CHRISTCHURCH CITY MEGA MODEL - MAGIC OR MADNESS?

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ABSTRACT (300 WORDS MAXIMUM)

The Canterbury earthquake sequence resulted in significant changes to the land drainage network in Christchurch. In order to better understand the impacts of the earthquakes on flooding the Christchurch City Council (CCC) undertook an ambitious three-way coupled hydraulic modelling project across almost all of 'flat-land' Christchurch. This will be used by the Land Drainage Recovery Programme (LDRP) to support identification and prioritisation of repair and remediation options. It will also be a powerful tool for CCC to use to investigate resiliency of the city against climate change and sea level rise effects.

The goal of the modelling was to establish earthquake effects and to develop a tool to inform options assessments. The level of detail required to accurately quantify the effects and to support investigations required modelling of the road corridors, 304 km of waterways and 554 km of pipes down to 300 mm diameter across an area of 17,195 ha. The high level of detail was required to capture the full extent of the earthquake changes, for example, settlement in areas remote from the main river channels. These project requirements have led to innovative modelling approaches.

This paper briefly explains the scale of the problem, solution definition, model development and some of the early findings of the modelling. Some of the challenges that were overcome include; building a high resolution surface model following a significant change to the land surface, deciding how a pre-earthquake model should be defined, building a large complex model that runs quickly, dealing with inter-catchment flows in very flat topography, addressing data gaps, and meeting tight programme deadlines. The paper also explains the benefits and detriments of the approach and how an open dialogue between the Council and the Consultant led to a robust and powerful tool.

KEYWORDS

Stormwater modelling, flexible mesh, flood hazard assessment, earthquake, coupling, risk

PRESENTER PROFILE

Tim is a Christchurch born and bred Civil Engineer (BE Civil First Class Hons University of Canterbury). His specialism in water engineering, is inspired by the natural beauty of flowing water, and the entertaining math. Significant career highlights have been leading the Christchurch City Council input into the operational response to sewer network restoration of service post the Feb 2011 earthquake and two years working as the resident engineer on a tertiary WWTP upgrade design build project in Puerto Rico.

Tom has been helping Christchurch City Council for the last 2-3 years on the Land Drainage Recovery Programme as Technical Manager. His focus has been on developing the programme from inception through to delivery. Tom relies on his experience in stormwater concept design and modelling from a range of different environments, here and overseas.

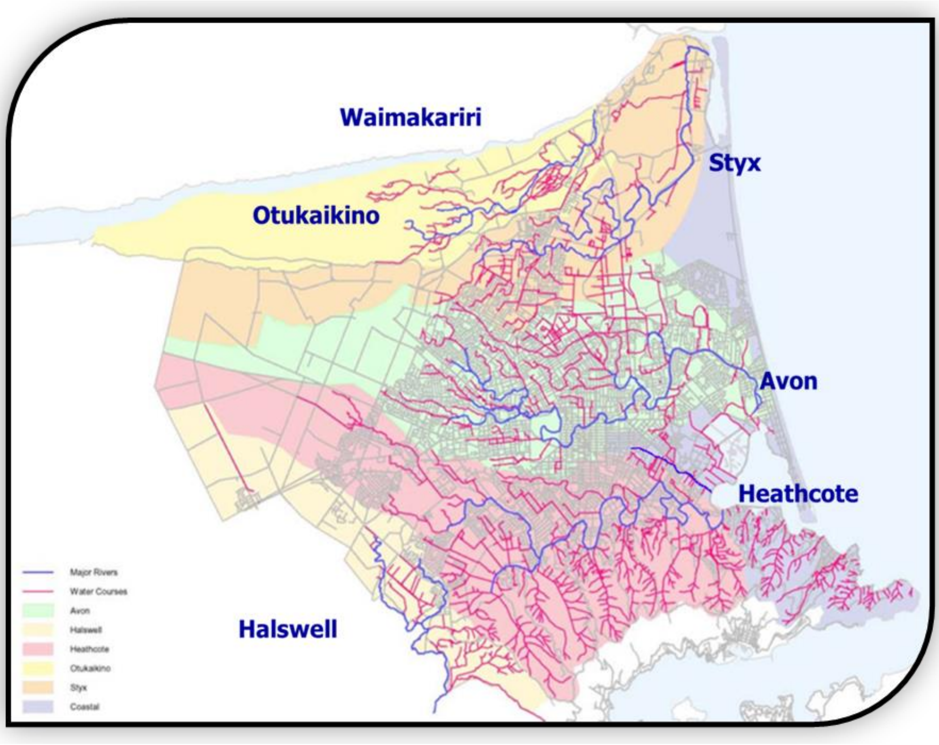
1 INTRODUCTION

The Canterbury Earthquake Sequence (the 'earthquakes') has increased flood risk in some parts of the Christchurch City by changing the topography and damaging land drainage infrastructure. The Land Drainage Recovery Programme (LDRP) was established by Christchurch City Council (the 'Council') in 2012 to understand the consequences of the earthquakes on the land drainage network within the City limits. In addition to the immense physical damage, the health and social impacts on communities has been severe. Initial estimates for an engineering intervention approach to repair and restoration of flood risk total approximately $1,200 million. Council currently has identified approximately $700 million in its 30 year LTP. The LDRP will help to restore community resiliency and wellbeing through engineering and adaptive management.

Prior to the earthquakes Council had developed models of individual catchments across much of the city, including the Ōtākaro / Avon, Ōpāwaho Heathcote and Pūharakekenui / Styx Rivers (Figure 1). These were developed at different times, to different standards and for different purposes. Council has used these hydraulic models to assess the magnitude of the earthquake impacts on flood risk. It was found through initial investigations that a greater level of detail was required in the models to assess earthquake change and support development of flood remediation projects.

The Citywide flood modelling project was scoped, tendered and started with the aim of delivering updated river catchment models for 'flat land' Christchurch with much greater detail and a single combined hydraulic model of the City's waterways and pipe networks (greater than 300 mm). The model represents much of the land drainage system in Christchurch of rivers and tributaries, utility waterways (lined and unlined drains), and stormwater pipe networks (Table 1).

