LONG BAY DEVELOPMENT – BENEFITS OF COUPLED MODELLING

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ABSTRACT

In certain complex situations, 1D models are less suited to reliably predicting actual flow and flood behaviour during larger storm events. A key advantage of coupled 1D-2D models is the closer spatial representation of the true physical catchment, thereby simulating flow behaviour with greater accuracy.

Extensive Environment Court proceedings have advanced the Structure Plan for one of Auckland's largest and original water sensitive communities at Long Bay. The Structure Plan area is over 380ha providing some 2500 dwellings and a town centre. This includes 25ha of the lower Awaruku Stream catchment undergoing significant landform changes to provide civil infrastructure, in particular, the creation of a large 2ha wetland within an existing flood affected area. This retrofit system provides quality treatment for 180ha of non-greenfield catchment.

This paper presents a unique and complex stormwater case study problem, explaining the use of current technologies (GIS, LiDAR, terrestrial survey and 3D land surface modelling) to produce a detailed integrated model used as both a hydraulic analyses and a design tool.

Coupled models require quality data and this project highlights a positive partnering between consultant and Council facilitating the use of a single hydraulic model, encouraging innovation and optimisation of Community Assets.

KEYWORDS

Catchment Planning, Stormwater Management, LiDAR, DTM, 1D, 2D, Coupled Model, Flood Risk.

PRESENTER PROFILES

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An environmental engineer working in water resources at Woods Consultants, Brett has specialist competency in stormwater planning, design and impact assessment. Sharing experience in public and private sector engineering, Brett is committed to achieving sustainability beyond rhetoric and interested in using emerging technologies to realise these principles.

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Jahangir Islam has over 22 years of working experience for local authorities and as a consulting engineer. Currently Jahangir is an engineer working as a Senior Stormwater Hydraulic Modeller in Stormwater Catchment and Asset Planning at Auckland Council. Jahangir has been involved with a wide variety of environmental management projects including stormwater catchment planning, hydrological and hydraulic modelling, storm water quality improvement and remedial options assessment.

Nick Brown – (MSc, BSc)

Nick Brown manages the modelling team at Auckland Council. Nick has experience working as a consultant and for local authorities in both New Zealand and Australia. His main areas of expertise are catchment management planning for wastewater and stormwater systems.

1 INTRODUCTION

Urban stormwater catchment planning, design, and restoration are as much an art as a science, demanding particular expertise to conceptualise the possibilities for optimal catchment management. The development of well organised and effective stormwater designs require a comprehensive understanding of urban and natural drainage systems to evaluate hydraulic performance and flood risk.

The progression of a new community at Long Bay on Auckland's North Shore involves essential civil works to facilitate transportation by constructing an arterial road and bridge which modifies the lower, natural stormwater catchment system. Connected with these works is the creation of a large constructed wetland designed to improve the current state of stormwater quality and reduce existing flooding problems. These issues defined the need to better understand the effects on the catchment and quality of the solution through the use of a computational fluid dynamic (CFD) model.

Constant evolution of engineering design and analysis software, combined with sophisticated measurement and data management systems, means they are now integrating more effectively to produce superior models of physical environments.

This paper presents a unique and complex stormwater case study problem and design solution used at Long Bay, explaining the use of current technologies (GIS, LiDAR, terrestrial survey and 3D land surface modelling) to produce a detailed coupled CFD model used as both a hydraulic analyses and design tool.

Each catchment planning partnership is unique, both in terms of the objectives that direct it and the stakeholders that participate in achieving the desired environmental outcomes and regulatory compliance. Coupled models require quality data and this project highlights a positive partnering between consultant and Council facilitating the use of a single 1D-2D hydraulic model, encouraging innovation and optimisation of Community Assets.

2 LONG BAY STRUCTURE PLAN

Well before the current form of the Long Bay Structure Plan (NSCC, 2010), Council strategic planning anticipated the growth to occur around the North Shore City periphery as part of the regional shift of the metropolitan urban limits. Council also recognised that for the protection and enhancement of the sensitive and high quality receiving aquatic and marine water environments would require greater integration of best practice stormwater management methods, existing District Plan policies, and rules. This awareness has led to the development of specific stormwater management policies and a range of methods that exceed current standards for compliance.

The North Shore City Council Long Bay Structure Plan, Proposed Plan Change 6 and Variation 66, has been the subject of significant and lengthy Environment Court proceedings and hearings with over 10,000 submissions made on the proposal.

The release of the first Interim Environment Court decision (Jackson, et al, 2008) on the Long Bay Structure Plan in July 2008 enabled the North Shore City Council and property owner to engage with more certainty in proactive negotiations to protect the natural environment and shape the future of the built environment at Long Bay.

A second Interim Environment Court decision (Jackson, et al, 2010) released in September 2010 on the Long Bay Structure Plan has now given determination on the District Plan zoning and future land use strategy. Figure 1 below illustrates the scale and mix of the Structure Plan land use zones and management areas. This area is over 380ha and will contain some 2500 future dwellings and a town centre. Also shown is the new access road through the stormwater management area (inside the red oval).

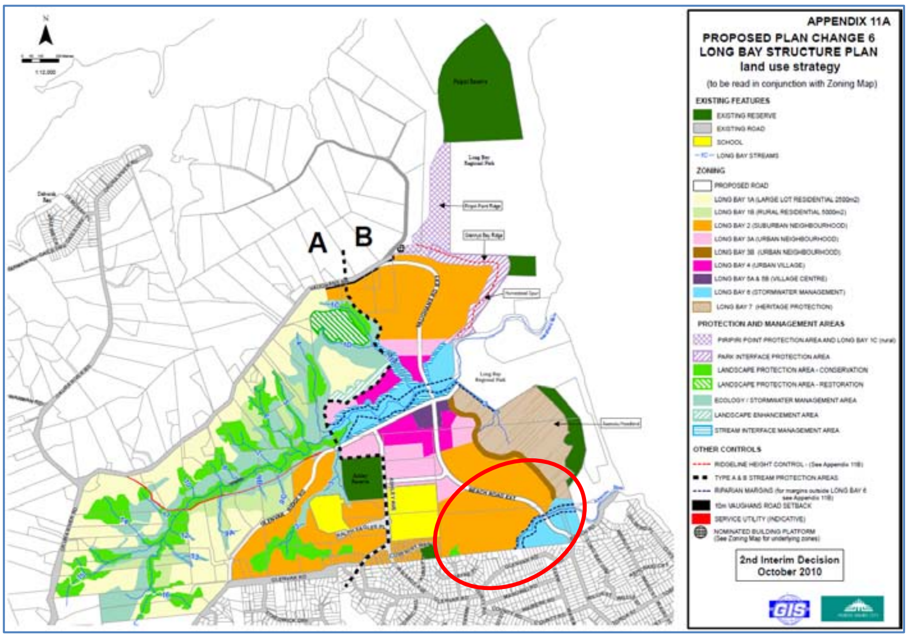

Figure 1: Proposed Plan Change 6, Long Bay Structure Plan Land Use Strategy

Two streams are covered by the Structure Plan, the Vaughan's and Awaruku. While these streams and their combined catchments (650ha) are very modest by river scale, their management and value is no less important to the proposed urban and existing natural environments. In total 4 constructed wetland systems are to be provided as part of the stormwater management facilities.

