DYNAMIC COUPLED MODELLING OF OAKLEY CATCHMENT- AUCKLAND, NEW ZEALAND

N. Nitsche, S. Jones and M. Summerhays, AECOM, Auckland
R. Smedley, Xeno Captain, Metrowater, Auckland
G. Ockleston, Auckland City Council

ABSTRACT

The Oakley Catchment (1230 Ha), centred around Oakley Creek, is a long narrow stormwater catchment on the Auckland Isthmus. The stormwater response to extreme events creates flooding across a broad floodplain adjacent to the creek. State Highway 20, Stage 1 was completed in 2007/08 and is now programmed for extension to Waterview. The highway will run alongside Oakley Creek, therefore the predicted flooding will influence the design of the motorway and portals for the tunnel section.

Previous models developed to represent flooding in the catchment provided low confidence results. Flooding in Oakley results in complex flow regimes including a wide range of velocity profiles and flow directions in the creek and surrounding floodplains. Recent advancements in modelling software allowed for complete dynamic modelling of flows by coupling the creek, pipe network (1D model) and floodplains (2D model) into one complete, higher confidence, dynamic model.

This paper outlines the improvements made and the lessons learned whilst developing this model. The paper concludes that a coupled model is a valuable tool for flood risk assessment and input to the motorway design and flooding solutions. It was identified that a 1D, and even a 2D model alone, is not appropriate for representing Oakley catchment hydraulics.

KEYWORDS

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

PRESENTER PROFILES

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

1 INTRODUCTION

1.1 OBJECTIVES

The purpose of this paper is to demonstrate the improvements that can be made to a one-dimensional (1D) hydraulic model for flood risk assessment by incorporating a two-dimensional (2D) model and dynamically linking it to a 1D model for a flat terrain catchment. This paper summarises the steps taken to improve a previous 1D/2D model and the lessons learned while developing the integrated 1D/2D modelling and concludes by demonstrating the improved results obtained.

Flood Hazard Mapping has been undertaken for the Oakley catchment several times and the coupled 1D/2D model shows improved results over previous models. The objective of Flood Hazard Mapping (FHM) in the Auckland City area is to identify Flood Hazards for the 10, 50, 100 year Annual recurrence Interval (ARI) storms and create flood hazard maps. These maps are then used by Auckland City Council and Metrowater for identifying problem areas, planning development, input to property files and assessing resource consent applications.

The proposed State Highway 20 (SH20) Waterview connection runs alongside Oakley Creek. The motorway will extend from the planned Maioro Street interchange along the rail designation through Hendon Park and then drop into a tunnel to pass under New North road, the existing railway line and Oakley Creek. The FHM will assist in understanding any flooding issues along the proposed motorway.

This paper discusses the model build complexities, re-calibration and issues encountered.

2 STUDY AREA DESCRIPTION

2.1 DESCRIPTION

The Oakley catchment is 1,230 Ha in size and therefore Auckland City's second largest catchment. The Oakley Creek, also known as Te Auaunga, is the longest urban stream in Auckland. Its headwaters are in Hillsborough and it flows through the centre of the catchment through Mt Roskill, Wesley, Owairaka, Mt Albert and Waterview before flowing into the Waitemata Harbour. Many stormwater outfalls and a number of wastewater overflow discharge into the watercourse.

Two main aquifers underlie Oakley catchment. The Mt Roskill aquifer solely lies beneath the Oakley catchment, and the Mt Albert West aquifer lies beneath the northern part of the catchment, as well as the Meola and Pt Chevalier catchments.