Figure 1: Christchurch City River Catchments



The scale of the model is internationally significant. The model is built in DHI software with three primary elements coupled together using Mike Flood. The three primary modelling elements are Mike 21 ground surface (M21), Mike 11 rivers and open channel

1D network (M11) and Mike Urban ID pipe network (MU). There are international precedents for larger models in terms of number of MU pipes and number of M21 cells, however the only examples reported from DHI global enquiry are either single element models or two way coupled MU-M21 models. No comparable sized three-way coupled models have been identified.

Table 1: Summary of land drainage network

FEATURE	APPROXIMATE SYSTEM LENGTH (KM)	LENGTH MODELLED (KM)
Rivers	79	79
Tributaries	160	150
Utility Waterways (lined / unlined drains)	130	115
Stormwater Pipe Network	790	660

2 BACKGROUND

2.1 CCC HISTORICAL MODELLING APPROACH

Prior to the earthquakes the Council developed a number of hydraulic models. These models were developed for a range of purposes; from small design models to large catchment models for the purposes of informing Stormwater Management Plans (SMPs). The models were typically developed utilising the DHI modelling suite and with appropriate levels of detail specified to meet individual project needs.

The large catchment models of the Avon, Heathcote and Styx Rivers had been developed, modified and updated over a number of years to consider the effects of new development, infrastructure modifications and long term planning, e.g. climate change adaptation strategies. These MikeFLOOD models also had a range in level of detail depending, typically, on timing of the original model build process, with newer models having greater detail.

Given the flat nature of Christchurch there are numerous points where inter-catchment flows occur, for example, Cranford Basin and the Central City pipe networks. Typically assumptions were made at these locations, however, other approaches were also used: existing models tested iteratively, or new models were developed that spanned the boundaries. These areas are of great interest to the Council, particularly Cranford Basin, as assumptions regarding inter-catchment flows can affect planning decisions.

2.2 CHRISTCHURCH EARTHQUAKES

There was extensive damage across the city to land and to stormwater and open channel networks. The damage is widespread across the city but more extensive in the Eastern suburbs. Changing land levels have altered drainage patterns across the city and impacted on capacity of the drainage network. Bed heave, lateral spread, liquefaction, subsidence and tectonic uplift movement have all influenced flood risk within the city.

The earthquakes have impacted all utility infrastructure, in some way, including the stormwater network. The Stronger Christchurch Infrastructure Rebuild Team (SCIRT) is tasked with rebuild of the Council's damaged horizontal infrastructure (CCC 2011).

Natural waterways were excluded from the SCIRT scope and SCIRT focused on the repair of damaged stormwater pipe networks. Investigation and delivery of remedial infrastructure relating to land drainage networks remained Council's responsibility and in response to this, the Council formed the LDRP. The LDRP work packages across many parts of the city. Modelling is required to inform the location and magnitude of earthquake impacts to inform decision making on potential intervention measures.

2.3 LAND DRAINAGE RECOVERY PROGRAMME

The goal of the recovery is to understand the consequences of the earthquakes on the land drainage network of rivers, streams, overland flow paths and major structures. Some of these consequences may mean that repair is needed but equally adaptation and careful management may be a better option. The LDRP sets out to deliver projects to:

- Repair damage to waterways and land drainage infrastructure; and
- Reinstate pre-earthquake levels of flood risk.

The LDRP consists of projects in two broad stages: investigations and capital delivery. Investigations involve assessment of earthquake impacts, development of options for repair, remediation and enhancement, concept design and approval of a preferred concept. Capital delivery involves progressing the approved concept through detailed design, construction and commissioning. Projects in both stages are informed through hydraulic modelling.

3 PROJECT CONCEPTUALISATION

To build greater confidence, transparency and equity in the option selection and design process a uniform modelling approach was required. For example, different modelling approaches could give rise to different magnitudes in earthquake impacts, proposed interventions and resulting costs. If the estimated project costs or benefits vary by catchment then a risk of inequitable decision making arises.

In addition, it was identified during early projects (e.g. the Dudley Creek Long-term Flood Remediation Scheme investigation) that a high level of resolution is required to accurately assess the earthquake impacts at a property level, particularly for flood predictions of more frequent design rainfall events (e.g. 10% AEP events). A high level of detail is required as there is significant variation in flood risk resulting from:

- Changes in pipe network capacity, channels and small overland flow paths, particularly in the frequent rainfall events;
- Varied height of buildings above ground level;
- Land damage at the property level;
- Impacts of local network damage / condition; and
- Differential settlement between stormwater networks and waterways.

Council considered three approaches to deliver on the programme objectives:

- *Continue the early approach:* developing and enhancing existing models on an individual catchment basis within the LDRP investigations programme. This option was discounted due to expected higher total costs, expected increase in variability in model deliverables, and delays in project scoping information.

- *Do nothing:* utilising existing models without modification. This was discounted as it would not meet the programme objectives.
- *Model the 'flat land' areas in one project:* development of the existing catchment models and combining them into one model. This approach was preferred as it was considered the approach which would provide most timely, consistent and reliable results at the earliest opportunity.

The preferred approach did present one major issue: practicality. In order for the models to be practical for the purposes of the LDRP they needed to run quickly. If the models were to take more than one day to compute then they would be unlikely to be suitable for options assessments, which require repeated model iterations and scenario testing. The strong desire of Council was to have a model or models which would run within 7 hours, to increase productivity during investigations and design work, as discussed in Section 4.4. If this could not be achieved then it is likely that development of smaller sub-catchment models would result to speed the delivery of individual investigations, potentially, resulting in additional costs to Council.

To support the project a technical specification was developed in March 2015 which supplemented Council's earlier stormwater modelling specification (2012), which is more generic in nature. The technical specification included direction on:

- Build Process: project reviews (DHI was engaged as technical peer reviewer), model schematisation through to results delivery;
- Hydrological Model requirements: rainfall profiles, catchment delineation and parameters;
- Model Build: individual model elements, acceptable variation from standard parameters, mesh generation, linkages, and other model components; and
- Output Requirements and Accuracy: results delivery, mass balance and model management.

