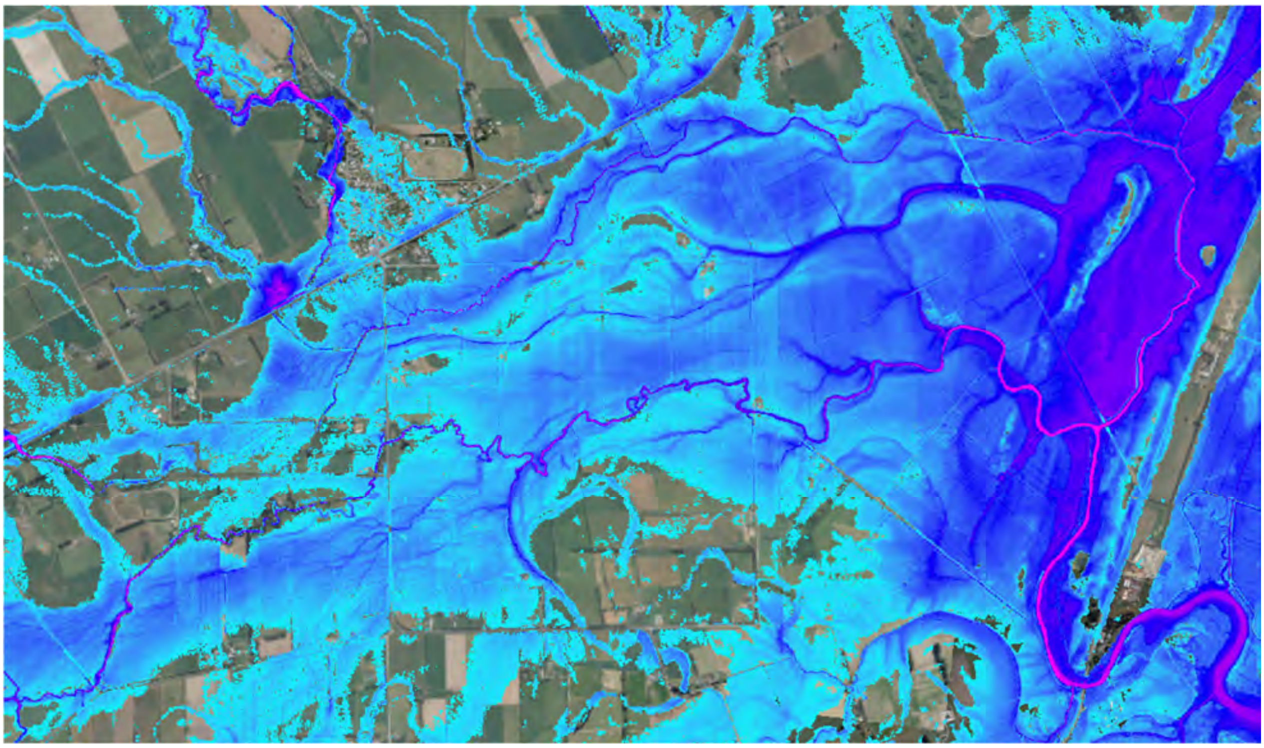
Flood Hazard Models Update

District and Urban and MIKE FLOOD models



Waimakariri District Council

Report

May 2020

The expert in **WATER ENVIRONMENTS**

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Flood Hazard Models Update

District and MIKE FLOOD Models

Prepared for	Waimakariri District Council
Represented by	Mr Chris Bacon

Project manager	Antoinette Tan

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DHI Water & Environment Ltd• B:HIVE, Smales Farm• 0622 Auckland• New Zealand•
Telephone: +64 9 912 9638 • Telefax: +64 9 912 9639 • lap@dhigroup.com• www.dhigroup.com

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1 Introduction

This report outlines the modelling completed by DHI in 2019/2020 for the Waimakariri District Council (WDC). The modelling includes the two district wide MIKE 21 models, North Ashley and South Ashley and the local urban flood models for Woodend, Kaiapoi, Oxford and Rangiora townships. The work involved updating existing models with the latest data and methodologies aiming to improve the accuracy in flood level predictions in the district. The model updates were generally based on suggestions provided to WDC as part of the DHI peer review of the District models in 2015, along with other suggestions recorded by WDC in their report (WDC 2015). These future update suggestions are listed in Table 1-1. In addition to this, the update includes features that relate to more recent advancements in the software, such as improved culvert definitions.

The results of these models will be used in preparing the upcoming district plan changes by identifying flood hazard risk and flood extents for low probability flood events, 1%, 0.5% and 0.2% AEP design rainfall events of a 24hr duration. The models also account for climate change using the HIRDS v4 RCP 8.5 rainfall.

The current modelling has been peer reviewed and accepted by WSP.

Table 1-1: Recommended updates identified in the 2015 modelling.

2015 review comment	Outcome
Roughness for built up areas in the North Ashley should be lowered to account for higher building roughness	More detail has been included in the roughness model for the North (and South) Ashley, with buildings now explicitly represented.
Recommendation to use the 2007/2012 LANDSAT survey of impervious areas for the region.	This was not included as this data is now 8 years old and will no longer reflect the current development. The latest planning data has been used instead.
Use Triangular mesh elements for more flexibility in resolution, and to include buildings into the mesh.	The mesh has been updated for the district models to be a triangular mesh. See section 3.3.1.
Switch to using low order calculations in the MIKE 21 FM engine to reduce model run times.	This was not done; however, the models are running within an expected timeframe and it is not necessary to potentially limit the model accuracy to get faster run times at this stage.
Updated LiDAR data (e.g. future development areas and western catchment)	The DEM has been updated to include the newest available data for all major developments in the region, as described in Appendix D
Updated Land Use data across the district	Landuse has been updated to use LCDB v4.1 which was the latest available at the time of building the model.
More refined assessment of the impervious area	The infiltration model has changed significantly. Which impacts on how the impervious areas behave within the model. See section 3.2.2 Infiltration.
Inclusion of more primary infrastructure in the models	This has been addressed by incorporating the source inflows extracted from the district models into the Urban Flood models. Allowing for the urban areas to be modelled with a higher level of detail while still accounting for the full catchment flows. See section 4.1.1.
More refined modelling of the rivers	Using the flexible mesh allowed for more detail to be added in

within the models	the river corridors to improve the conveyance of these areas. See section 3.3.1.

2 Data

The following is the data that was used in the update of the model, if not stated otherwise the data was provided by WDC:

- 2m DEM of the district, as updated by WDC (see reference – Appendix D)
- District Gross Rainfall files – Rainfall files spatially varying 2D rainfall, as processed by WRC derived from HIRDS v4. These covered the 1%, 0.5% and 0.2% AEP, 24hr design rainfall events. See Appendix C and E.
- General Shapefiles – building outlines, culvert start and end points (with level and size data), embankments, river corridors where more detail is required, road centrelines and urban area outlines.
- Stormwater asset data covering the Waimakariri District – i.e. pipes and nodes
- MIKE URBAN Flood models for Woodend, Kaiapoi, Oxford and Rangiora – this included both the MIKE URBAN setup and the 2D overland flow module setup.
- District wide MIKE 21 models for North and South Ashley

The models all use the NZGD 2000 New Zealand Transverse Mercator projection, and are based on the Lyttleton vertical datum.

3 District Models

3.1 Overview

The Waimakariri district models update follows on from the district modelling work completed in 2015-2016 (completed by WDC). The main changes to the modelling are the introduction of the infiltration module which significantly changes the amount of runoff coming into the model, and the adoption of the variable sized triangular flexible mesh. Previously the model used pre-processed rainfall to account for infiltration and a uniform rectangular element mesh. The following sections describe the model setup with a focus on the updates made to the model, with the understanding that the reader should be reasonably familiar with the previous work completed.

3.2 Hydrology

3.2.1 Rainfall

Time varying rainfall files were provided by WDC and these were used as is without modification for the district models. The generation of the rainfall files is described in Appendix C with discussion on the use of HIRDS in Appendix E. The rainfall used is based on HIRDS version 4, and accounts for climate change using the RCP 8.5 emissions scenario.

3.2.2 Infiltration

The infiltration and leakage module in MIKE 21 was used to model the infiltration. The methodology for deriving the spatially varying rates and parameters is described in Appendix A. This approach uses a simple sub surface layer to represent infiltration into the ground, where the initial soil saturation was derived using a long term MIKE SHE model. And the soil infiltration rates were derived from calibrated parameters. MIKE SHE is a specialised platform for modelling surface water, the unsaturated zone and the saturated zone interactions. The goal for deriving the infiltration parameters using MIKE SHE was to ensure that the MIKE 21 model behaves in a similar manner to the more detailed infiltration definition in the MIKE SHE model.

The base infiltration rates derived in the infiltration analysis reflect the underling soil condition but do not account for impervious areas due to roads or built up areas, to account for these areas the input dfs2 (grid) files were modified so that the initial infiltration for buildings and roads were set to 0, the residential areas were set to a value of 50% of the original, and the industrial areas were set to 20% of the original. The exception to this were the areas categorised as wastewater treatment plants and crop fields which were unchanged.

3.3 Hydrodynamic model

3.3.1 Terrain and mesh

A triangular mesh was used for the 2D modelling. The mesh was built to ensure a higher level of detail in key areas such as around buildings, roads and key flow paths. Allowing for higher resolution in these areas provides more accurate hydraulic connectivity of flow paths, and a more accurate representation of flooding in these areas. Before choosing to upgrade the model to use a triangular mesh, testing was done to ensure this method would be viable and beneficial to the modelling, this testing is detailed in Appendix B. Detail in the mesh is defined by two separate constraints, point spacing for line features (i.e. road line or a building outline), and general maximum element size.

The following constraints were set in the mesh generation:

- Buildings – point spacing of approximately 5m
- Roads – point spacing of 5m
- Key river centrelines – point spacing of 8m
- Stopbanks – point spacing of 8m
- Rural flat areas maximum element size of 225m^2
- High elevation areas maximum element size 400m^2 (and up to 600m^2 in areas that were producing hydraulic instabilities)
- Culverts used square elements with an area of 49m^2 (7m x 7m)
- The minimum mesh element angle used was 28°

The ground level of the culverts was also specifically set to be equal to the supplied invert level of the culvert to ensure that water could reach the culvert structure. The level was set around a radius of 10m to ensure that the element would be set to the correct level. In order to better improve the stability of the model around the culvert structures, square elements were generated in these areas to ensure that the element size did not become too small, see figures 3-1 and 3-2 for examples at some locations.

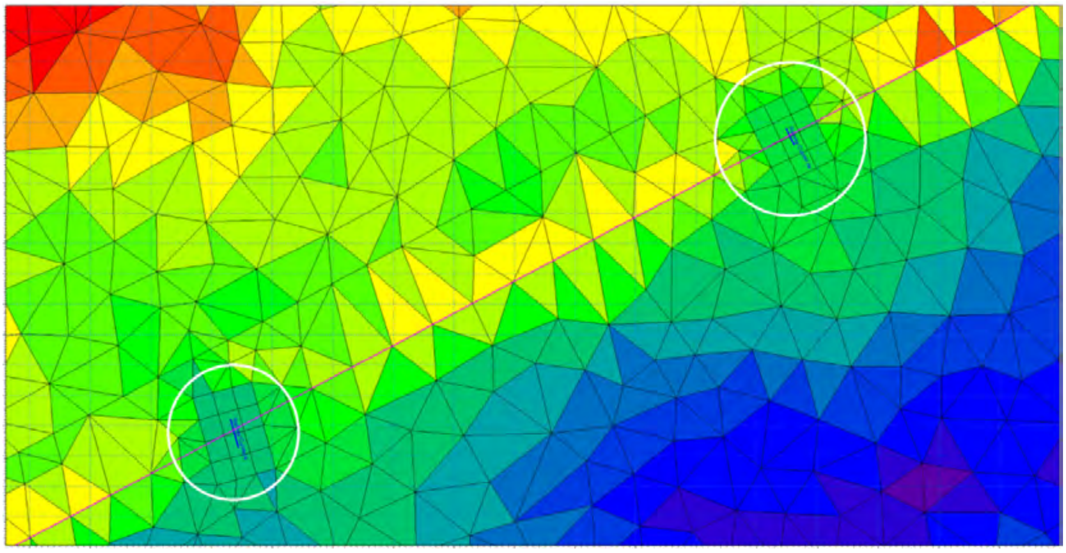

Figure 3-1: Zoom of North Ashley mesh around Culverts 4 and 4a (blue) crossing dike structure (purple)

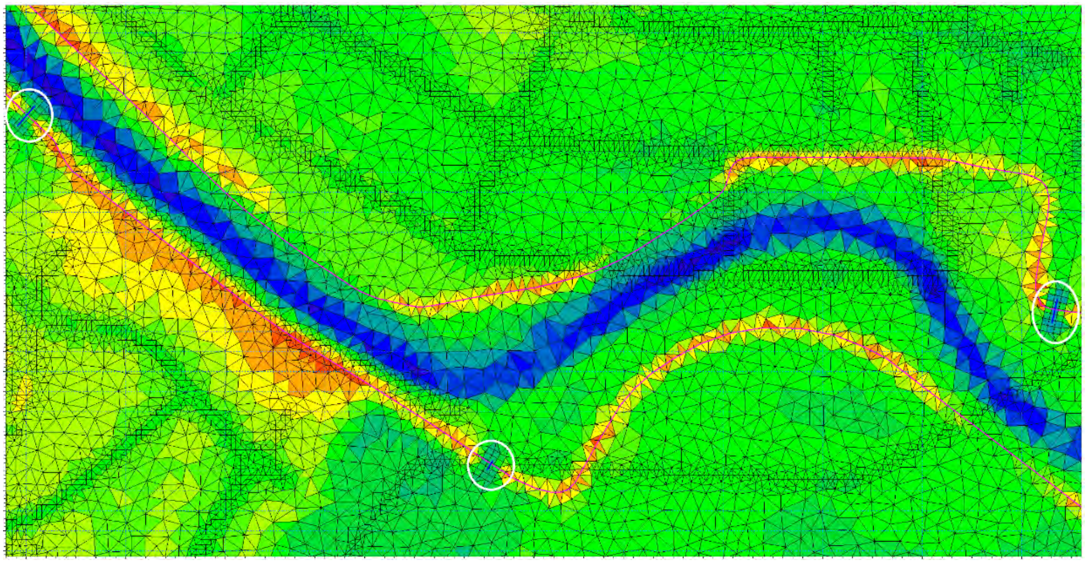

Figure 3-2: Zoom of South Ashley mesh around Culverts Bowler, Courtney and Feldwick streams (blue) crossing dike structures (purple)

Building platform levels were included by increasing the level of the DEM by 0.1m at the building locations, as specified by WDC.

A 5m DEM with all modifications to building and culvert levels was then used for interpolating all mesh levels. This 5m DEM was based on the DEM provided to DHI by WDC and is discussed in Appendix D. The DEM is based on the 2014 LiDAR survey but also includes the majority of new developments, in the district, that have been constructed since the 2014 survey. These updates included 435ha of development revisions.

3.3.2 Structures

Three structure types are used within this model, the number of each of these structures included in the models is described in Table 3-1.

Table 3-1: Number of structures included in the district models

Structure type	No. in North Ashley	No. in South Ashley
Culvert	8	38
Weir	0	10
Dike	4	22

In the previous version of these district models the roads and stopbanks were modelled by setting these levels directly in the DEM, however in this current model dike structures have been used instead. All culvert structures are the same as were modelled previously, however now the long culvert option is used in MIKE 21. The long culvert feature allows for the structure to move water between two elements that are not adjacent to each other, much like a source/sink pair. Where necessary, to improve the culvert stability, the alpha zero parameter was used (increased by 0.01), and the momentum factor was adjusted. In terms of the weirs, these are used to model the road overflows at structures. This means that there were locations where there was both a dike structure and a weir at the same location, in this situation the weir was removed.

Five new embankments were added to the model as per WRC's request. These were provided as a shapefile, with the reference object IDs:

1. OBJECTID 22 – This is part of a new stopbank constructed by ECAN (note OBJECTID 4 is a portion of the stopbank constructed before 2014 and can be seen in the existing DEM)
2. OBJECTID 26 – This is also part of a new stopbank constructed by ECAN (note OBJECTID 4 is a portion of the stopbank constructed before 2014 and can be seen in the existing DEM)
3. OBJECTID 24 – Part of a new embankment constructed by the Townsend Fields development (note that there is a gap between OBJECTID 24 and 25 to let flood flow along a natural flow path to the east)
4. OBJECTID 25 – Another part of the Townsend Fields embankment (note that there is a gap between OBJECTID 24 and 25 to let flood flow along a natural flow path to the east)
5. OBJECTID 23 – A new embankment constructed by the Braeburn Subdivision to divert floodwaters to the south

In addition to these five banks, the stopbank on the North side of the Ashley river was set to a very high level to prevent overtopping. The reasoning behind this is discussed in the Validation section. An example of some of the embankments are shown in Figure 3-3 and Figure 3-4.

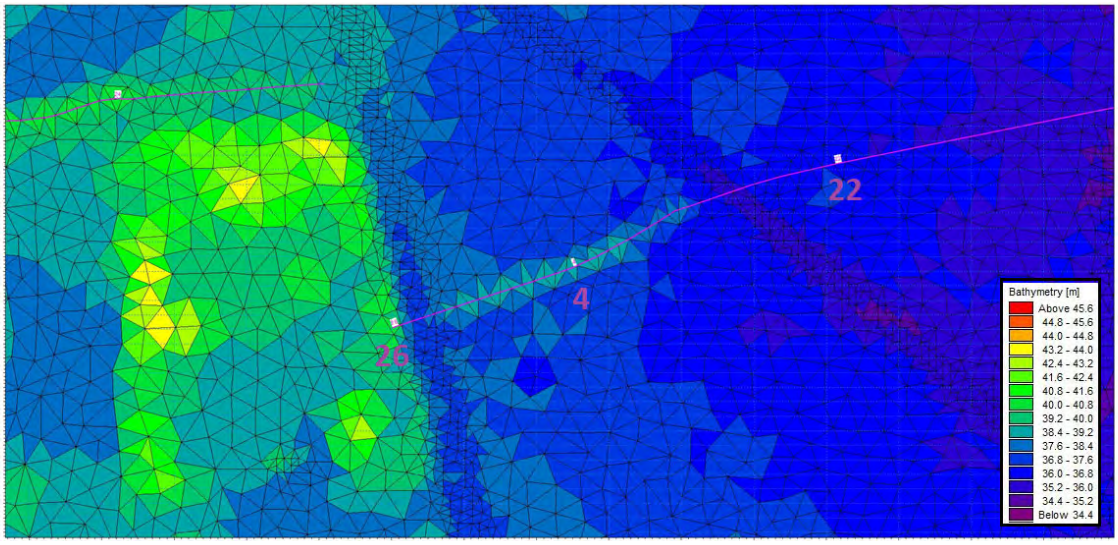

Figure 3-3: Spatial location of Embankments OBJECTID 26 and 4 with South Ashley mesh

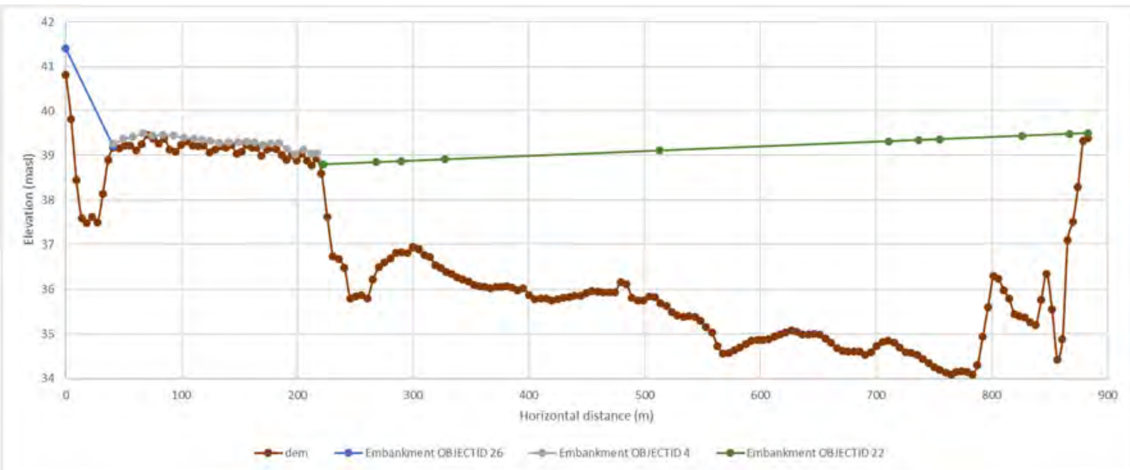

Figure 3-4: Profile of Embankments OBJECTID 26, 4 and 22 in comparison to DEM used to generate mesh

3.3.3 Downstream boundaries

Constant water level downstream boundaries were applied in a similar fashion to the previous models. These boundaries are located at the river outlets, assuming that the dunes that follow the east coast in this region would act as a barrier to flow in all areas except the river mouths. The boundaries use a constant water level of 1m RL. Computational and Simulation parameters

The models use the following computational and simulation parameters:

The same parameters were used for both the North Ashley and South Ashley models.