2.1 AWARUKU CATCHMENT

The Awaruku Catchment is adjacent to the Vaughan's Stream Catchment, which makes up the bulk of the Long Bay Structure Plan area. This catchment is largely urbanised and has an area of 280ha that discharges across the southern shores of Long Bay beach into the Long Bay-Okura Marine Reserve, shown in Figure 2.

A 25ha lower Awaruku catchment area shown by the red ovals in Figures 1-3, is undergoing significant landform changes to provide civil infrastructure, in particular, the creation of a large 2ha constructed wetland within an existing flood affected area. This retrofit system also provides stormwater quality treatment for an estimated 180ha of non-greenfield catchment. The total Awaruku stormwater catchment area of 266ha is presented as this case study example.

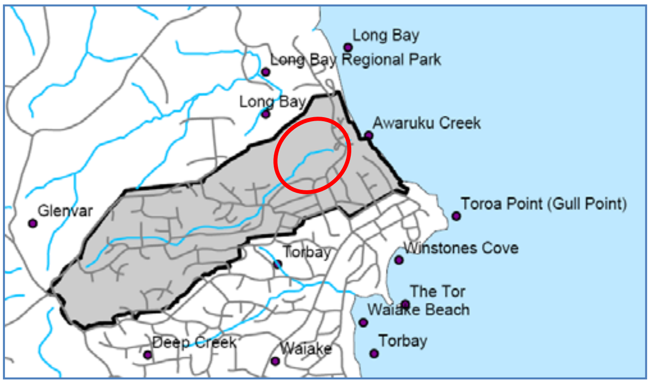

Figure 2: Awaruku Stormwater Catchment

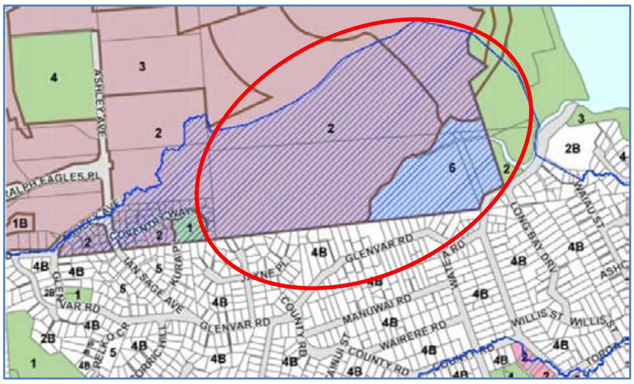

Figure 3: Awaruku Wetland Location & Structure Plan Boundary

3 PROJECT OBJECTIVES

Earlier catchment management planning work completed by North Shore City Council and the Long Bay Structure Plan processes acknowledged several concepts for the inclusion of a large retrofit constructed wetland in the lower Awaruku Stream catchment. These concepts existed in various catchment, planning and discussion documents prepared across a ten year period.

Catchment management plans are typically high-level, long-term, strategic planning documents that explain the issues and objectives, and the guiding methods to be implemented in achieving desired outcomes over a projected timeframe. These plans typically require information on flood risk when assessing policies, evaluating options and identifying preferred methods to be implemented. This is generally:

- Flood risk under existing conditions;
- Flood risk under future scenarios of land use and also climate change; and
- The impacts of the proposed policies and methods.

The only possible location for the proposed wetland is within a large area of flood affected marginal terrain, which was ideal for adaptation and purpose. The hydraulic complexity in this proposal came from:

- The highly modified character of the non-greenfield upstream stormwater networks (natural and engineered);
- Existing flood prone and flood sensitive urban areas;
- The quasi-offline wetland concept and associated hydraulic structures; and
- A significant reduction in the existing lower catchment flood-way zone caused by the creation of a new arterial road and bridge access to the new community.

The large wetland was required to satisfy two water quality performance objectives:

- Provide regulatory compliant secondary water quality treatment for the 25ha greenfield area that is part of the Long Bay Structure Plan extent; and also
- Provide a best practicable option for water quality treatment for the non-greenfield, existing 180ha urbanised upstream Awaruku catchment.

The expected performance of such systems is the interception of suspended sediments achieving a removal of 75% from discharges over a long term average (ARC, 2003). The system is based on a banded trapezoidal bathymetry and has the primary functional objective of providing water quality improvement to the receiving environment. The position in the lower catchment tidal influence zone did not require typical volume attenuation, however, peak flow buffering was also an important objective.

The proposed wetland and new road has flooding implications for at least 35 individual allotments that border the Awaruku Stream and 6 that are located directly adjacent to the constructed wetland. All of these are in secondary flood-way and storage zones and exposed to potentially non-linear flow when in flood.

Following this, it became evident that the range and detail of information required to answer many of the questions asked by cross discipline specialists to achieve the multiple objectives set, not only by the stakeholders but also by policy, regulatory and environmental constraints, identified some unique elements in the nature of detail to be analysed.

3.1 SPECIFICATION

Specifications for modelling problems must be sufficiently thorough to ensure the design team and modeller can access all necessary information to appropriately define the hydraulic problem within the software model environments (Shaw, 1992). This is achieved through a good understanding of the flow problem which is generally defined through consultation with the people who require the varying results of the simulation scenarios. In particular, the modeller needs to obtain three important details:

- Why it is that the simulation(s) are required;
- The geometry of the problem in broad terms; and
- What the possible flow behaviour may be for the given situation.

To provide reliable solutions, the production of an original and reasonably detailed hydraulic model was acknowledged as a necessary priority by the stakeholders. This model was required to simulate the performance of major drainage networks, natural channels, secondary flow paths, and the large wetland under a variety of storm events to assess the proposed physical improvements, and future changes in land use. Simulation results in terms of quantities and duration of flows, velocities and water surface elevations would not only be used in important flood plain mapping, but also for:

- The iterative design of stormwater and related infrastructure (pipes, channels, weirs, wetland and road);
- The performance of the primary and secondary conveyance systems to meet specified levels of service;
- Mitigation or avoiding exacerbating existing urban flooding;
- Assessment of alternatives;
- System optimisation; and
- Environmental and regulatory compliance.

