled to the 1D model and run it for the 10, 50 and 100 year ARI events for the Existing and the Maximum Probable development land use scenarios.

4.2.2 CATCHMENT CHARACTERISTICS

Madills Farm reserve is a low lying undulating flat area. There is a natural open channel that runs down the eastern side of the reserve. It is piped under Melanesia Road and continues via a concrete-lined open channel to Speight Road and Tamaki Drive. The outlet is adjacent to the Kohimarama Yacht Club.

The Eltham Road area is a wide flat area at the north-west of the catchment. The area is serviced by two pipes under Tamaki drive which discharges into the harbour.

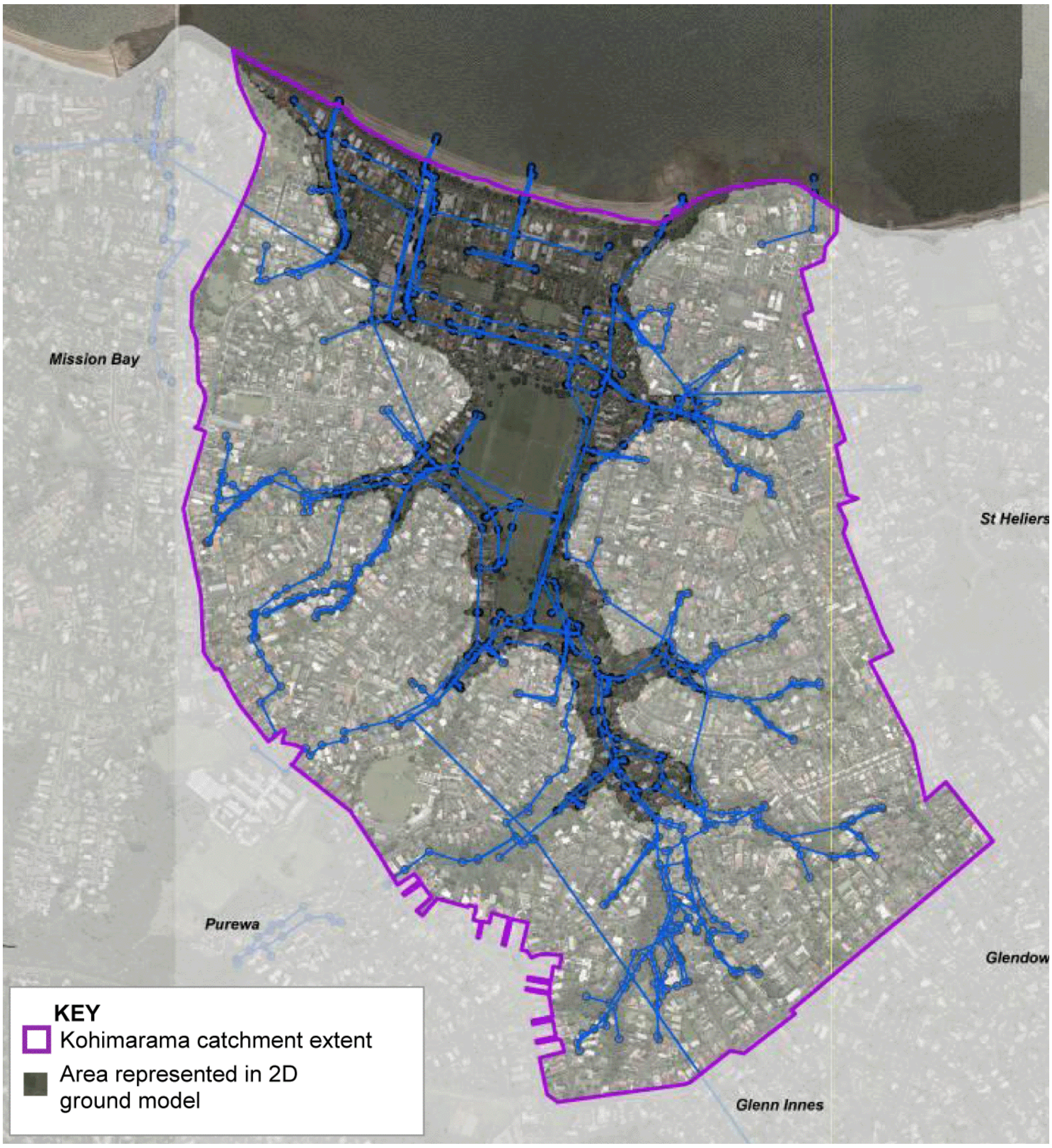
4.2.3 MODEL DEVELOPMENT

The study developed flood mitigation options for the Eltham Road and Madills Farm / Melanesia Road areas. However, as low levels of confidence were associated with the flood hazards and the resulting predicted affects of the mitigation options, it was decided that a further study was required in the form of a 2D model.

The model developed during the ICS FHM study for Kohimarama was imported into updated software. Existing Development and Maximum Probable Development land use scenarios were run for 10, 50 and 100 year ARI rainfall events. The open channel running through Madills Farm was revised and represented with dummy nodes every 4m. This allowed every grid cell of the 2D surface to have a dynamic link along the natural channel without the need for a 1D open channel