Parameter	Value	Comment
Maximum Timestep	5s	Global timestep is 30s although this is only used when defining the outputs.
Minimum Timestep	1e-05s	Set to consider short simulation periods where timestep may drop sharply and so that stability can be maintained.
Critical CFL number	0.8	
Eddy Viscosity	0.1	
Solution Technique	High Order	
Results save timestep	20 minutes	
Outputs saved South Ashley	25	Time varying results of Water Level, Depth, Current Speed, inundation output of Depth and Speed as well as 23 timeseries outputs of discharge to be used for generating the urban models source inflows.
Outputs saved North Ashley	2	Time varying results of Water Level, Depth, Current Speed, inundation output of Depth and Speed
Average Length of simulation modelled South Ashely	69 hours	Time between AEP scenarios is similar, urban developments downstream are the last to fill and the catchment is elongated, making simulation longer.
Average Length of simulation modelled North Ashely	12 hours	1% AEP scenario is twice as long as the 0.2% AEP scenario due to a significant increase in flooding.

3.3.4 Roughness

The following roughness values were used in the modelling, as per the LCDB v4.1 database shapefiles. Roads and buildings have also been added to this categorisation.

Table 3-2: MIKE 21 roughness

Name_2012	Manning's M	Manning's n
Broadleaved Indigenous Hardwoods	8	0.125
Buildings	3	0.33
Built-up Area (settlement)	10	0.1
Deciduous Hardwoods	8	0.125
Depleted Grassland	50	0.02
Estuarine Open Water	35	0.029
Exotic Forest	8	0.125
Fernland	8	0.125
Flaxland	8	0.125
Forest - Harvested	8	0.125
Gorse and/or Broom	8	0.125
Gravel or Rock	50	0.02
Herbaceous Freshwater Vegetation	10	0.1
Herbaceous Saline Vegetation	10	0.1
High Producing Exotic Grassland	20	0.05
Indigenous Forest	8	0.125
Lake or Pond	35	0.029
Landslide	50	0.02
Low Producing Grassland	10	0.1
Manuka and/or Kanuka	8	0.125
Matagouri or Grey Scrub	10	0.1
Mixed Exotic Shrubland	20	0.05
Orchard, Vineyard or other Perennial Crop	20	0.05
River	35	0.029
Road	50	0.02
Sand or Gravel	50	0.02
Short-rotation Cropland	20	0.05
Sub Alpine Shrubland	20	0.05
Surface Mine or Dump	50	0.02
Tall Tussock Grassland	10	0.1
Transport Infrastructure	10	0.1
Urban Parkland/Open Space	20	0.05

It is noted that roughness values around the berms of the Ashley river differ from the ECAN modelling, where this model tends to higher roughness values, which will potentially increase water levels. However, given that the Ashley river is not the focus of this particular study these roughness values can possibly be refined in future modelling.

3.4 Model Results

The two models were each run for the three design rainfall events 1%, 0.5% and 0.2% AEP, 24hr duration. The results were processed into a raster format for depth, water level, velocity and hazard.

Converting the depth values of a triangular mesh into a regular grid format, such as an ArcGIS raster format, can be done by using a number of methods. A combination of two methods were chosen to provide results that appear realistic. In the flat areas the depth was processed by intersecting the water level output with the 5m DEM used for generating the mesh. This created a detailed depth map that better reflected what the depth would look like at the peak water levels. For the steep areas this method was not possible, as due to the large mesh element sizes the result would not appear realistic, giving regular gaps in the flood result. Instead the raw triangular results were converted directly to a raster. In addition, all depths below 0.05m were removed from the rasters, so that only significant flooding was shown, water level, water depth and velocity were also clipped to this same extent.

Hazard maps were generated without clipping their extent. The hazard was calculated using the DHI flood modelling toolbox tool, with a hazard categorisation used from the WDC guidelines, Figure 3-5.The hazard calculation was performed at every timestep and the maximum hazard from this calculation was produced as an output.

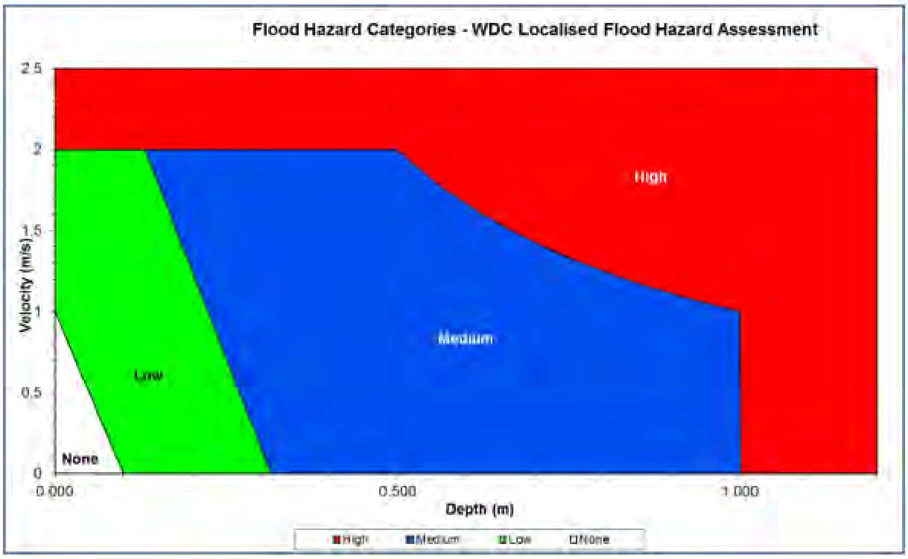

Figure 3-5: Flood Hazard Categories

3.5 Validation

There was very limited data available to validate the modelling updates, however a simplified assessment was undertaken to assess hill runoff for the Okuku catchment. The reason for this focus was due to significant changes, compared to the 2015 modelling, of input infiltration rates used in hill areas. In the earlier model version, the soil class for the hill catchments was described as high drainage, however further investigation indicates that this is unlikely, with the area being steep and having an underlying geology of basement rock. The updated model assumes a low nominal infiltration rate in these areas, producing significantly more runoff in the overland flow model. Further discussion on the classification of the soil drainage classes can be found in Appendix A.

Using DHI's Extreme Value Analysis (EVA) software, a simple flood frequency analysis was conducted on the 30 year Okuku (at Fox Creek) flow record to estimate a 1 in 100yr flow. This analysis gave an estimate of approximately 400m^3/s, comparable to similar ECAN (Environment Canterbury) analysis completed in 2011, which gave a value of 446m^3/s. Given the relatively short flow record available, it should be noted that there is substantial uncertainty around these estimates.

The MIKE 21 model results for a 1 in 100 year event give a peak flow of 910m^3/s at the Fox Creek Okuku gauge, Figure 3-6. This is around double the flow estimated using frequency analysis, indicating that the infiltration rates may be too conservative in the hillside areas. However, given the uncertainties involved in the flood frequency analysis, it is difficult to determine by how much. As most of the water from this hillside catchment flows directly to the Ashley River, bypassing the key developed areas in the catchment, the only impact of a potential overestimation of this hill derived flow will be on breakout flows occurring further downstream.

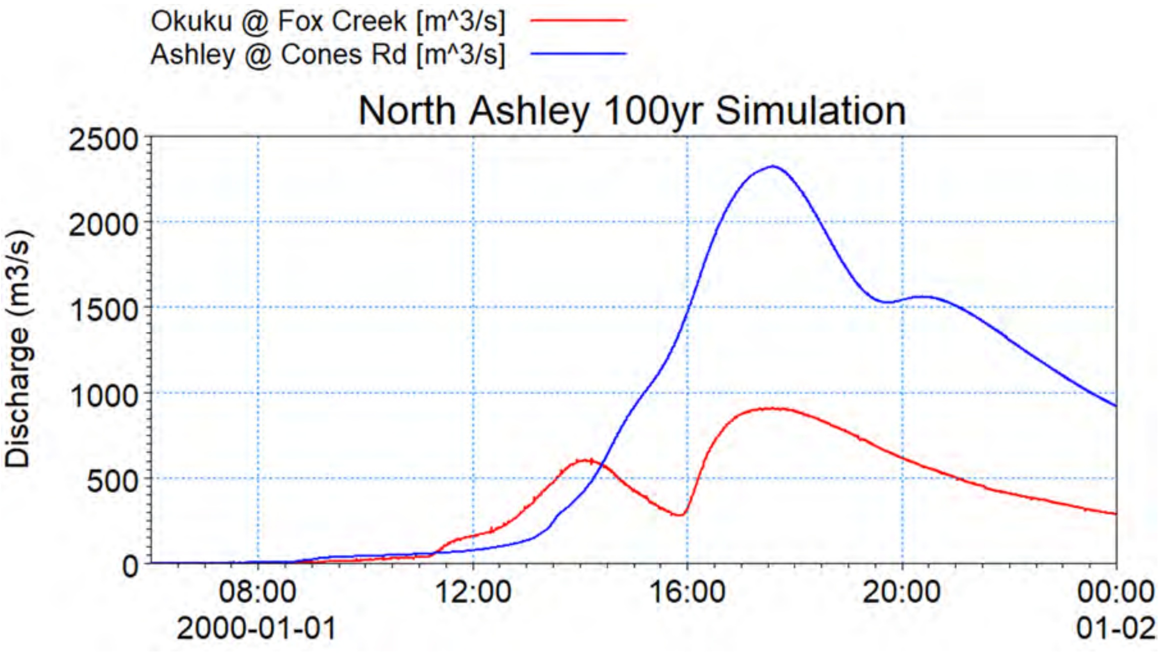

Figure 3-6: Ashley Catchment Flows

Despite the potential overestimation of flow, it is believed that the model is still performing better in this area than in the earlier modelling. The previous WDC modelling used rates of 75-10mm/hr which resulted in almost no runoff from the hillside areas for the 100yr event. This is completely unrealistic given the flows measured on the Okuku. The updated North Ashley model's hillside areas use infiltration rates of 2 to 0.75mm/hr, comparable with rates that have been used in the modelling of other Canterbury hillside areas. Future work could be done to calibrate the hillside infiltration rates to the Okuku flow gauge to give more confidence in these infiltration rates.

As further confirmation of the model hydrology, the flow in the Ashley river was discussed with ECAN. ECAN have conducted their own modelling of the Ashley river the peak flows provided are presented in Table 3-3. Because the North Ashley MIKE 21 model does not include the catchment upstream of Ashley Gorge it was necessary to make an approximation of the ECAN flow by removing the gorge flow, in order to compare with the North Ashley MIKE 21 model. The flow extracted from the MIKE 21 model at Cones road was used for the comparison and is also shown in Figure 3-6 for the 100yr event. The MIKE 21 model matches well to the ECAN modelling for the 100yr event but is higher in the 500yr event. This may also reflect the uncertainty in predicting the larger flood events.

Table 3-3: Ashley Flow Comparison

Return Period	ECAN total Ashley flow	ECAN Gorge flow	ECAN Total - Gorge	M21 North Ashley Model
100yr	3,200	1,200	2,000	2,300
500yr	4,200	1,800	2,400	3,800

As previously mentioned, even if the Ashley flows are overestimating the only significant impact these will have, on the downstream flooding, is if these flows become high enough to cause overtopping of the Ashley Stopbanks. ECAN predict that overflow would occur over the North Ashley stopbank at a flow of around 3,200m^3/s. This reflects well with the modelling, with overtopping observed in the 500yr flood event. The overtopping is also likely caused by some differences in how roughness was modelled on the banks of the Ashley. It was agreed with WDC to prevent any overtopping from the north Ashley stopbank in the base district modelling, by setting the North Ashley stopbank to a very high level. Overtopping of the stopbanks would reflect a more conservative scenario where high flow in the hills also coincided with high flow in the local catchment, as well as the indication that the current MIKE 21 model appears to be overestimating flows based on available data.

3.5.1 Sensitivity Testing of downstream water levels

Sensitivity testing was completed on the South Ashley 200yr model to assess the impact of raising the Ashley tail water (boundary) level to 2m RL. Figure 3-7 shows the area of impact of raising the tail water levels by 1m. The dark orange colour indicates a level increase of around 1m, and the light orange area to the south indicates an increase of 30mm. This increase in water level extends around 3km south of the stopbanks. Given the small impact outside of the river itself this indicates that the model has only minor sensitivity to the tail water level in the Ashley.

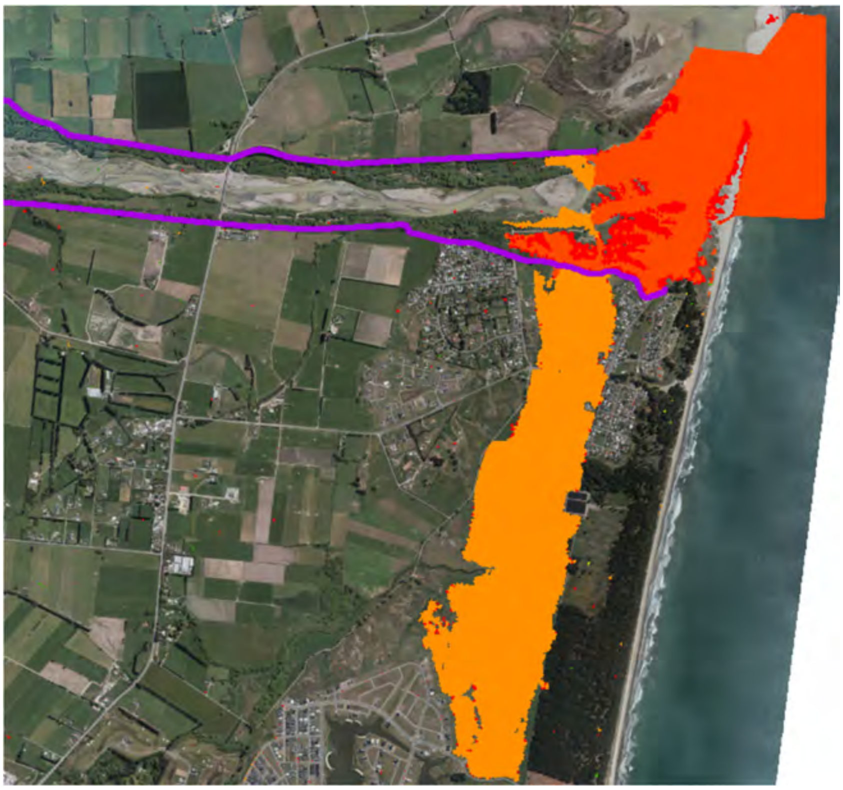

Figure 3-7: Sensitivity testing of the Ashley River water level boundary

4 Urban Flood models

There are four urban areas that have been modelled using MIKE FLOOD. For each of these models the 2D domain is modelled using MIKE 21 Flexible Mesh, and the pipes and open channels are modelled using MIKE URBAN. The basis for these urban models were the WDC in house produced MIKE URBAN models:

- Woodend Urban Flood Model (WFM 2019.mdb)
- Kaiapoi Urban Flood Model (KFM 2019.mdb)
- Rangiora Urban Flood Model (RFM 2019.mdb)
- Oxford Urban Flood Model (OFM 2019.mdb)

The urban flood models are modelled with the same design rainfall events as the district models, consisting of the 1%, 0.5% and 0.2% AEP, 24hr design rainfall events. The modifications made to these models and the MIKE 21 and MIKE FLOOD model build is described in the following sections.

4.1 General model setup

4.1.1 Hydrology

The rainfall runoff in the previous modelling consisted of either catchments loaded to the MIKE URBAN network or in rural areas rain directly on the gird. The updated models do not use MIKE URBAN catchments but only use rain directly on the grid combined with infiltration. The inputs for rainfall and infiltration are the same as those used in the District Models, described in Section 3.2.

Discharge hydrographs were extracted from the District Model results and added into the Urban Flood models via source points at 5m intervals along the extraction lines. To improve the distribution of the discharge a depth adjustment was applied which weighted more flow to areas with higher depth. This process resulted in a total of 1856 timeseries for each of the 3 flood events. Source points were applied to the Woodend, Kaiapoi and Rangiora models. The Oxford model is a self-contained catchment and does not receive any overflow from the upstream catchments.

4.1.2 Open Channels

The open channel sections of these systems are all modelled in MIKE URBAN. In order to more accurately link the channels to the 2D surface in MIKE FLOOD, it was necessary to create a smaller point spacing. A spacing of 10m was used which is 2x the grid size. Where the open channels were defined as natural channels these were changed to the CRS type to facilitate breaking up the channel into 10m sections.

In some locations the stream alignment did not match with the DEM provided. Where this occurred the open channel alignment was adjusted to match.

The existing models were also representing some of the road kerbs as overland flow paths in the MIKE URBAN model. However, because the roads are now being modelled using MIKE 21 the MIKE URBAN kerb definitions were removed. The open channels with CRS type KERB, FLAT CHANNEL or DB1*FC were all removed from the MIKE URBAN model and all intermediate pipe elements were retained.

4.1.3 Pipe network

Minor MU pipe network updates were made to improve the model stability and robustness. The following adjustments were made to the pipe network each of the models.