The two modelling specifications provided the backbone of an RFP that was open to 'pre-qualified' consultants within the LDRP. Given the magnitude of the work and the need for rapid progress (to inform LDRP investigations projects) the Council promoted collaboration between suppliers and issued a notice that it would accept responses from multiple organisations.

There were a number of issues and questions raised during the tender period. In order to provide the prospective suppliers more confidence in the project requirements and Council expectations a workshop was held. During this workshop potential suppliers asked questions of Council technical staff to seek clarification on a broad range of issues. This workshop was successful with questions from many parties that were asked and responded to in an open way. This openness can, in part, be attributed to the desire from most people and organisations to get good earthquake recovery outcomes. To give further confidence to respondents and Council on project delivery, Council engaged DHI to supply up to 18 days of time (at Council's expense) to be solely directed by the successful supplier in support of the project, in addition to any technical review time.

Submissions were received and evaluated. The project was awarded to GHD with AECOM providing significant resource to the team.

4 MODEL DEVELOPMENT

This section describes only key issues identified and resolved during the model development. For brevity, it excludes generic model development tasks.

4.1 GAP ANALYSIS AND DATA FILLING

The initial work on the project involved receipt, collation and analysis of all model build data that Council provided for the purpose. This included most notably, GIS data, previous modelling efforts and survey information, including a large survey data set that was collected by SCIRT.

Analysis of this data was carried out to identify gaps in relation to the project's needs. A Gap Analysis report was prepared and presented to Council, outlining areas where more or better data would be beneficial and suggesting options to gather this and suggested priorities. In a series of collaborative discussions with Council staff, priorities were reviewed and in some instances new opportunities were identified by Council. The most challenging areas of gap filling were onsite soakage systems, mitigation basins and pump stations.

Data on these network features was held across a number of systems and databases such as, historical as-built data, GIS databases, spreadsheets and calculations. Information on some assets was only available as design calculations, consent applications, reports or survey surfaces. For some assets there was no information available. Considerable effort was applied between the Client and Consultant to transfer the data and convert it into a consistent format ready for modelling.

One key aspect of the project which lacked data was the pre-earthquake condition of many structures and cross sections for which only post-earthquake survey had been collected. A strategy was mapped out to fill this gap for the larger structures with deep foundations by analysing the movement of bridge decks using pre-post LiDAR differential. It was planned to then use the difference data to develop a 'deep foundation difference surface' to produce a predictive model of such movements throughout Christchurch. This strategy failed unfortunately because in most cases pre-earthquake LiDAR levels had been removed from the processed LiDAR point data prior to supply to CCC. Previous enquiries seeking original detail from the 2003 pre-earthquake LiDAR work has already confirmed that the supplier had since discarded the raw data.

A similar strategy was applied to develop the difference surface utilising the Council system of staff gauges measuring water levels. These are typically fixed to a bridge or similar substantial structure and had been thoroughly surveyed both pre and post-earthquake with well-known differential movement. Sufficient spatial trends were evident in this data. The project team was able to create a satisfactory predictive model across Christchurch to estimate the pre-earthquake level of deep foundation structures where only post-earthquake data was available.

It has been assumed that structures with shallow foundations move a similar amount to the adjacent surface as shown through standard LiDAR difference maps.

4.2 2D MODEL

During tendering of the project Council specified the 2D model grid to take the form of a 10m x 10m square mesh (still using the flexible mesh computation engine and GPU technology). During the project it was agreed to improve the mesh resolution dramatically, by using a variable sized triangular mesh. This change was made to provide greater resolution so that road gutters, road crests and rail crests were better represented in the model surface. The aim of this increased resolution was to better represent overland flowpaths in frequent rainfall events.

The shift in grid resolution was influenced by some preliminary work that had been done for Council by DHI showing that the representation of these features was feasible. This initial approach used two rows of triangles with a flat road cross section at the gutter invert level and dyke structure on the road centerline to represent the road crest. This concept was further refined and improved during the project by using three rows of triangles with their levels controlled explicitly using DHI’s depth correction function. The outer triangles centroid levels were set directly to be at estimated gutter invert level and the central row of triangles at the road crest level.