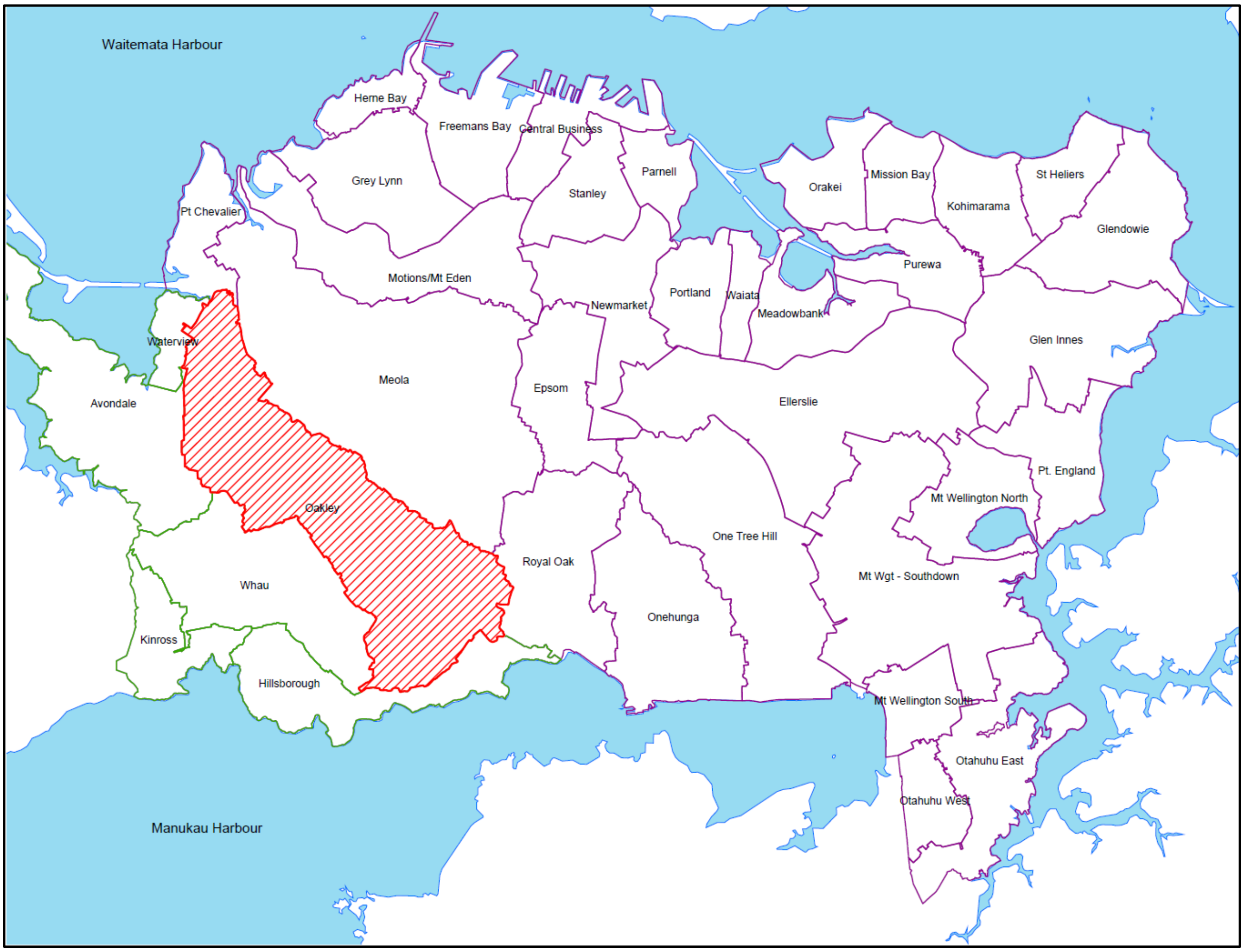

Figure 1: Location of Oakley catchment

2.2 STATE HIGHWAY 20 EXTENSION - WATERVIEW

To complete the western ring route, part of State Highway 20 (SH20) has been built. It crosses the Oakley Creek at Keith Hay Park in the upstream part of the catchment and runs along to Maioro Street. Extensive motorway stormwater drainage has been built. To complete the proposed SH20 Waterview connection, the motorway will be extended from the planned Maioro Street interchange along the rail designation through Hendon Park and then drop into a tunnel to pass under New North Road, the existing North Auckland railway line and Oakley Creek. This tunnel then emerges at Waterview to connect to the SH16 interchange.

2.3 FLOODING CHARACTERISTICS

The flooding experienced in the Oakley catchment is primarily due to the creek capacity and secondly due to soakage capacity being exceeded.

Contrary to most other catchments, the central part of the catchment is very flat, with the downstream part of the catchment and the creek being steeper. Due to this characteristic, flooding along the creek results in a wide, relatively shallow floodplain adjacent to the creek. This flooding is often contaminated with wastewater overflows and therefore presents a potential health risk. The flooding experienced along Oakley creek results in complex flow regimes including a wide range of velocities and flow directions at any cross-section. Due to this nature of flooding, a 2D model seemed to be the appropriate model to reflect the characteristics of the catchment. As the catchment is very flat, pipes often surcharge due to backwater experienced from the creek. A coupled 1D/2D model has the benefit of representing the hydraulics on the flat terrain in 2D, as well as taking the hydraulic effects of the pipe system and the creek into consideration by modelling them in a 1D model.

3 MODELLING METHODOLOGY

3.1 MODEL HISTORY

A one dimensional Mouse model was developed in 2004 during the Integrated Catchment Study (ICS) in accordance with the ICS modelling Framework (Metrowater, 2005). It was recognised that a one-dimensional model is limited and unable to accurately represent the complex flow regimes as experienced in the flat terrain of the catchment. 1D models only consider flow perpendicular to a cross-section and are unable to calculate the velocity varieties over a cross-section. The confidence of the 1D models to represent the flooding in the Oakley catchment has therefore historically been very low (Smedley, 2010).

In 2007 it was decided to build a 1D model of the creek and a 2D model of the terrain, and use the results of the existing 1D pipe model to allow better representation of the flooding in the creek. The creek model and the 2D model were linked with lateral links. Due to the software limitations at the time, the coupling of the pipe and 2D models was limited. A number of issues were encountered during the model development phase of the project which centred on model stability and robustness. The modelling results also still did not accurately reflect the flooding experienced (Smedley, 2010).

Despite the previous model build results being of low confidence, Auckland City and Metrowater still have a need to utilise the Oakley model for planning and engineering purposes. Additionally, with the Western Ringroute of SH20 in the planning phase, Auckland City and the New Zealand Transport Agency (NZTA) recognised the importance of working together to ensure that flooding solutions would not adversely impact each other and any flood alleviation options could be considered together to fully understand their impacts. An independent peer reviewer was commissioned to undertake a model review and provide a clear understanding of what was required to improve the model to be able to be used as a planning tool. Following this review, AECOM were commissioned by Metrowater to further develop the model and to undertake flood hazard mapping and optioneering.

The following steps were to be undertaken:

- Model Update
- Model Integration
- Model Calibration and Verification
- Flood Hazard Mapping
- Optioneering

During the project duration, regular workshops were held between AECOM, the software providers (Danish Hydraulic Institute –DHI), and the client. This enabled the modelling methodologies proposed, calibration process and software technical issues to be discussed and agreed to ensure that best technical solutions were applied. These regular workshops added much value to the project, helping to produce a robust model that would meet the client's needs.