- Pipe levels – where there were discrepancies i.e. negative slopes causing instabilities or pipe levels above the ground levels
- Pipe lengths – updated so that these match the computed pipe length
- Applying glass wall for CRS – Using the ini file the glass wall is applied to prevent errors in the calculation
- Manhole sizes – in some areas manholes were artificially large, these have been reverted to sensible sizes.
- Basins were removed from the MIKE URBAN model and replaced with dummy nodes (in most cases where the basin area was >400m^2), where these are to be modelled in the MIKE 21 model.

Some spot checks were done comparing the MIKE 21 basin volume to the original model stage storage relationships. In general, it was found that the MIKE 21 volumes were slightly larger than the stage storage, although the methodology to calculate the volume of the MIKE 21 basins generally assumed vertical walls which would overestimate the total volume. The differences in volume can also be explained by errors in the MIKE URBAN definition, or in an oversimplification in the MIKE 21, given the mesh resolution.

4.1.4 2D model setup

The MIKE 21 models consist of 5mx5m rectangular flexible mesh grids. A dfs2 file based on the DEM file provided by WDC was used to represent the grids. A number of adjustments were made to the DEM to allow for better coupling with the MIKE URBAN model.

Stormwater basins were modelled in the MIKE 21 grid by lowering the DEM to the level of the invert of the lowest outlet. This allows only the live storage to be modelled with no need for filling the basins at the start of the simulation.

Modelled basins in 2D

- 9 in the Woodend North Kaiapoi Urban Model
- 24 in the Kaiapoi Urban Flood Model
- 29 in the Rangiora Urban Model
- 2 in the Oxford Urban Model

Where the open channels are linked to MIKE 21, the MIKE 21 levels were adjusted to be set to the bank height. This reduces double counting of flow. In this situation the low flow is modelled in the MIKE URBAN model while the overflow is modelled in MIKE 21.

The remaining parameters of the MIKE 21 models are as described in:

Table 4-1: MIKE 21 parameters for MIKE FLOOD models

Parameter	Value	Comment
Critical CFL number	0.8	
Eddy Viscosity	0.5	
Roughness	dhi_manning_waima_corrected_V3.dfs2	Same as used in District Models

Parameter	Value	Comment
Solution Technique	High Order	
Results save timestep	5 minutes	
Outputs saved	2D (Horizontal) – xxx_res.dfsu	Time varying results of Surface elevation, Total Water Depth, U and V velocity, Current Speed, Infiltrated Volume and CFL number.
	Inundation – xxx_inu.dfsu	Maximum Water Depth and Current Speed.
	Mass Budget – xxx_mass.dfs0	Flow

Dikes that were setup in the district models were also included in the local urban flood models. In addition to this where culverts were not present in the MIKE URBAN model these were also included as 2D structures. The exception to this is the Kaiapoi and Rangiora models where 3 and 1 culverts respectively were causing issues and needed to be removed.

4.1.5 MIKE FLOOD Coupling

In the MIKE FLOOD coupling, open channels, sumps and outlets are linked to the 2D surface.

Open channels are linked as inlet links using the weir equation. A width of 10m is used for each weir, matching the 10m point spacing. Dummy basin nodes also used the same parameters.

Sumps and some manholes are linked to the surface directly at the location of the inlet. These use the inlet linking method and the orifice equation. In some of the models inlet area and maximum flow were pre-defined by the previous modelling. However, where default values had been used or the value did not appear to represent reality a global value of 0.045m3/s was used for max flow and 0.158m^2 for the inlet area.

Outlets were linked to the 2D surface unless the outlet was close to the model boundary, in which case the outlet was not linked and the water was left free to exit directly from the MIKE URBAN model. These free outlets are illustrated in the figures in the following sections as the yellow dots.

All links used the Qdh value of 0.2 to improve the model stability of the linkages.

4.2 Rangiora

The Rangiora model consists of a combination of open channels and pipe network. The location of the source points and open boundaries is shown in Figure 4-1.

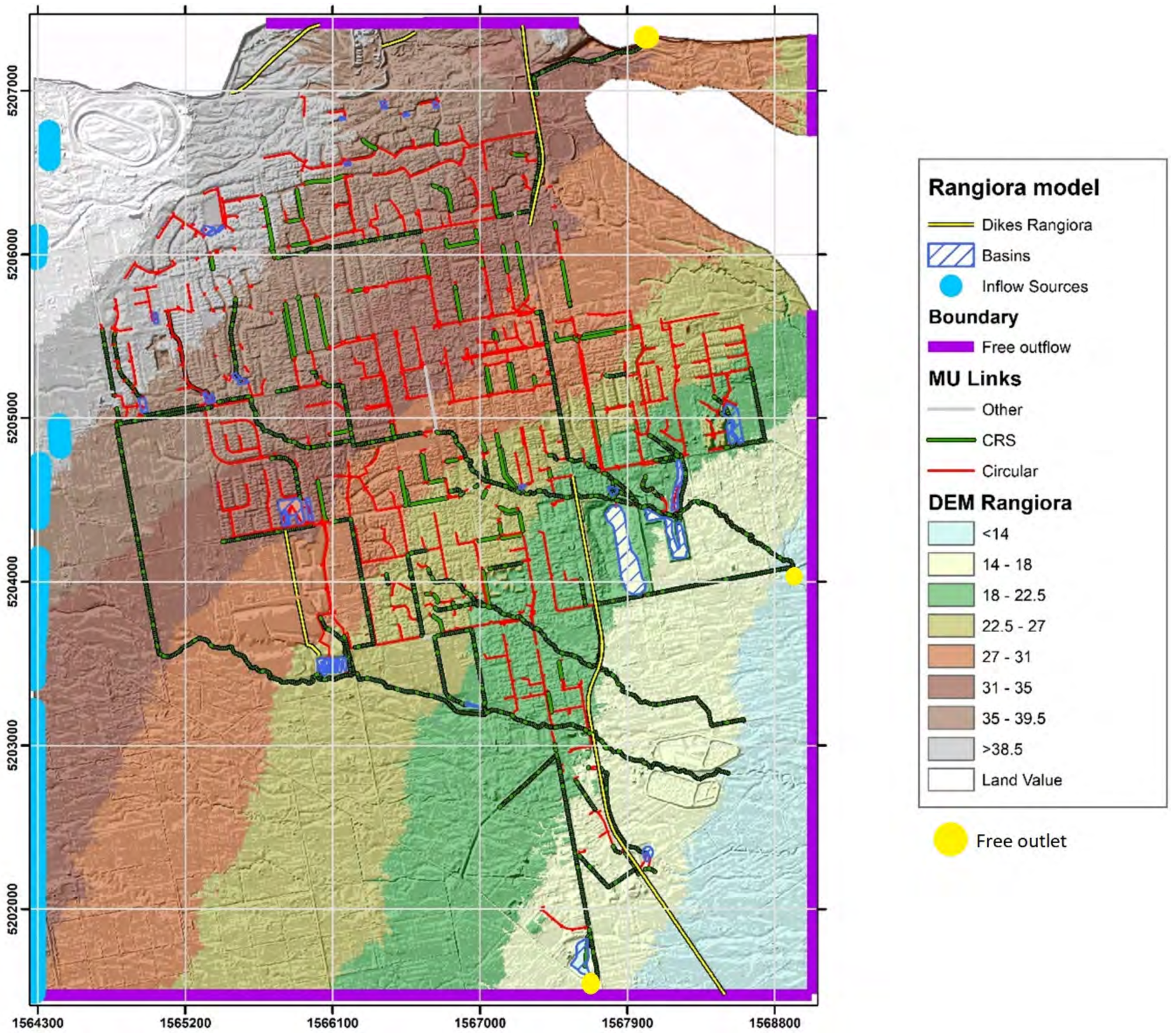

Figure 4-1: Rangiora Model

Table 4-24- lists all of the basins modelled in the Rangiora model and their sizes. For some of the basins the data available was sparse, so best efforts have been made to represent reality, using the existing model data, aerial photography and DEM levels. In general, the location of the incoming pipes to a basin have been kept as they were in the original MIKE URBAN models provided by WDC. This means that in some locations the inlet and outlet to the basin is modelled via spilling from the original location of the basin node itself into MIKE 21. However, this basin node has now been converted into a manhole with a minor volume. The location of these inlet and outlet pipes, orifices and weirs may differ in reality, however, the volume into and out of the basins should still be correct. For basins with a longer flow path in the Rangiora model some of the inlet/outlet locations have been shifted to ensure a better representation of flow paths through the basins. These could be improved further with more detailed information on the basin design.

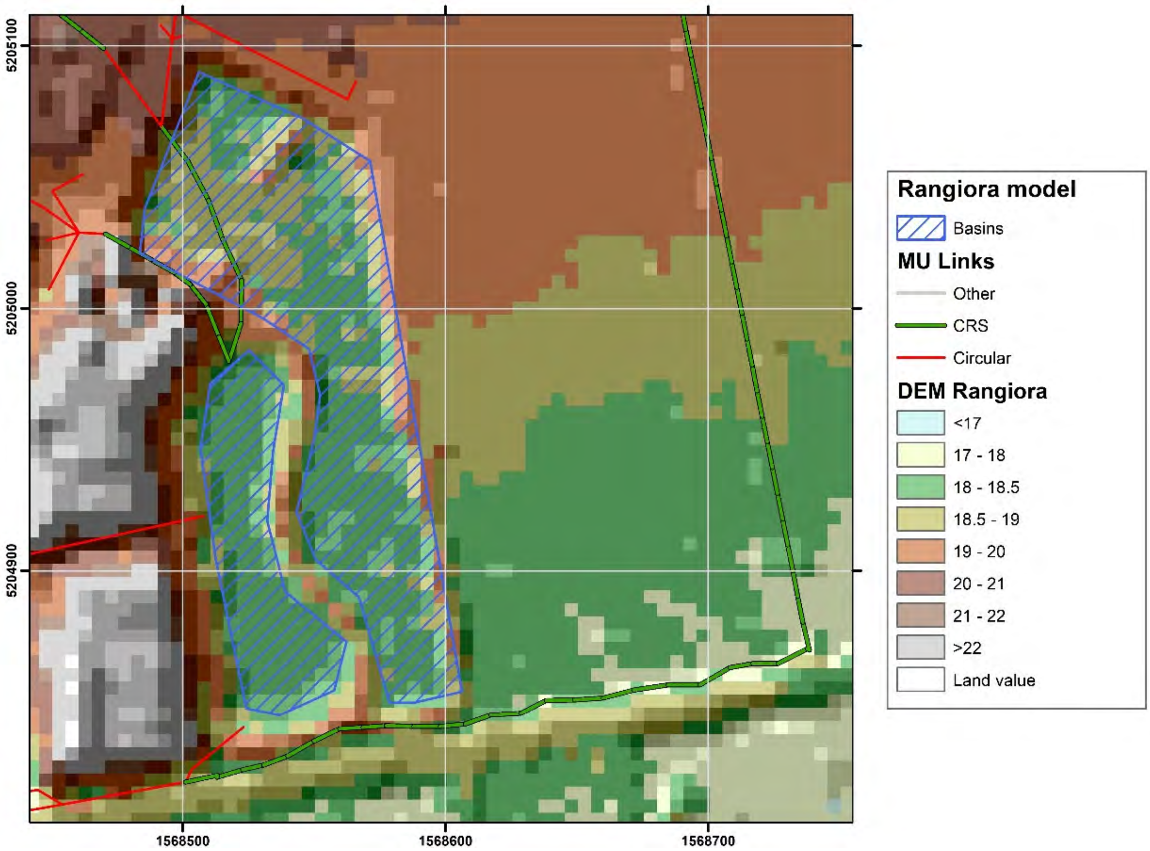

Figure 4-2: Basin added to the Rangiora model

Figure 4-2 shows a new basin that was added to the model around Northbrook Road This basin was not present in the WDC models provided. Because data was limited in this area, assumptions have been made in terms of inlet/outlet locations and the basin levels are currently only using the DEM level.

Table 4-24-: Rangiora Basins information

BASIN	Model	X (m)	Y (m)	Invert level (m)	Area (m^2)
Arlington 2nd Basin	Mike 21FM	1565327	206149	40.00	1,962
Arlington FF	Mike 21FM	1565383	5206133	39.40	1,843
AWA PLACE BASIN	MIKE 21FM	1566730	5206913	34.51	863
Ballarat Road Pond	MIKE URBAN	1565914	5206961	38.77	<500
Chesterfield Pl North Basin	MIKE 21FM	1566413	5206912	36.43	1,231
Chesterfield Pl South Basin	Mike 21FM	1566546	5206855	35.89	564
Covane Mews Basin	Mike 21FM	1566193	5206549	36.94	716
Detention Basin	Mike 21FM	1565848	5204465	30.30	14,693
East Rangiora Stormwater Pond	Mike 21FM	1568208	5204585	16.50	8,771
Enverton Drive Basin	Mike 21FM	1566156	5206825	37.00	408
First Flush 1	Mike 21FM	1565798	5204387	30.40	1,859
First Flush 2	Mike 21FM	1565956	5204441	30.30	3,068
Lilybrook Park Basin	Mike 21FM	1567247	5204568	21.81	618
Northbrook Waters	Mike 21FM	1567886	5204164	15.85	53,823
NPB Forebay	Mike 21FM	1567807	5204568	16.70	1,975

BASIN	Model	X (m)	Y (m)	Invert level (m)	Area (m^2)
NPB Main Ponds	Mike 21FM	1568157	5204360	16.20	20,532
Ryman Detention	Mike 21FM	1565337	5205120	34.00	1,377
Ryman FF	Mike 21FM	1565368	5205124	35.14	902
Southbrook Park Basin	Mike 21FM	1566927	5203246	20.50	1,001
Southbrook Pond A	Mike 21FM	1568011	5202344	12.80	3,557
Southbrook Pond C	Mike 21FM	1567645	5201654	13.20	14,985
Springbrook Det Basin	MIKE URBAN	1568138	5204434	17.10	<500
Springbrook FF Basin	MIKE URBAN	1568126	5204502	17.16	<500
The Oaks Basin	Mike 21FM	1565536	5205230	35.90	2,572
Townsend Cell1	Mike 21FM	1566037	5203489	23.80	3,317
Townsend Cell 2A	Mike 21FM	1566063	5203505	24.90	936
Townsend Cell 2B	Mike 21FM	1566080	5203485	24.80	1,266
Townsend Cell 2C	Mike 21FM	1566098	5203495	24.70	913
Townsend Cell 2D	Mike 21FM	1566114	5203483	24.60	919
Townsend Cell 3	Mike 21FM	1566153	5203475	23.20	2,710
Westpark Detention Basin West	MIKE URBAN	1564815	5205008	37.30	<500
Westpark Detention East	Mike 21FM	1564943	5205066	37.00	3,019
Westpark FF Basin West	MIKE URBAN	1564838	5205013	37.30	<500
Westpark FF East	MIKE URBAN	1564933	5205127	37.40	<500
Windsor Park Basin	Mike 21FM	1565018	5205614	38.60	1,560
South Basin – North Northbrook Road (unnamed)	Mike 21FM	1568527	5204926	(17.50 manhole) (18.11 DEM)	5,404
North Basin – North Northbrook Road (unnamed)	Mike 21FM	1568529	5205027	(17.50 manhole) (18.00 DEM)	10,229

The Rangiora model has the following simulation settings, Table 4-3.

Table 4-3: Rangiora model information

Parameter	Value
Maximum Timestep	1s
Minimum Timestep	1e-05s
Simulation period	32 hours
Average Simulation elapsed time (for each event)	9.7 hours

4.3 Kaiapoi

The Kaiapoi inflow sources and downstream boundaries are illustrated in Figure 4-3. The red boundary in the South East corner is a constant water level boundary set to 1.4m. This represents the level of the Kaiapoi/Waimakariri confluence, which would be affected by the tide. The level of 1.4m was derived from monitoring undertaken by WDC at the McIntosh Drain outlet into the Waimakariri River. The monitoring showed a mean water level of 0.4m RL. The figure of 1.4m RL is 0.4m plus 1.0m of sea level rise.

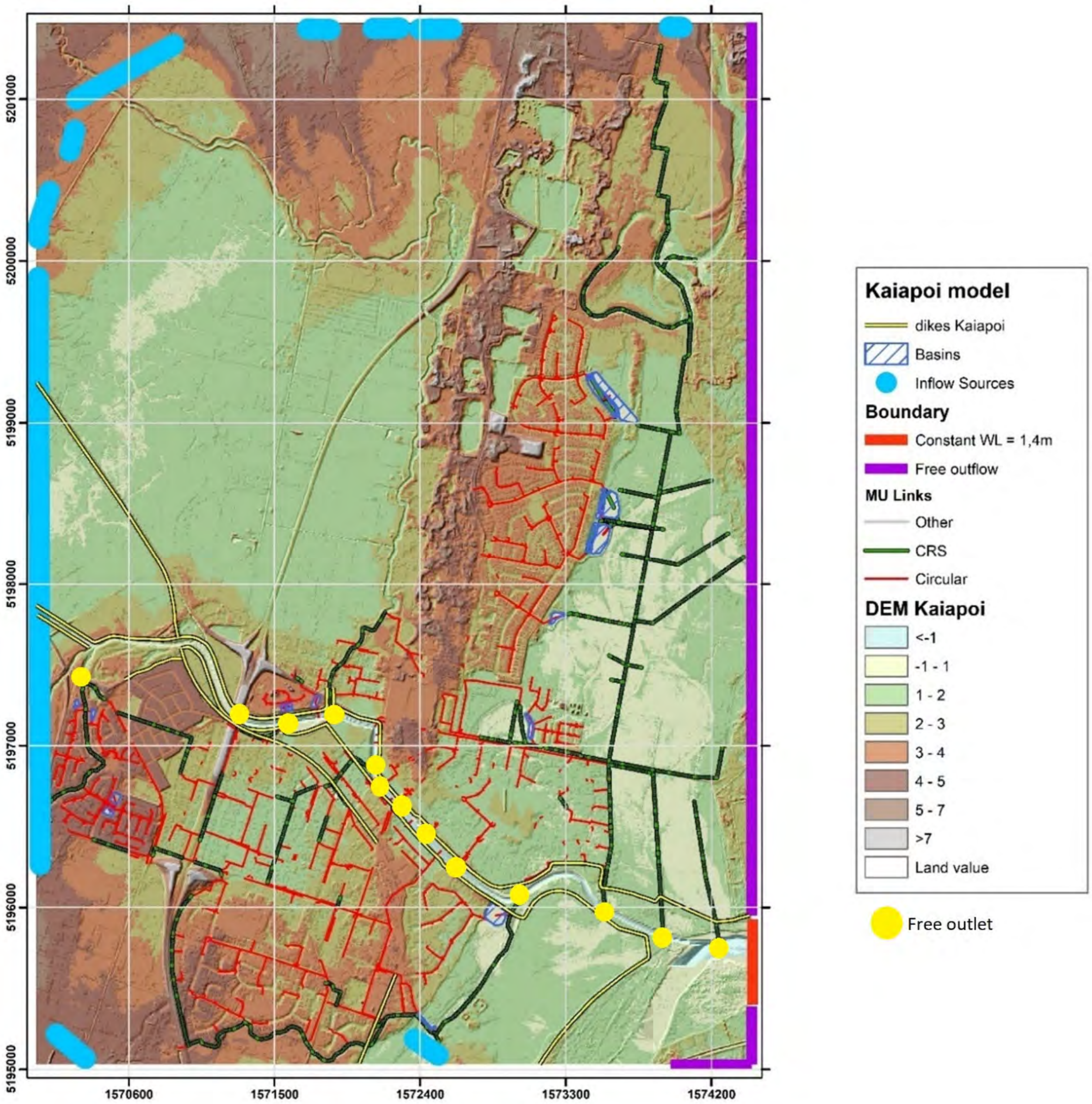

Figure 4-3: Kaiapoi Model

Two areas were specifically modified in the Kaiapoi model to improve the model stability. The first is at the Cridland pump station, Figure 4-4, two dummy nodes were added, and the sealed manhole at N1645 had the ground level increased from 2.5m RL to 5m RL. This helped to improve the stability, especially when inflows from the district model were include into the model as these inflows contributed to significant flooding in the area.