Figure 2: Illustration of typical DHI 2 triangle method mesh

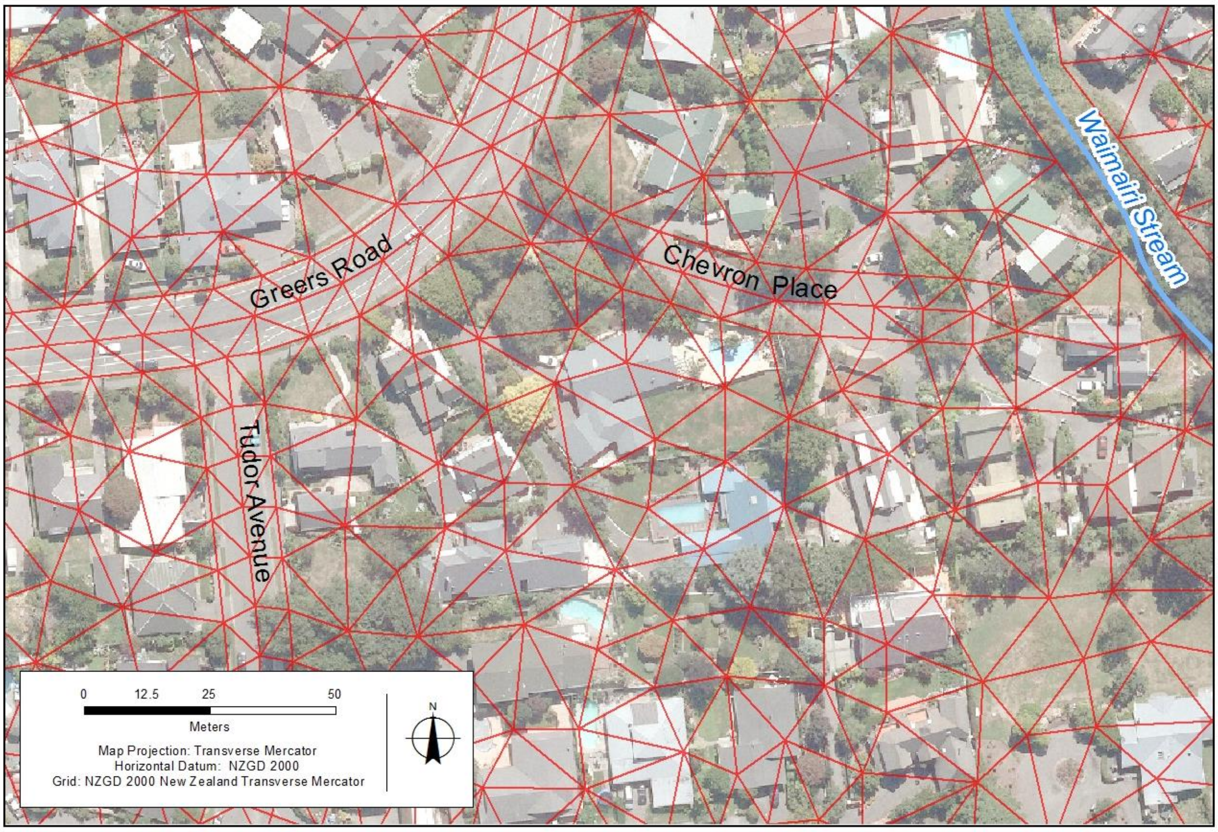
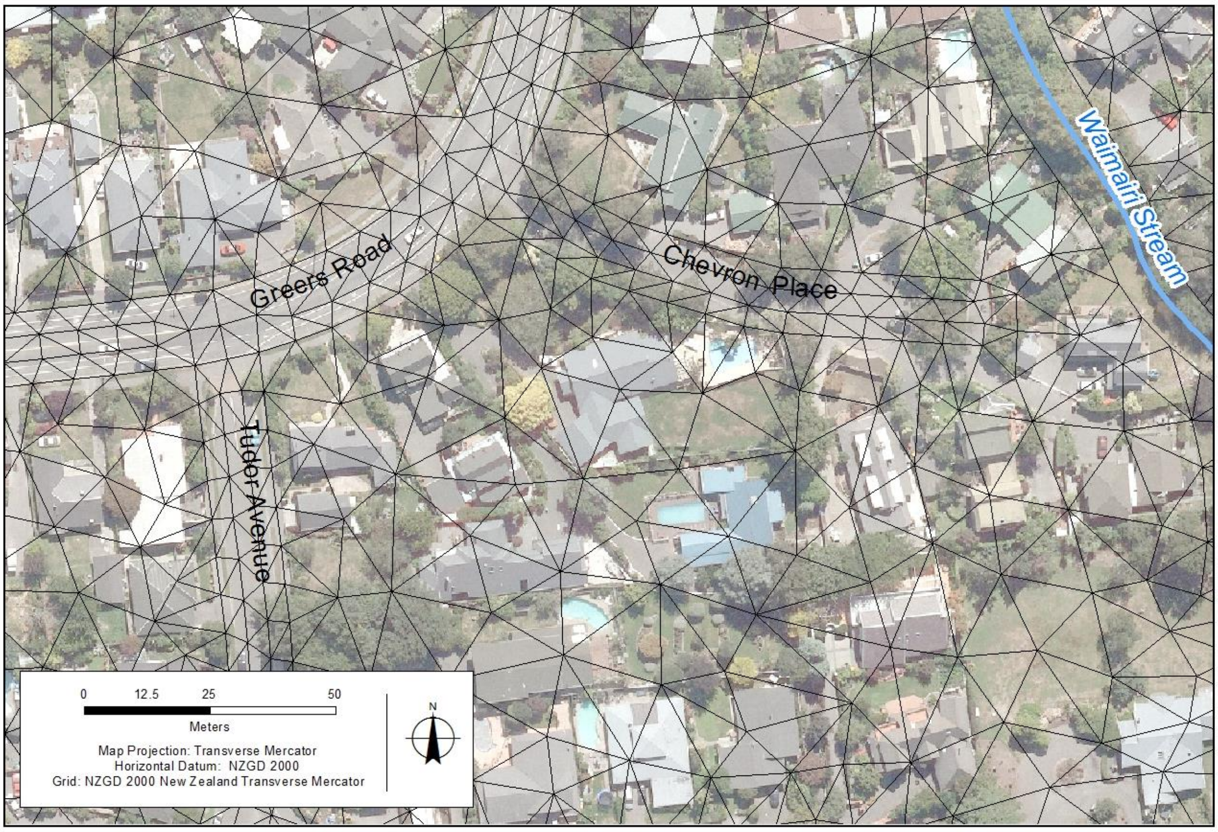


Figure 3: Illustration of typical GHD 3 triangle method mesh



Despite the reduced triangle size and increased number of mesh elements, preliminary testing on the previous existing 3-way coupled Avon base model showed the three triangle method was not only a better representation of the reality but also had faster model runtimes and was therefore adopted.

Techniques to suitably form the mesh triangles around the road centreline network were conceptually simple, but complex in detail. The initial stage was sanitising the road and rail centerline data into a suitably logical network topology. Hydraulic features such as M11 blockout areas were given priority over road / rail so that these centerlines were ignored when they were close to higher priority features. As measured road width data was not available then average or typical road widths were defined following the roading hierarchy classification.

Strategies were then developed as to how to generate mesh build input data to control mesh formation at intersections and at road ends (cul-de-sacs), and the lengths of road between them defined with equally spaced points. Various forms of road geometry created different challenges such as motorway intersections with very narrow angles (distinct from the commonly near 90 degree intersections) and roads on the Port Hills with sharp zig zags in them. A variety of strategies were developed all in a repeatable overall bulk data process to generate mesh building input data in an attempt to eliminate any repetitious manual grid editing.

The project team found that where individual points were used to control mesh formation these were reasonably easy to produce in bulk, but that where elements required arcs or polygons to be defined and particularly where those features coincided that care and manual work was required to successfully develop a mesh generation script that did not produce small mesh elements. The computational speed of the model is heavily influenced by the size of the smallest 'wet' mesh elements so there is considerable incentive to increasing the size of the smallest elements in the mesh.