3.2 MODEL SCENARIOS

In order to undertake the recommended updates to the model, it was recognised that the catchment has changed since the first model build and is changing further due to development over the years. The following models shown in Table 1 needed to be set up to reflect the different model phases considered.

Table 1: Model Phases

	Calibration Phase	**Verification Phase**	**Flood Hazard Mapping**	**Optioneering**	**SH20 Future Model**
Bathymetry	Pre-motorway (2001)	Part–motorway: SH20 to Maioro Interchange (2006)	Full-motorway: SH20 to Waterview	Full-motorway: SH20 to Waterview	Full-motorway: SH20 to Waterview
Stormwater Network	Pre-motorway	Part-motorway	Full-motorway	Full-motorway	Full-motorway
Development	2001	Existing development 2006	Maximum permissible development (MPD)	Maximum permissible development (MPD)	Maximum permissible development (MPD)
Hydrology	2001 Rain events	2006 rain event	10, 50 and 100 year design storm event	50 year design storm event	100 year design storm event including climate change (17% increase)

4 MODEL UPDATE

A suite of DHI software has been used to represent the hydrological and the hydraulic systems of the Oakley catchment.

4.1 PIPE MODEL

The peer review of the previous model reported that the hydraulic deficiencies of the Mouse model and the manual coupling to the Mike21 model by source points, were driving the erroneous results. The first step towards a better representation was to update the existing pipe model and review it.

The model was imported into Mike Urban. Overland flowpaths and the creek section, represented as standard cross-sections, were stripped out of the model. All pipe outfalls connecting to the creek or open areas were modified to actual model outfalls.

As the project concentrated on flooding issues, the wastewater system was removed in order to simplify the coupling process and improve computation time. This was deemed acceptable by the client as the model was further developed for stormwater planning purposes. It was decided that if an integrated model was required in future application, that it could be added again.

A thorough review of the how the soakage was represented in the 1D model was undertaken. The soakage was represented as public and private soakage. The public soakage rates were compared to the rates that were tested in the field. The soakage rates generally showed that they were significantly lower than the 1 in 10 year Annual Recurrence Interval (ARI) flows that they are generally assumed to be able to take. The soakage storage volumes modelled were too great and were able to store most of the soakage catchments runoff and therefore needed adjusting. The private soakage tests showed the same. This will therefore lead to the model generating significant overland flows, especially in the Mt Albert area, which predominantly relies on soakage.

The assets, structures and creek alignments that were affected by the SH20 Mt Roskill Extension were checked against the design and construction drawings which were received from NZTA. For the future model, the stormwater drainage for the proposed motorway extension and the stormwater ponds were inserted into the model.

4.2 CREEK MODEL

The Oakley creek is represented in DHI Mike11 (1D) model, which is a modelling tool for the analysis of river and open channel systems. All critical structures are represented in the 1D creek model. The culverts and cross-sections in the creek have been checked and modified were necessary. Oakley creek has some complex culverts such as the culverts at Bollard Ave (Figure 2). This culvert allows low flow to pass through the twin rectangular culverts which branches off to the left under Bollard Avenue and the high-flow circular culvert which runs straight under Great North Road. A low flow weir exists in front of the high flow culvert to ensure low flows are diverted through the twin rectangular culverts. As the flow regimes are quite complex for this structure, a modelling strategy to deal with these flows has been developed in the previous study and applied to the 1D model (MWH, 2008).

Figure 2: Bollard Avenue Culverts

In previous study models, interaction between the pipe 1D and the creek 1D model had been represented by hydrographs as boundary. This has been refined in this study and all hydrographs along the creek have been removed and dynamically coupled via outlets to the pipe model.

4.3 SURFACE MODEL

Mike21 is a modelling system for 2D free-surface flows. The hydrodynamic module simulates water level variations in response to forcing functions such as sources and sinks, flooding, drying and momentum dispersion.

The model grid size is generally selected according to the study requirements. The cell grid size (3*3m) was used for this. The resolution of the grid generally directly influences the duration of the model simulation and the accuracy of the results.

For the existing scenario the bathymetry that has been set up, included the existing SH20 Mt Roskill extension. To obtain the pre-motorway bathymetry, the initial Digital Terrain Model (DTM) was created using previous LIDAR data. The interface between LIDAR data and NZTA data has not been inspected in detail.

To represent the bathymetry for the future model scenarios, the existing DTM was updated to reflect the construction of the proposed SH20 Waterview extension. This was achieved by incorporating the 3D Road Design model from the SH20 design consultant into the existing bathymetry using the ESRI suite of software.

4.4 HYDROLOGY

The hydrology in the catchment is mainly represented by the kinematic wave runoff model for fast response (Model B) and rainfall dependent inflow (RDII) for slow response. The resulting runoff hydrographs were originally either represented as boundary conditions in the creek model or as source points on the Mike21 model. As this manual integration was not required anymore, and seemed to provide erroneous results, the hydrology needed checking.

The catchments draining directly to the creek were inserted into the Mike11 model in the Rainfall-Runoff module. The catchments draining into the pipe model were imported into the Mike Urban model. Several catchments were originally coupled to an overland flowpath or a short open channel which had been removed from the pipe model. For these catchments, dummy nodes have been inserted which would then directly flow onto the 2D surface during the coupling of the various models. The soakage catchments have been modified to represent areas contributing to the public soakage and areas which are contributing to the private soakage.

