FLEXIBLE MESH MODELLING OF THE UPPER TAIERI PLAIN

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ABSTRACT

Dunedin City Council (DCC) requires residential buildings to be built above the 100 year flood level. This approach currently creates difficulties as there are no generally established flood levels for areas vulnerable to flooding.

This places the onus on each applicant to develop a defensible flood level, increasing costs, timeframes and uncertainty. In reviewing their District Plan, council staff seek to improve this situation by developing minimum floor levels.

Otago Regional Council (ORC) have collected significant anecdotal and historic records and have done some flood risk analyses, however further work was required to develop this information into recommendations for minimum floor levels.

GHD are bridging this gap for DCC, building on the ORC work and providing estimates of flood levels and recommended minimum floor levels to support DCC planning controls. The work involves a mixture of modelling and non-modelling methods, chosen strategically to provide maximum planning benefit to Dunedin ratepayers within their project budget. It is anticipated that other areas of Dunedin may have flood hazard modelling work completed in future years as budget allows.

This paper summarises Dunedin City's strategy for progress in their planning controls and presents the Upper Taieri Plains model, which was one element of the above work. This model is technically interesting because it uses DHI's latest flexible mesh and GPU processing technology and contains no 1D elements.

Of particular interest will be our key learning steps as we moved from a traditional classic modelling background into flexible mesh and GPU based modelling and comparative overview of model runtimes and results using different mesh resolutions. We will also outline how modelling results plus freeboard were extrapolated to provide floor level recommendations for areas both within and beyond the predicted flood areas.

KEYWORDS

Flood risk management, planning controls, flood modelling, flexible mesh, GPU, floor level, DHI, Taieri plains, Dunedin

PRESENTER PROFILE

Tim has 23 years of water engineering experience and a sound knowledge of the applied principles, standards and guidelines for stormwater modelling. Tim has carried out numerous stormwater modelling projects for system performance and concept design purposes. Tim has developed strong instincts for what minimum level of modelling is fit for purpose, keeping costs to a minimum.

1   INTRODUCTION

Dunedin City covers a geographic area of 3,350 square kilometres, making it the largest city in New Zealand by land area. Dunedin City Council (DCC) provides stormwater services to around 107,000 residential customers.

Historically, DCC planning policy requires residential buildings to be built above a notional 100 year flood level. This planning approach creates difficulties as there have been no generally established 100 year flood levels for areas vulnerable to flooding.

This places the onus on each applicant to develop a defensible flood level, increasing costs, timeframes and uncertainty for developers. It also creates difficulties for consent staff, conflicted by the typically unreasonable cost that would be imposed on developers to conduct a rigorous (usually regional) analysis of flood risks and equally challenged by their lack of technical expertise to define flood study requirements or challenge the suitability of developer proposed flood risk and floor level assessments. In reviewing their District Plan, Council staff seek to improve this situation by developing minimum recommended floor levels.

Traditionally in Dunedin's areas of jurisdiction, Otago Regional Council (ORC) and its predecessor organisations, have been responsible for flood mitigation engineering works such as stopbanks and related projects. They have collected a substantial data set of flood observations and have a variety of stormwater models which are used to assess the standards of stopbanks in various waterways. ORC for their purposes have not needed to extend this modelling in order to predict flood levels beyond the waterways and particularly into areas of current or proposed future development. Further work was required to develop this information into recommendations for minimum floor levels and DCC engaged GHD to assist with this requirement.

The work involved a mixture of modelling and non-modelling methods, chosen strategically to provide maximum planning benefit to Dunedin ratepayers within their project budget. The upper Taieri Plain area was selected for modelling, with other areas addressed through non-modelling methods. It is anticipated that these other areas of Dunedin will have modelling work completed in future years as budget allows.

This paper summarises Dunedin City's strategy for progress in their planning controls and presents the Upper Taieri Plains model, which was the one modelling element of the above work. This model is technically interesting because it uses DHI's latest flexible mesh and GPU processing technology and contains no 1D elements.

The paper also presents our experience on runtimes with the flexible mesh GPU software and our approach to setting floor level recommendations (adding freeboard plus an extrapolation process) based on the flood modelling results. Of particular interest will be our key learning steps as we moved from a traditional classic modelling background into flexible mesh and GPU based modelling.

2   DUNEDIN'S STRATEGY FOR PLANNING CONTROLS

Dunedin City Council is presently undertaking a District Plan Review for their Second Generation District Plan (2GP). One objective of the plan review is to revise the planning framework for areas potentially prone to flooding.

Council staff have recognised that their present planning controls resulted in some undesirable development in recent years in flood vulnerable areas. One of the

recognized weaknesses is that while houses are required to build above the 100 year flood level (via conditions on consents), no practical guidance is given with respect to estimating that flood level.

Determining a robust flood level in any area subject to flood risk inherently requires study of stormwater catchment areas which are typically much larger than any individual building consent area. This makes it expensive and often impracticable for developers to robustly demonstrate that proposed developments are built about the required level. This situation typically results in a combination of high cost and delays for applicants as well as significant residual uncertainty and inconsistency resulting from low cost flood level assessments.

Due to the cost for robust area wide flood level studies, it is unreasonable for consent staff to require such analyses from individual developments. In addition to this, consent staff are typically not skilled at evaluating the merits and robustness of such analyses.

Dunedin accordingly set out to improve their planning controls with a suite of improvements. These include implementing the following controls across many areas of Dunedin's jurisdiction.

- flood hazard mapping (levels and extents)

- restrictions on the types of land use activities (e.g. new residential activity) and associated development in some high flood risk areas

- provision of floor level requirements where knowledge is considered sufficient for that

- provision of advisory floor level guidance where knowledge is insufficient to set requirements

- Dunedin also control earthworks and are reviewing their current policy on filling in flood plains with the intention of improving their control of risks that such filling could exacerbate other flood risks through constraining overland flow paths or displacing flood volume.

To ensure best value for money for Council in their first flood modelling exercise, GHD worked with Council to identify area(s) in which development was popular and for which the costs of flood hazard modelling and mapping were modest. We identified the upper Taieri Plains area as having both of these characteristics and this led to the work which is described below.

3   MODELLING ON THE UPPER TAIERI PLAINS

3.1   THE TAIERI PLAINS GEOGRAPHY

The Taieri Plains are an area of floodplains, bounded by hills on all sides except the southwestern end. The catchment is approximately 25 km long and typically 6 km wide, with typical ground levels varying from 30m in the upper northeast end down to and below 0m (ie: mean sea level) in the lower southwest end. All levels in this paper are relative to mean sea level, Dunedin Vertical Datum 1958.

The key feature of the Plains in terms of flood hazard is the Taieri River which flows through the Taieri Gorge and into the northwest edge of the plains near Outram. It flows across the width of the plains and then follows the southeastern boundary to where it

drains out to the ocean through the Lower Taieri Gorge. The Taieri River at 200km long is the fourth longest river in New Zealand (Wikipedia), with a catchment area of 5,700 sq.km (ORC 2013). Several extensive engineered flood control systems (including stopbanks, spillways, flood detention storage and pumping stations) are used to mitigate flood risks associated with the Taieri River.