It was discovered that converting GIS shapefile closed line formats into mesh was more successful than converting GIS polygon data. Problems were also noted where arcs or polygons shared snapped nodes in the GIS data, but on export to xyz mesh build format they sometimes had micro differences at the last decimal place, forming two points in the mesh instead of one and either causing the mesh build process to fail or to produce a useless mesh with extremely small elements. In a small number of situations the interaction of key elements (such as M11 blockout with a mitigation basin) were such that small elements formed around the interaction and manual editing of the points in some areas was required to resolve this.

With the process documented (including the few manual edits documented) Council will be able to repeat this mesh build process in future or amend it, as the City development evolves over time.

4.3 PRE-EARTHQUAKE MODEL

Definition of both post- and more significantly pre-earthquake model was modified during the course of the project. The pre-earthquake model become defined as the post-earthquake model (March 2014 condition), with all the development and infrastructure present at that time, modified in reverse by earthquake only changes.

The first priority for the modelling work was always to produce a post-earthquake calibrated model. Producing a pre-earthquake model to a comparable specification was then required in order that comparison could provide understanding as to how the earthquake sequence had modified flood risk in Christchurch.

At project inception it was envisaged that the pre- and post-earthquake models would be nominally August 2010 (pre September 2010 earthquake) and January 2012 (post the December 2011 earthquake). With this narrowly defined date range and given the various interruptions to normal development progress in that time, it was reasonably expected that anthropogenic changes during the period would be minor and have only small effects on flood risk in localised areas.

What was recognised during the project were a number of opportunities associated with the nominal post-earthquake date being March 2014 rather than January 2012. The main reasons were;

1. March 2014 was the best post-earthquake calibration event available;
2. At the start of the project the currency of Council's GIS data was close to the March 2014 condition and preparation of a January 2012 version would not be straightforward; and,
3. For immediate planning and project needs primary interest is in a more current day model, and January 2012 is increasingly becoming a historic condition.

However the March 2014 nominal post-earthquake date posed problems due to much greater significance of anthropogenic change in the period between 2010 and 2014, including motorway development, subdivision expansion and stormwater mitigation basin development. This would mean that a comparison between the August 2010 and March

2014 flood results would provide only a poor indication of the impacts of earthquakes on Christchurch flood risks.

While carrying out pre- / post-earthquake comparison of flood risk is intrinsically unconventional in nature, it would be fair to describe the resulting agreed approach to pre- / post-earthquake modelling as innovative.

In order to retain the benefits of a March 2014 post-earthquake model while retaining a good understanding of the impacts of the earthquakes on flood risk it was therefore decided to replace the Aug 2010 pre-earthquake model with a hypothetical March 2014 'pre-earthquake' model. This was defined in principle as being a good estimate model of what would have been the stormwater condition immediately prior to March 2014, if the combined ground movement effects of the Christchurch earthquake sequence had not happened.

This approach provides model results that solely identify earthquake impacts without the confusion of including anthropogenic changes while retaining all the benefits of the March 2014 date for the post-earthquake model. This also provides the benefit of having to calibrate only one model and avoid the inherent differences induced through the process of calibrating a pre-earthquake model. It also avoids the costs associated with development of multiple models which would only be used for the single purpose of defining earthquake impacts.

4.4 ACHIEVING MODEL RUN TIME OBJECTIVE

Council objectives for a useful model runtime (time doing computation) were defined as being a model that could be run repeatedly for testing new conceptual designs with a cycle time of two runs per working day. In practical terms that means a runtime of near seven hours, allowing for an hour or so to assess previous results and setup a new trial, within an eight hour working day.

There are several key variables (other than model components and scale) which can strongly affect runtimes and so this objective needed definition such as;

- Single or double precision;
- High or low order calculation;
- Limiting courant number;
- What M21 results would be saved during runtime and how frequently;
- What specific rain event would be the benchmark for runtime;
- Citywide or individual river catchments; and,
- Computer hardware employed.

The project team developed a runtime specification being;

1. Single precision on the basis that the topographic variation within Christchurch was low enough that the model domain could be represented with adequate resolution in single precision.

2. Low order calculations on the basis that repeated design runs could reasonably be expected to be tested using low order calculations and then final conclusions verified with a high order run.

3. Limiting courant number of 0.9 on the basis that this would provide faster computation on the M21 domain with a moderate risk of instability or computational failure (crashes), assuming models were built to be sufficiently stable with this courant setting.

4. Saving of four M21 computational variables during runtimes at ten minute intervals with maxima calculated post run completion.

5. 2% Annual Exceedance Probability rain event with climate change rainfall and sea level rise, for the critical duration for the overall river catchment.

6. Individual river models on the basis that most design work would not require a fully integrated Citywide model and that the integrated model would only be run for specialised purposes of understanding interactions at the boundaries and used to improve initial boundary condition assumptions.

7. A suitable computer was defined as a 16 core Dell Precision T7610 with Intel Xeon processors, 32 GB memory and running 64-bit Windows 7 operating system, with one Nvidia GeForce GTX Titan GPU and with a solid state local hard drive.

The single GPU is a soft requirement in terms of hardware cost, given the low and decreasing cost of GPU hardware, however this was adopted more due to the higher costs of the computer case typically required to house and power dual GPU technology and the difficulties most consultants IT would face with procurement and setting up of dual GPU technology.

Initial work to assess the feasibility of the runtime requirement has coupled the proposed new M21 mesh with the simpler pre-existing 1D model components. A 12 hour rain event, which is significantly less than the historically assessed 36 hour critical duration for the Avon River, produced runtimes of 6.5 hours. This suggests further challenges ahead in achieving the 7 hour runtime expectation.

The final model will have considerably greater 1D details, especially in the Mike Urban component and the relative importance on runtime of the detail between the individual model components is not well known. The project team does not expect to fully understand runtime performance until the models are built and stabilised.

4.5 INTER-CATCHMENT FLOWS

Between most of Christchurch’s four main river catchments (Styx, Avon, Heathcote and Halswell) there are the flows (potential and observed) between adjacent river catchments depending on the rainfall event distribution and the state of flood in each catchment at the time.