The hydrology had to be set up for the different scenarios discussed in Table 1. The motorway split some of the catchments into two different catchments, draining to different areas. For the future Waterview connection it was assumed that the motorway catchment would drain as per the design provided by the SH20 design engineers.

None of Auckland City's permanent rainfall stations lie within the Oakley catchment and therefore the four neighbouring rainfall stations were used for calculating the hydrology for the calibration phase. The previous modelling used only one of Auckland City's rainfall station for calibration. However, as Auckland City's rainfall is highly variable in nature it was considered appropriate to use more than one station for calibration purposes.

5 MODEL INTEGRATION

The three models (pipe, creek and surface model) were integrated in Mike Flood.

5.1 PIPE 1D/2D COUPLING:

All spilling manholes were coupled dynamically to the Mike21 surface model to allow for spilling onto the 2D surface. The coupling process allows for inlet control to the flow entering the system. Once a model node is linked to the 2D surface, any flow entering the node (catchment or overland) is automatically passed through the coupling and its limiting discharge criteria – which represents some form of inletting (cesspits or scruffy domes). The coupling method (weirs or cesspits) needs to be decided depending on the actual on-site conditions. It is crucial to review the coupling assumptions taken during the model process as they may affect the flood spread in areas and also determine the amount of water that can enter the primary system. This highlights that calibration of a model needs to be done with the complete coupled model and not only one module of it.

Outfalls which drain to short open channels or overland flowpaths were connected to the 2D surface to represent the overland flowpath before entering another pipe system or the creek.

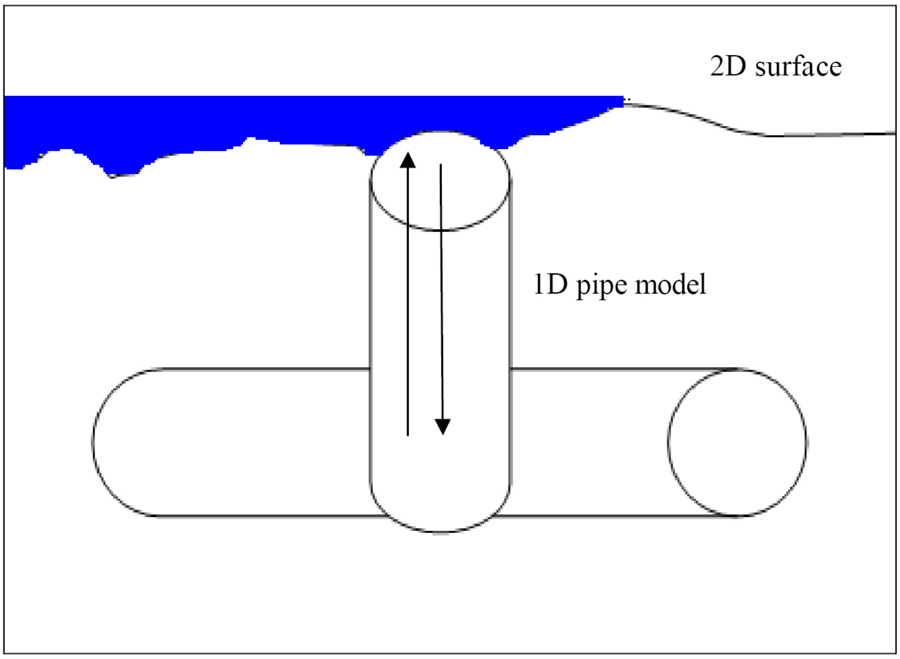

Figure 3: Schematic showing the coupling of pipe model to 2D surface

5.2 PIPE 1D/CREEK 1D COUPLING

All stormwater outfalls were connected from the pipe model to the Mike11 creek model as inlets.

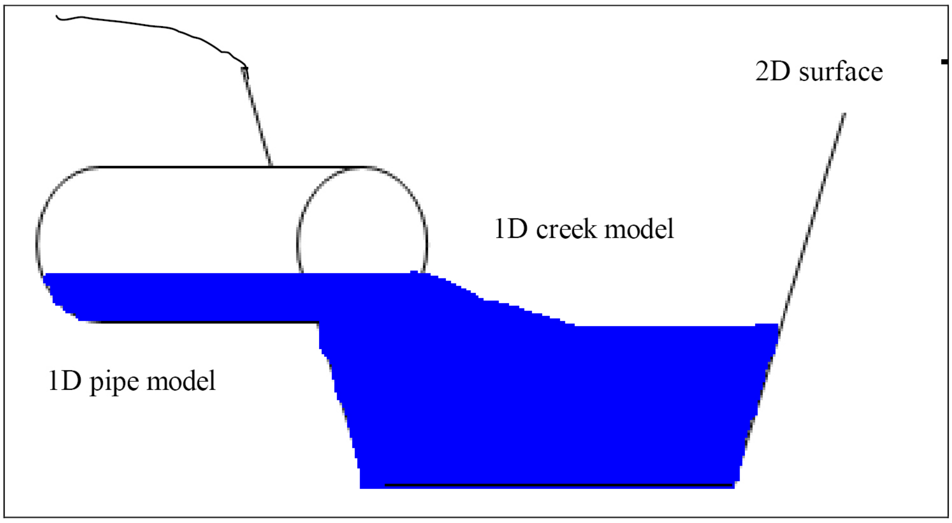

Figure 4: Schematic showing the coupling of pipe model to the creek model

5.3 CREEK 1D/2D LINKING:

The creek model was "laterally" linked to the 2D surface model. The linking allows the creek to spill out onto the 2D surface when it overtops. It also allows for overland flowpaths entering the creek if the creek has capacity to accept additional flows.