component. LIDAR points of the Kohimarama DMA were used to build a 4m grid as the 2D surface. A roughness map was created using land zoning information and aerial photos. Representative Manning's roughness values were determined for each zone and assigned accordingly.

Figure 4 shows the extent of the ground model represented in the 2D model.

Figure 4: Extent of 2D Ground Model for Kohimarama



The 1D pipe network was dynamically linked with the 2D representation of the overland flows and flooding. The weir equation was chosen for the volume transfer from 1D to 2D systems with a crest width of 2m. The integrated 1D/2D model was run for the 10, 50 and 100 year ARI rainfall events for the Existing and Maximum Probable Development land use scenarios.

The use of the coupled 1D/2D model approach also allowed for options to be assessed alleviating the predicted habitable floor flooding during a 50 year ARI design storm event (MPD scenario).

To investigate the proposed options in Kohimarama the DTM was modified. The options investigated are:

1. Excavation/lowering of Madills Farm to create a dry detention pond: The LIDAR DTM was modified to lower the proposed area and represent the detention pond in the ground model.

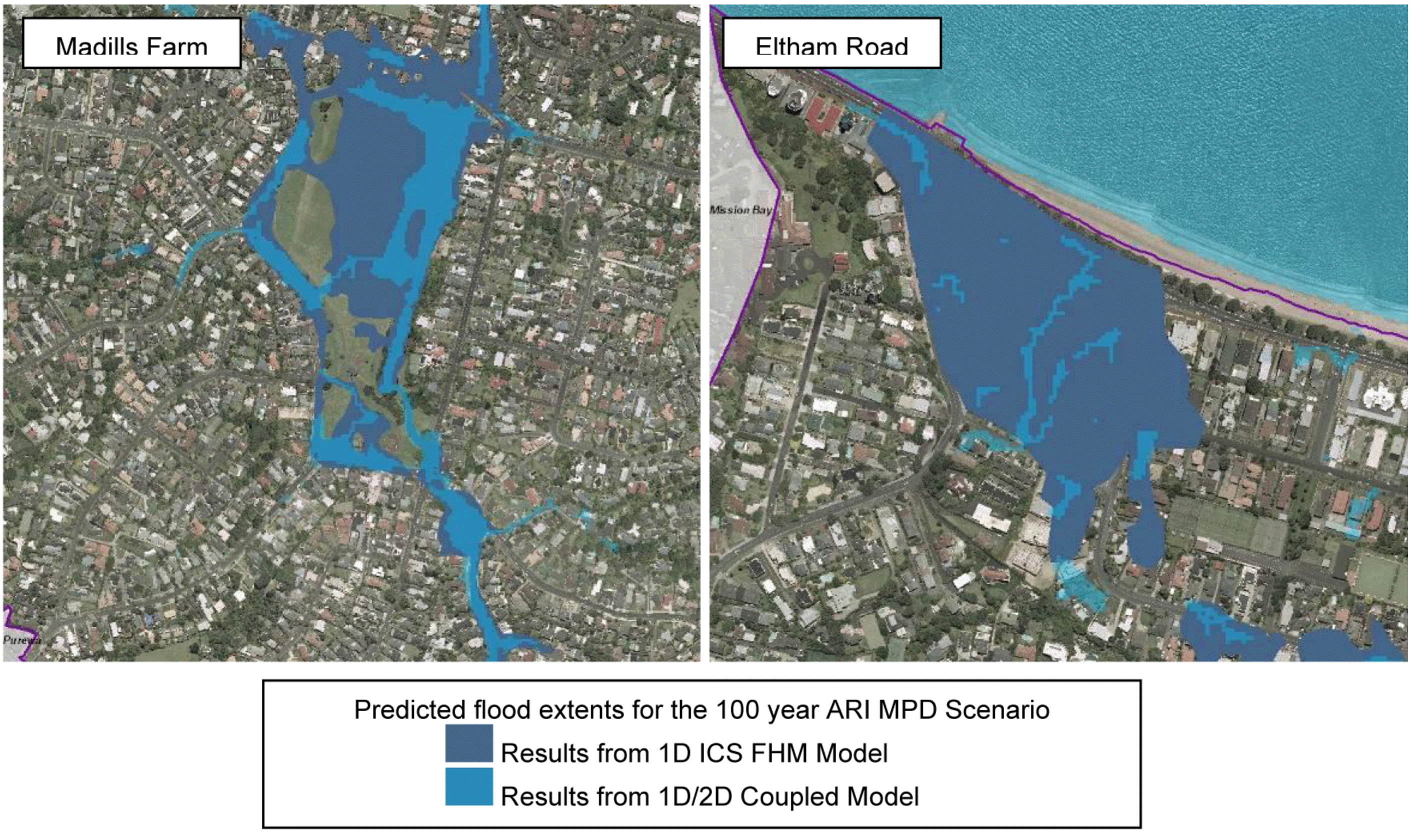
2. The creation of a barrier wall around Madills Farm to divert high flows from the stream into Madills Farm during storm events. The LIDAR DTM was modified to elevate the proposed area and represent the wall in the ground model.