The Plain is divided into upper and lower plains where the Taieri River crosses it. The upper plains have a significant typical slope of approximately 1/250, whereas the lower plain has a minimal typical slope of approximately 1/10,000.

The second largest natural waterway is the Silver Stream, which enters the plains at the upper northeastern end, and flows through the upper half of the plains to join the Taieri River. Relative to the Taieri, flood protection from the Silver Stream consists predominately of stopbanking, with a spillway and detention storage area near the confluence with the Taieri River.

Settlement and development on the plains is heavily biased toward the upper (northeastern) end, driven primarily by land quality and proximity to Dunedin. The township of Mosgiel (population 9,000) is the largest settlement on the plains, located near the upper end of the plains adjacent to the preferred road route through to Dunedin. Mosgiel is popular due to being only 16km from central Dunedin and on flat land which is limited near Dunedin and essentially already fully developed. The extensive rural flat land available first near Mosgiel, and in the upper and lower Taieri Plains, make this a popular area for growth of urban and lifestyle properties.
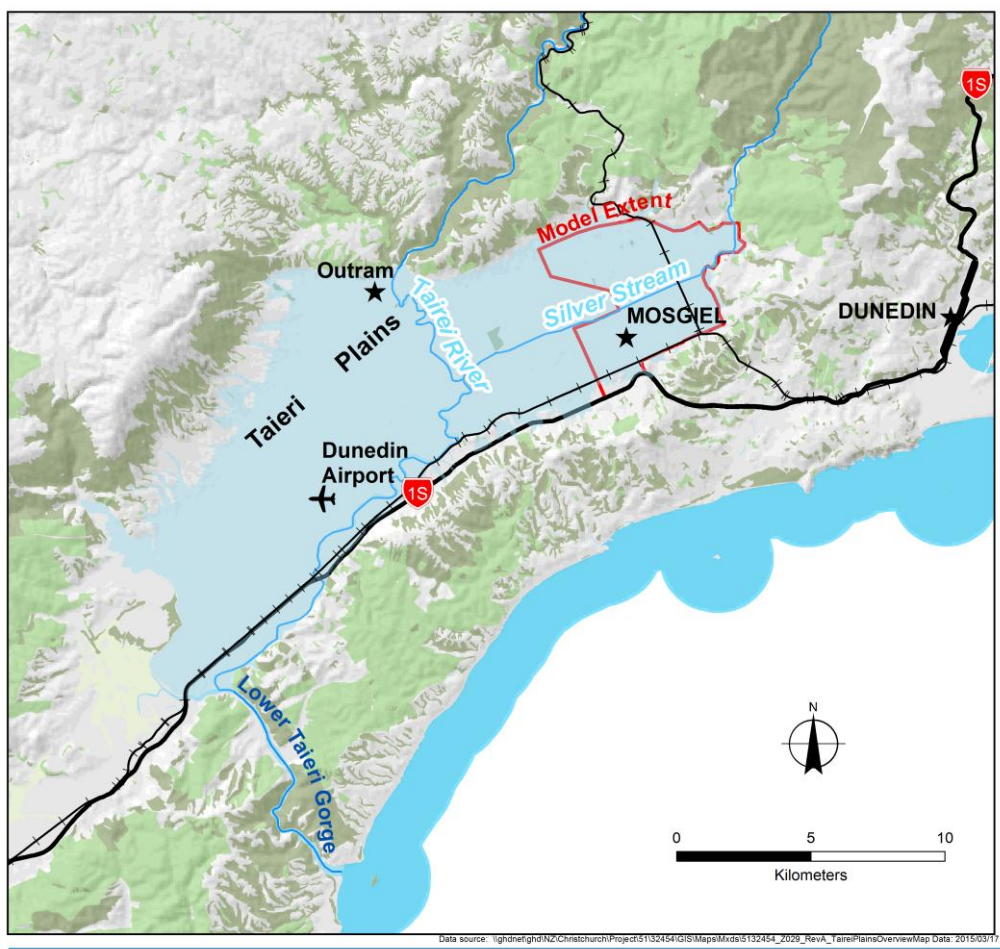

Figure 1:   Taieri Plains Topography

In addition to building development, State Highway 1 and railway lines cross the upper flood plain and in some areas include significant embankments or cuttings

In recorded history the plains have been extensively flooded on several occasions. From a geomorphological perspective the formation and topography of the plains has been driven by accumulation of sediment from successive flooding events. The largest recent flood event was the June 1980 flood in which the Dunedin airport (being lower than all the river stopbank heights) was flooded and unusable for 53 days (ORC, 2013).

Photograph 1:   Dunedin International Airport, during the June 1980 flood (Adapted from Natural Hazards on the Taieri Plains, Otago (p.12) by Otago Regional Council, 2013.)

3.1   THE UPPER TAIERI PLAINS MODEL

3.1.1   MODEL OBJECTIVES

The primary objective of the model was to predict 100 year flood levels so that DCC could advise developers as to specific floor levels that would comply with regulatory requirements.

3.1.2   MODEL EXTENTS

The extents of the hydraulic model were determined so as to include as much land as possible that was popular for future development while minimizing model complexity and cost. In response to those drivers it focuses on the more popular upper Taieri plains, excluding the steep hillsides, and excluding land potentially subject to Taieri River flooding (mid plains and lower plains). The model focus area covers 30 sq.km.

Due to confidence in the Silver Stream stopbanks integrity and performance for the 100 year flood event, the Silver Stream was also able to be excluded from the model, which was thus bounded by the Silver Stream stopbanks.