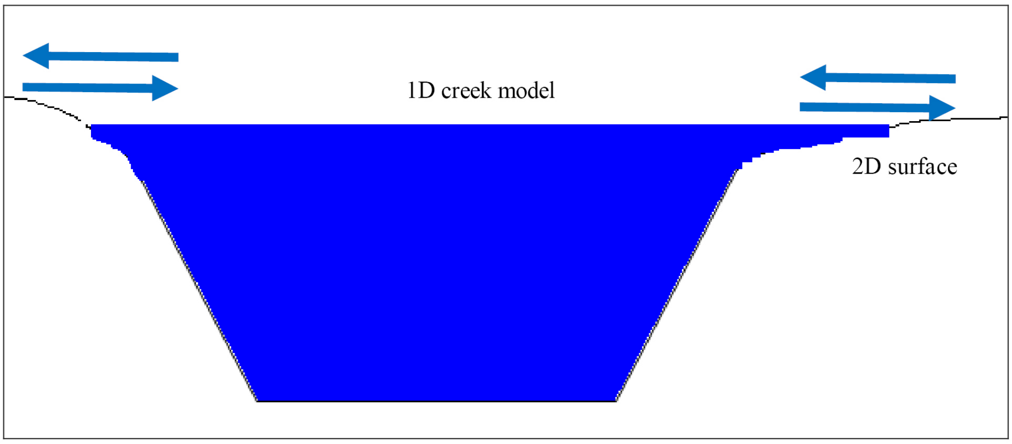

Figure 5: Schematic showing the coupling of the creek and the surface model

6 MODEL CALIBRATION AND VERIFICATION

6.1 MODEL CALIBRATION

Calibration and validation events were run through the Mike Flood model and the results compared against recorded flow/level gauge data. This was an iterative process, with results presented to Metrowater and the peer reviewer until agreed tolerances when achieved.

The existing 1D pipe model had previously undergone detailed calibration and validation of the pipe model (Connell Wagner, 2004) only. The creek had not undergone any calibration, which is why not much confidence in the creek flood extents existed in previous modelling attempts of the Oakley catchment. The calibration undertaken in this project was only carried out for the gauging stations along the creek model. If calibration couldn't be achieved, the pipe model would need to be re-visited.

The calibration data that was available consisted mainly of low flows gauged during the ICS period. To validate these low flows another calibration period was chosen from the permanent Richardson road gauge, which had a higher flow of 12m^3/s monitored peak flow (Figure 6).

Figure 6: Richardson Road gauge

Table 2: Gauged Data for Oakley creek

Gauge	Location	Duration
ICS_028	Keith Hay Park	6 months
ICS_016	Stoddard Tributary	10 weeks
ICS_031	Olsen Ave Tributary	10 weeks
Richardson Road gauge	Richardson road gauge	permanent