Obvious benefits and an opportunity to use a more innovative approach to modelling this problem became apparent early in the engineering consultation between consultant and Council. The Catchment and Asset Planning, and Hydraulic Modelling team at the former North Shore City Council (now Auckland Council) had already developed an innovative approach to flood studies using a two dimensional (2D) method now known as the Rapid Flood Hazard Assessment (Islam & Brown, 2007). This method has received positive recognition and been used across the City catchments and had also been implemented by other Councils in coarser forms.

The following synergistic opportunities were identified at the onset:

- The hydraulic modelling problem contained sufficient complexity to justify the creation of a coupled 1D-2D model;
- The Council modelling team had significant understanding and depth of experience with advanced modelling methods;
- Council were custodian to high quality geographic information system (GIS) asset attribute and digital terrain LiDAR grid point data sets;
- The consultant was custodian to significant terrestrial field survey data of the Structure Plan area (including specific stream survey data); and
- The consultant had the technical capability and design and analysis modelling tools to create a quality coupled 1D-2D model.

Given the obvious benefits in combining these available data and knowledge resources, it was requested of Council that a coupled model be developed by the consultant to best model the problem. This was evaluated by the Council Water Services team and approved by the Infrastructure Planning Manager.

This consultation provided a process where a reasonably clear specification could be agreed in regard to what was to be achieved, the general methodology, what information was available (and missing), and responsibilities, resulting in a productive and positive partnering arrangement between consultant and the Water Services Planning Engineers and Hydraulic Modelling Team.

4 MODELLING

Conventional one dimensional (1D) models have long been used to model flows in urban drainage and open channel networks. However, in certain complex situations, 1D models are less suited to reliably predicting actual flow and flood behaviour during larger storm events and variable terrain areas. This is particularly the case when modelling areas where flow may be non-linear, such as flooding roads, secondary flow paths and also river overbank flood-ways and flood-plain storage that may occur during lower probability storm events.

As a flood management tool, 2D models like the method developed by Council are at least as accurate and produce results that are far more readily accepted and understood by stakeholders than those generated by a 1D model. The limitations on use of exclusive 2D models for more frequent storm events in urban areas is the omission of primary below ground drainage and underestimation of open channel sections.

The main advantage of coupled, one dimensional-two dimensional (1D-2D) models is the significantly closer spatial representation of the true physical catchment, and the more accurate solution of governing equations (Syme, 2006), and therefore, being able to simulate flow behaviour with greater precision and accuracy.

Coupled models are being used with significant benefit in appropriate situations but their complexity and data requirements can in some cases limit their application. In this example, access to quality data was easily obtainable from the consultant and Council, enabling some common limitations to be avoided.

4.1 CALCULATION METHODS

Hydraulic modelling of unsteady flow is based on three elements:

1. Expression of physical laws using a partial differential equation;
2. A finite difference scheme producing a system of algebraic equations; and
3. A mathematical algorithm that solves the equations.

Most current hydraulic models apply calculation engines using complex algorithms based on continuity (conservation of mass) and momentum (conservation of momentum) known as the Saint Venant equations (Chow, 1988). While in-depth discussion on the theory and derivation of these governing equations of fluid flow is beyond this paper, the basic differences between the concept of 1D and 2D models is covered in the following paragraphs.

When most flow occurs parallel to the longitudinal direction of flow, this is described as 1D. Gradually varied, unsteady, 1D flow models use the Saint Venant equations to perform fully dynamic hydraulic simulation.

When flow across a surface has many changes in direction and little correlation with the longitudinal alignment of the source from which it originated, this can be described as 2D flow. Gradually varied, unsteady, 2D flow models use the free surface, shallow water, Saint Venant equations and are solved in the X and Y dimensions for the depth averaged condition using grid cells.

4.2 DATA REQUIREMENTS

The minimum data needed to create a coupled model are:

- A digital terrain model (DTM) having resolution and accuracy to represent the terrain, defining correctly; flow paths and storage areas in the 2D domain. The vertical accuracy depends on modeling objectives and sources, though for detailed urban models < +/-100 mm is recommended minimum;
- Linear and sectional data for 1D pipe networks (if needed);
- Survey of important hydraulic controls such as natural stream channels and embankments, culverts, bridges;
- 3D break lines;
- Terrain surface typology determining bed resistance categories over the DTM, using aerial imagery or GIS layer where land-use zones are appropriately clear to set Manning's *n* values;
- Boundary conditions (e.g. hydrology, catchment inflows, tidal levels, point of ultimate discharge); and
- Preferably calibration or validation data locations. Typically, GIS points where known or other modelled levels are attached as attributes to the calibration/validation points (e.g. rating curves).

4.3 METHODOLOGY

In basic terms, the methodology used was to evaluate effects on the lower Awaruku catchment by the proposed land use changes, assess the significance of these, and where possible improve the situation through robust analysis and best practice design. Key activities undertaken as part of the modelling methodology included:

- Literature review;
- Existing modelling review;
- Physical stream investigation, wetland location assessment, stormwater network and key asset validation;
- Collection of topographical data and analysis (LiDAR and terrestrial field survey);
- DTM and audit;
- Consultation and review with Council Hydraulic Modelling Team;
- Coupled model development and review by Council experts;
- Wetland design hydraulics options evaluation and consultation with stakeholders;
- Impacts assessment; and
- Resource Consents.

4.3.1 STANDARISED PARAMETERS

Producing any integrated hydrological-hydraulic model and running simulations for the required scenarios can be a considerable body of work. Therefore, a set of standardised input parameters for the modelling was collaboratively produced by suitably qualified experts and agreed for use before the model build. The approach provided consistency in the model build with existing Council standards and models, and eliminated any potential debate with respect to parameters after the modelling work was completed. This is to avoid unnecessary amendments and simulations. The standardised parameters included:

- Runoff model method;
- 24 hour rainfall depths, (current and climate change);
- Rainfall hyetograph (current and climate change);
- Manning roughness values (for 1D and 2D); and
- Coastal boundary conditions (engineering design high water).

4.4 TERRAIN MODEL

Coupled hydraulic models require domains, boundaries and interfaces that define zones where 1D or 2D flow may occur, connections and boundary conditions. The main 2D model domain is the grid which defines the extent of the model and active cells. This domain must be integrated with a DTM. Topographic layers are then used to further define 2D flow properties.

In this example access to a very high quality DTM was not an issue, however, preparing and auditing this element was one of the more time consuming activities of the of the model. Conversely, the effort dedicated to producing a high quality DTM returned significant efficiencies in the geometric and hydraulic model discretisation.