The second area was between nodes 0257 and 0284 near Adderly terrace, Figure 4-5, this was originally a long reach of pipe that was becoming very unstable. This was fixed by including a number of dummy nodes (with default losses) between 0257 and 0284. This improved the stability but the model may be overestimating the head losses in this area.

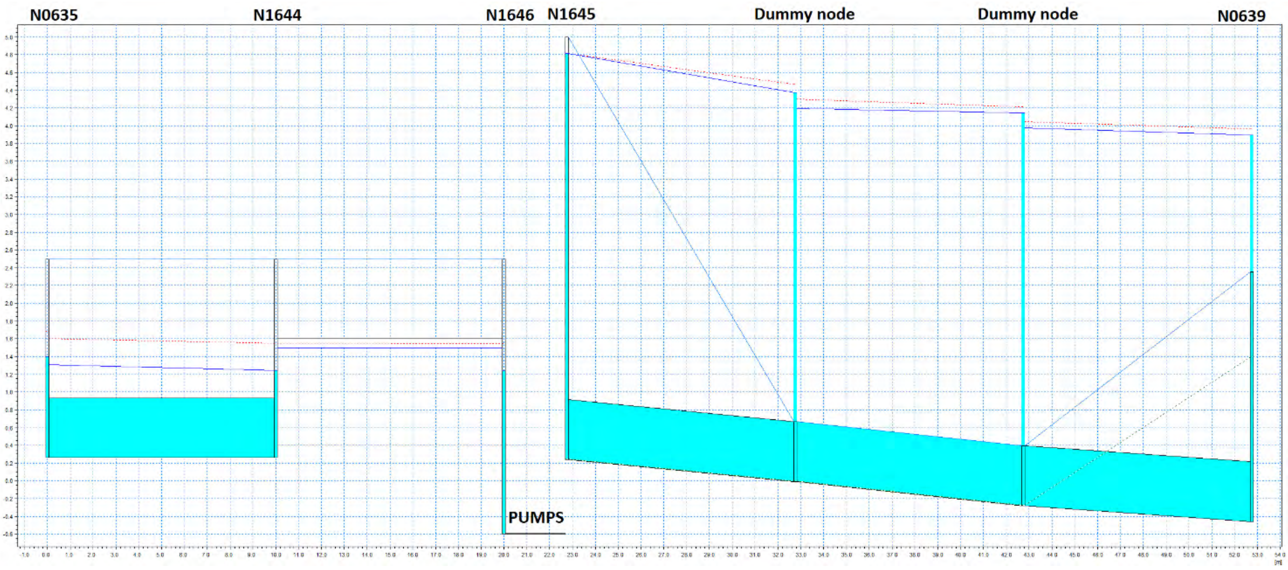

Figure 4-4: Cridland pump station

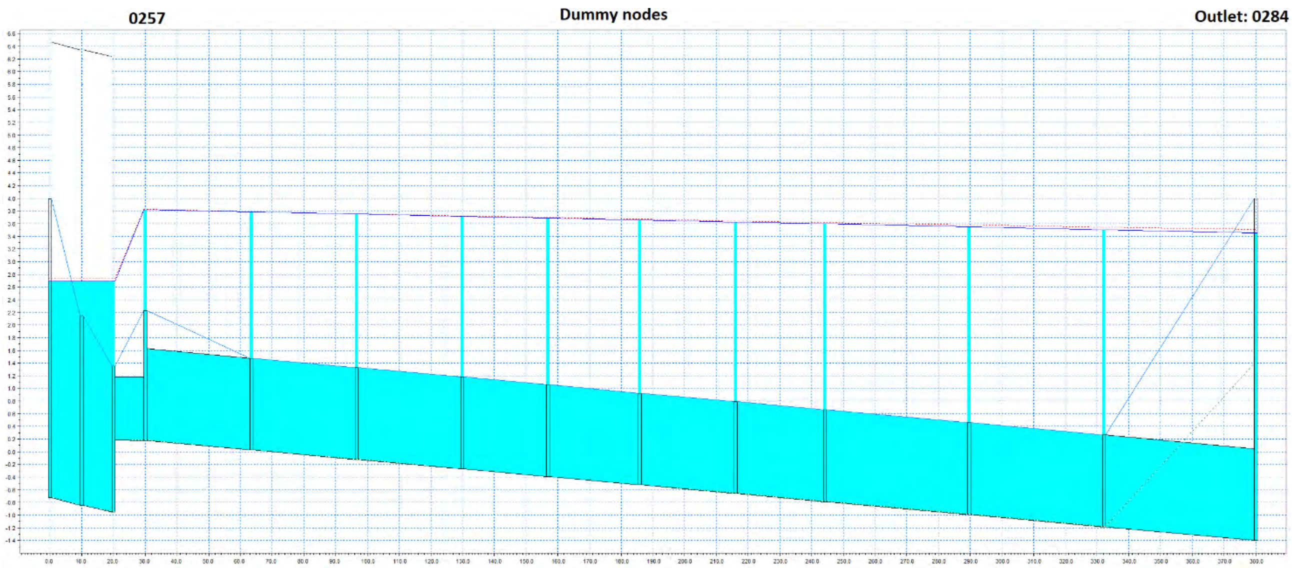

Figure 4-5: Pipe near Adderley Terrace to the East of SH1

Table 4-4 lists all of the basins modelled in the Kaiapoi model and their sizes. For some of the basins the data available was sparse, so best efforts have been made to represent reality, using the existing model data, aerial photography and DEM levels. In general where the location of the incoming pipes to a basin have been kept as they were in the original MIKE URBAN models provided by WDC. This means that in some locations the inlet and outlet to the basin is modelled via spilling from the original location of the basin node itself into MIKE 21. However, this basin node has now been converted into a manhole with a minor volume. The location of these inlet and outlet pipes, orifices and weirs may differ in reality however the volume into and out of the basins should still be correct. These could be improved further with more information on the basin design.

Table 4-4: Kaiapoi Basins

BASIN	Model	X (m)	Y (m)	Invert level (m)	Area (m^2)
Courtenay Stormwater Pond	Mike 21FM	1572865	5195952	0.30	11,990
Kaikanui Treatment Pond	Mike 21FM	1572423	5195294	0.50	1,471
Silverstream Pond A	Mike 21FM	1570275	5197243	1.90	1,018
Silverstream Pond B	Mike 21FM	1570511	5196668	2.33	2,727
Silverstream Pond C	Mike 21FM	1570477	5196605	2.50	2,186
Silverstream Pond D	Mike 21FM	1570371	5197188	1.90	1,283
Hakarau05	MIKE URBAN	1571694	5197211	1.36	<500
Hakarau06	Mike 21FM	1571751	5197269	1.27	2,328
Hakarau03	MIKE URBAN	1571533	5197188	1.41	<500
Hakarau04	MIKE URBAN	1571609	5197199	1.90	<500
Hakarau02	Mike 21FM	1571551	5197235	1.31	1,253
Hakarau01	Mike 21FM	1571593	5197240	1.41	1,364
BeachGrove 1	Mike 21FM	1573097	5197108	0.00	3,661
Sovereign 7	Mike 21FM	1573592	5198372	0.80	13,439
Sovereign 6	Mike 21FM	1573489	5198375	0.71	3,223
Sovereign 5	Mike 21FM	1573420	5198191	-0.20	355
Sovereign 3	Mike 21FM	1573598	5198476	1.00	13,161
Sovereign 2	Mike 21FM	1573530	5198593	0.12	301
Sovereign 1	Mike 21FM	1573507	5198445	0.71	2,364
Sovereign 11	Mike 21FM	1573561	5199162	0.90	19,190
Sovereign 10	Mike 21FM	1573536	5199144	0.83	10,891
Sovereign 9	Mike 21FM	1573591	5199033	0.08	289
Sovereign 8	Mike 21FM	1573432	5199288	-0.34	387
Moorecroft	Mike 21FM	1573235	5197792	0.32	3,051

The model parameters for the Kaiapoi model are described in Table 4-5. Due to the input distribution of the source points the simulation time was increased to account for a large amount of flow arriving from the upstream district models as an inflow boundary. The minimum timestep was also reduced to help improve the model stability. This model takes the longest to run, partially due to the large area of flooding in the north east of the model domain. It may be possible to further refine this model to reduce the size by removing this area and adjusting the location of the discharge extraction from the district models.

Table 4-5: Kaiapoi model information

Parameter	Value
Maximum Timestep	1s
Minimum Timestep	1e-05s
Simulation period	56 hours
Average Simulation elapsed time (for each event)	26.5 hours

4.4 Woodend

The layout of the Woodend model is shown in Figure 4-6. Two locations were identified as overland flow paths from the district model, and these have been applied as source inflows as indicated by the blue lines in the figure.

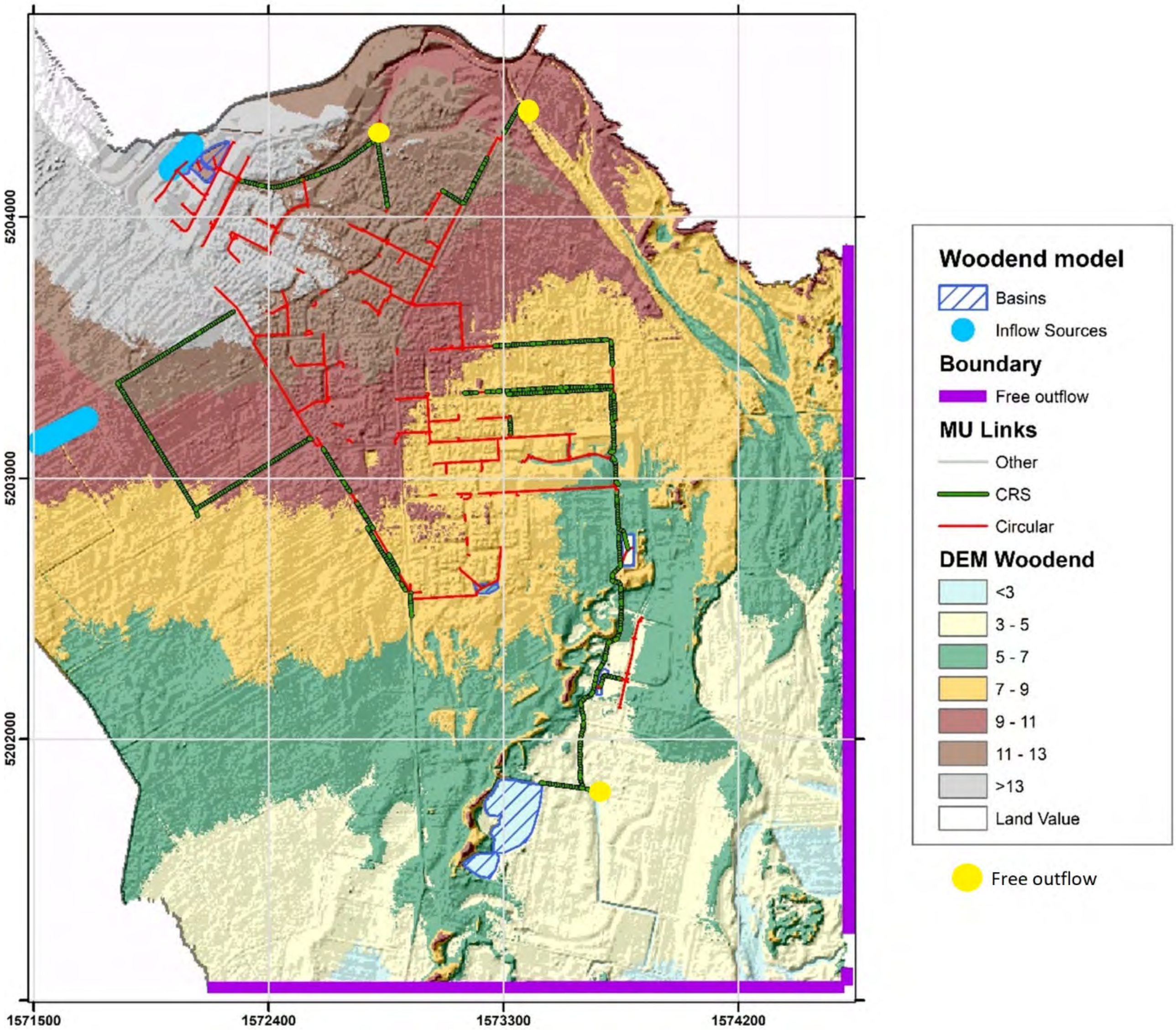

Figure 4-6: Woodend Model

Table 4-6 lists all of the basins modelled in the Woodend model and their sizes. In general, where the location of the incoming pipes to a basin have been kept as they were in the original MIKE URBAN models provided by WDC. This means that in some locations the inlet and outlet to the basin is modelled via spilling from the original location of the basin node itself into MIKE 21. However this basin node has now been converted into a manhole with a minor volume. The location of these inlet and outlet pipes, orifices and weirs may differ in reality, however the volume into and out of the basins should still be correct. These could be improved further with more information on the basin design.

Table 4-6: Woodend Basins

BASIN	Model	X (m)	Y (m)	Invert level (m)	Area (m^2)
Archers Forebay	MIKE URBAN	1573443	5201832	2.45	<500
Archers Splitter	MIKE URBAN	1573605	5201811	2.20	<500
Archers Pond 1 (Large)	Mike 21FM	1573443	5201825	0.00	51,433
Petries 1	Mike 21FM	1573775	5202730	2.00	5,234
Judsons Rd Detention basin	Mike 21FM	1573216	5202575	5.50	2,738
CooperBeech01	Mike 21FM	1573668	5202199	3.61	1,568
Ravenswood 01	Mike 21FM	1572086	5204210	12.00	4,184
Ravenswood 02	Mike 21FM	1572188	5204228	12.00	6,256
Ravenswood 03	Mike 21FM	1572140	5204177	11.81	4,071

The model parameters are described in Table 4-7. Due to the input of the source points the simulation time was increased to account for flow arriving from the upstream district models.

Table 4-7: Woodend model information

Parameter	Value
Maximum Timestep	1s
Minimum Timestep	0.001s
Simulation duration	56 hours
Simulation elapsed time (for each event)	3.7 hours

4.5 Oxford

The Oxford model is a standalone catchment and thus does not use any inputs from the district models, unlike the other townships modelled. The location of the urban model and outflow boundaries are shown in Figure 4-7. The model mainly consists of open channels with some smaller sections of pipe network. The model only has two basins which are described in Table 4-8.

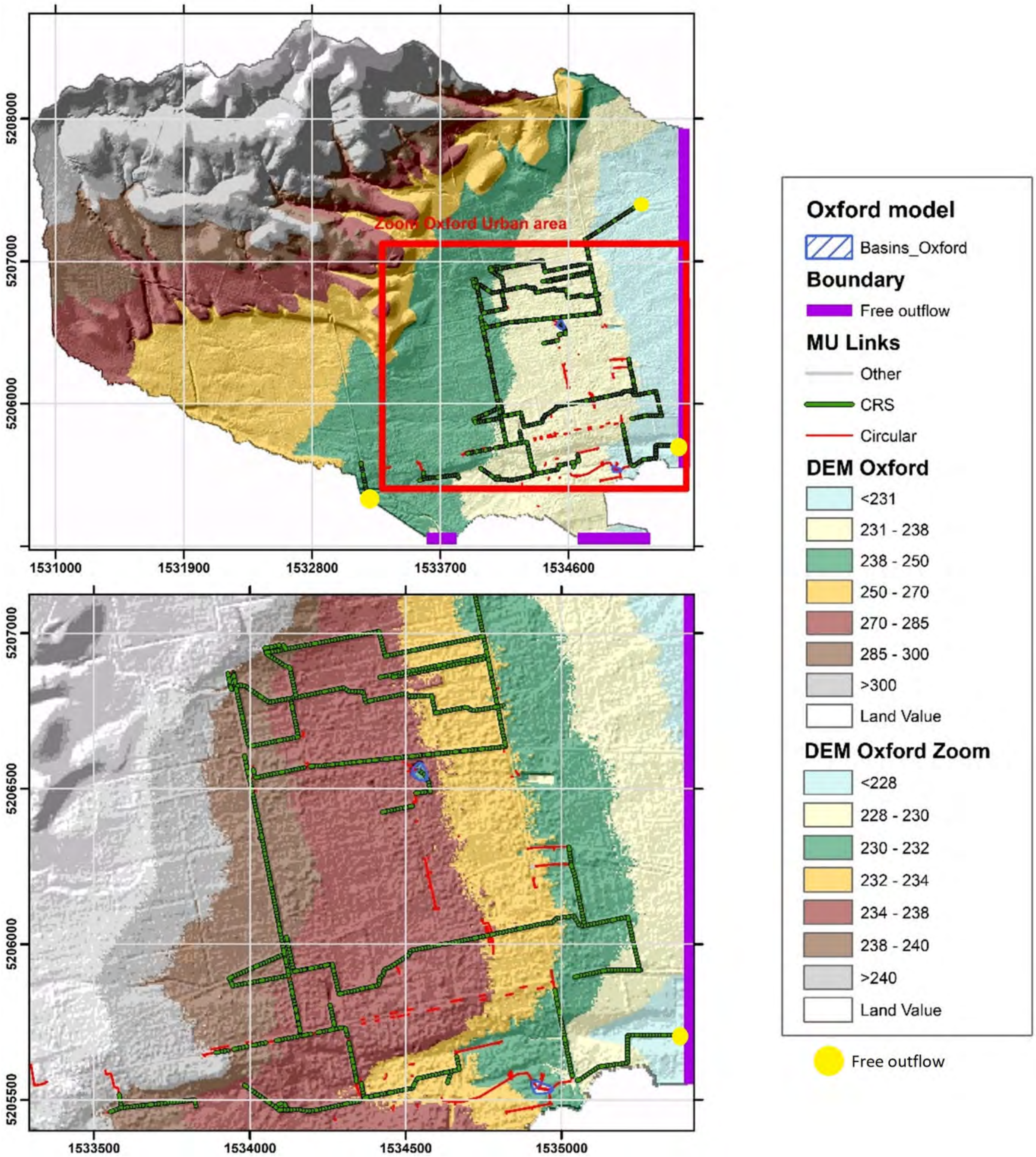

Figure 4-7: Oxford model

The Oxford model only has two basins these have been setup in a similar manner as for the other models. The basin details are outlined in Table 4-8.