4.2.4 RESULTS OBTAINED

The flood extent as identified by the 2D model at the Eltham Road and at Madills Farm Reserve was drastically reduced in both the Existing Development (ED) and Maximum Probable (MPD) land use scenarios when compared to the previous FHM produced during the ICS (Metrowater/AECOM 2009). However, the general shape of the flood plain in the Madills Farm is similar to that produced by the 1D FHM model.

The revised floodplain has reduced the number of habitable floors in the Eltham Road area from 48 to 17 habitable floors flooded for the 100 year ARI MPD scenario. The Madills Farm/Melanesia Road 2D modelling showed two more floors flooded at the 100 year MPD ARI (the flooded floors increased from 13 floors to 15) and a reduction of 18 floors within 500mm of the modelled flood water level.

Figure 5: Comparison of results obtained from the 1D model and 1D/2D coupled model for Kohimarama



As expected, since the extent of the predicted flooding is reduced, the number of habitable floors affected by the flooding has reduced, especially around Eltham Road area. The revised floor count shows a significant reduction in flooded floors and floors within 500mm of flooding. This is mainly due to a reduction in the flood level and extent in the Madills Farm and Eltham Road areas.

4.3 PUKA STREET

4.3.1 OBJECTIVE OF THIS STUDY

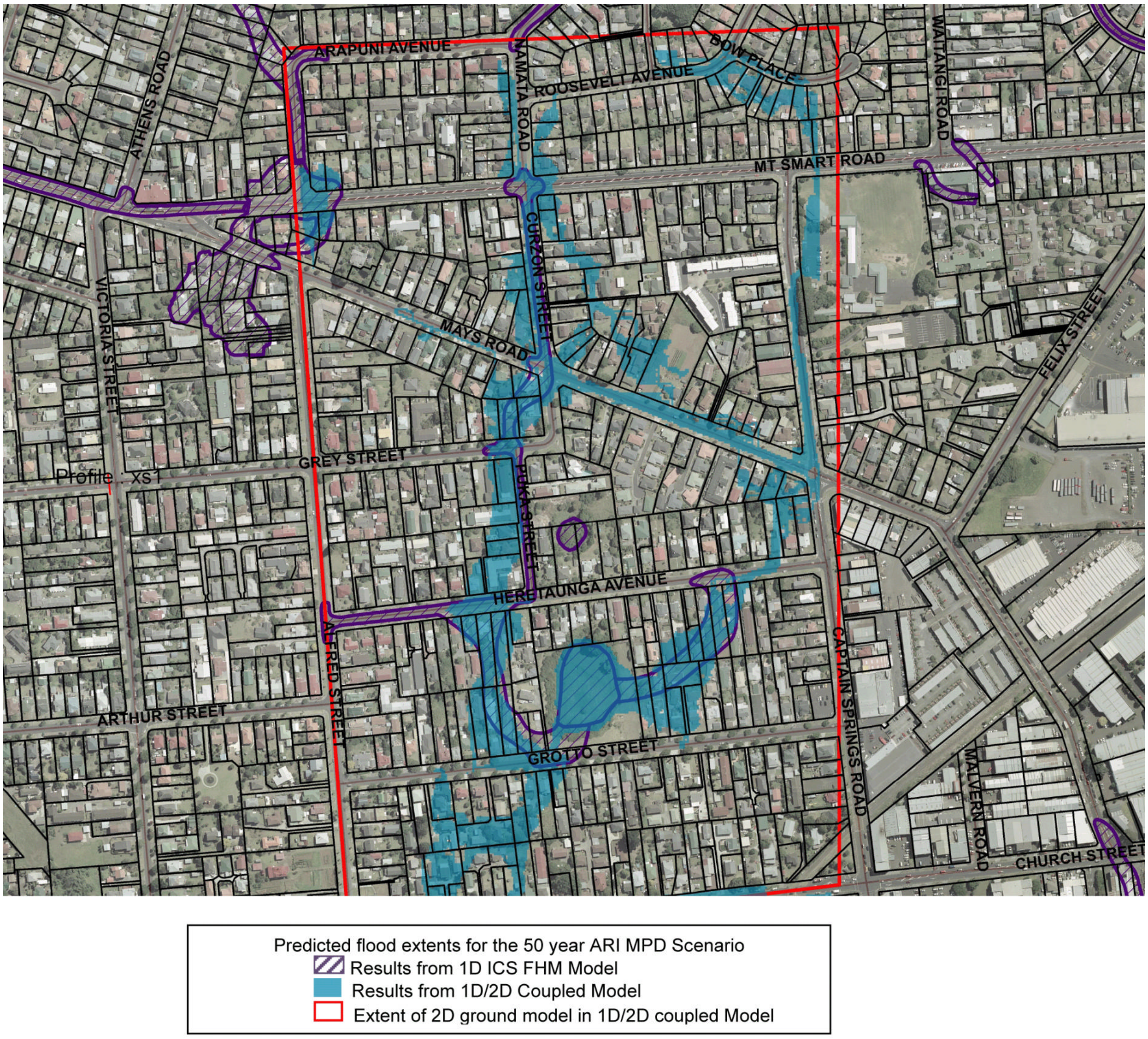
The Onehunga Flood hazard mapping undertaken during the ICS identified the Puka Street area as being at risk of habitable floor flooding. It was determined that further work was required to understand the flooding in this area and to analyse potential improvement options. The additional work included reviewing the ICS Onehunga 1D model in the areas of Puka, Heretaunga and Grotto Streets, to more accurately simulate current flooding problems. Using soakage borehole investigation results the model needed further development to reflect these and the using this information. Once the Flood hazard Mapping model had been refined it would be used to identify potential flood mitigation options using soakage.

4.3.2 CATCHMENT CHARACTERISTICS

The Puka Street catchment area has a contributing catchment size of approximately 45.3 hectares and is located in the Auckland City suburb of Onehunga. The Onehunga catchment is situated along the edge of the Manukau Harbour and slopes down to the harbour. The geology of the northern area of the Onehunga DMA predominantly consists of volcanic soil and rock types, with almost the entire southern coastal edge comprised of reclaimed land in the form of construction fill. The stormwater generated in the Puka Street catchment in Onehunga is disposed of through soakage. Onehunga has 146 publicly owned soakholes (Metrowater, 2005). Stormwater piped networks discharging to the Manukau Harbour service the rest of the Onehunga catchment.