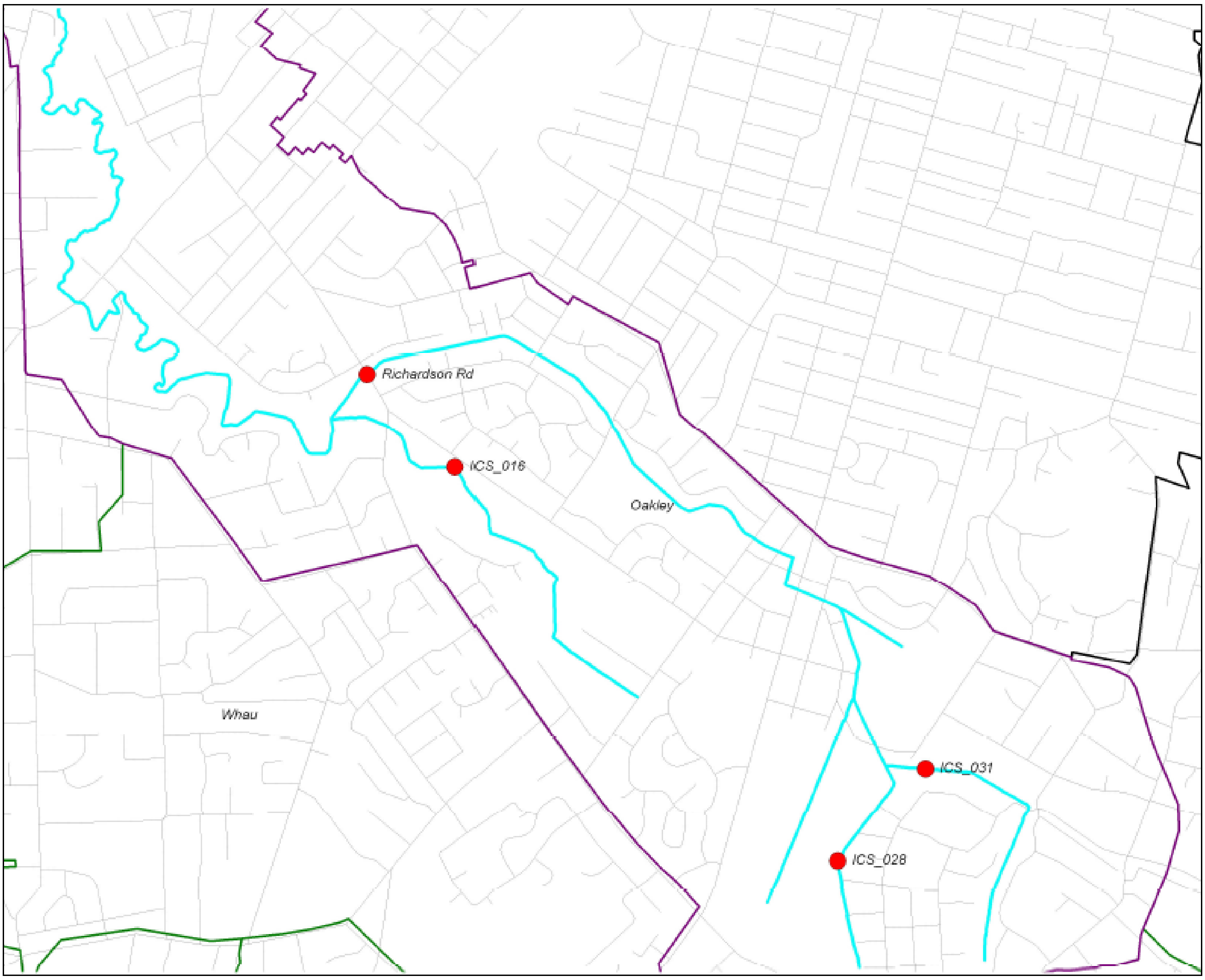

Figure 7: Location of calibration gauges

The storms that were available for calibration were generally single peaked events, except for one event which was multipeaked and therefore gave a better understanding of the catchments response to a storm. All storms were generally small (between 1 and 12 m^3/s). Whilst these calibration events were small, modelling them in a coupled 1D/2D model showed that, although the flow at the gauge locations were mainly contained within the channel, some parts of the creek upstream of the gauges spilled out of the banks and overland flow occurred for these minor events. The creek at May Road especially is very narrow and not very deep and only takes a minor storm event to overtop. This demonstrated the importance of calibrating these events by running the complete coupled model and not only the creek model as was done in the previous studies. This would ensure that the volume, level and flow would be calibrated accurately.

The flooding experienced in the O'Donnell area (Figure 9) is due to the very flat topography and affects a number of habitable floors. From the model runs it was evident that a slight increase in water level in the creek results in a major difference in flood spread in this area. It was therefore deemed crucial to not only get the flow peak and the volume calibrated but also the water level within the creek.

The calibration was mainly achieved by modifying the hydrology runoff parameters in the 1D pipe model and the 1D creek model. Once the calibration tolerances, as set out in the ICS Modelling Framework (Metrowater, 2005), were achieved the hydraulic Mannings roughness was altered in order to better represent the level and flow at the Richardson gauge (Figure 6). The variables that were calibrated against were peak flow, volume, depth and timing of peaks. The parameters were compared statistically as well as visually.

Variation in rainfall was evident from the four rainfall stations used and this variation explained why the timing of the peaks could not be quite achieved for one of the gauging periods.