Table 4-8: Oxford Basins

BASIN	Model	X (m)	Y (m)	Invert level (m)	Area (m^2)
Church Street	Mike 21FM	1534545	5206553	230.72	2,057
Weka Street	Mike 21FM	1534933	5205538	228.72	1,880

The model parameters are described in Table 4-9. The Oxford model uses a smaller minimum timestep from the other models to improve the stability in the steep areas of the 2D model.

Table 4-9: Oxford model information

Parameter	Value
Maximum Timestep	1s
Minimum Timestep	1e-05s
Simulation duration	29 hours
Simulation elapsed time (for each event)	4.0 hours

5 Conclusions

5.1 Model Results

The volume error in both the MIKE 21 district models and the MIKE URBAN Flood models is calculated to be less than 1% which is consistent with the use of the flexible mesh explicit engine. Some areas of the model do exhibit higher than normal velocities which indicate some model instability if not significant water generation. The high velocities are generally localised in the hill catchment which is not an area of interest. Elsewhere high velocities are localised to a handful of elements and are not considered significant.

The results in general appear sensible. When observing the urban model results it is noted that a double peak is observed in some areas of the catchment. This double peak occurs due to secondary flow arriving from the source inflows extracted from the district models. This is most notable in the Kaiapoi model where the model area is at the downstream end of the larger South Ashley catchment.

When comparing the urban models with the district models in the same area we are seeing similar results in general, however it is noted that in the Oxford Model there is a reasonable difference in water level at the downstream end of the model. It is believed this discrepancy is caused by differences in conveyance of flow between the two models. The district model has a larger element size and thus it is more likely that smaller drainage paths would be missed or smoothed out in this terrain, while the urban models have a higher resolution mesh including stormwater infrastructure to allow for water to flow downstream more readily. This issue highlights the sensitivity of the models to drainage pathways, highlighting the need for using the more detailed urban models to represent flooding in the urban centres of the Waimakariri District.

Earlier modelling was showing that high runoff from the hill catchment, which then enters the Ashley River, appeared to be exacerbating the Ashley River overflows, to avoid potentially overestimating the flooding in the lower North Ashley catchment these flows were prevented by including a higher stopbank.

5.2 Benefit of modelling to WDC

The model upgrades have included the following improvements that are considered to improve the accuracy and robustness of the model.

- Updating the terrain to include all major developments in the region, allows for improved accuracy in these areas.
- Updating the district model mesh to use smaller elements in areas of interest such as around roads, streams, and urban areas allows for a more accurate representation of the flow paths and restrictions. Using larger elements in the rural and hillside area allowed for improved stability when calculating the hill runoff and an overall smaller number of mesh elements.
- Update to the rainfall to utilise HIRDS v4, using the most up to date predictions of rainfall from NIWA.
- Update to the infiltration module. Although it is acknowledged that the hill runoff may be overestimating, the previous model was predicting almost zero runoff from the hills which was not realistic. Using a more robust methodology based on the more detailed and physically based processes in MIKE SHE will give more confidence in the model parameters for infiltration.

- Using the new long culvert feature in MIKE 21 allowed for more flexibility in defining the culvert inlet and outlet locations, and the ability to save the culvert discharge as a result was useful in ensuring that these were producing stable results. Previously the save option was not available so it could not be confirmed that the culvert discharges were sensible.

- Various improvements made to the natural channel definition in the MIKE URBAN models allowed for reduced double counting of flows (caused due to large manholes), and significantly improved detail added to where the channels can spill to the 2D domain. Changed from over 100m intervals to 10m.

- The improved flooding and dying module in the MIKE 21 2019 release, used for this modelling, allows for improved handling of small depth overland flow which occurs in rain on grid models such as this. These improvements allow for using smaller mesh elements while maintaining improved model stability and representation of shallow flow velocities.

- Addition of the source inflows from the district models into the urban models allows for the representation of the larger catchment while still representing the higher level of detail in the urban models.

5.3 Model Limitations

As will all models one of the main limitations of this modelling is the data availability, especially with regard to calibration data and the length of any data records that are available. The following is a list of limitations that DHI have identified in the modelling.

- Lack of calibration data and short records limit the ability to calibrate the models, and to estimate the flood frequency to a high level of accuracy.
- As identified when comparing the urban models to the district models the model mesh size does impact on the conveyance of flow through the catchment. As such the results from the district models should be considered as a lower level of accuracy than the urban models.
- In areas where new development terrain data was not complete or did not tie in well with the existing terrain there are some discontinuities in the model results. One of these areas is the Ravenswood development. Results in these areas should be assessed with care and an understanding of the underlying terrain used to build the model.
- Sump, manhole and pipe data was not surveyed as part of this upgrade and it is assumed that the data provided by WDC is correct, however there is the possibility that data was missing, especially for stormwater inlets, this may impact on the amount of water able to enter the stormwater network, and connecting basins.

5.4 Future Improvements

The following is a list of recommended future improvements for the models:

- Sensitivity testing could be performed to assess the impact of key parameters on the model results. Including roughness, infiltration and rainfall. The aim of the sensitivity testing would be to build a better understanding of any uncertainty in the model parameters especially given the lack of calibration data.
- Given that there is a rated water level recorder available at Fox Creek on the Okuku River, calibration to a larger event could be undertaken to give more confidence in the hill catchment infiltration rates.
- When new LiDAR survey data becomes available this should be incorporated into the model domain.
- Update pipe networks and terrain data for new developments as they are built and data becomes available to ensure the models are always up to date.
- The models could be used to derive the Ashley flows along with breakout modelling. In this case the two models could potentially be merged and the upper Ashley catchment included.
- Refine roughness used on the Ashley River berms, with reference to ECAN work and possible calibration.
- Make use of the upcoming MIKE 21 feature of depth varying roughness to improve the stability of hillside runoff.

6 References

ECAN (2011) *Review of Flood Frequency in the Canterbury region.* Prepared by NIWA.

Durney P (2019). University of Canterbury. *Quantification of the probable environmental effects of the Hinds Managed Aquifer Recharge trial using mathematical modelling and advanced uncertainty techniques.*

WDC (2015). *WAIMAKARIRI DISTRICT Localised Flood Hazard Assessment 2015*. Waimakariri District Council Report No. DRA-20-10.

APPENDICES

APPENDIX A

Derivation of the Waimakariri Soil Infiltration Layer

MEMO

To: Waimakariri District Council

Cc: Antoinette Tan

From: Patrick Durney; Antoinette Tan

Date: 25/03/2020

Subject: Generation of soil infiltration layers

DHI developed an infiltration layer data set for Waimakariri District Council for use in their flood models. This data set is designed to provide an estimate of the initial soil saturation, initial infiltration rates, and final infiltration rates. The original memo was provided to WDC on the 30/08/3019 and has subsequently been updated on the 25/03/2020 based on comments from the model reviewer.

Specifically, the deliverables for this project are:

- Initial infiltration rate
- Final infiltration rate
- Initial saturation
- Porosity
- Depth of soil layer (assumed in this study to be uniformly 1 m[1]).

Data for this project have been sourced from:

- Waimakariri District Council - Landuse, roads, buildings, DEM
- Canterbury Maps – Environment Canterbury soils classification
- LRIS - soils polygons
- NIWA CliFlo - Precipitation and PET
- Durney (2019), Durney et al. (2014), and Durney et al. (2019) - soil properties, e.g. hydraulic conductivity and porosity.

1 MIKE SHE model components used in layer generation

The modelling platform utilised for the generation of the infiltration layers is MIKE SHE, which is an integrated modelling package that allows simulation of the terrestrial water cycle components. In this instance, we modelled overland flow and simplified unsaturated flow.

1.1 Overland flow

Overland flow was simulated by a diffusive wave approximation and was used to prevent ponding of water in areas that should not have standing water due to topography and ability for surface flow to occur. If ponding occurred in these areas, the soil water balance would be incorrect and lead to erroneous estimates of average soil saturation. In the model, if precipitation is at a rate that exceeds

[1] All other soil parameters are calibrated around the soil depth.

soil infiltration capacity as well as potential for evaporation, then overland flow is considered to have occurred. Once overland flow has occurred, the water is routed down gradient on grid cell by grid cell basis until it is either infiltrated or exited a model boundary.

1.2 Unsaturated flow

Unsaturated flow modelling used a simplified two-layer soil moisture balance approach to represent the unsaturated zone. One layer represented the processes within the plant root profile, and the other layer represented the processes occurring at greater depth. Flow through, and moisture content in the unsaturated profile is controlled by the soil's properties. Specifically: porosity, wilting point, field capacity and saturated hydraulic conductivity. These properties were taken from Durney (2019).

1.3 Model domain and grid resolution

The model infiltration layer extent is shown inFigure 1-1. This extent is based on permeable soils on slopes less than 15 degrees, beyond which overland flow is likely to dominate infiltration potential. The model was discretised on a 50 m by 50 m finite-difference grid. Once the datasets were generated, they were reprocessed to 10 m by 10 m. The original coarser-resolution was used to both aid in computational efficiency and to give respect to the accuracy of the input layers, often sourced from 250,000 scale maps. The grid was resampled to the 10x10 size to allow for integration of more detailed impervious features such as roads and buildings, and to align with the MIKE 21 model mesh size.

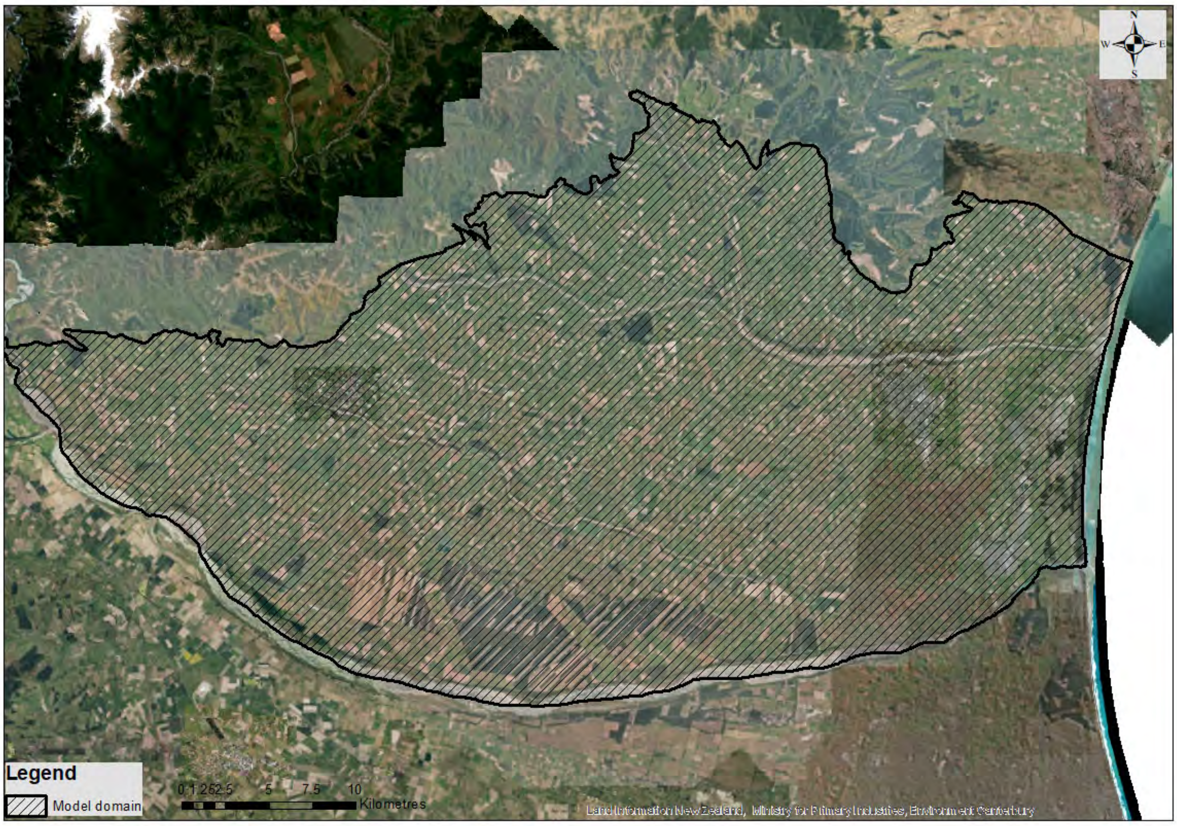

Figure 1-1 Model domain

1.4 Climate

Climate data were sourced from NIWA's CliFlo database. Four precipitation and Potential Evapotranspiration (PET) stations were used (Table 1-1). Climate data spanned 24 years (1991 to 2015). Gaps in the climate record for a given station were filled by correlation with the nearest station with data. PET was mapped to the model by Thiessen polygons, while precipitation data were mapped to the model using a temporally and spatially varying grid file. Precipitation was interpolated between the climate stations using the inverse distance weight method. The simpler spatial definition for the PET was used because the low spatial variability, in the PET, did not warrant a more detailed method here.

This study tried to utilise a full IPO cycle to enable estimation of long-term soil moisture content. However, data limitations meant the simulation had to be limited to 24 years. This should be sufficient to account for most climate variability

Table 1-1 Climate stations

Precipitation station ID	Potential evapotranspiration station ID
4809	4836
4836	4843
4843	17244
11601	39224

1.5 Soils

The soils layer used in the model is shown inFigure 1-2. This layer was generated from three files downloaded from the LRIS Portal and merged to replicate the soil classifications used by Environment Canterbury (ECAN). Soil properties from Durney (2019), Durney et al. (2014), Durney et al. (2019) and Thorley and Ettema (2007) have been used populate the model.

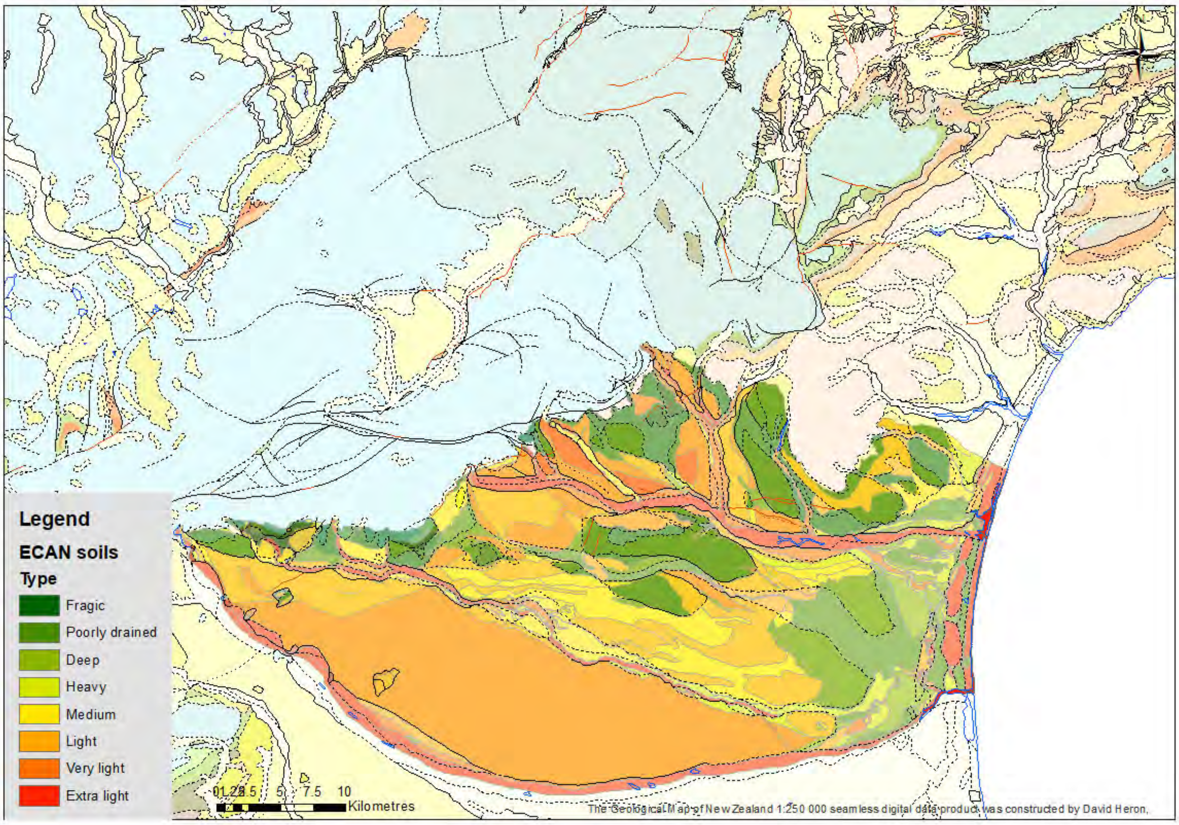

Figure 1-2 Amalgamated soils layers to replicate ECAN soil types

Eight soil types were mapped in the area of interest. However, due to lack of calibration data, only six were modelled, these being extra light, very light, light, medium, heavy and fragic. Deep, poorly drained and heavy soils were merged into a single “heavy” class. While not usually considered a class in and of itself, fragic soils are important to model as they are generally low permeability. While water may infiltrate initially, the hardpan layers that define fragic soils generally prevent significant infiltration. In line with studies by Thorley et al. 2008 and Durney et al. 2019, we adopted a maximum infiltration rate of 3mm/day on the fragic soils.

Soil initial infiltration rate is influenced by several factors, such as initial moisture content, porosity, field capacity and wilting point; these values have been derived through calibration (Durney 2019). The final infiltration rate is controlled by the saturated hydraulic conductivity, which is the maximum rate at which the saturated soil can infiltrate water. In this instance, saturated hydraulic conductivity is likewise derived through calibration (Durney 2019).

MIKE FLOOD uses a simplified infiltration model dependent on initial moisture content, porosity, infiltration rate and leakage (saturated hydraulic conductivity). MIKE Flood (M21 FM) porosity is MIKE SHE effective porosity. Effective porosity is the difference between total porosity and the soil water content at field capacity. Field capacity is the water content when free drainage under gravity ceases. Using effective porosity and the other data created from MIKE SHE in the MIKE 21 FM model generates approximately the same infiltration as produced by MIKE SHE, giving confidence the layers perform well (Figure 1-3toFigure 1-5). This confirms that the MIKE 21 model will be able to mimic the behaviour of the MIKE SHE model to a reasonable degree.