The main overland flow coming along Namata Road crosses Mt Smart Road and continues to travel down Curzon and Puka Street and into the basin in Grotto Street. The second significant overland flow path begins in Captain Springs Road before travelling down Heretaunga Ave, through the residential properties between 45-55 Heretaunga Ave and discharging into the basin in Grotto Street. This can be seen in Figure 6.

Figure 6: Location of flooding extents in Puka Street catchment



4.3.3 MODEL DEVELOPMENT

The original Onehunga FHM model was developed as a 1D model and it was proposed to build a 2D model for part of the catchment to better understand the flooding. This is due to the flat topography of the Puka sub-catchment. A 2D hydraulic model of the Puka sub-catchment was built utilising existing LIDAR data to develop the DTM and the existing Onehunga FHM model was utilised for the existing pipe model and hydrological model.

From analysing the previous 1D result, it appeared that the existing 1D model over-estimates the capacity of private soakage in the catchment. It was recommended to carry out a sensitivity analysis of the capacity of soakage to determine the effect private soakage capacity has on the flooding extents. These changes included alterations to the model to ensure the model accurately represents reported flooding incidences.

4.3.4 RESULTS OBTAINED

A sensitivity analysis of the effects of private drainage on the overall runoff has shown some discrepancies and it was recommended that further investigation was done to determine a better understanding of the private soakage capacity.

Flood results for the 2D model extent were extracted, plotted and compared with the previous ICS FHM results. The comparison of flood extents can be seen in Figure 7. It appears that the coupled 1D/2D model provides a better representation of the overland flow path. This is due to the fact that the location of the overland flow path in 1D modelling often tends to be subjective and not always reflects what it is on site. In very flat topography, such as this catchment, it is hard to exactly estimate the path of overland flow and therefore the coupled 1D/ 2D is a better tool to represent flood extents.

4.4 TAMAKI NORTH

4.4.1 OBJECTIVE OF THIS STUDY

The Tamaki North catchment comprises three (3) separate Drainage Management Areas (DMA): Glen Innes, Point England and part of Mt Wellington North. Point England and Glen Innes DMA have previously been modelled as 1D models as part of the ICS. The objective of this study was to determine for Auckland City whether the proposed District Plan changes, had any additional effect on the flooding in the area. The District Plan changes which have been considered are:

- Auckland –Manukau Eastern Transport Initiative (AMETI)
- Panmure – District Plan changes 58/59/71/142 and Liveable Community Plan
- Glen Innes – District Plan Changes 58 and 61
- Tamaki Innovation Precinct

The proposed district plan changes will change the current development and it is therefore expected that it will increase the runoff.

4.4.2 CATCHMENT CHARACTERISTICS

The upper section of Tamaki North study area, particularly to the northwest, is relatively steep; while the lower section near the estuary is relatively flat. It covers predominantly residential areas with small amounts of commercial and industrial areas. The stormwater catchment discharges directly in an easterly direction to the Tamaki estuary via three main channels, the larger being the Omaru Creek.

Flooding problems generally arise in the catchment during a flood event largely due to areas of low-lying land and tidal effects from the Tamaki Estuary. The areas around the open channels leading to the estuary may flood, but there is also a significant portion on the far western edge of the catchment that is very flat and some areas contain slight depressions (Maunsell, 2005).

4.4.3 MODEL DEVELOPMENT

The Tamaki North Stormwater Model was developed from three separate 1D models previously created during the ICS project: Glen Innes, Pt England and Mt Wellington North to form a single model. The total catchment area for the Tamaki North Stormwater model was 1164 Ha.

A total of 2826 links and 2889 nodes were imported from the three ICS models. From these models, 1446 links and 1371 nodes representing overland flow paths and basins were removed and represented in the 2D ground model. All stormwater pipes, manholes and inlet/outlet structures were directly imported from the previous models. No significant changes were made. The open channel and overland flow components of the model were removed and replaced with the 2D module with the above-ground components of the model converted to a 2D ground model. The three ponds included within the model extent (Pt England Pond, Tamaki Campus Pond and Van Dammes Lagoon) were checked in the model conversion to ensure correct representation of outlet head losses, overflow regimes and overall storage volume. All three ponds were checked using survey data. All open channels to pipe transitions were checked to ensure correct representation of flow regimes and head losses.