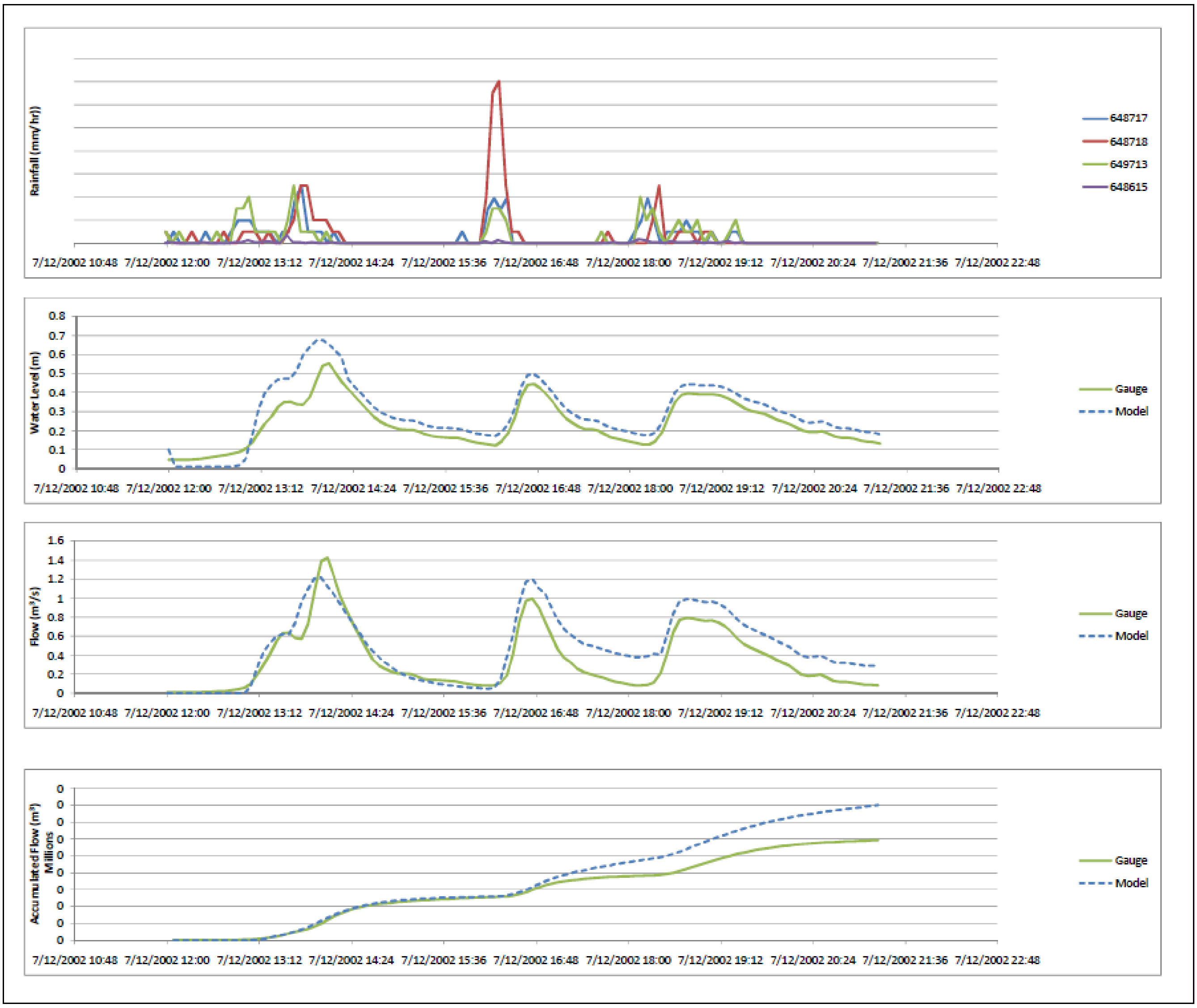

Figure 8: Figure showing rainfall variation and calibration at gauge ICS028 for a multi-peaked event

Two events were used for verification. One event was recorded in February 2004 and the second event occurred in February 2009. The second validation event was not gauged, but photographs and the timing of them was taken all along the creek shortly before and after the peak. The modelled levels and the photographs were compared visually. Good correlation was achieved.

7 MODEL RESULTS

7.1 MODEL RESULT EXTRACTION

Model results are extracted separately from the 1D and 2D models. The results from the 1D model are the water level and the velocity at each model node, and at each time step. Similarly, the results from the 2D model are the water level and the velocity at each grid cell, and at each time step.

The results from the 2D model can easily be reviewed by plotting them on a 3D projection or plotting against aerial photography. The 2D model results can be viewed as animation in a 3D view or against aerial photography. The 2D model shows a good representation of the overland flow over a complex surface.

7.2 MODEL RESULTS

The Oakley model results show that coupling a 1D/2D model offers significant benefit in shallow areas, such as experienced in the O'Donnell area in the Oakley catchment (Figure 9). The results show how the creek fills up and due to the backwater effects in the shallow pipe model, stormwater drains out of manholes onto the surface.

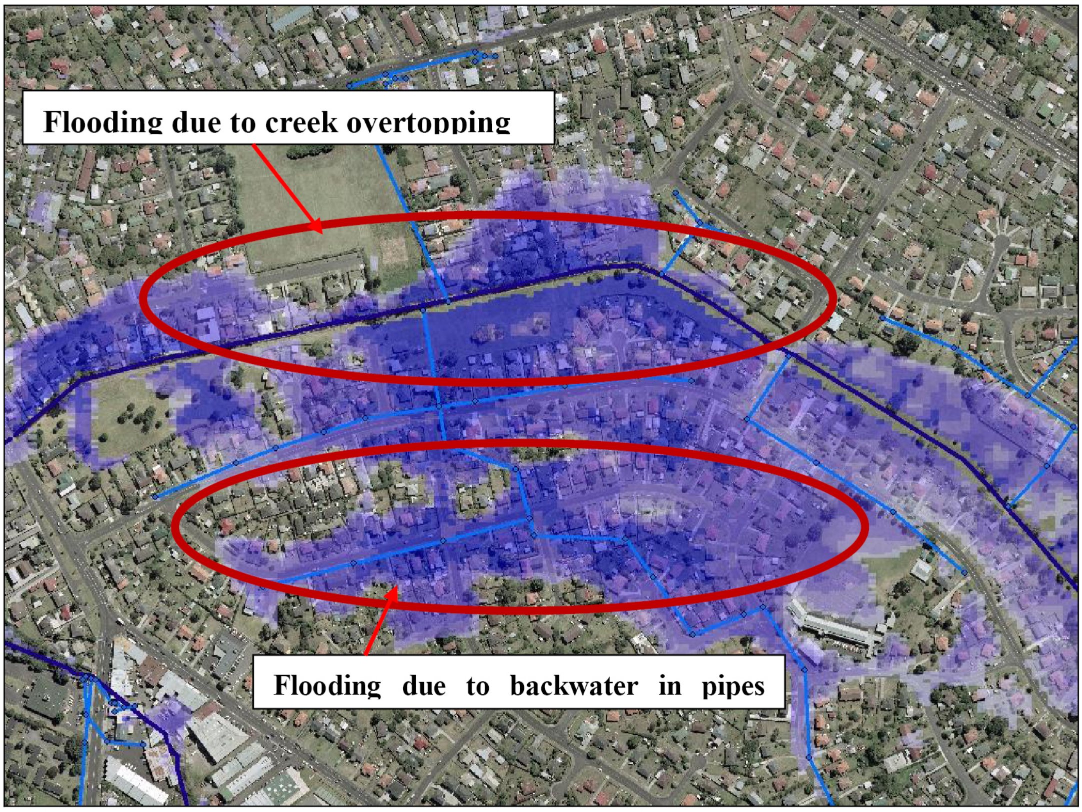

Figure 9: Flooding in O'Donnell area

In areas where the creek has capacity, the flooding can re-enter the creek. These flow regimes are too complex to be represented by a 1D model alone. From viewing the results graphically and in animation, we can see how the creek overtops and the water re-enters the creek further downstream. This would not have been represented in a 1D model alone (although taken into consideration in the calibration).