The model catchment area is larger than the 30 sq.km hydraulic model extent as the model catchment area includes numerous hillside catchment areas that flow onto the floodplain. The total catchment area for the model covers 67 sq.km. The downstream boundary condition was established as a free flowing boundary to the southwest, above any areas that could reasonably be subject to Taieri River flooding.
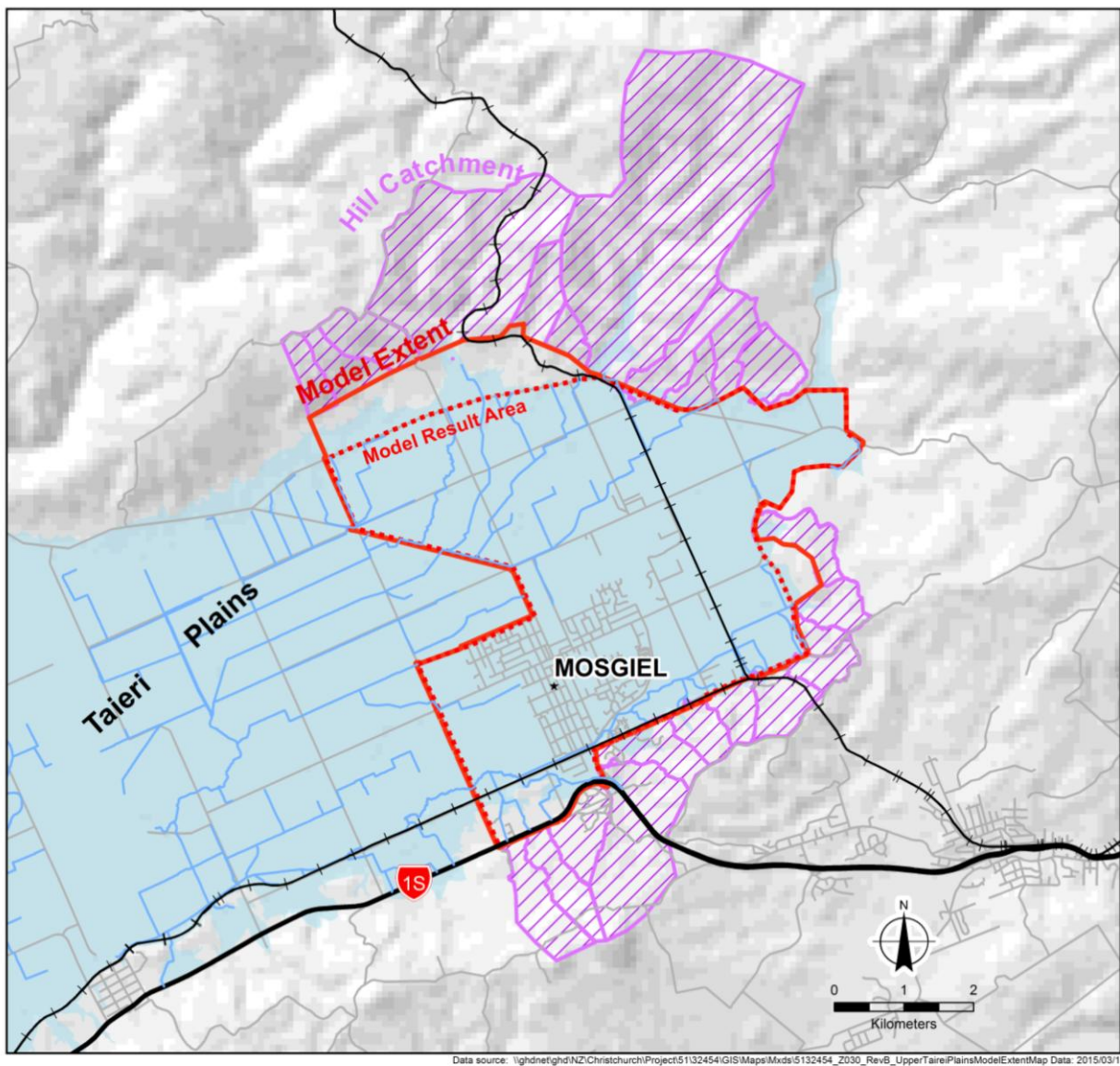

Figure 2:   Upper Taieri Plains Model Extent

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Note: * Figure 2 shows both the model extent of the 2D mesh (30.8 sq.km), and the model result area (26.9 sq.km - where we had confidence in results) within that mesh. Other figures focus on the model result area.

Within the floodplain study area, with a few notable exceptions, the topography is characterized as flat, with generally small and gentle variations in ground level. Natural drainage channels in the area (other than the Silver Stream with its stopbanks) are typically shallow and broad. The extensive man-made drainage channels in the area are predominantly steep sided and narrow. These are recognized through recorded flood history as being sized to accommodate smaller storm events but not being adequate during large events such as the DCC 100 year flood event.

Notable exceptions to this topographical description are associated with embankment or cuttings along either State Highway 1 (including motorway) to the southeast of the study area, and rail lines parallel to SH1 and a branch line heading northwest to the Taieri gorge.

3.1.3   MODEL FEATURES

Due to the model extent and topography, it was anticipated that model flood results would show flooding over a wide area with typically low depth (<1m). This expectation was also observed from historic flood events. The model was able to be constructed of simple features keeping the modelling costs low.

Key features of the model are;

- A 100 year design storm used the nested storm approach, with rainfall derived from High Intensity Rainfall Design System version 3 (HIRDSv3). A higher rainfall intensity was used for the hills compared to the plains. This was represented using two distinct rainfall intensity relationships in the model. While the design rainfall pattern therefore varied in magnitude spatially, it was applied uniformly across time so that all the peak intensities occurred simultaneously.

- Climate change allowances 2.5°C mean temperature increase (producing +20% increase in extreme rainfall intensity) was applied following DCC adopted policy (ref DCC 2011)

- 23 conventional hydrologic catchments were developed on the hillsides with theoretical hydrology developed from literature and available landuse and soils information

- A 2D flexible mesh topography with high resolution (7 m^2) around the drains, and low resolution (35 m^2) on the balance of the area developed from 2005 LIDAR data.

- The rain on grid method was used on the plains

- No allowance was made for infiltration on the plains

- The mesh was extended for between 1-3km beyond the end of the study area to enable an open boundary condition to be applied at the edge of the flexible mesh, allow water to freely exit the model. This edge was distant enough to avoid meaningful impact on results within the study area. (This extension area is not shown in Figure 2).

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It is unconventional, using classic DHI modelling techniques, for an area of this size and nature to be modelled without pipes, culverts or 1D representation of drainage channels. The opportunity for this simplified modelling approach in this case was however provided by the new GPU flexible mesh computational process and it's suitability to the particular circumstances in this project.

FLEXIBLE MESH BUILD

The simplicity of the modelling approach in this case was generally justified due to the widespread nature of flooding in the 100 year flood event, the modest significance of the narrow drainage channels in this event together with the LIDAR / flexible mesh channel representation being sufficient to adequately represent the flow area (and volume) of the channels. Spot checks, described later, were carried out to confirm the suitability of the flexible mesh channel representation.

Building the flexible mesh representation of the area from the LIDAR data was one of the more substantial tasks in this modelling project. The initial LIDAR data had an available resolution of 1 m^2 cell size (30,000,000 cells over the model focus area).

In order to produce a model that would run and with reasonable runtimes, simplification of the LIDAR was essential. Detail was important in hydraulically significant areas such as drains, waterways, roads and railways, but through the bulk of the model area a much reduced level of detail could be used as this would have minimal impact on results.

We initially carried out a series of simple mesh building trials, using a uniform maximum cell size for the mesh builder.

Max Cell Area (m^2)	Cell Side length (m)	Nodes	Elements
175	20.1	138,000	274,000
35	9	687,000	1,370,000
10	4.8	2,402,000	4,796,000
7	4	**Failed***	6,851,429

Table 1:   Mesh size vs cell size

Note: * at this resolution the mesh building application failed. We did not explore the cause but were advised that this limit may depend on computer hardware.

Following various trials, we decided to use a combination of 35m^2 cell maximum size over the bulk of the model, with 7m^2 maximum cell size with a 6m wide strip over the drain alignments (as defined by the GIS mapped lines). Our final mesh had 1,450,000 cells (20 times less than the LIDAR).