The following key assumptions were applied while developing the 2D ground model:

- *Ground Model Roughness* – The 2D engine uses a Manning's M Roughness value to calculate water depth and speed. Three key land use types were represented within the 2D mesh:
    - Roads: Manning's M = 40 (n = 0.025)
    - Buildings: These were represented using 'voids' within the 2D mesh. This removes the building from the 2D ground model and water is forced to flow around the void. This assumption differs from that applied on Waiheke Island where buildings were represented using a very low Manning's M value.
    - All Other Areas: Manning's M = 16 (n=0.0625)

- *Mesh Size* – 2D uses an irregular triangular mesh to represent the terrain. A mesh size between a maximum 100m^2 and minimum of 25m^2 was defined for specific areas that had previously been identified as flooding. For all other areas a size greater than the maximum of 100m^2 was applied in order to minimise the number of mesh triangles created in non-critical parts of the catchment.
- *Mesh Break lines* – A break line defines where the edges of the mesh triangles meet. This is an important feature of mesh generation as it defines changes in elevation. For flood mapping applications, it is generally accepted that roads create well defined overland flow paths and have a significant effect on flood propagation. The road kerb lines were used to define break lines in the 2D mesh for Tamaki North.
- *Sea Level Boundary*- Mean High Water Spring (MHWS) constant tidal boundary condition was applied to the model (as per Metrowater Standards).
- *LIDAR Representation* – No detailed checking of LIDAR information was undertaken in heavily vegetated areas.
- *Building Floor Levels* – Where no floor level survey data was available, the building floor level was assumed to be the average of the LIDAR data points surrounding the building footprint plus 150mm. This method is intended to provide a list of potential buildings for detailed site inspection and field survey.

4.4.4 RESULTS OBTAINED

Figure 7 shows a comparison between the flood extents predicted in an area in Tamaki North Study using the 2D Model and those from previous studies (1D Model). The two historic studies used for comparison are the Glen Innes / Point England Flood Hazard Mapping Study (Maunsell, 2004) and the Mt Wellington North Flood Hazard Mapping Study (Maunsell, 2009 - Draft).

Glen Innes and Point England - The previous FHM study undertaken in these two areas during 2004 identified 25 habitable floors at risk of flooding during the 50year ARI MPD event. The revised floor count for this study is 62 habitable floors. It should be noted that no floor level survey has been undertaken in these two areas. The flooded floor count requires confirmation via detailed site inspection and survey. In addition, detailed site inspections should also confirm if identified building footprints are habitable or non-habitable.

Mt Wellington North - The Draft Mt Wellington North FHM study (Maunsell, 2009) predicts 90 residential habitable floor floods and 28 commercial floor floods for the 50year ARI MPD scenario. This compares well with the revised floor count for the coupled 1D/2D study of 85 residential habitable floors and 27 commercial floors. The slightly lower floor count from the coupled 1D/2D study can be attributed to a lesser area of flooding predicted.

Floor level surveying was undertaken in Mt Wellington North as part of the 2009 FHM study. These floor levels have been incorporated into the calculation of floor floods for this study. However, it should be noted that the survey did not cover the entire floor floods predicted due to programme constraints. The surveying was done prior to production of flood hazard maps using the previous flood hazard study as a guide.

Figure 7: Comparison of results obtained from 1D ICS FHM models and 1D/2D coupled model for Tamaki North

The differences between the flood hazard predictions can generally be attributed to the following factors:

- Changes in Hydrological Model (Glen Innes / Pt England Only): The 2004 FHM study used a different runoff model to that applied for the Tamaki North Study. Both runoff peak timing and total volume will be different between these studies. The runoff methodology used during the 2004 study was considered appropriate at that time as the ICS FHM runoff method had not been developed.
- Different Representations of Topography: The change between a 1D and 2D representation of topography is significant. The 1D representation generally consists of an approximated cross section to represent the topography. The 2D method applied for this study uses a digital terrain model interpolated from detailed ground level data to represent the topography. This 2D method produces a much higher confidence representation of flood extent and depth – especially in areas with flat topography, but can have issues in heavily vegetated areas where LIDAR may not be accurate.