One benefit of a coupled 1D/2D model is that the results can clearly be seen visually and therefore easily be interrogated. Additionally, property flooding is taken into account by overland flowpaths which might have been missed by a 1D model alone.

8 FLOOD HAZARD MAPPING

Depending on the requirements of the Client, a variety of post-processing techniques can be used to display the results on flood hazard maps. For Metrowater and Auckland City, flood hazards are defined as follows (Metrowater, 2005):

- Flood Plain: The area has a significant water depth and a low velocity.
- Significant Overland Flowpath: The area is characterised by high velocity and shallow water depth or a combination of moderate depth and velocity.
- Modelled Overland Flowpath and Minor Flooding: The area does not exceed the depth and/or velocity criteria, but still contains moving or ponded stormwater.

The end result of this project will be a flood hazard map showing the 10, 50 and 100 year inundation.

Flood depths can readily be extracted to property level and in a more detailed level from the 2D results. This can then be used to update the stormwater and flooding information in Property Files. For new developments, the flood depth can be used to establish new floor levels to be above predicted flood levels (with appropriate freeboard).

9 OPTION ANALYSIS

Auckland City has a responsibility to mitigate habitable floor flooding for the 50 year ARI as set out in the Drainage Strategic Plan. Together with the proposed SH20 Waterview connection there is a huge benefit to working together with NZTA to improve the flooding in the catchment. The model was therefore run with the motorway and the proposed flood mitigation options in place to determine the effect of any additional flows downstream in the catchment on the motorway.

Having a coupled model benefits this complex option analysis and the combined effects of improving the primary pipe network together with the open channel flow were able to be analysed. In the O’Donnell area, where extensive flooding occurs due to flow not arriving at the creek, as well as actual creek flooding, the mitigation effects of increasing capacities in the pipe and creek networks could be analysed dynamically.

The coupled model was run for the 50 year event to determine the extent of the flooding. Options were then investigated for the main watercourse, local flooding as well as for individual sites. A large range of various option models were run to obtain the suitable mitigation options for the catchment.

As the coupled model already deals with three individual models (pipe, creek and surface), the option analyses resulted in a complex range of model scenarios.

10 CONCLUSIONS

After the development and the recalibration of the Oakley integrated 1D/2D model, the following conclusions are made:

- The model build of the Oakley catchment is complex with many different aspects. Time spent on schematization and ensuring the best technical approach was used was crucial to achieve a model which represents the catchment characteristics.
- Complex models cannot be rushed – model schematisation, model calibration, extensive validation is critical to ensure confidence in a model.
- Regular workshops with the client and an independent technical expert ensured that a model was build that would meet the client's needs.
- An integrated 1D/2D model is a valuable tool for flood risk assessment for catchments where flooding occurs due to creek flooding, primary stormwater network under capacities and flat floodplains.
- An integrated 1D/2D model is a valuable tool for option analyses to mitigate habitable floor flooding by analysing the opportunities with improving the stormwater network or the creek capacity.
- Use of an integrated 1D/2D model in the Oakley catchment results in flood estimations of higher confidence than for 1D modelling alone.
- The assumptions taken during the coupling process between the 1D and 2D model need to be reviewed with actual on-site inletting capacities (cesspits and scruffy domes) to ensure the correct coupling method is chosen.
- Calibration and Validation of a coupled model is necessary to ensure that confidence in the model is gained.
- The models should reflect the scenario at the time of calibration, validation or application.
- Use of the methodology described in this paper can be applied in other contexts with adequate consideration of model limitations.

The updating and the use of an integrated 1D/2D model in the Oakley catchment demonstrates that a coupled 1D/2D model produces flood hazard results in more detail than a 1D model alone for catchments with similar characteristics such as Oakley. Furthermore, the use of a 2D component allowed a more accurate representation of flood hazards in the flat part of the catchments studied. The dynamic linking of the pipe model to the creek model demonstrates where the pipe model has insufficient capacity. This allows flood hazard mitigation option analysis to be done by looking at the creek and the pipe system dynamically and optimised solutions can be found.

The added value a coupled 1D/2D model provides to a study should be considered when selecting modelling methodologies for future studies.

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REFERENCES

Connell Wagner (2004). Oakley Model development Report prepared for Metrowater, Auckland.

Metrowater, (2005). Integrated Catchment Study Modelling Framework for Auckland City. Metrowater Limited.

Smedley, R (2010). Managing the Oakley catchment model Build and other client-side Frustrations – Auckland, New Zealand. 2010, NZWWA Stormwater Conference, Rotorua, New Zealand.

van Winden, M., Summerhays M., Davis M.D. Kinley P. Sharman B. and Paterson G. (2006) The Integrated Catchment Study of Auckland City: Integrated Modelling – Integrated Modelling of Urban Drainage Systems – Two Applications. The 7th International Conference on Hydroinformatics, Nice, France.