Difficulties were encountered due to the drainage network linework having significant positional inaccuracies relative to the LIDAR ground surface shapes (up to 25m in one case). Various attempts using automated GIS processes to identify the correct drain locations from LIDAR analysis were only partially effective. We therefore decided to test proceeding with accepting these inaccuracies and built the flexible mesh grid with high density around the imperfect linework. The effect of this approach was tested as described below in "Model Spot Checks on Flexible Mesh".

Initial model results with the above grid made us more aware of embankments associated with either the railway or State Highway 1 and especially their crossing

waterways and drains. These locations justified some manual adjustments to the grid as described below under Model Results.
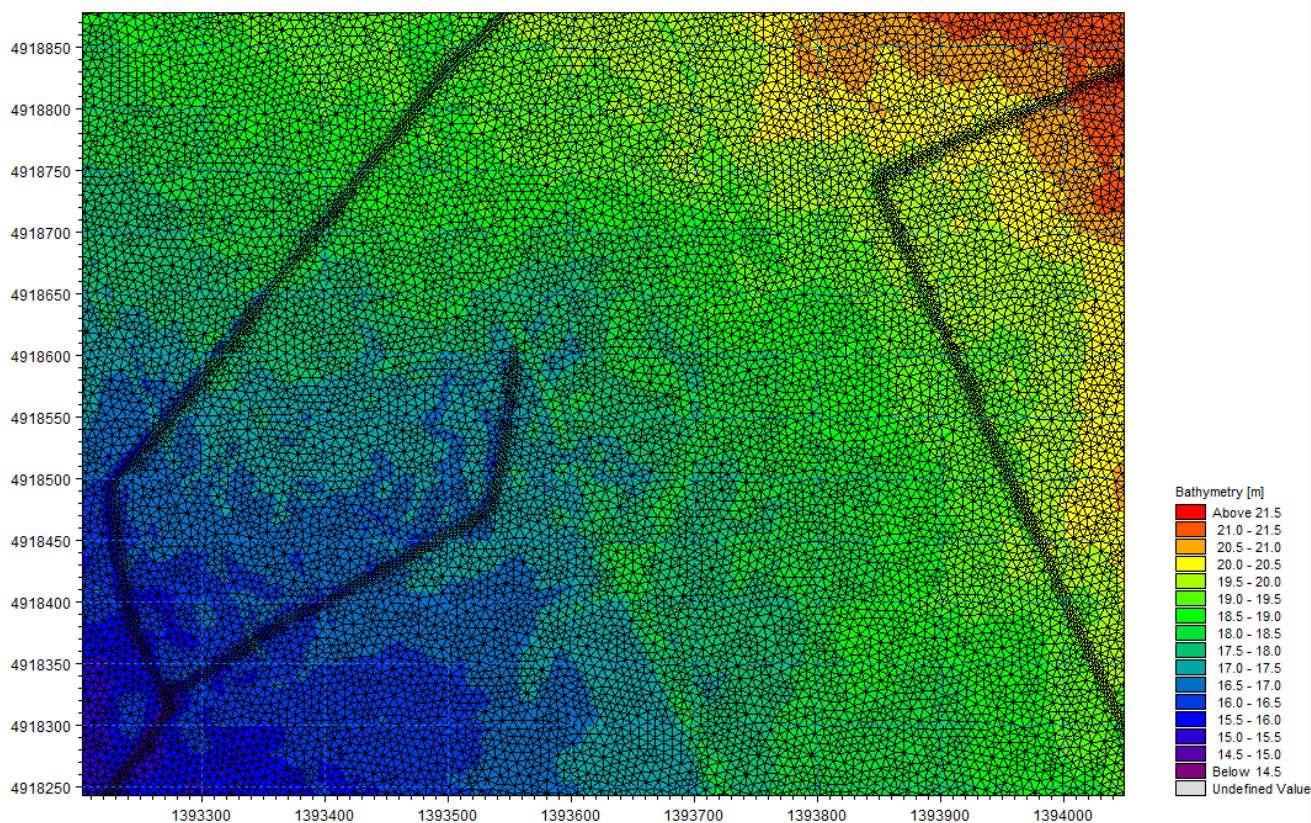

Figure 3:   Flexible Mesh Illustration

HYDROLOGY ASSUMPTIONS AND FLOODPLAIN ROUGHNESS

The simplifying assumption of nil infiltration on the plains, enabling a simple application of rain on grid methodology is recognised as being conservative, but is not considered overly conservative because the area is prone to high water table and groundwater levels at the ground surface are anecdotally thought to be not uncommon across much of the study area.

While the purely theoretical catchment hydrology for the hills and rain on grid with nil infiltration on the plains provides a lower than typically desired confidence in the flows generated in the model, sensitivity analyses described in this paper successfully showed that for the vast majority of the study area, flood levels are very insensitive to the flow rates and hence satisfactory confidence in flood levels is established despite the uncertainty in flows.

The other significant modelling parameter was floodplain roughness. This was evaluated from available landuse data and reference to literature guidelines.