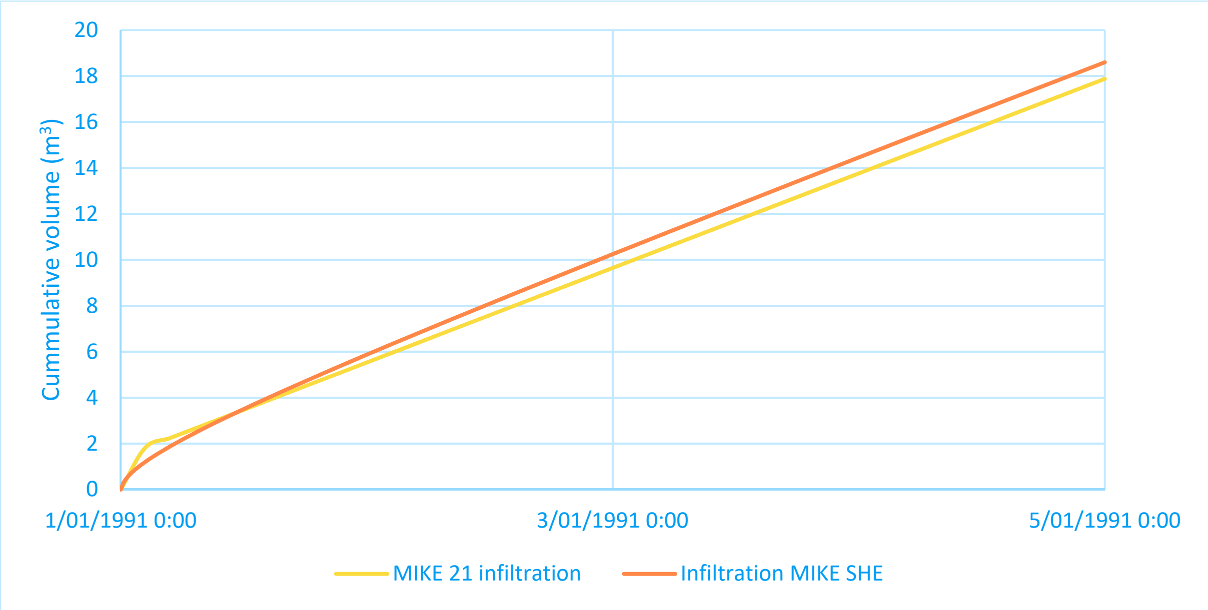

Figure 1-3 Infiltration under heavy soils

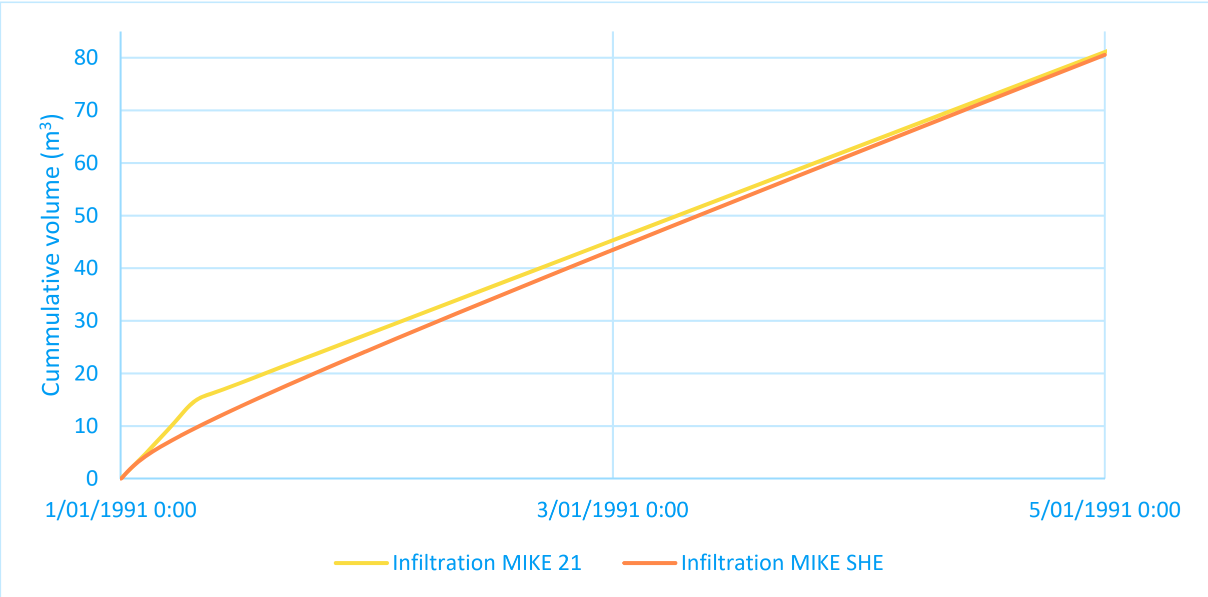

Figure 1-4 Infiltration under extra light soils

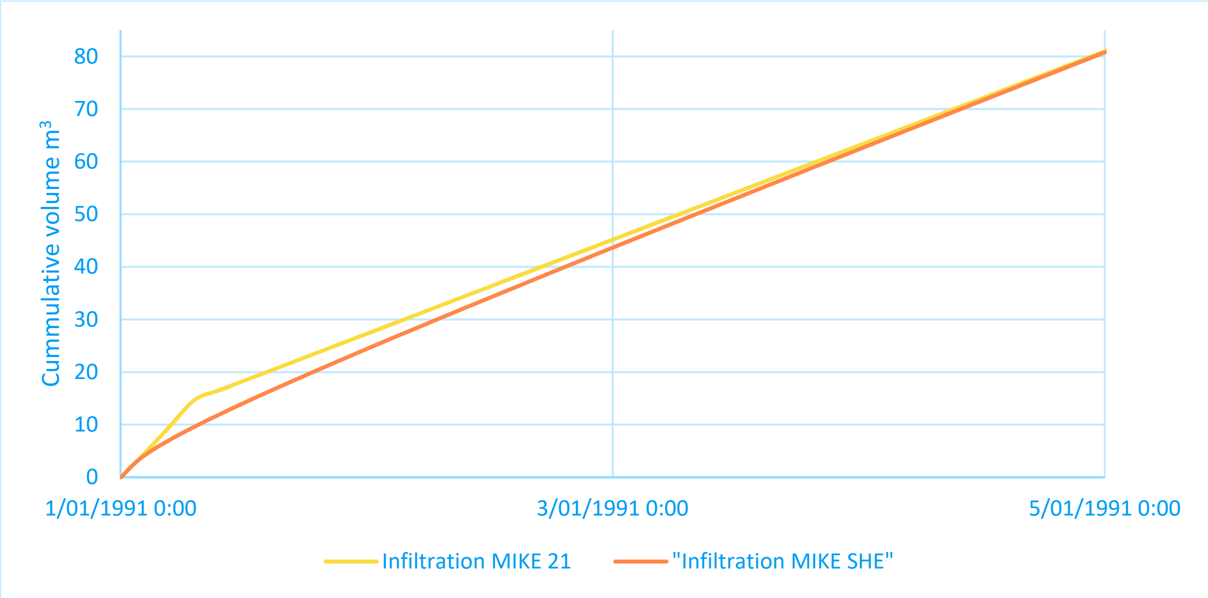

Figure 1-5 Infiltration under very light soils

1.6 Irrigation

Irrigation was included in the model set-up to ensure that the average moisture content in the soil profile was accurately represented. A shapefile of irrigated area was downloaded from Canterbury Maps and applied to the model (Figure 1-6). Inside this area, irrigation was allowed when the soil moisture content dropped below a specified interval; irrigation starts when the soil moisture content drops below 0.4 Field Capacity and stops at 0.39 Field capacity (Durney 2019). This broadly replicates Good Management Practice as per Environment Canterbury's Land and Water Plan change 5. Irrigation was specified to be from an external source and allowed to occur between September and May of each year. Irrigation was allowed to occur at a maximum rate of 0.6 L/s/ha.

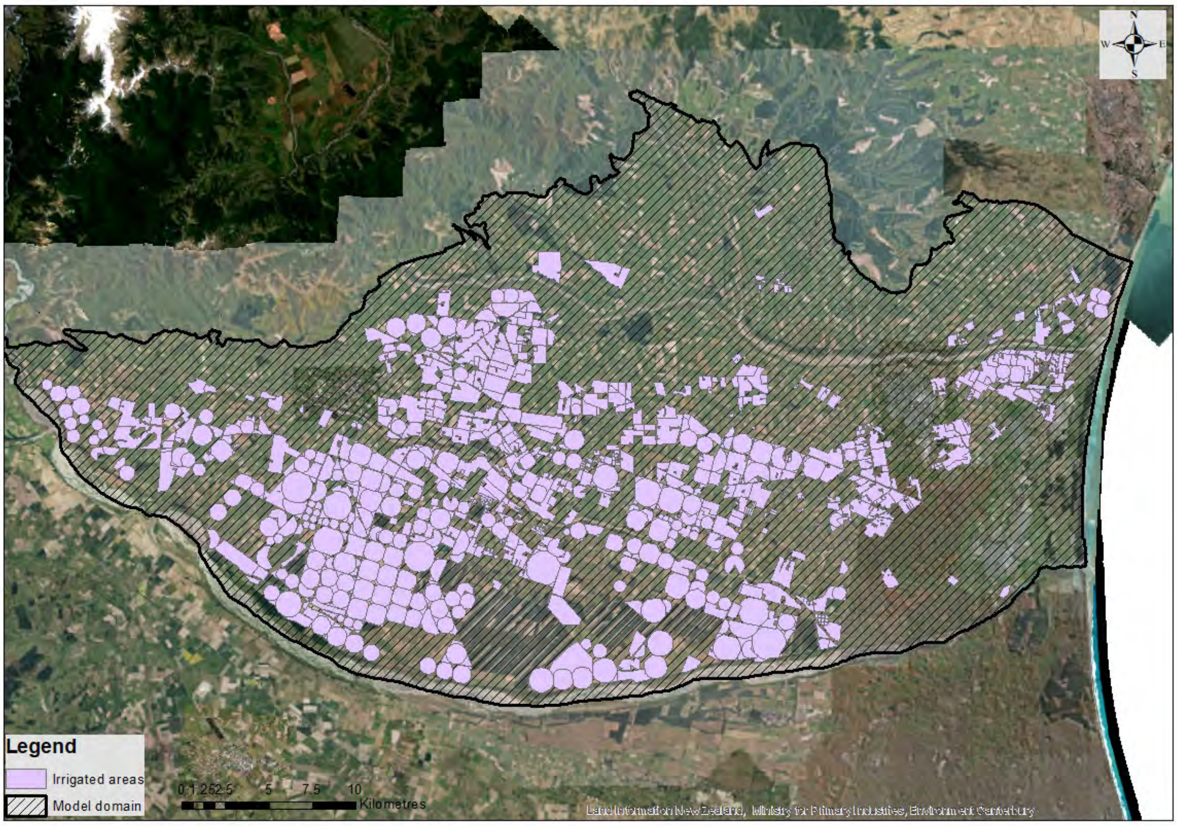

Figure 1-6 Irrigated areas

1.7 Roads and built-up areas

Roads and built-up areas reduce infiltration potential compared to rural land. These features were included in the infiltration layer to reduce both the initial and final infiltration rates where appropriate. WDC provided shapefiles of roads, buildings and building zone classifications. These were used to modify the infiltration capacity of the soils inside their footprints to best represent on-ground infiltration capacities.

The road shapefile was in the form of a road centreline polyline. The polyline was buffered either side by 5 m. Areas inside the buffer were set to zero infiltration. The building footprint shapefile was used to specify further impervious surfaces; areas inside the footprints were set to impervious. Residential areas had their imperviousness set to 50%, while in "Business areas" the imperviousness was set to 90% as per WDC (2015).

1.8 Areas outside the extent of the model domain

There are several areas included in WDC models that lie outside the extent of the model domain. One such area is along the Waimakariri River. This was not included in the model domain as no soil layers existed for this area. The model layers have been extended into this area by applying the extra light soil properties and linear interpolation of the nearest extra light soil initial saturation.

There is an area further to the north and west that is beyond the model domain. In these areas, the topography is steep and geology suggestive of basement rocks (Figure 1-7). In these areas, the soil initial and final infiltration rate has been set to 2 mm per hour rather than impervious in recognition that some soils will be present in these areas, allowing infiltration. This soil infiltration rate is considered a nominal value compared to the 20.8 mm for extra/very/light soils, and because it occurs in areas of high topography, it is unlikely to negatively impact overland flow estimates.

Review of the available geological maps (QMap) revealed that these areas were largely Torlesse greywacke basement, unlike the areas covered by SMAP. Were it not part of the WDC model domain we would not consider it appropriate to produce a soil infiltration model for these areas. Even if fundamental soils layers are available they are generally very shallow and overly hard rock basement. As such most of this area is not considered to be classes as soil, given the generally very low porosity and hydraulic conductivity of graywacke it did not seem appropriate to apply a higher infiltration capacity as this would likely unrealistically underestimate overland flow from these areas. If a check was required for these assumptions, a rainfall run-off model of a similar gauged catchment could be produced to compare the equivalent streamflow generated.

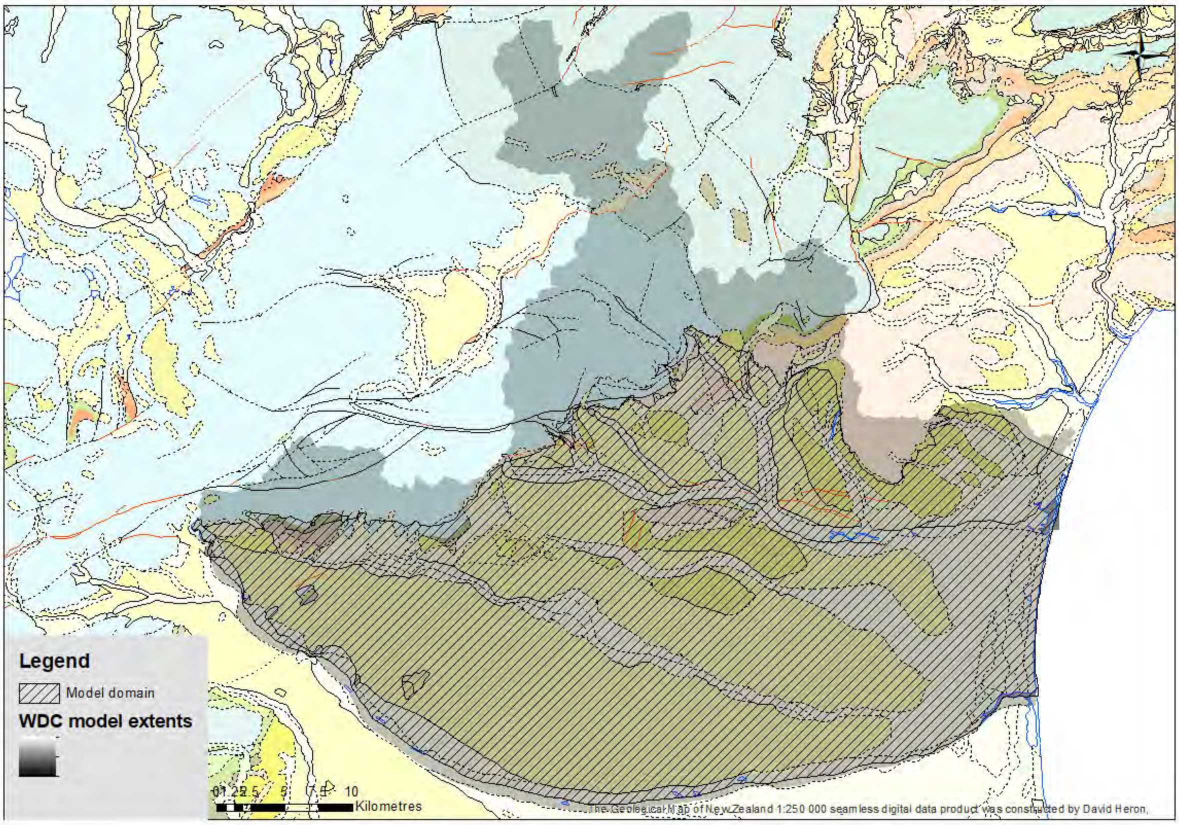

Figure 1-7 Model domain and WDC model extents overlaying geological map

1.9 Results

Results were generated as a 10 m by 10 m grid of infiltration rates, saturation percentage, and porosity. Depth was uniformly set to 1 m, and the soil properties calibrated to this value. Average properties are shown inTable 1-2.

Table 1-2 Soil infiltration layer statistics

	Mean	Standard deviation	Range
Initial infiltration rate (mm/hr)	3.8	3.3	0-7.50-20.8

Final infiltration rate (mm/hr)	10.4	8.6	0-7.5
Initial saturation (%)	46.9	14.2	32-79
Porosity (effective)	0.168	0.07	0.07-0.24

By comparison, these infiltration values are lower than previously used by Waimakariri District Council for their division of five soil classes shown inFigure 1-8. Table 1-3 shows a comparison of the original WDC infiltration rates and porosity compared to the present modelling.

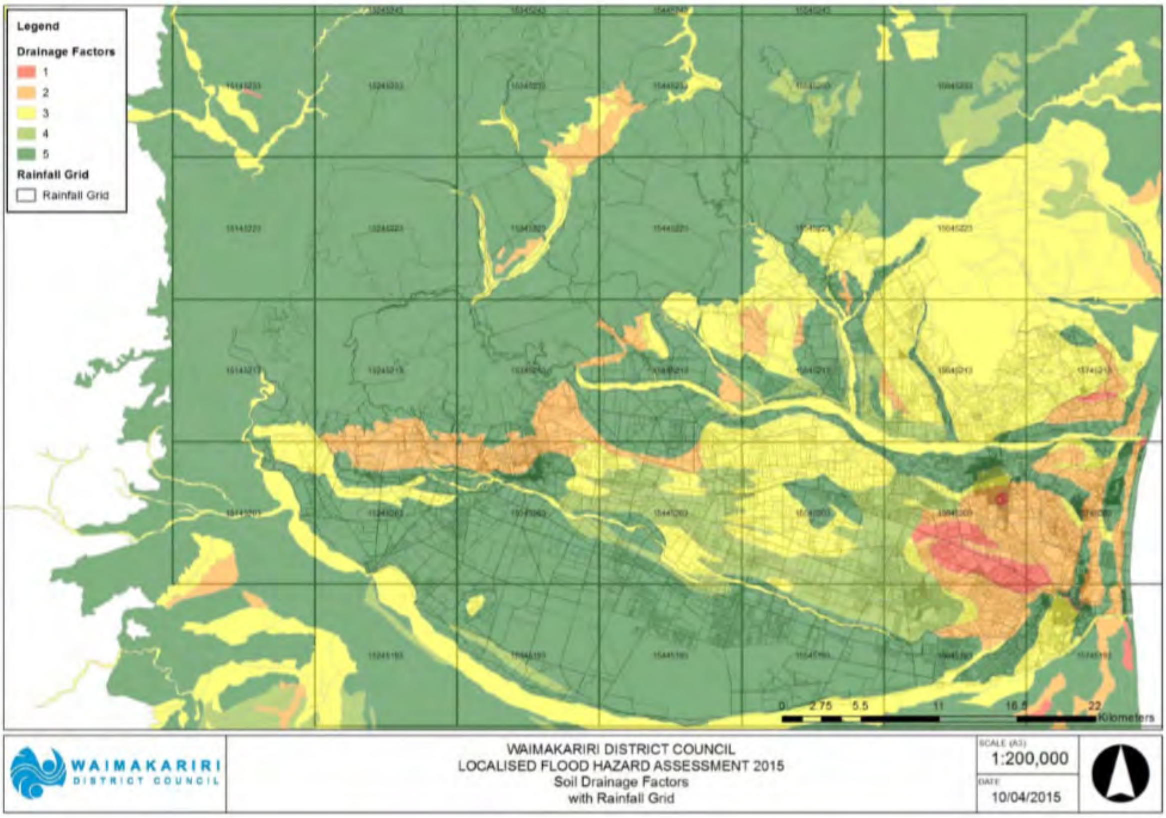

Figure 1-8 Waimakariri District Council soil infiltration classes from Project Delivery Unit Waimakariri District Council (2015)

Table 1-3 Soil infiltration properties from current modelling compared to Project Delivery Unit Waimakariri District Council (2015)

WDC drainage class	Storage Impervious Flat (m)	Porosity (effective)	Start infiltration pervious (mm/hr)	New model start infiltration pervious (mm/hr)	End infiltration pervious (mm/hr)	New model end infiltration pervious (mm/hr)
DRAINAGE 1	0.0015	0.06	1.50	20.60	0.45	1.67
DRAINAGE 2 (Covers 2 new classes)	0.0015	0.06 and 0.01	5.00	20.60 and 0.125	1.50	1.67 and 0.125
DRAINAGE3 (Covers 2 new classes)	0.0015	0.196 and 0.01	10.01	20.8 and 0.125	3.00	7.5 and 0.125
DRAINAGE 4 (Covers 3 new classes)	0.0015	0.21	24.98	20.5 to 8.6	7.49	7.46 to 1.67
DRAINAGE 5 (Covers 2 new classes)	0.0015	0.24	74.88	20.83 (2 mm inland over basement rock)	22.50	7.5 (0.75 mm inland)

Initial infiltration rates were estimated for the six modelled soil classes using a simple box model. A 3rd order polynomial relationship between saturated moisture content and infiltration rate was developed for each soil class. This relationship was then used to generate the initial infiltration rate at the average moisture content (Figure 1-9). The final infiltration rate is simply the calibrated saturated hydraulic conductivity of the soil class (Figure 1-10).