A completed final fully integrated model will provide the first comprehensive opportunity to represent and study these flows through computer modelling in a holistic way. The early phase work will develop the individual catchment models independently. As a result it is necessary to estimate boundary conditions at several locations between the models. There is a substantial increase the number of these locations due to the increase in pipe network detail compared to previous models.

The initial process prior to establishing inter-catchment flows is to first establish catchment boundaries. This project scope provided the opportunity to consider the ideal boundaries from 'both sides of the boundary' in the same project. Due to the interest in surface flooding and the greater difficulties in representing estimating 2D boundary flows compared to pipe network flows, it was decided generally to focus primarily on the natural ground surface boundaries and allow pipes to cross these boundaries on the occasions where the pipe network flow direction did not coincide with the ground surface.

In general at these locations where the pipe network crossed a catchment boundary, one of two assumptions was made.

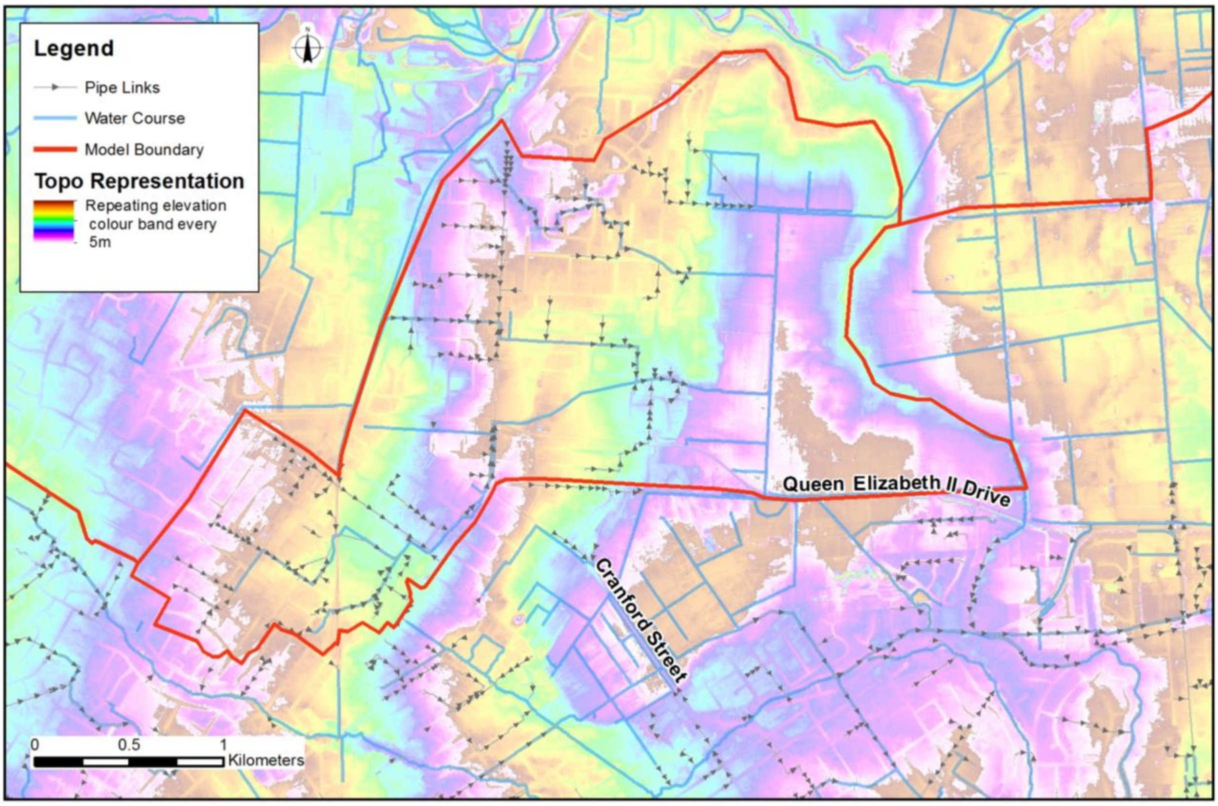
1. If the pipe network was connected completely across the boundary and the boundary was drawn at the high point in the pipe network invert levels then a zero flow boundary assumption was adopted.
2. If the pipe network had a catchment area in low flow conditions crossing the boundary (which included any crossings where the pipe network was not continuous across the boundary) then a pipe flowing full assumption was adopted at the boundary, in and out of the two respective models.

Both assumptions are simplifications of what would really be expected. These boundary conditions are recognised to be temporary placeholders until the Citywide model is completed and so do not warrant a great deal of effort. Even with exhaustive effort a high level of uncertainty is unavoidable in these areas until the Citywide model is completed. Council modelling costs were reduced by these simplified assumptions.

There were two areas of exception that are of particular interest: Cranford Basin and the CBD.

The primary area is the Cranford basin area, which lies between the Styx and Avon catchments roughly due north of Hagley Park. This basin is a large natural depression with three main flood cells separately by Cranford Street and Queen Elizabeth II Drive. In large events flood water within the basin can drain through open drainage channels into either the Avon or Styx rivers depending on the prevailing flood conditions and by how the structures within systems are operated.