3.2   MODEL RESULTS

The model results showed extensive area flooding, typically of modest depth but sufficient to confirm initial assumptions that the drainage channels were thoroughly overwhelmed in the 100 year flood and that modelling them with a high degree of accuracy was not vital to producing reasonable predictions of flood risk.
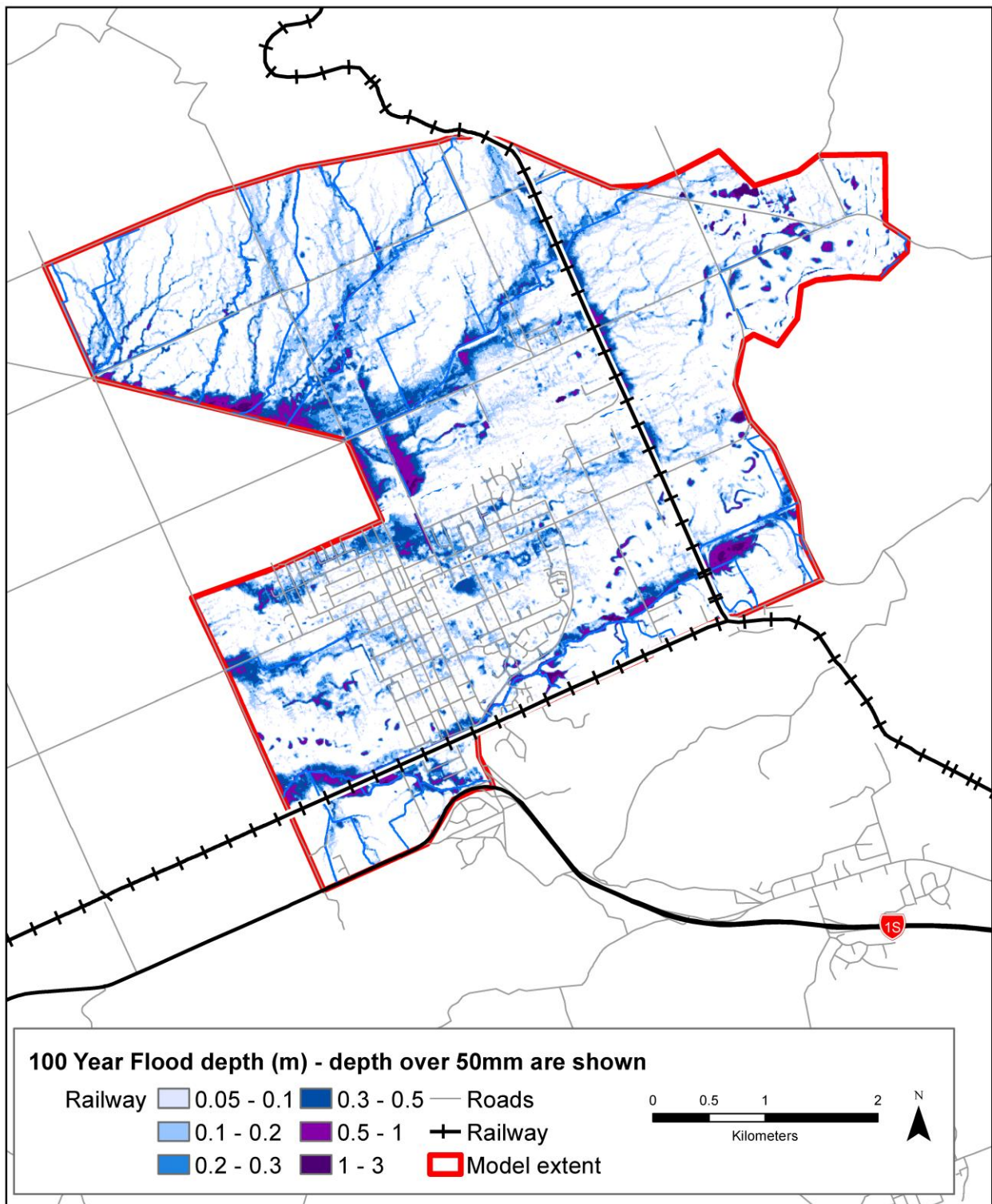
Figure 4:   Upper Taieri Model Results

Initial model results highlighted isolated areas of high depth and detention associated with the railway embankment. Examples were flow diversion southbound along the railway embankment toward Dukes Road North, storage on the Wingatui Racecourse behind the railway embankment, storage on the southeast of the railway embankment near Wingatui Road and storage on the south of the embankment near Riccarton Road.

The significance of these features became evident during the initial model runs and some manual adjustments to the flexible mesh were subsequently made to improve

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representation of these areas. Penetrations of the embankments were made to crudely imitate the function of the real bridges and culverts and to provide realistic flows to areas downstream. The areas around these embankment crossings, however, remain as weak areas in the model and are identified as areas for future improvement.

There were also a few localised depressions in the LIDAR surface, in the form of quarries or possible temporary excavations for foundations. These were minor in relation to the study area but locally significant, however their form was such that flood risk was an obvious local issue, and development in the base of depression would obviously be precluded without need for a regional flood study.

Quality assurance of the results focused first on verification of common sense outcomes consistent with general qualitative knowledge of the area and it's flood history. The more technical phase of QA was focused on searching for evidence of instabilities and confirming water balance calculations.

Within a 2D only model, evidence of instabilities are primarily indicated by results with high velocity. We had several instances with maximum velocities well in excess of 10 m/s, however the geographic extent of these was limited to small numbers of cells and in areas of low flow depth and were consequently confirmed as being immaterial to the overall results.

We did several runs saving the Courant number results (more specifically the Courant–Friedrichs–Lewy number commonly abbreviated to CFL) as a second indicator of instabilities, but we found it was giving essentially the same message as the speed results and we didn't find it provided additional value.

We ran most of our model runs, and the final model runs, with auto water balance calculations switched on. The results were consistently good with typically <0.1% percent error. We consider anything under 1% to be satisfactory in these circumstances.

3.3   MODEL SPOT CHECKS ON FLEXIBLE MESH

Because the adopted flexible mesh resolution was insufficient to represent the shape of the narrow open drains well, it was essential to test the representation of the open drain hydraulic capacity at the peak of flooding through inspection of cross sections and comparison of the LIDAR to the flexible mesh.

Through the reduction in resolution with the flexible mesh, the shape of the drains was typically smoothed and simplified. However in all cases the wetted area of the flow path was comparable and we concluded that an adequate representation of the drain had been achieved for the 100 year flood condition.

Cross sections for checking were selected through a mix of strategic selection in areas expected to be worst cases, and from random sampling. Confirmation of the suitability of the cross sections was a key milestone in the model development, effectively finalising the choice of flexible mesh.

Particular attention was given to the areas where the GIS linework for the drains was misaligned from the actual drain locations as evidenced from the LIDAR topography. In these areas the drains were represented by the larger $35m^2$ cells, but still met our requirements for a reasonable hydraulic representation.

3.4 MODEL SENSITIVITY TESTING

Modelling relied on theoretical hydrology to estimate flows. Because validation against actual storm observations was not attempted (due to budget limitations) in most cases, model results from such work could be considered to be unreliable. In the case of this project however, due to the characteristic sheet flow nature of the floodplain and defining constraints such as roadway overtopping in the 100 year event, it was expected that sensitivity testing to the model hydrology would show that the model results would generally be reliable despite uncertainty around the hydrology and flows.