5 LESSONS LEARNED

5.1 MODEL DEVELOPMENT

The first step of any modelling study comprises of model conceptualisation. Models should reflect the hydraulic network and also the catchment characteristics. It is therefore important that during the model conceptualisation prior of the model-build process, the modeller needs to become familiar with the catchment characteristics.

The conceptualisation will enable the modeller to:
- Assess key issues and constraints relevant to the catchment
- Define approximate model extents
- Define methodologies
- Confirm the concept with the end user

The task of model conceptualisation often does not get as much attention as deserved and it is important to spend the time necessary to assess the points listed above and to identify the necessary tools to be able to replicate reality as near as possible. It is necessary to understand the limitations, approximation and assumptions of the various tools available to be able to determine which hydraulic modelling system would be suitable to produce the results desired for the catchment. Every catchment is unique and the issues and key features will need to be understood if they are able to be replicated in the model.

In all the catchments described in this paper it has been important to conceptualise the model in order to be able to represent the issues to the best detail possible. The lessons learned are that various tools are considered, the catchment characteristics fully understood and the level of data reviewed prior to making a recommendation. The future use of the model needs to be considered when making these decisions.

In the case of the Kohimarama study the optimal runtimes and robustness was achieved by identifying where 1D and 2D approaches would best suit each area of the catchment according to its characteristics. It is clear from the Tamaki North study that the choice of 1D vs 2D influences the robustness of the results. The clarification of differences between the 1D and 2D model flood representations is particularly important for the Mt Wellington North area as the two modelling studies have been completed in parallel. For the comparison of these studies it is important to note that the 1D modelling has been done using a combination of LIDAR data, site inspections, engineering judgement and detailed survey of significant hydraulic features. The 2D study has solely LIDAR information combined with building footprints and road kerblines to define surface hydraulics. LIDAR topographic data has known inaccuracies in areas of dense vegetation and poor representation of narrow stream channels. This reinforces the need to recognise the limitations of each and take the best of both approaches.

5.1.1 LIDAR DATA

In areas with little vegetation cover and regular surface topography, the elevation of the LIDAR DTM was generally found to be within 0.3m of the surveyed elevation (Arthur, et al, 2008). The main differences between the survey data and the LIDAR DTM were found in areas with dense vegetation cover and streams / existing ponding areas (where the water surface level is picked up by LIDAR). It is recommended that LIDAR data in critical areas should be verified with survey, particularly for areas covered in dense vegetation or where the DTM accuracy is insufficient to provide an adequate representation of surface flows.

5.1.2 RUN TIMES

The run times achieved for the different models are dependent on the size of the model, model complexity, extent of model represented in 2D, and mesh type and grid sizes used. As the flood hazard mapping models are often used by various parties after the actual model build (developers, options investigated for flood mitigation, district plan changes etc) the run times achieved and the complexity of the model is an important aspect which needs to be considered at the beginning of the study. The type of mesh often determines the level of complexity of the model. A structured mesh is a mesh with a uniform size, whereas the unstructured mesh can be in any form or also in different sizes. The unstructured mesh therefore allows the modeller to define key areas in higher levels of detail. Table 3 below illustrates the different run times achieved for the studies described in this paper.

There are varying mathematical equations used by the various software to calculate the hydraulics which can influence the run times achieved. This appears to be a trade-off against the level of robustness required to meet study objectives. However, there are ongoing improvements being made by software vendors to improve on run times.

Table 3: Run-times achieved for the catchments modelled

Catchment	**Catchment area**	**Extent of 2D ground model**	**Type of 2D mesh used** [1]	**Grid size** [2]	**Run times achieved**
Waiheke Island Catchments	64 - 223 ha	Flat Areas 25 - 90	structured	5m (25 m^2)	18- 32 hours
Kohimarama	246ha	65 ha	structured	4m ($16m^2$)	18-24 hours
Puka St	45 ha	45 ha	structured	2m ($4m^2$)	18-24 hours
Tamaki North	1164.08 ha	All	unstructured	$25m^2$ - $100m^2$ in critical areas, $100m^2$ for other areas	5 hours

Notes: 1) Structured mesh uses regular grid sizes, generally square size. Unstructured mesh can be of irregular size and form
2) The grid size depends on the structured or unstructured mesh

5.1.3 INSTABILITIES

Instabilities encountered when modelling in 1D and 2D is magnified when the two components are coupled. As a first priority the instabilities need to be identified and rectified where possible. Sometimes instabilities can be reduced, but never completely eliminated. Model stabilisation often proves to be an iterative process requiring various fixes to the model. It is recommended to allow time in the projects for this model stabilisation phase when considering coupling 1D and 2D models.