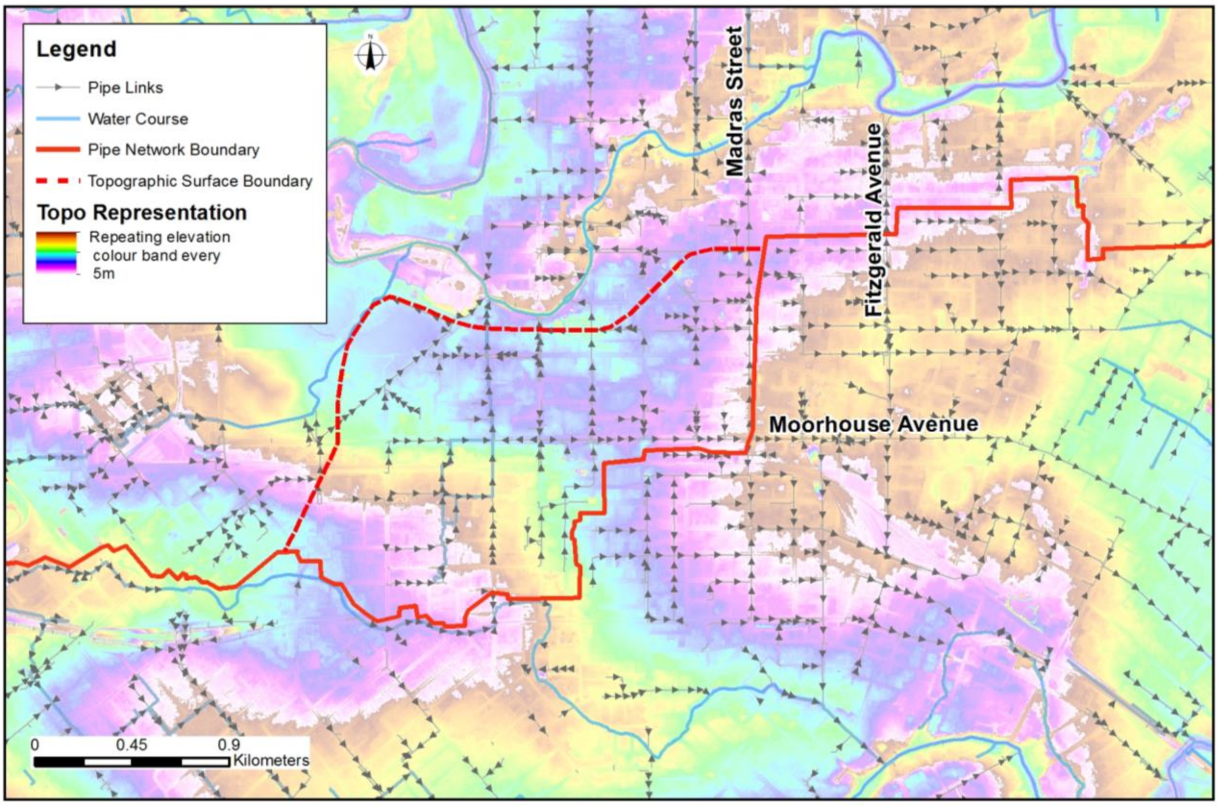
Figure 4: Cranford Basin Area topography and drainage



This topography is more complex that normally encountered with conventional stormwater modelling as large, unpredictable cross boundary flows can be expected to occur. After careful deliberation it was decided to include this area into both the Avon and Styx models, with extents taking advantage of monitored water level recordings on the northern boundary (north edge of Avon model) and previously modelled flow boundary condition assumptions at the southern boundary (south edge of Styx model) with good prospects that the surface flooding within the basin area as a whole would not overtop the ground surface and the 'extended' boundary of either model.

The second area of interest is the south east corner of the CBD, (ie: west of the southern half of Fitzgerald Ave). In this vicinity an extensive interconnected pipe network drains flows north to the Avon River, contrary to the natural ground surface which draws flow east and then southeast to the Heathcote River. In this area a model catchment boundary following the ground topography would have resulted in numerous cross boundary pipe connections, many of which were large and often with a rectangular network topology with redundant connectivity (rather than the more typical dendritic network type which is more typical of drainage systems).

Figure 5: Southeast CBD Area topography and drainage



The alternative to base the model catchments on the pipe network in this area was appealing because there was a natural separation between the pipe networks and only a single major pipe interconnection at a natural highpoint which makes for a simple zero flow boundary condition assumption. This alternative will result in any surface flow in large events being trapped against the model M21 boundary, which is also undesirable, although the extent and significance of such flows is yet to be explored.

It was decided to adopt the alternative pipe network based boundary condition in this area. In essence, until the Avon and Heathcote catchment models are integrated (or significant effort put into quantifying appropriate pipe and/or M21 boundary conditions) then model results from this area would be lower than usual confidence regardless of any possible boundary definition.

In all cases, future comparison of the results from the individual models will educate the project team as to the validity (or not) of the adopted simplified boundary conditions and this could enable their future refinement as boundary conditions. However, it is planned and preferred that these boundary conditions be eliminated from the modelling entirely through use of the full Citywide model.

4.6 IHUTAI / AVON-HEATHCOTE ESTUARY

Ihutai / the Avon-Heathcote estuary is a key feature in Christchurch waterways but has not been included in previous flood modelling work. Instead specialised work has been done to estimate reasonable boundary conditions at the ends of the two major rivers where they enter the estuary. This work has limitations in that it is inherently complex, is not easily updated as new data becomes available and does not generalise well to future sea level rise scenarios. It also fails to provide realistic boundary conditions for numerous smaller areas which drain directly into the estuary such as Monks Bay and Southshore.

For these reasons the project was conceptualised to include the estuary explicitly in the modelling, with data based from a pre-existing NIWA model. This model configuration then only requires a single tidal boundary condition to be defined in the open ocean, which is a much simpler location to predict and update with new data and for future climate change scenarios. This same boundary condition is also used for the Sumner model area.

Two challenges arise from this approach: wind set-up and sedimentation.

The estuary is a large waterbody that responds to wind setup forces. Through the course of this project a better understanding of the significance of this will be developed and to apply some wind boundary condition into the flood modelling. The sophistication of this wind boundary will depend on the significance of the phenomenon once it is better understood.

The second challenge is that the bathymetry of the estuary changes continuously through natural sediment movement processes. The present rate of change is expected to be higher than normal due to the disruptive effects of earthquake ground level movements. The future rate of change can also reasonably be expected to relate to future trends in sea level rise. In essence future Maximum Probable Development (MPD) modelling would logically provide an estimated future estuary bathymetry, however there is presently little scientific basis for such an estimate and much work would be needed to inform this. Also as the current model is maintained over the foreseeable future, updating the model every few years to reflect the then current estuary condition could be expected. Any consideration of future estuary bathymetry is outside the scope of the current project, but will be a natural subject of ongoing interest for Council.

4.7 AUTOMATION TOOLS

A key aspect of this project was the large scale of the work that provided strong motivation to automating process and developing labour saving tools. One key tools that is being developed is to convert couples to GIS and back again.