While the theoretical framework within which the hydrology was assessed would have suggested perhaps a +/- 20% uncertainty in the hydrology, much of its method was derived internationally and it's applicability to the Taieri plains has not been demonstrated.
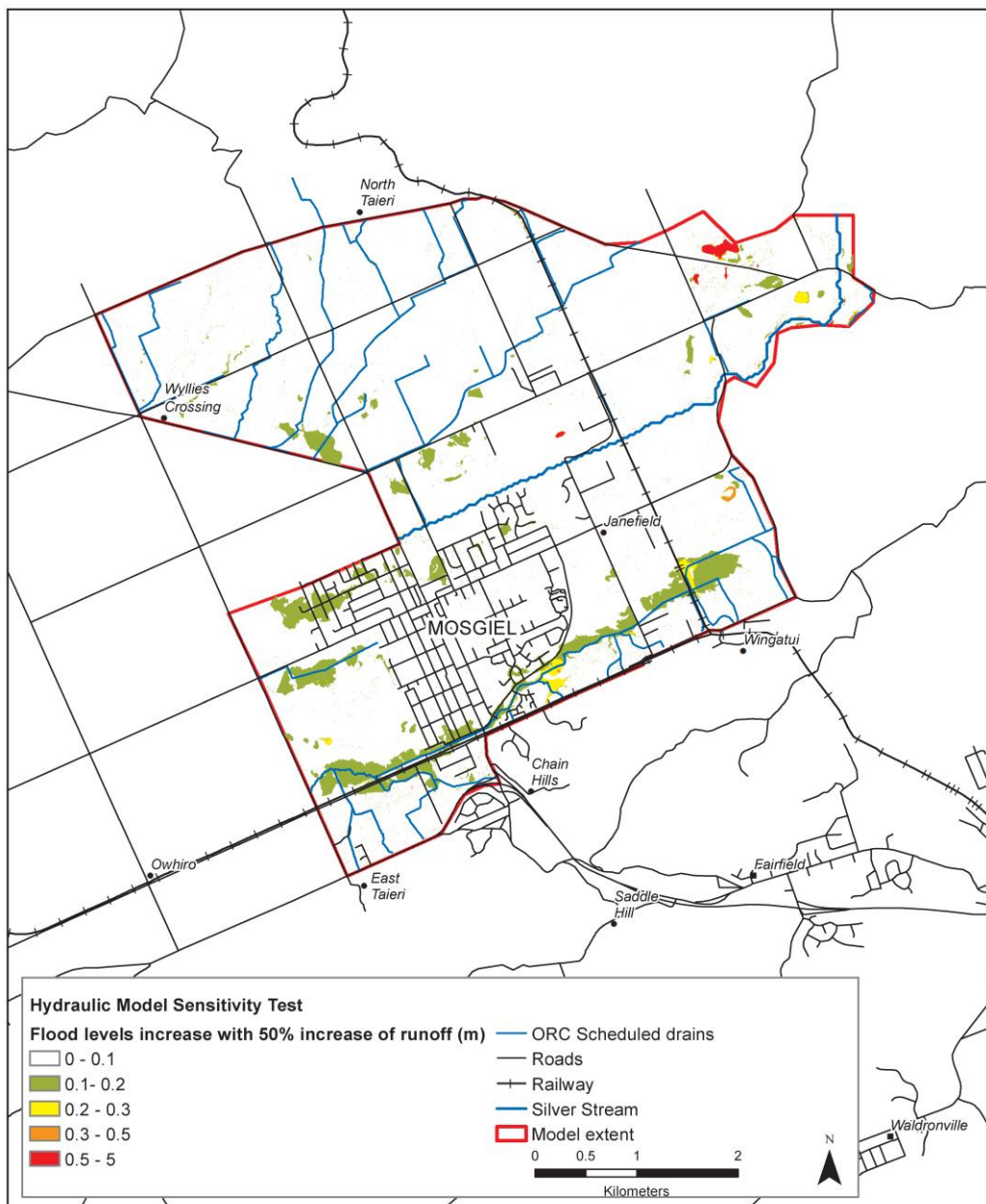

Figure 5:   Upper Taieri Model Sensitivity to 50% Increase in Flow

Consequently we adopted a much more rigorous + 50% uncertainty in flows, applying this increase in flow equally to both the hillside catchments and the rain on grid part of the model.

The results of this sensitivity test confirmed prior expectations that the majority of the floodplain was insensitive to this type of increase in flow rate. Also as expected there were isolated exceptions to this. The sensitivity test was effective in highlighting such areas with high sensitivity and caution as to use of the model results and allowing any development in those areas was recommended.

4   COMPARISON OF RUNTIMES AND RESULTS

4.1   KEY MODEL RUN PARAMETERS AFFECTING RUN TIME

Critical CFL number: this parameter defaults at 0.8, but can be adjusted to 0.9 or even 0.95 to speed up the calculation time. As it is increased however, the risk of instability increases and it is mathematically limited to being below 1.0. We generally used 0.95, but ran comparisons for speed tests at 0.80.

High (or low) order of calculation: This parameter relates to the number of terms used in the numerical approximation of the differential equations. Low order provides significant simplification but at the cost of accuracy. Testing can be carried out each way to determine whether the lack of accuracy is important to the specific situation. We used low order for all preliminary work and high order for the final results.

We compared results for water level between our next to final model run (with CFL set at 0.95 and using single order calculation) against our final model run with (with CFL set at 0.80 and using double order calculation). We found that differences typically affected small individual cells or clusters that were generally scattered without any coherence across the model grid. Differences in water level positive or negative in excess of 100mm affected a small percentage of cells but were widespread over the grid and certainly justified the use of high order and low CFL number for the final model run.

Single or double precision calculation: This parameter determines whether 8 or 16 significant figures of precision are carried through the calculations. We understand that models with a large vertical extent suit representation with double precision as calculations of level spread the available precision over the vertical extent. As our vertical extent was less than 50m we used single precision.

Calculation of volume balance: One important indicator of model integrity (or not) is the volume balance calculation. This is a modelling term that broadly speaking aggregates all the generally minor errors and approximations in the calculation. If a model has significant instabilities for example, it will typically show up as a poor volume balance result.

The volume balance can be calculated manually for the entire model run after the run is complete, notwithstanding that some calculation effort required. It can also be auto-calculated continuously throughout the model run, slowing down the calculations but avoiding the need for later manual calculation. This also provides volume balance per time step which is particularly useful if model instabilities are limited to short parts of an overall model run duration. We used the auto-calculation for most of our work.

4.2   IMPACT OF GRID AND PARAMETERS ON RUN TIME

We found that runtime varied almost directly with the smallest typical cell size specified in the mesh build process. Smallest cell size was certainly more significant than the total number of cells in the grid. Running with high order calculations approximately doubled the runtimes, and increasing the critical CFL number from 0.80 to 0.95 approximately halved the runtimes.

The following table provides a summary of runtimes for our model with various grid sizes and selected runtime parameters.

Precision	Unique Mesh resolution	Order of Calculation	Critical CFL number	Output Mass Balance	Runtime duration (hours)	Note	GHD ref
Single	175m^2	high	0.80	Yes	1.1	*	v3
Single	35m^2	high	0.80	Yes	4	*	v4
Single	35/7	Low	0.95	Yes	5		v28
Single	35/7	High	0.80	Yes	16		v31

Table 2:   Model runtime vs Runtime parameters and grid size

Note: * the two results with preliminary crude grid sizes also had simplified rainfall and edge of grid boundary conditions and constant flood plain roughness which significantly improved their runtimes in comparison to the two later runs.

4.3   COMPUTER HARDWARE

With the bulk of a 2D only flexible mesh calculation being carried out on the GPU card; a high-performance GPU card is essential. However a high-performance CPU is also important especially when running coupled models with extensive 1D components and couplings. Our experience with another coupled model has shown a 3x speed improvement by improving the CPU with the same GPU.

We used a Nvidia GeForce GTX TITAN GPU with a 6 core Intel® Xenon ® CPU E5 -1660 @330 Gz with 64 GB Ram and running the 64-bit Windows 7 operating system. DHI have recently suggested using 2 Nvidia GeForce GTX Titan GPUs with 16 core Dell Precision T7610 with Intel Xeon processors, 32 GB memory and running 64-bit Windows 7 operating system, or similar.