The initial average soil saturation was based on the average soil moisture content across the 24-year simulation. It is represented as a percentage (Figure 1-11). Porosity was estimated from textbook values for soil class (Tarboton 2003) and calibration of infiltration rate to lysimeters across the Canterbury region (Figure 1-12) (Durney 2019).

Comparing the infiltration rates to the original modelling significant changes are noted, however the new properties are based on calibration to dataset for Canterbury soils, and should be considered to be more robust for this reason. While there are limitations to the approach, as with any, this represents the best available data at the time of writing. The calibration detail is discussed in Appendix A of Durney 2019 available online from the University of Canterbury Library. It should also be noted that the initial infiltration rates are maximum potentials, that won't be achieved unless the soil is dry at the start of any simulation.

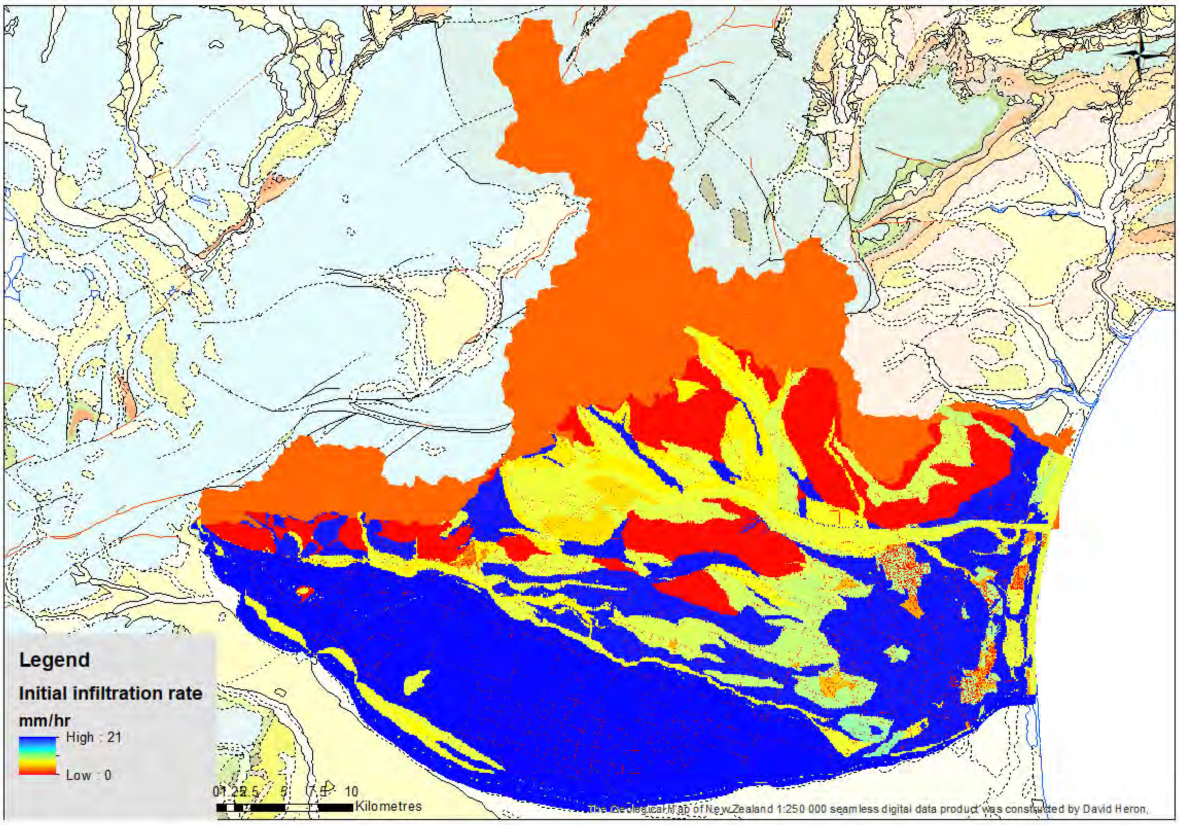

Figure 1-9 Initial infiltration rate

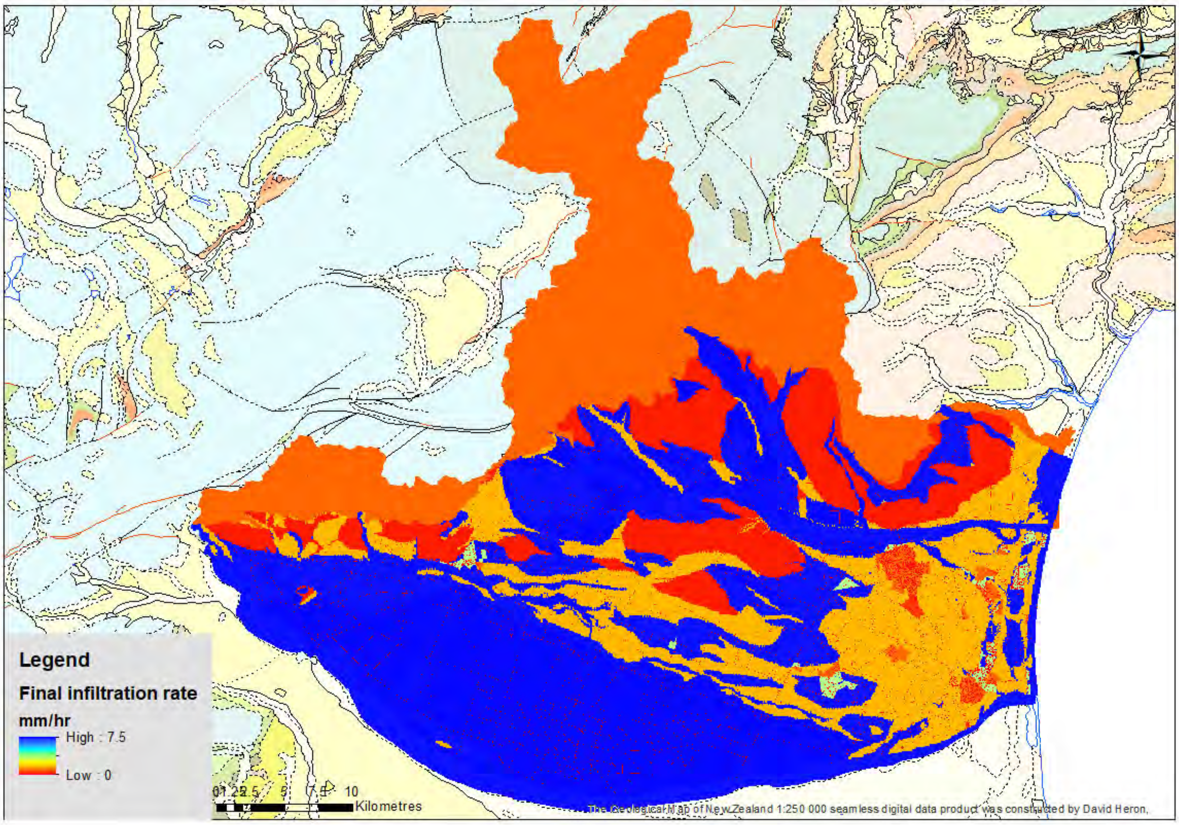

Figure 1-10 Final infiltration rate (saturated hydraulic conductivity)

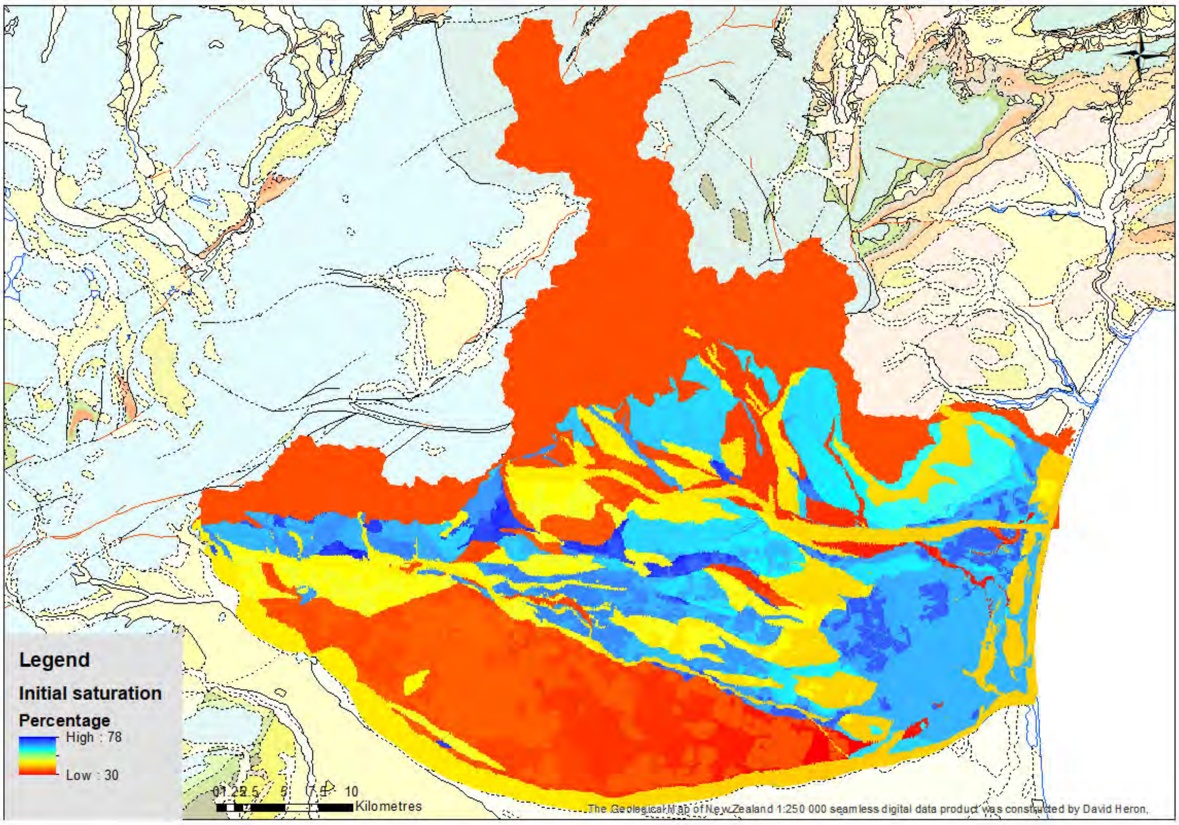

Figure 1-11 Initial average soil moisture

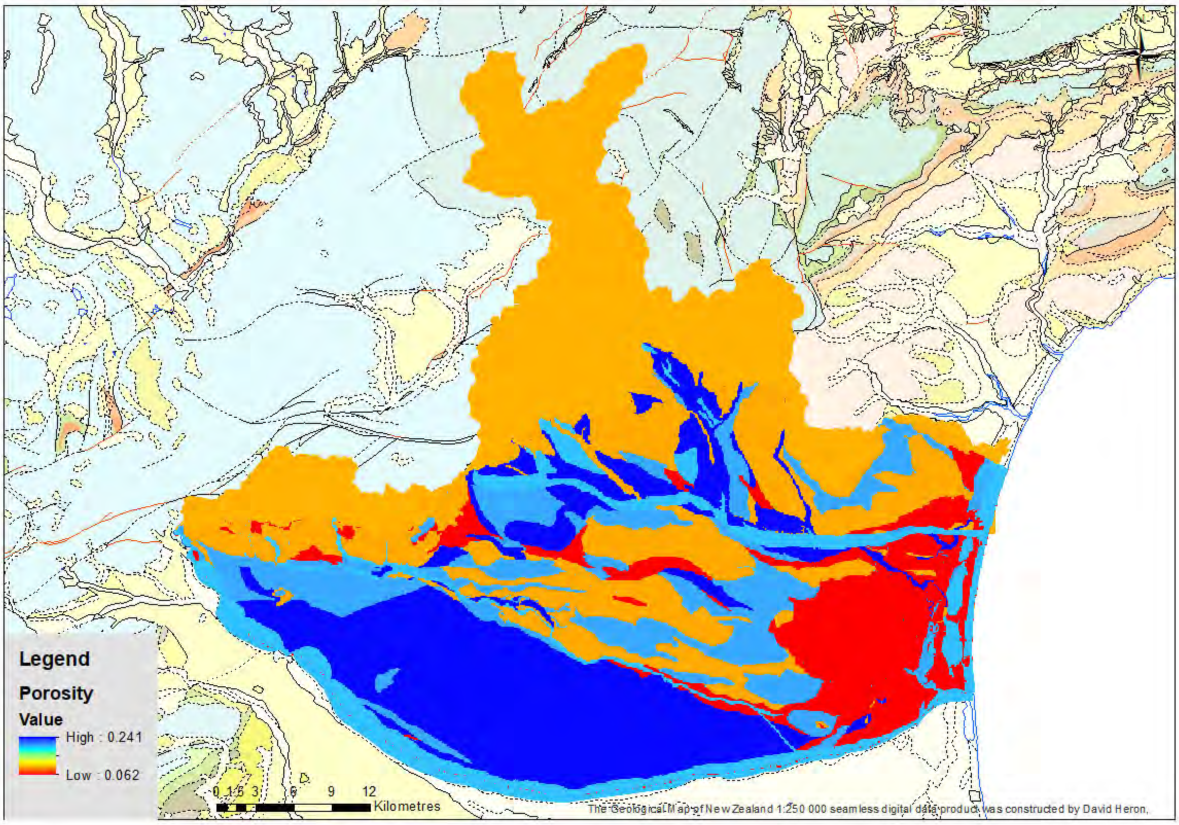

Figure 1-12 Soil porosity (effective)

2 References

Durney P (2019). Quantification of the probable environmental effects of the Hinds Managed Aquifer Recharge trial using mathematical modelling and advanced uncertainty techniques. Thesis submitted in partial fulfilment of Master of Water Resource Management. University of Canterbury.

Durney P, Calder-Steele N, Aitchison-Earl P, Dodson J (2019). OTOP Inland Basins Current State Model. Environment Canterbury

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Tarboton D (2003). Rainfall Runoff Processes. Civil and Environmental Engineering Faculty Publications. Paper 2570. https://digitalcommons.usu.edu/cee_facpub/2570

Thorley M, Ettema M (2007). Review of allocation limits for the South Canterbury downlands Environment Canterbury Unpublished Technical Report U07/09.

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APPENDIX B

Waimakariri Triangular Mesh Testing

MEMO

To: Chris Bacon

Cc: Andres Marin Munoz

From: Antoinette Tan

Date: 18/10/2019

Subject: Waimakariri triangular mesh testing

DHI have developed updated models of Waimakariri South Ashley basin to identify what benefits could be gained from using a triangular mesh versus the existing rectangular one. The triangular meshes were generated by specifying polygons around the main urban centres and specifying a maximum element area in these areas, for the rural areas a larger maximum element area was chosen. Four scenarios were run as part of this testing:

Name	Type	Actual minimum Element area	Specified maximum size for Rural	Specified maximum for Urban
Mesh1 – original	rectangular	144	144	144
Mesh2	triangular	0.6	225	25
Mesh3	triangular	25	225	81
Mesh4	rectangular	25	25	25

Data for this project has been sourced from Waimakariri District Council (WDC): Mike 21 FM model, spatially distributed rainfall, manning's values, processed DEM, Lidar 2005 and Lidar 2014. As this testing was done during the earlier stage of the project the input files do not reflect the latest updated DEM, rainfall and Manning's values, which will be updated in the next stage.

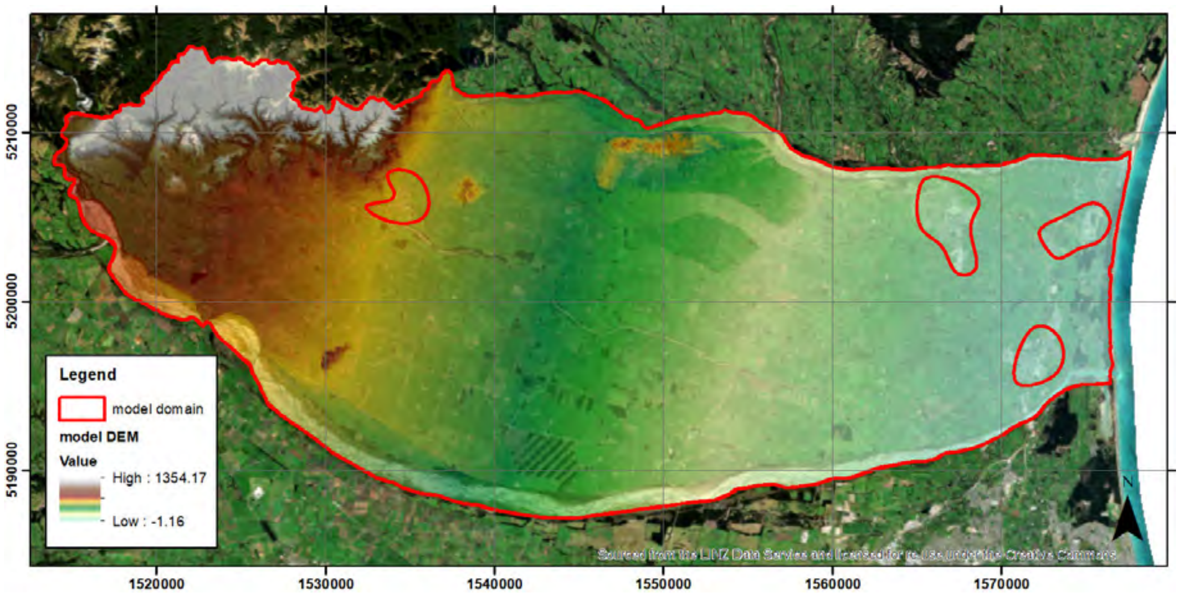


Figure 1. Mesh outline showing the South Ashley catchment and detailed urban areas

1 Processing the DEM

Because the final DEM was not available from WRC at the time of testing a DEM was generated by merging the exiting 12x12m model terrain with the higher resolution LiDAR grids, for the higher detail areas the main grid size used was a 5x5m grid.