4.4.1 COUNCIL LIDAR

North Shore City Council commissioned a high quality city-wide terrestrial survey using aerial laser scanning during 2004. This is commonly referred to using the acronym LiDAR, short for; light detection and ranging. This technology scans the terrain and records large numbers of ground points per unit area. These massive data sets are analysed and filtered using proprietary software, removing elements like trees, vegetation, cars and buildings and then provided as raw ground elevation point data with other layers available. These are most commonly converted to GIS shape file grids.

LiDAR data was obtained from Council for the full Awaruku and Vaughan's Stream catchments as filtered; XYZ grid points as a database file format. This Council urban data is referenced as having a point density of at least 1 pt/m^2 with a horizontal accuracy of 400 mm, and vertical accuracy of 100 mm (95% confidence).

The resulting depth of flow in 2D areas using LiDAR is dependent on the vertical accuracy of the data and when the LiDAR grid points were checked against adjacent survey controlled data the accuracy was generally significantly better than the specification.

4.4.2 TOPOGRAPHIC SURVEY

A considerable part of the early project foundation work undertaken as part of the feasibility and option analysis and Structure Planning was terrestrial field survey. This accurate measurement data was recorded and used for cadastral and engineering design purposes.

Specific supplementary field survey was also undertaken in the lower Awaruku Stream and surrounding proximity of interest from a weir at Glenvar Road to the beach at Long

Bay. Surveying included a detailed stream reach and cross sections from Long Bay Beach to a weir and double culverts at the intersection of Glenvar and Awaruku Roads. Within this area a reasonable quantity of topographical spot height, stream channel, reticulated network and manhole asset, weir, culvert, road and critical information was collected and utilised in the DTM and hydraulic model. This was also used to validate some GIS drainage asset attribute data.

4.4.3 COMPOUND DTM

There are various methods available to execute the reconstruction of a DTM using XYZ data. The method used in this case was the creation of a triangular irregular network (tin) file using a 3D survey and design modelling software package named *12D*. The use of a tin has efficiencies in planar surface creation and is a native format to both *12D* (12D Solutions, 2009) and the CFD model, named *XP Storm* (XP Software, 2009) used for the design and analysis.

The XYZ data were translated into a common geodetic datum and projection used by Council, New Zealand Transverse Mercator (NZTM) 2000, and reconstructed into a compound DTM for integration with the hydraulic model. The compound DTM was validated for the number of pt/m^2 and vertical accuracy against controls, exceeding the recommended specification.

A sample of some of the terrestrial field and cadastral survey used, shown as the cyan points, are illustrated in Figure 4. This shows the detailed stream and road survey with particular emphasis on changes in channel width, grade, embankment crest and complex areas.

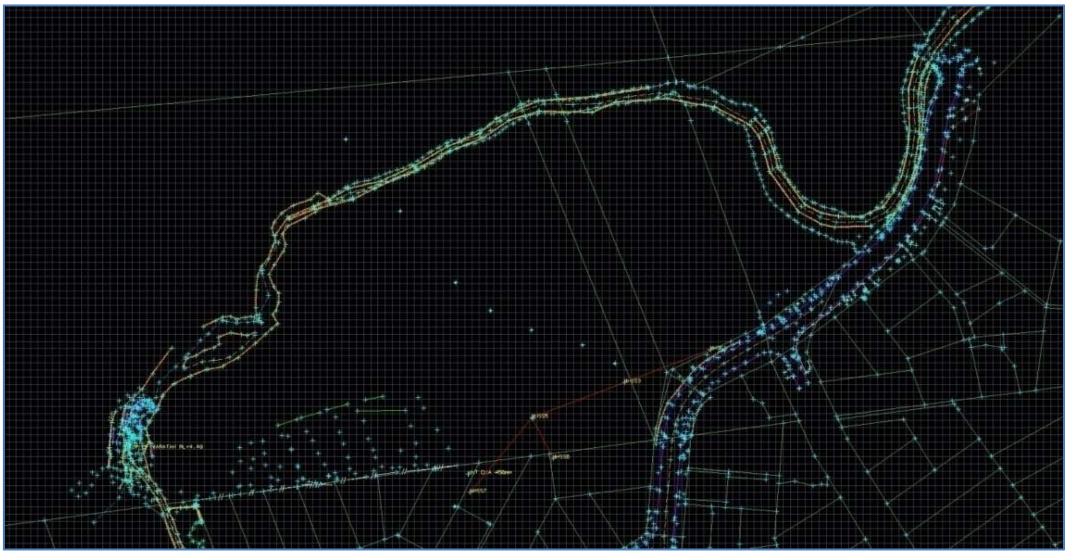

Figure 4: Field Survey Data

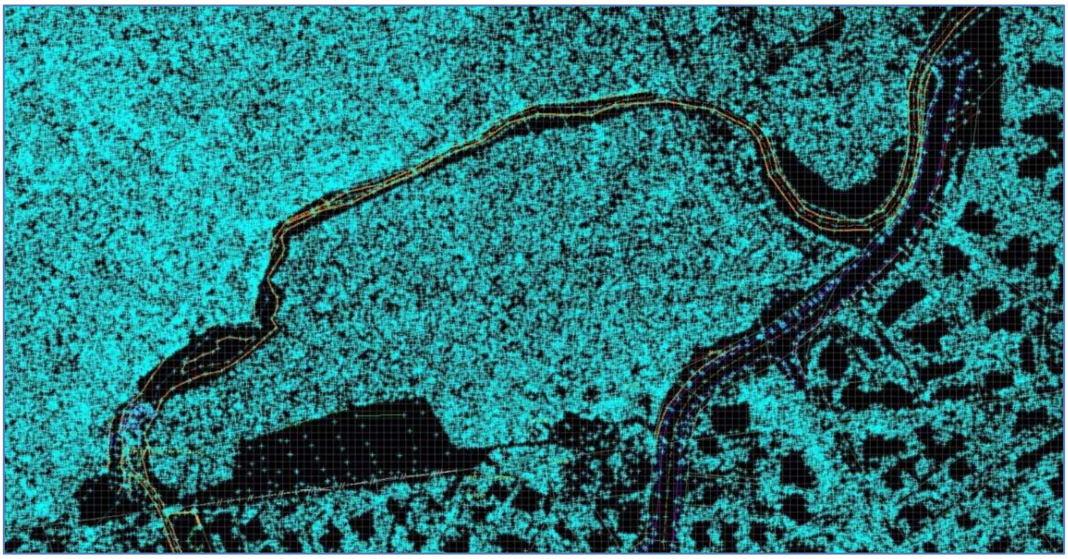

Figure 5: Field Survey and LiDAR Data Combined

Figure 5 illustrates the combined survey and LiDAR data sets used in creating the tin and compound DTM. The areas where there are a less dense point scattering are the filtered areas such as trees and vegetation, buildings, and field survey. The point density demonstrates the quality of the resultant DTM in modelling the real physical situation.