5   DETERMINING THE FLOOR LEVELS

Two subjects are critical in determining floor level recommendations once flood modelling results have been established. They are determining the freeboard to be applied and determining how best to extrapolate beyond the margins of the flooded area. These concepts are both illustrated below.
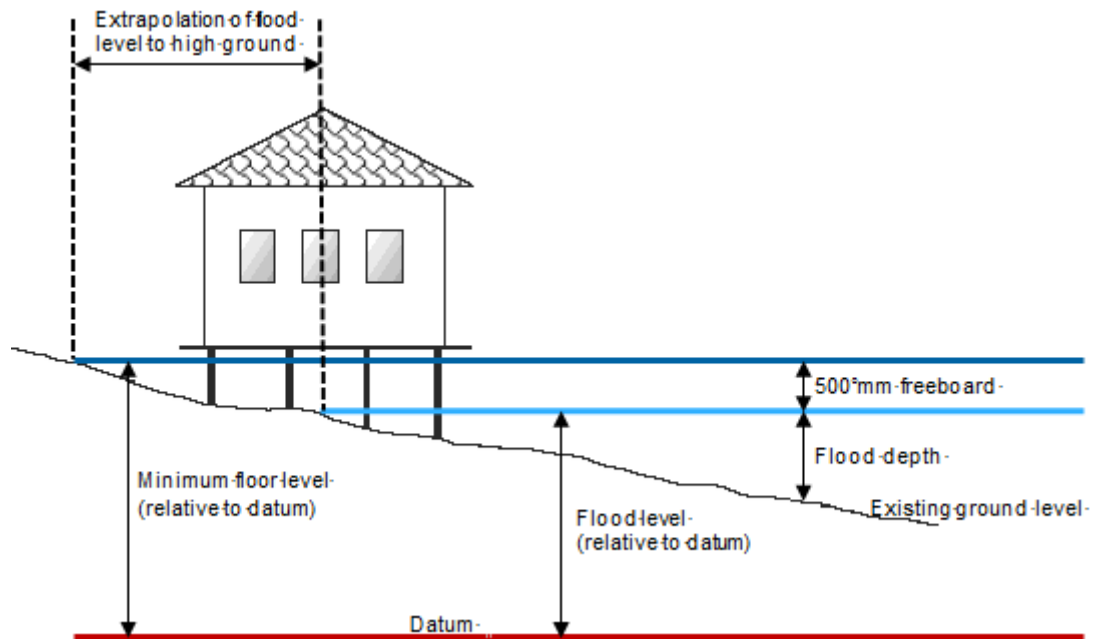
Figure 6:   Key aspects for setting floor levels

5.1   FREEBOARD

In consultation with Council, we adopted a freeboard level of 500mm for this study. This choice is based on a number of fundamental factors, including un-modelled factors such as wave heights, wind setup as well as intrinsic modelling uncertainties and willingness to accept risks.

The recommendation for freeboard is also heavily influenced by 500mm being common practice across New Zealand no doubt due to it being recommended in clause 4.3.1 of Verification Method E1/VM1 of the New Zealand Building Code.

5.2   EXTRAPOLATION OF RESULTS

As is illustrated in Figure 6 above, substantial areas of property may lieoutside of the predicted flood extents, but below the freeboard level. If floor levels are only set within the predicted flood extents, then houses in this marginal area could be allowed to build lower than houses in the flood affected area, which is usually not a desirable outcome.
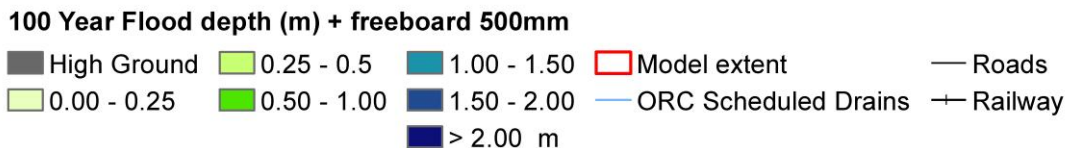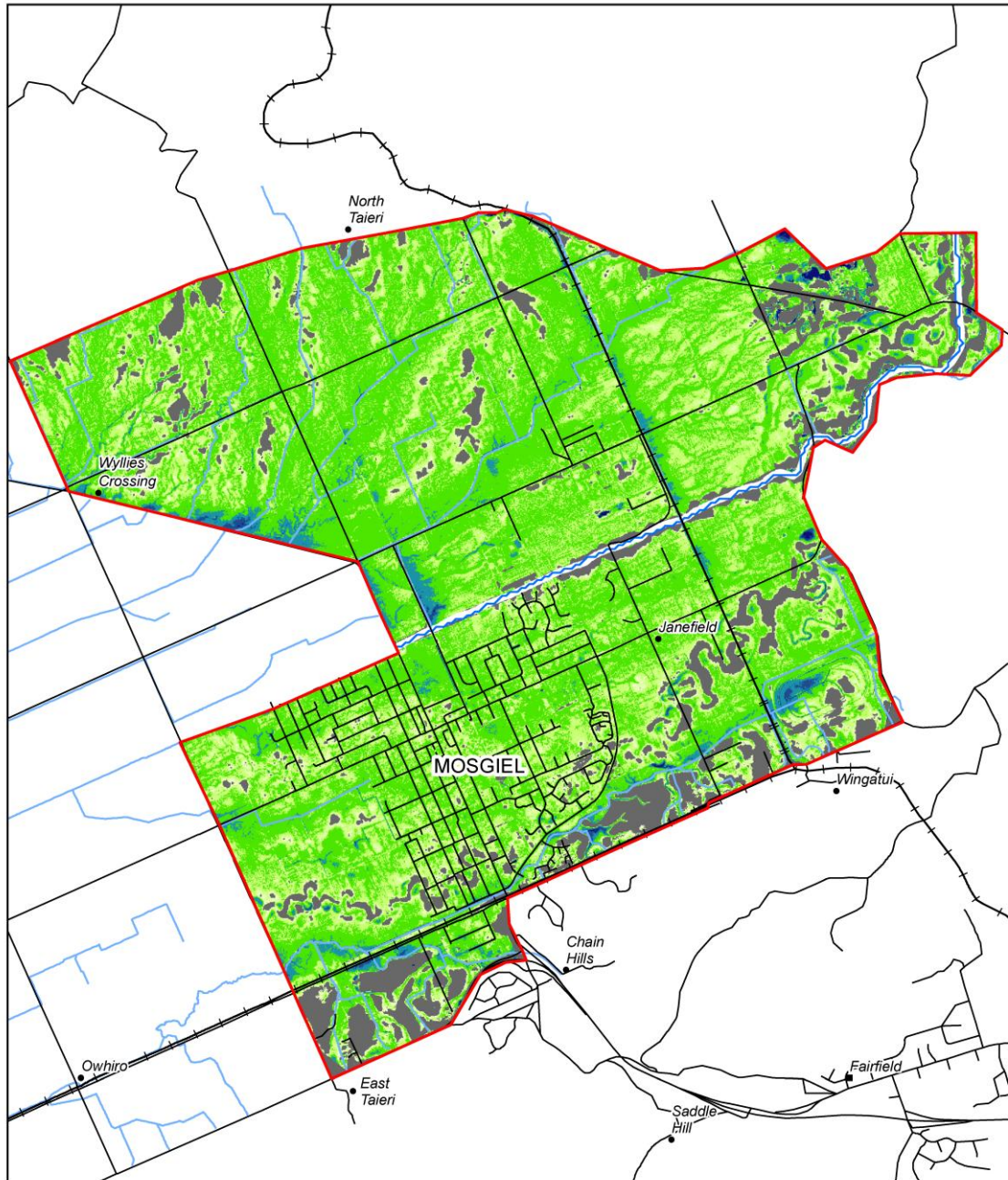
In order to address this issue, common practice is to extrapolate the freeboard surface as illustrated in the figure above. In a simple cross section representation, this concept is simple to apply, but in a real three dimensional situation where the direction of flow is curvilinear, and may be interrupted by features such as major embankments the extrapolation needs to be undertaken with care.