The couple conversion tool enabled the visualisation and inspection of all types of Mike Flood couples in the GIS environment. This provided significant advantages over the visualisation and query tools available in the native DHI software package, such as;

- Superior interface responsiveness for viewing and inspection;
- Spatially intelligent selections and property inspection;
- Visual comparison with background GIS information, such as, aerial photos;
- Visual comparison with the coupled model elements; and,
- Identification of abnormal couples (such as those spanning a long distance or those with otherwise irregular geometric properties such as lateral links at skew angles).

An intended future development of this tool will be the ability to convert in reverse from GIS back into DHI format. This should significantly expedite future cutting of submodels out of a larger model which is expected to be of significant future benefit to Council.

5 PROJECT MANAGEMENT AND CLIENT INTERACTION

5.1 PROGRAMME DRIVERS

There a strong drivers for quick completion of the project. These include: identification of post-earthquake flood risk for homeowners (to give certainty for the community), interest form a range of stakeholders (such as central government), political commitment, the need to inform a rapidly progressing investigations programme and the significant capital investment programme. These drivers have led to a closely managed modelling programme that is presented and critiqued at weekly or fortnightly intervals. The importance of the project has provided significant motivation to the project team.

5.2 CLIENT COMMUNICATION

With a project as extensive and complex and this one, regular and deep communication with Council's project manager and technical staff was seen as essential to the success of the project. Meeting subjects typically included;

- Confirmation of assumptions, methodology and technical details not fully defined in the tender and contract process;
- Incidental new issues discovered during the course of the project;
- Decisions and management of gap filling activities;
- Opportunities for project improvement through redefining the scope; and
- Usual project management progress updates on programme and budget.

Though most of the project weekly technical meetings of 1-2 hours duration have taken place. The agendas have often been full and prioritisation of agenda items has been essential due to in several instances being unable to complete discussion of agenda items in the time available. During the gap filling phase agreement authorising a series of gap filling activities were required and meetings were held twice weekly.

From the consultant's point of view these meetings have proven invaluable in order to better appreciate Council's goals and priorities and to ensure that the resulting model is tailored to suit those. This minimised the risks of surprise and perhaps disappointment had the project proceeded with the best understanding from the contract documents. In addition Council have contributed richly to the project in finding and provision of in house data and knowledge especially during gap filling, without which the project would have either been disappointing or hugely more expensive.

Council has seen good value in these meetings as they have given greater confidence in the nature and quality of the deliverables. It has also enabled a common understanding to be developed prior to the handover of deliverables.

5.3 SCOPE MANAGEMENT

Scope management was one of the key themes of the regular client technical meetings. The bulk of the project was defined as lump sum work, and scope management naturally focused on defining the extent and quality of such work. A number of opportunities were agreed to through the duration of the project (most notably improving the mesh resolution and consideration is being given to changing from catchment based hydrology to rain on grid). These opportunities were typically defined and approved in advance as new lump sum work, although in some cases alternative payment mechanisms were used.

The area where scope management was however most challenging was during the gap filling phase. In the contract this was defined as a provisional items with Council cost risk, as this allowed Council to control efforts closely in response to opportunities and priorities and also to contribute significant Council staff input into gap filling work which was often highly valuable to outcomes.

Due to the compressed programme and collaborative approach to gap filling, the number of individually small gap filling activities was large and expectations changed rapidly in response to new discoveries. The project team found it was often impractical to define this work in advance and for some work reverted to a more retrospective approach, updating Council on costs and progress regularly, but defining and agreeing the variation terms after the work was completed, as can only be undertaken in a trusting relationship. This was overall more efficient as the effort to estimate, define and redefine individually small tasks would have increased costs for only a small increase in control for Council, but more critically a more formal approach would have extended the programme substantially which made it clearly undesirable.

6 FINISHING THE PROJECT

The phase of work collecting data and building the model components is now practically complete. The next phases will be linking the components together and making necessary adjustments and refinements to ensure the model runs stably. At this point the project team will have the first real evidence of model run speed and compliance with the target seven hour runtime.

Once the model is running well, it will be calibrated using the March 2014 flood event and verified using the June 2013 event. This will trigger two new phases of work to run in parallel, the first being completion of flood modelling, mapping and reporting based on the individual models and the second being joining the models together to create a Citywide mega-model, potentially inclusive of all the Styx, Avon, Heathcote and Halswell river catchments in a single, unified model.

This Citywide mega-model is clearly an ambitious goal, given the world leading scale of details in the individual river models already. The scope of work in this phase is under a provisional contract sum and will be managed similar to the gap filling work with a highly collaborative approach anticipated in terms of scope and risks. The easy risks of model coordination at the existing boundaries have been effectively mitigated through anticipation and creating inherently compatible individual models. The more challenging anticipated risks will be:

1. The software / hardware capabilities to process the large input data files while creating the joined models.

2. Working with the model in terms of interface responsiveness (screen refresh times) and practicality (finding tabulated data within what will be very large tables) and

3. Ability for the computation engine to handle the scale of data and computational speed.

4. The software / hardware capabilities to process the large results data files.

While a Citywide mesh has already been created in the mesh builder (4.6 million elements) combined versions of most other model components have yet to be created and the above risks are difficult to measure or mitigate until it is first attempted.

The team is working toward a future for Christchurch where 'their model' is a single Citywide model containing all four river catchments. The benefits of a mega-model are clear and include: a significant a significant reduction in model maintenance / updating, avoidance of duplication of data entry and representation of inter-catchment flows. When small or large subareas are desired to be 'cut from' the Citywide model, the project team anticipates creating tools to enable this cut using geographic boundaries enabling the rapid creation of submodels on any scale, such as:

- Small study areas for specific design purposes;
- Existing single river catchment study areas; or,
- Paired river catchments enabling study of their interactions across the boundaries.

7 CONCLUSIONS

The scale and magnitude of the modelling task is significant. The project is essential to the Land Drainage Recovery Programme. It will also give certainty to the Christchurch community and provide good information for decision makers when they consider the merits of the capital investment programme. The project still has some way to go before completion and significant technical challenges have already been overcome, with, undoubtedly, more to come. A strong consultant-client relationship is seen as key to delivery of this important project.

The project team is optimistic about successful completion however much work remains to be done before the Christchurch 'mega-model' magic or madness question can be answered conclusively.

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