4.4.4 COUNCIL GIS DATA

Having the DTM in the NZTM 2000 projection meant that complete hydrological catchment geometry, stormwater reticulated drainage and stream network, and land use zones could be obtained from Council as GIS database and shape files, which were easily imported into the 3D design and coupled model. This provided very detailed catchment and asset attribute information from which the appropriately simplified 1D network was developed.

4.5 COUPLED MODEL

Having a shared and clear articulation of objectives with Council had led to a better understanding of general data availability, requirements and selection of a coupled model for use in this case. The depth of experience in the Council modelling team meant that the use of a coupled model in enhancing predictive performance was not construed as an unnecessary complexity.

4.5.1 RUNOFF MODEL

The subject *hydraulic analyses* catchment has a total area of approximately 266ha made up of 31 hydrological sub-catchments. For the purposes of the coupled model the sub-catchments were appropriately combined into 10 larger sub-catchments to simplify the number of stream inflow nodes.

As part of the standardised parameters, the guidelines for stormwater runoff modelling in the Auckland Region, Technical Publication No. 108 method (ARC, 1999) were used to set up the hydrologic model. The hydrologic model is integrated with the hydraulic model. This enables a deterministic distributed unsteady runoff model (Chow, 1988) to be set up which considers certain hydrologic processes occurring in the sub-catchments and defines the model variables as functions of sub-catchment dimensions. These variables were determined using the Council GIS catchment data.

4.5.2 1D NETWORK

Council GIS data was again used in the discretisation of; the 1D network above the Glenvar Road weir, important hydraulic structures (culverts) and storage nodes for the upper catchment flow control and treatment facilities.

The lower network 1D discretisation was completed manually in the hydraulic model using the field survey data identifying critical points for nodes, links, complex sections and hydraulic structures. The 1D model network is geospatially accurate and consists of:

- 2 Storage Nodes (upper catchment quality attenuation Ponds);
- 44 Nodes;
- 1 Outlet Node (Beach discharge);
- 2 Multi-Links (Pipes & Spillways for the Emlyn & Stredwick Ponds);
- 2 Weirs;
- 37 Natural Links and cross sections;
- 2 Trapezoidal Links and cross sections;
- 2 Box Culvert Links; and
- 3 Pipes and culverts.

4.5.3 2D DOMAINS

The lower Awaruku catchment provided an uncomplicated area to set up the 2D domains. This is characterised by a well-defined area where flood flows were either known, or could be expected to leave (or enter) the defined channel as overland flood-way flow or flood-storage zones. The key domains required are illustrated in Figure 6 and consist of:

- The 2D grid and cell size which sets the ultimate boundary of the 2D model (green mesh);
- The active areas where 2D flow can occur (blue grid); and
- The 1D-2D interface boundaries (red dashed line) between the 1D channel and 2D area that lies along the edge of the active 2D area.

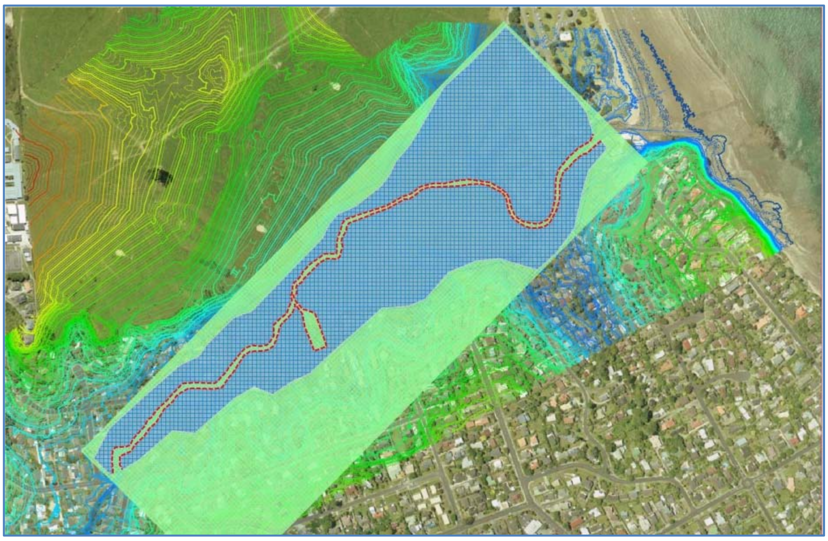

Figure 6: Primary Lower Awaruku 2D Domains

Another very important domain that is not illustrated is the land use zones for the 2D roughness characteristics (i.e. Manning's). These values are typically much higher than used in conventional calculation which is related to the shallow flow equation. The manning values used for the overbank and flood-way were in the order of n = 0.08 and as high as 0.15 through the wetland.

The model used a grid resolution of $1m^2$ and total count of 2×10^5 cells i.e. 20ha. Efficiencies in cell count and active areas were achieved after the first maximum event simulation by reducing the areas that were clearly not 2D wet cell zones.

Additional result plot output tools to specifically interrogate 2D areas were also used.

4.5.4 VALIDATION

Two other recent models of the catchment were held as Council corporate data (Circa 2003 – 1D; and 2008 – 2D). The results from these were used to validate rather than calibrate the coupled model under the unmodified, most probable scenario. As this was a design and analysis exercise using reasonably conservative hydrologic and hydraulic parameters, and there were difficulties obtaining suitable calibration data, the coupled model was validated using the Council models.

Figures 7 and 8 below show the comparison of the results between the Council and consultant models for the 100 year design storm, existing scenario flood extents. These results show very close conformity between the two models which were created using different methods and software.