We used the Arc Toolbox Terrain Dataset tools to build a terrain (DEM) within the model boundaries, using the flood model results plus freeboard as inputs.

5.3   PROVISION OF FLOOR LEVELS DATA

A set of recommended floor levels in digital terms is a 3D surface, often referred to as a Digital Elevation Model (DEM). There are numerous electronic formats for DEM's but most of them require specialised software such as GIS to interrogate.

For Dunedin we agreed to supply the floor levels data in a continuous raster format, with no data in areas where ground level is above the freeboard level, together with summary level mapping of floor levels and estimated depth (height) of the freeboard levels above existing ground levels for presentation purposes. Data supplied was rounded up to the nearest 0.1m, removing the false precision, simplifying presentation and communication of the results.

100 Year Flood depth (m) + freeboard 500mm

High Ground	0.25 - 0.5	1.00 - 1.50
0.00 - 0.25	0.50 - 1.00	1.50 - 2.00
		> 2.00 m

Model extent — Roads
ORC Scheduled Drains — Railway

Paper Size A3
at scale 1:40,000

Map Projection: Transverse Mercator
Horizontal Datum: NZGD 2000
Grid: NZGD 2000 New Zealand Transverse Mercator

Dunedin City Council
Minimum Floor Levels for Flood Vulnerable Areas

Flood depth with freeboard 500mm
Upper Taieri Plain

Job Number 51-32454
Revision B

Date 19 Dec 2014

Figure 7:   Mapping of freeboard height above ground

Note the few grey areas indicating where naturally high ground is sufficient that recommended floor levels are not influential.

The almost complete absence from study area of ground higher than the recommended floor levels was a striking outcome of the study, as illustrated in Figure 7 above.

6   KEY LEARNINGS FROM MOVING TO FLEXIBLE MESH

Building the flexible mesh is not intuitive and needs training and time to develop the skills. Our experience with the tools and advice to building a variable density mesh using shapefile boundaries using DHI 2014 SP1 software were unsuccessful, but were later resolved by DHI providing an improved software tool "Shp2xyz" for importing shapefiles into the DHI mesh builder tool.

Further in relation to the flexible mesh generation, despite various investigations and enquiries we were unable to identify a robust and consistent process or tool from either ArcGIS or DHI that would suitably identify the correct location of drains and roads. Several tools were helpful to highlight these for human interpretation, but typically failed to provide continuity and produced variable results and would not facilitate the variable density mesh which we sought to build, without significant manual intervention.

Another learning that we found was that it was more important for flexible mesh model runs to specify the types of results which were desired. In the classic model setup it is simple to derive either the flood level (or depth) through GIS raster math given the initial model bathymetry. In flexible mesh however, the water level results are associated with the cell element (think of the triangle centroid), whereas the bathymetry (ground level) is associated with the cell vertices. This means that simple cell by cell arithmetic is not practicable and that deriving any results that are not saved at runtime is a more significant challenge.

7   RECOMMENDATIONS FOR FURTHER WORK

While the model has been shown to be satisfactory in the majority of the study area for the specified purpose of predicting the 100 year flood levels, further improvements to the model would be advisable to address some of the localised weaknesses and to improve its suitability for other purposes.

The first opportunity would be to collect data and represent the few major bridges and culverts through railway and motorway crossing realistically. This would principally benefit understanding of flood risks around and upstream of these structures.

Another opportunity to build more generalised confidence in the models predictive ability would be to compare the results with one or two actual major storm events. This would rely on having sufficient recorded understanding of actual major flood events. ORC have recently suggested that the April 2006 floods could be suitable for this purpose. This would involve estimating actual rainfall conditions during the event, running these through the model and comparing the model results with observed flooding extents and depth.

Further work could be undertaken to improve the flexible mesh. The ideal method for this would first involve improving the accuracy of the drainage linework, and then using

that improved definition to redefine the grid, probably including a third level of grid resolution.

ORC have also suggested that it would be of value to test the model sensitivity to adopted roughness values. This would be a reasonably straight forward exercise to test the impact on results from either a global increase in roughness or a varying pattern of roughness and would further reinforce confidence in the model.

8   CONCLUSIONS

A reasonable model of the 100 year flood scenario for the Upper Taieri plains has been prepared. The results have been shown to be reasonably robust in most parts of the study area by demonstrating that the flood levels are insensitive to the major uncertainty in the modelling (hydrology assumptions and consequent flow rates).

The results have also confirmed that, in general, the predominantly open channel drainage network is substantially overwhelmed during the 100 year flood event, such that accurate representation of these drains and their associated culverts is not essential to providing reasonably robust predictions of flood levels.

There are some exceptions to the generally low sensitivity for flows and the importance of drains and associated culverts. This study has however been effective in identifying those areas. Additional detail could readily be applied to those areas if future confidence in model results for those areas was required.

This modelling work was able to be carried out at reasonably low cost due to the combination of circumstances that made the study well suited to a simple 2D only flexible mesh model. Key circumstances include:

- availability of suitable quality LIDAR information

- the modest scale of the mainly open channel drainage network relative to the size of the desired 100 year flood modelling event

- the lack of other complexities such as risks of stopbank overtopping or stopbank collapse, pump station functions or tidal interactions

Flood modelling in itself is only partially useful as a planning control. Determining of minimum floor level requirements based on flood levels requires setting a freeboard, determining a methodology for extrapolation of floor levels into the marginal areas above the flood level but below the freeboard level and providing the results in form(s) that the client can make use of in both their planning documents and online mapping systems.

Through this project the freeboard was set, floor level requirements extrapolated beyond the flooded area and data provided to Dunedin City Council in continuous raster GIS format enabling them for the first time to make these recommendations available to staff and the public through their web mapping platform.

Flexible mesh GPU modelling is a relatively new function in DHI software. It can reduce modelling costs in some areas which would previously have been considered unaffordable. Making the change from classic DHI 2D modelling into the flexible mesh GPU software requires a significant investment in training and on the job learning.

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