Typical instabilities that have been encountered in the projects described above were:

- *Small mesh sizes*- these are more susceptible to instabilities, but generally can be fixed with small time steps.
- *Sudden changes in elevation* –This could occur where a DTM has not been edited to remove vegetation interference.
- *Differences in invert levels between 1D and 2D*: Areas where 1D and 2D are coupled could become unstable where differences in the bed level causes mass calculation errors and instabilities when calculating the water level and the discharge (e.g. along channel banks where the channel is modelled in 1D and adjacent flood plain is modeled in 2D).
- *Low flows*: Instabilities generally occur at the 2D cells where there are low flows.
- *Transition areas*: significant sudden change in velocity or flow depth could generate instabilities. This most commonly occurs around structures and changes in bed gradient, or changes in cross-sectional areas.

Not all fixes required the same level of effort to implement. For instance, changing the time step is a fairly straight forward process; however modifying time series and iteratively checking the input and outputs between the 1D and 2D will take more effort. Generally, the more complex the model is and the more factors need to be considered during the model development, the more factors could contribute to instabilities. Therefore model conceptualisation - is an important process at the beginning of any modelling study to determine the right level of complexity for the study area and the objective of the study. It also takes sound engineering judgment to determine whether the model has the ability to accurately represent the flooding in the study area.

6 CONCLUSIONS AND RECOMMENDATIONS

From the studies described in this paper and the discussion on the results obtained from the modelling studies, the following conclusions can be drawn:

- A coupled 1D/2D approach has been proven to be an effective method to represent different aspects of the stormwater system and enable more realistic representation of surface flows and flood hazards. It proves that it is difficult to represent the overland flowpaths in 1D when the terrain is very flat and the water could flow in any direction. The overland flowpaths represented in the 1D appear to be subjective to the modeller and do not always reflect where the water flows in reality. The 2D models allow the digital terrain to determine where the water would flow which can then confirm by site inspection.

- The interpretation of the results is important for the modelled 1D floodplain in flat terrain. The 1D representation of the floodplain is from simplified 1D overland flow path or floodplain representation of the flooding and then plotted to contours. This may over predict the flooding extents. The 2D modelling of the floodplain uses the terrain model to represent the flooding extents and therefore can represent hazardous areas in more detail. It is therefore recommended that the results are analysed and verified on site.

- Model conceptualisation is important. A lot of time can be saved later in the project if conceptualisation is done. Choosing the right tool to determine flood extents for the catchment and taking the catchment characteristics into consideration when determining the right tool can save money and time later in the project. It is recommended that the model conceptualisation is discussed with the client to determine whether the objectives can be met.

- During the model conceptualisation phase of the study the division between the 1D and 2D flow representation should be defined and used to determine where surveying and site inspections are required. Once defined, a site visit is recommended to confirm these.

- It is recommended that an open mind is kept during the model development. As issues are encountered it may prove invaluable to revisit the model conceptualisation and to readdress issues encountered. This may show that a more detailed model may be required or even less detailed.

- Model run time is dependent on the calculation effort – extensive 2D components will cause the run time to be significant. It is recommended to optimise the 2D component by using 1D where appropriate.

- The availability to redefine the mesh in key areas from a course larger mesh to a smaller mesh proved to be an effective method of first determining the flooding areas and then concentrating with smaller mesh sizes on the key areas. This helped with optimising run times and post processing the results.

- It is recommended to allow model stabilisation time in the projects to allow iterative fixes when trying to solve instabilities. It can generally be expected, that when coupling 2 models together, such as a coupled 1D/2D model, instabilities will occur.

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