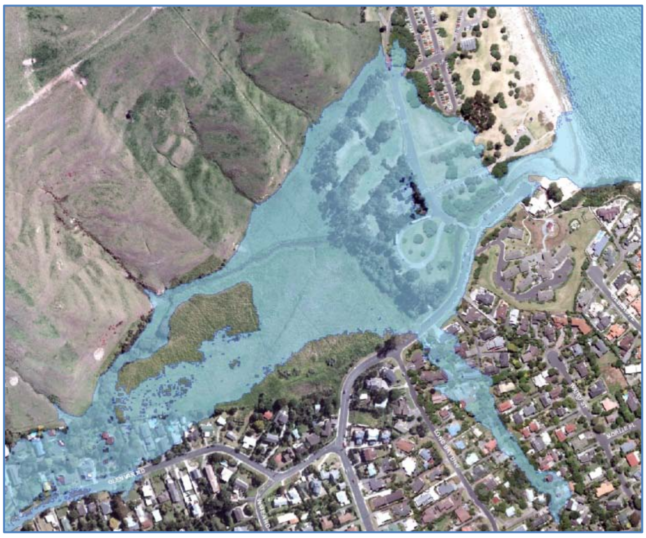

Figure 7: 100 Year Flood Extent

Exclusive 2d Model

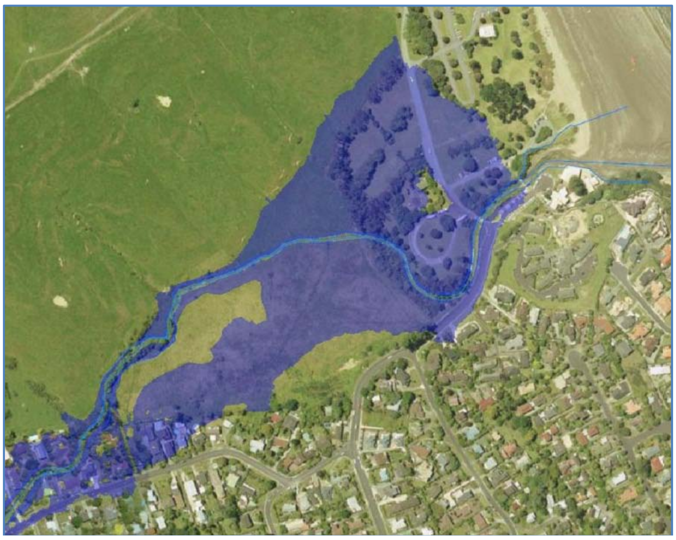

Figure 8: 100 Year Flood Extent

Coupled 1d-2d Model

The visually observable differences are the inclusion of a 2D flow path (lower right) and lower channel extent and sea level shown in the Council example. These are not shown in the coupled model 2D extent as they are contained within the 1D model and not graphically shown in the model interface.

5 BENEFITS

The existing and design scenarios were simulated for the: 2; 10; and 100 year design storm events. Furthermore, steady state flow was also simulated to evaluate the wetland hydrodynamics. In addition to overcoming some limitations of a conventional 1D model the coupled model provided the benefits of:

- Improved quality in detail and accuracy of model discretisation;
- The model was more useful across the wide range of simulations;
- Superior representation of flow systems in complex areas;
- Better representation of non-linear shallow flow;
- Comparative analysis of results is easier; and
- Increased confidence in results due to reduced interpretation required.

5.1 CHANNEL SECTIONS

1D hydraulic models use cross sections that are linear in plan form and perpendicular to the corresponding link channel. There are limitations in generating cross sections using LiDAR DTM's, and further limitations caused by the effect of applying a grid and the related resolution.

Cross sections can however be created using a LiDAR DTM, although the points that produce the interpolated planar surface can underestimate the actual channel section area. This can be caused by reflection, dense vegetation and the slope of the channel sides. An example of a corrected stream section from the model is illustrated in Figure 9 below. The sections created using LiDAR and corrected survey data show a reasonable difference in actual area.

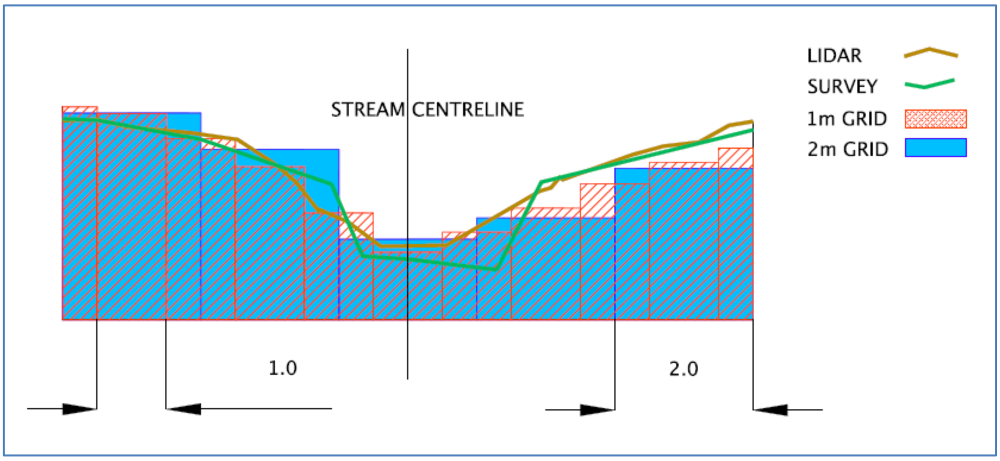

Figure 9: Stream Channel Cross Section Correction

This can be further problematical using 2D depending on the grid resolution, as shown again in Figure 9 by the resultant sections for 1 m and 2 m grids. This is less important when modelling infrequent larger events, as evident by Figures 7 and 8, however, this method is not suitable for modelling in channel flow.

Point data in the compound DTM avoids this as the surveyed embankment crests form the interface boundaries between the 1D network and 2D domain and an accurate section is used for each channel link. The in-channel results are therefore more reliable.

5.2 3D DESIGN MODEL

One of the more significant benefits in this case study example was the use of a 3D modelling package (*12D*), to produce the compound tins of the existing and design models.

These tins are integrated to the coupled hydraulic model as the DTM which meant the designers and modeller used the *same* 3D project and tin models.

This provided a comprehensive understanding of existing flooding and constraint issues before any solution options or design was started.

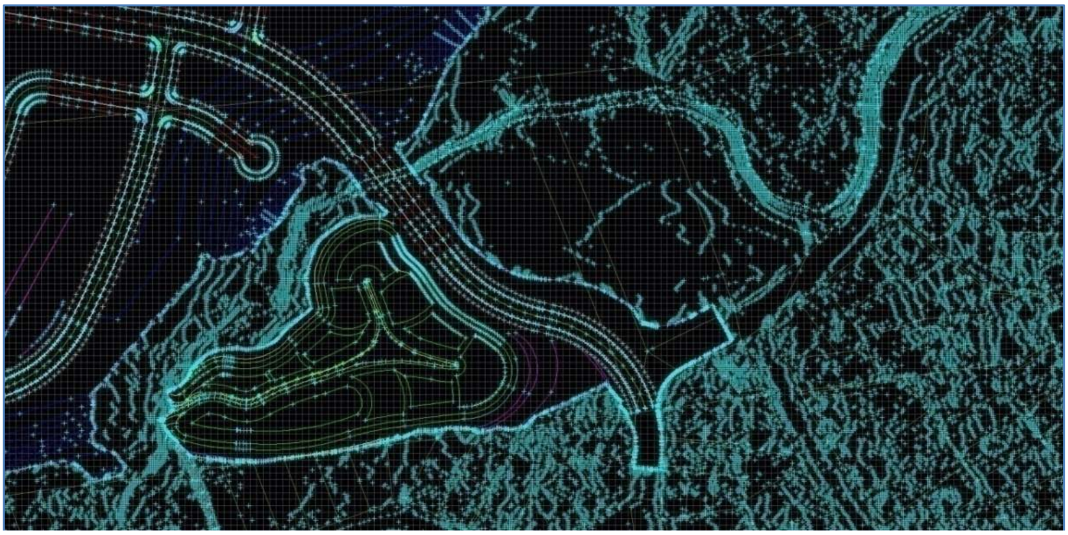

Figure 10: 3D Design Model Vertices interfaced with Compound DTM

It was identified that the coupled model could be discretised in a way that included the in-channel modifications (i.e. channel widening, diversion weir and dam, outlets) to be appropriately defined and contained within the 1D network for both scenarios, while the more major earthworks design changes to the existing tin and DTM occurred entirely within the 2D model domain. Identical coupled models were used for each scenario with the exception of the 1D structures noted.

The civil design of the road and wetland was then modelled using the existing compound tin as the source project data in *12D*, as shown in Figure 10, and seamlessly linked to the coupled hydraulic model for analysis. This provided a direct correlation between the hydraulic model, simulation results and civil engineering design of the wetland and hydraulic structures.

In addition to the design efficiencies, the simulations and results evaluated using the integrated tin and coupled model has meant that the iterative design process achieved beneficial optimisation that may not have been possible otherwise. Therefore avoiding unnecessary cost and eliminating redundancy in functional performance. Ultimately, this translates into capital and long term operational cost reductions through a more precise design providing significant advantage to stakeholders and long term operation by Council.

5.3 RESULTS

The most common results of interest to engineers are the spatial and temporal distribution of depth and velocity of various discharges.

The graphic interface and variety of result interrogation tools in coupled models greatly enhance the results analysis process. Figure 11 illustrates the model results interface showing the water depth gradient and contours and flood extent for the 100 year design event.

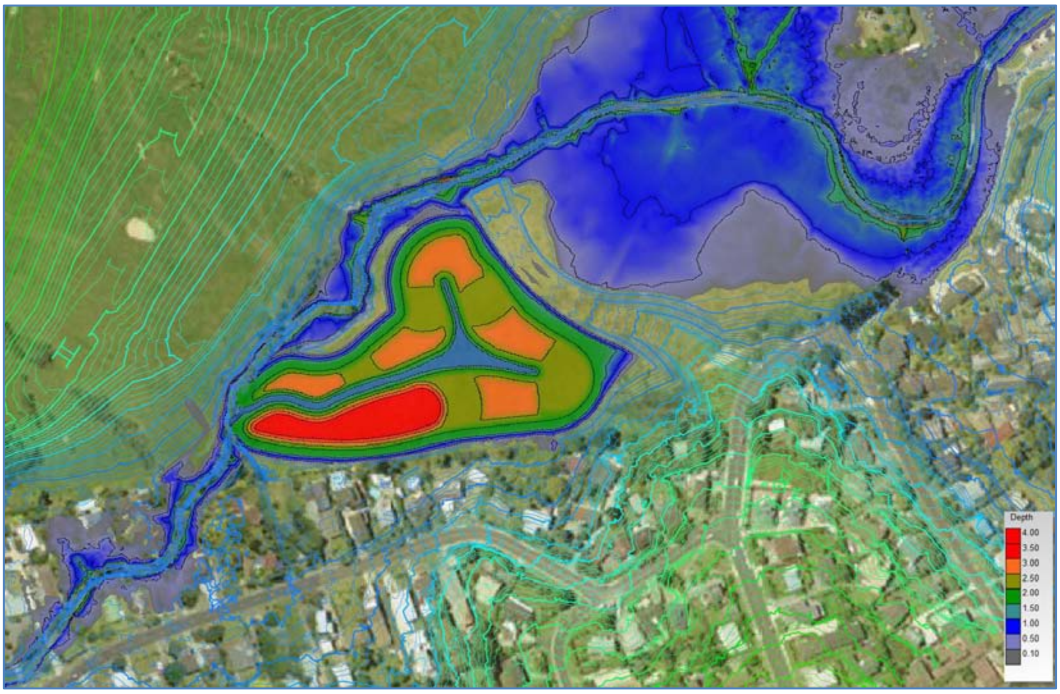

Figure 11: 100 Year Flood Extent Water Depth and Depth Contours

This scenario used estimated future rainfall to 2090 and a modified hyetograph producing very conservative flow results.

The graphic results are very useful to the modeller and designers in more efficiently evaluating and vetting the engineering designs and supporting quality assurance processes. This provided greater confidence in the design achieving the specified objectives, including the alleviation of existing flooding problems and future risk, even with the modification to the lower flood-way. Various numerical results still require analysis, however, a significant level of complexity is removed with beneficial gain in result accuracy. The variety and flexibility of graphic results produced are simpler and offer improved understanding by engineers and stakeholders resulting in more informed and confident decision making.

5.4 WETLAND HYDRODYNAMICS

Designing regulatory compliant wetlands in the Auckland Wards typically requires using the TP-10 method (ARC, 2003). The sizing of which is based on the area of a conventional wet pond with the prediction of their actual hydraulic performance somewhat anecdotal. The hydrodynamics of a wetland, are however, very different to conventional deeper wet ponds and can require a more detailed hydraulic analysis if they do not perform a specified attenuation function and differ from the generic parameters. Constructed wetlands treat urban stormwater through a number of pollutant removal processes, including sedimentation, filtration and biological uptake. Complex micro-topography, frequency of inundation, depth and flow velocity through the system all influence the growing environment for wetland plants with indefinite hydrodynamics resulting in potentially lower plant diversity and habitat value.

The proposed wetland has an uncharacteristic shape and was evaluated using the 2D model to assess the depth and velocities through a range of dynamic and steady state flows. Figure 12 illustrates the depth as a colour gradient and flow direction and velocities as scaled arrows during a 0.5m^3/s steady state simulation.

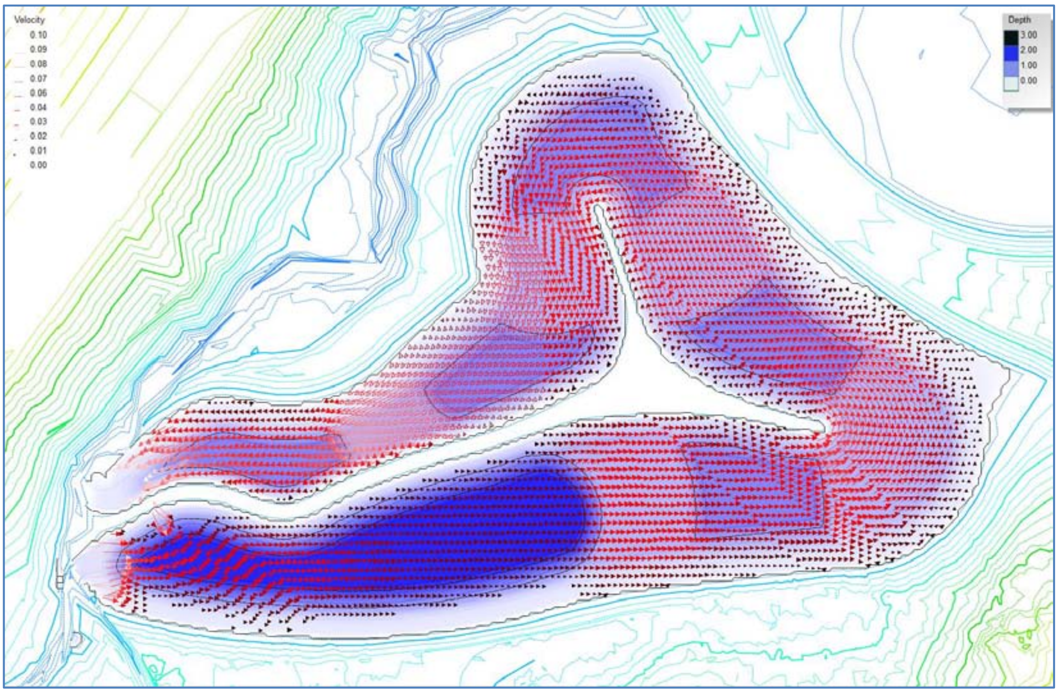

Figure 12: Steady State Simulation 0.5m^3/s

Figure 13 show a close-up of the wetland inlet, forebay and outlet at the normal operating depth (2m in forebay).

The velocities and flow direction are displayed as vectors and in this example the length is scaled and has a range from 0.0-0.1m/s, zero velocity shows no arrow while the longer lighter arrows show the upper limit of the range. The arrows inside the yellow circle show discharges into the forebay from a secondary inlet from the Structure Plan greenfield development area.

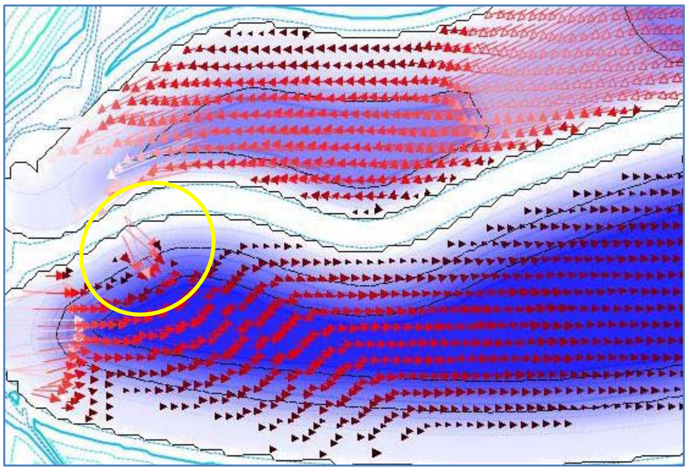

Figure 13:Forebay and Outlet

Wetlands are progressively emerging as central elements in treatment trains and implemented in urban catchments to ameliorate stormwater quality and buffer peak flows. Analysing the wetland hydrodynamics in the 2D domain, across a range of scenarios, has facilitated a better understanding of spatial and temporal distributions of depth and velocity resulting in enhanced design outcomes and public amenity value.

6 LIMITATIONS

Coupled models do not necessarily need to be a time consuming and expensive exercise, however, the following points are some of the main limitations that will commonly be encountered.

One of the main limitations to coupled models is access to data. Coupled models add calculation complexity but can also simplify the problem in terms of representation and parameters required. Understanding the amount and quality of data required is important in creating models that produce the right results for the right reasons.

The 2D grid resolution must be appropriate to represent the physical terrain in the DTM cell elevation. The critical issue with the 2D grid resolution is the attaining an optimum size to effectively create a DTM of the true physical topography to accurately simulate the flow at an appropriate level of detail. Compromise will often be made in using larger cell sizes to reduce simulation run time, but caution must be applied. This example was tested with a range of cell sizes up to 4 m with the final models shown using 1 m. The total number of wet cells in the 100 year design storm was in the order of 1.1×10^5.

Simulation run times are inherently longer and this is relative to the size and resolution of the 2D grid. The run time is directly proportional to the number of time-steps required to calculate model behavior for the required time period. As a general guide, halving the cell size typically corresponds to increasing the simulation run time by a factor of eight. In this example the 100 year design storm had a simulation run time in the order of 300 minutes for a 16 hour event using a 0.5 second time step.

Depending on the results options selected these models create large results files. These are in the order of gigabytes as opposed to megabytes. High specification computer hardware facilitates a reduction in simulation time and stability in larger models.

7 CONCLUSIONS

The main intention of this paper is to demonstrate the benefits of using a coupled hydraulic model across a modest scale catchment, satisfying multiple objectives. There are several different fundamental methods to creating hydraulic models and pragmatic selection must be made concerning an appropriate level of model complexity and the consequences on predictive performance. The model is required only to support decision makers by simulating (preferably observed) flow at an established accuracy and provide results that are correct in providing solutions to the problem identified.

Modelling in many ways also follows the axiom of art and science combined, with the creative and technical ability, shared with depth of experience in a modelling team a dominant factor that contributes to the quality of the model developed to analyse any given problem. The clearly defined objectives and open exchange of ideas between consultant and Council supported the shared understanding of available data resources and concluded that a coupled 1D-2D model was better suited to simulating complex flows in this case.

The stormwater retrofit process is very different to designing greenfield devices. Gaining a comprehensive understanding of existing catchment factors causing flooding and affecting stream and stormwater quality has been key to the improvements made. Setting environmental and compliance objectives early in the process was extremely important in the selection, preparation and quality of the modelling completed. Rather than just maintaining the status quo, the design has resulted in a predicted alleviation of existing flooding, plus fully compliant quality treatment of not only the Structure Plan stormwater discharges but also the, 180ha non-greenfield Awaruku catchment which is considered laudable.

The coupled 1D-2D method has been used in both Structure Plan stormwater catchments (Vaughan's & Awaruku) and demonstrates the innovative use of technologies in the creation of lasting value in an urban stormwater system and the ecosystem services they provide. By definition, innovation means new and inherently carries risk, but in this example it has been a robust contributor in sustainable management and impact on objectives.

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