The merged DEM covers the whole extent of the model. During the mesh generation, the DEM information was also extrapolated in the areas were spaces were created due to smoothing of the outer mesh extent and they could create failures in the meshing.

2 Model Scenarios

2.1 Original scenario

- Solution technique: Using the higher order solution with a minimum time step of 0.5 seconds, maximum timestep of 30 seconds and a CFL factor of 0.95.
- Flood and Dry: Using a drying depth of 0.001m and wetting depth of 0.003m.
- Resistance: Using the same manning's map provided by WDC without any changes
- Precipitation: the precipitation was provided by WDC in their original model and it was unchanged.
- Infiltration: At this stage the new infiltration settings developed by DHI were not included, however the infiltration was still accounted for in the rainfall.
- Boundary conditions: There are two openings in the south and north of Waimakariri basin discharging directly to the sea, they are set by default as 1m for both boundary conditions called Waimakariri and Ashley.
- Initial conditions: These were set constant at 0m RL.

2.2 Unstructured mesh scenarios

There were two unstructured mesh scenarios, the first scenario was a mesh defined with a maximum mesh size of 25m^2 in the urban areas while the second one had a maximum of 81m^2. Both models were run and the time until it reached completion was recorded and it is shown below in Figure 2. In the rural areas a maximum mesh size of 225m^2 was specified. It should be noted that when the mesh is generated the minimum element area can become much smaller than these values, this is why two tests were completed one that used a maximum element area of 25m^2 in the urban area while the other aimed for a minimum of 25m^2 in the urban area.

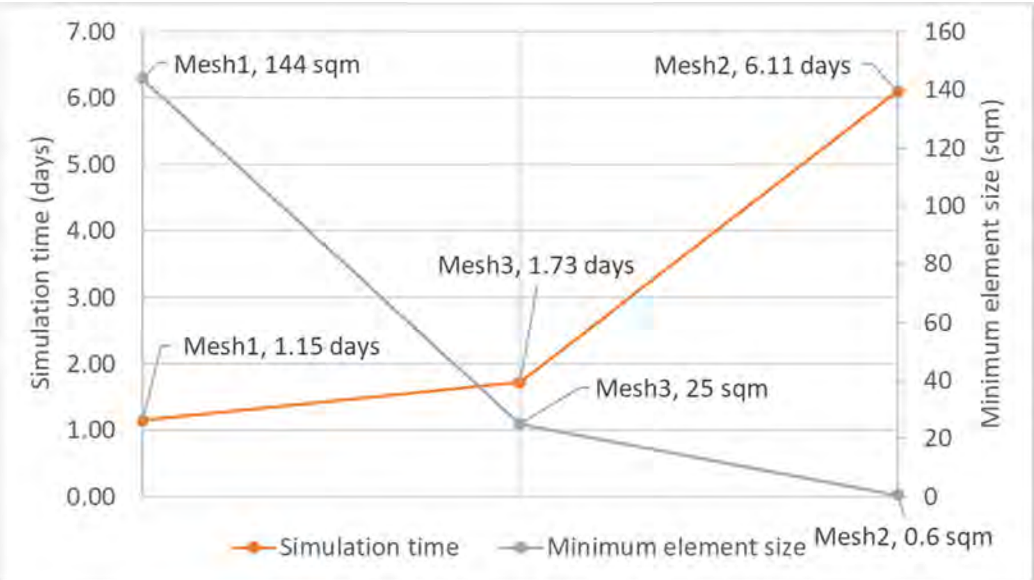


Figure 2. Mesh simulation comparison.

It was found that, even though the original Mesh1 was the most efficient in terms of simulation duration Mesh3 had a more optimal configuration with the time until completion only being 50% greater than for the original mesh, while still including a higher level of detail.

The worst case was found for Mesh2 as this took 6 times longer than the original mesh, this was caused mainly due to extremely small elements generated using the simple methodology. With more effort a mesh with more optimised elements would be able to be produced but at the moment this test serves the purpose of giving a high-end range to the anticipated runtime.

2.2.1 Mesh 2

This mesh was processed the model run under the same parameters of the original model. Time to completion was 6 days. This length of time may reduce the usefulness of the model.

2.2.2 Mesh 3

The mesh created under these conditions was reconverted to a 9x9m raster format to allow an easy visual comparison to see the differences between the two model DEM's. Some close up views were taken to be able to identify zones in which it is possible to see an improvement in the quality of the grid, especially in the urban areas, the differences are more noticeable in the areas with higher detail like the urban streets.

2.3 Structured mesh scenario

2.3.1 Mesh 4

A structured mesh of 5mx5m was created based on the base DEM created for all simulations but it didn't run as it required a large amount of RAM on the GPU cards which was impossible to achieve for the current DHI machines.

3 Results

Results show clearly an improvement in the definition of the flooded urban area with flow more localised to the main roads rather than extending to the surrounding houses. The water levels have become generally higher in the roads as the water is now more concentrated here.

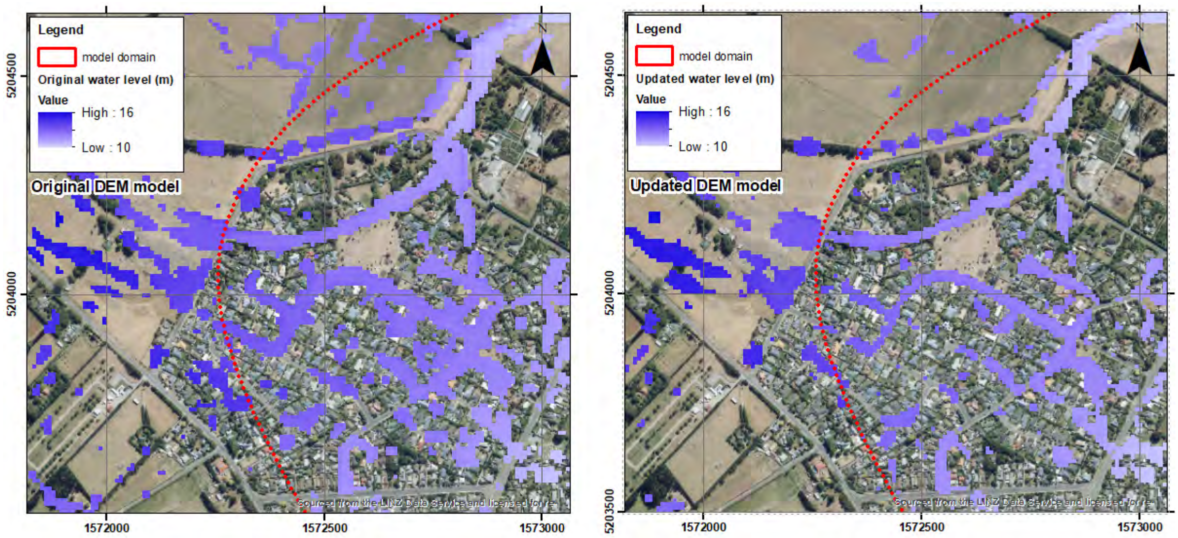


Figure 3. zoom of urban area of Kaiapoi water level of mesh2 (left) and mesh3 (right)

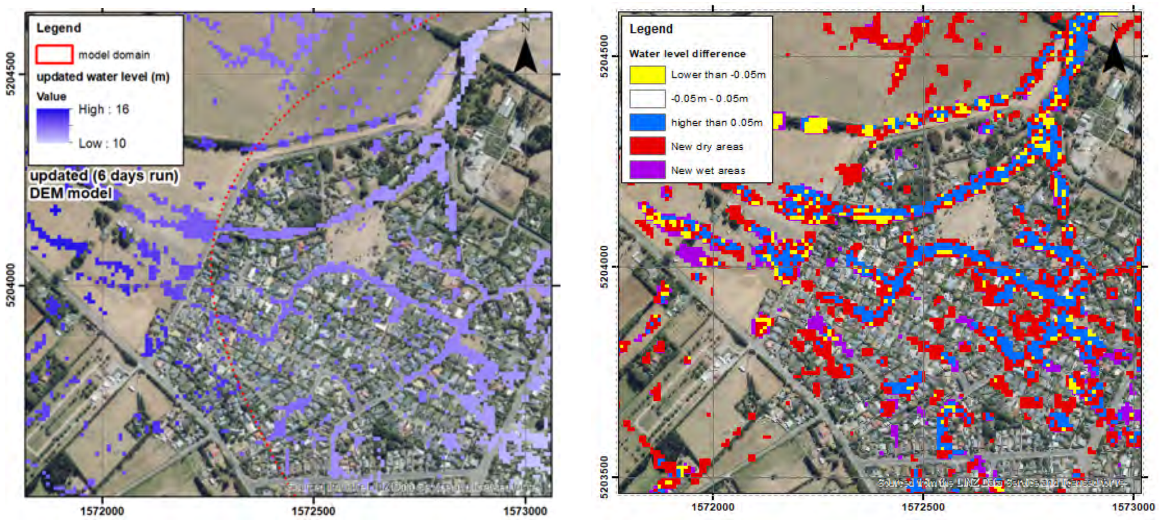


Figure 4 zoom of urban area of Woodend water level for mesh 2 (left) and the difference of water level between mesh1 and mesh3 (right)

With the new mesh it is possible to see new dry areas around buildings and highly dense areas.

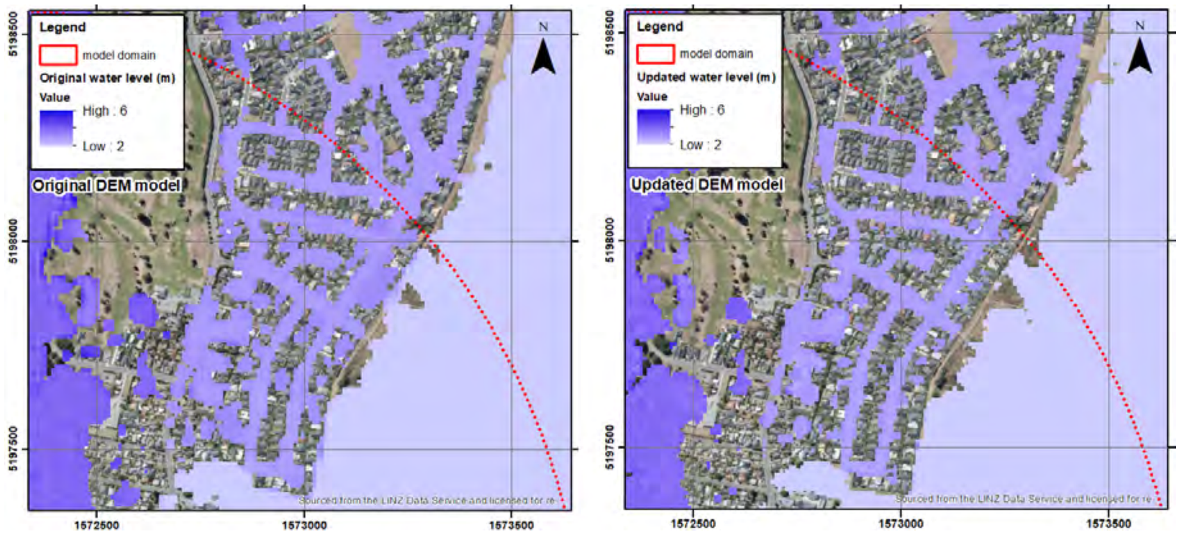


Figure 5. zoom of urban area of Kaiapoi water level of mesh1 (left) and mesh 3 (right)

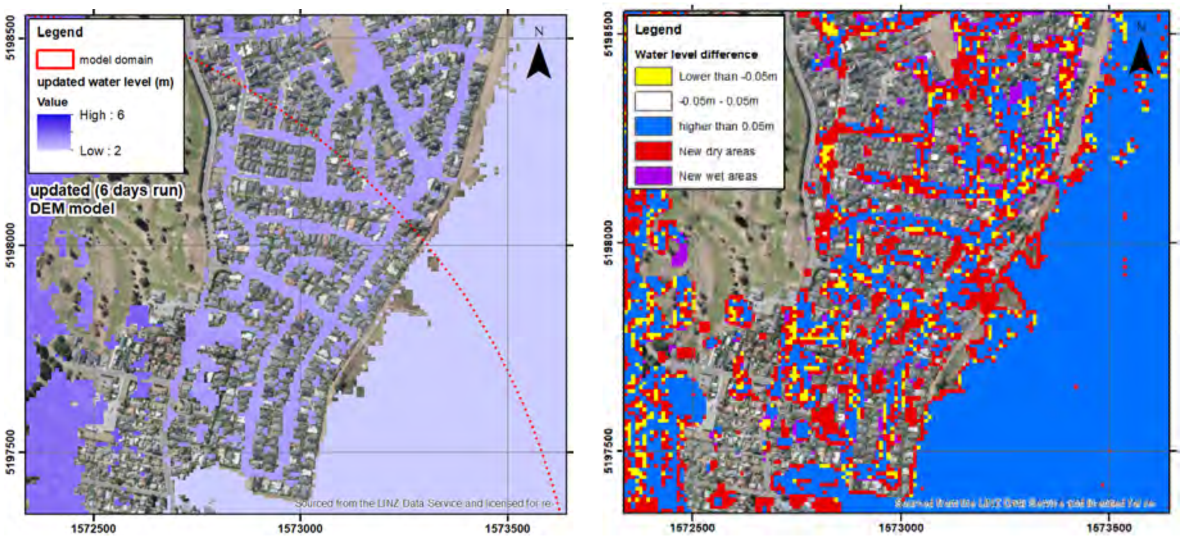


Figure 6 zoom of urban area of Kaiapoi water level for mesh 2 (left) and the difference of water level between mesh1 and mesh3 (right)

In the very flat areas around Kaiapoi the water level was higher for the original model, with a level difference of around 10cm to 20cm while the urban areas of Kaiapoi were dryer and there was more definition to the flooding in the streets with water levels varying between 5cm to 25cm.

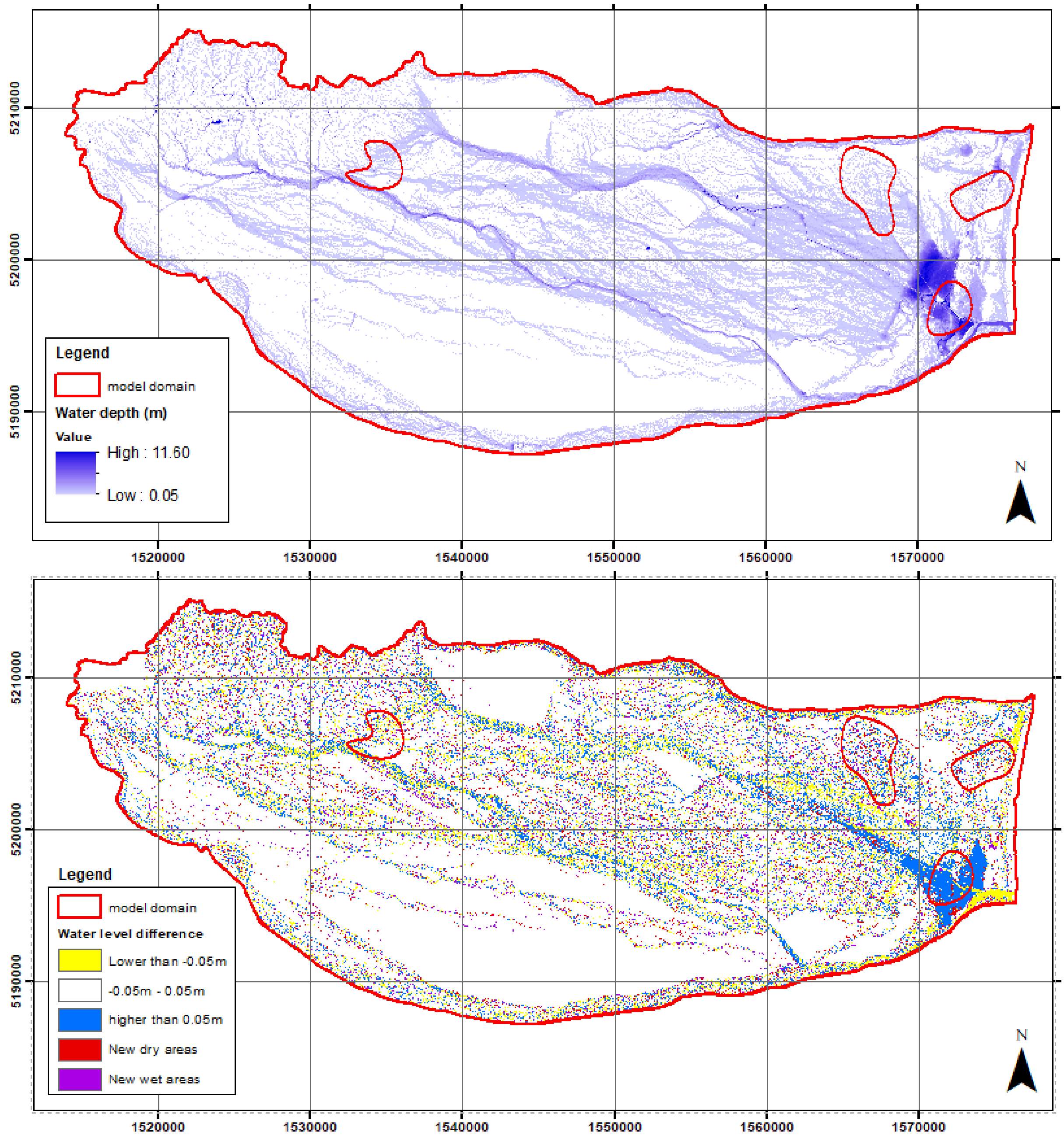


Figure 7. Results of water depth (top) and water level difference bewtween mesh1 and mesh 3 (bottom)

3.1 Conclusions and recommendations

In conclusion there appears to be benefit in using a triangular mesh to gain better resolution in the urban areas, but it is expected that the model run time will increase. Because it is not an option to use a 5x5m rectangular mesh the best option seems to be to go with the triangular mesh method.

The recommended way forward is to build another mesh with the following components:

- Higher level of detail in the urban area, with minimum element size between 12-25m2
- Inclusion of embankment lines in the mesh which can be included as dikes in the M21 model
- Setting of culvert invert levels at all crossings (note long culverts are not available in M21 FM)
- Possible inclusion of simplified building outlines into the mesh and setting of the building platforms for these.
- Inclusion of the road outline (using a buffer of the centreline) into the mesh

The following data will be required to make these additional changes

- If possible 2m resolution DEM for the urban areas
- 5-10m resolution DEM for the rural areas
- 3D polylines of the embankments, to allow for banks to be modelled as dikes
- Building outlines
- Road centrelines (can be sourced from LINZ)
- Shapefile of culvert start and end points with invert levels (for modifying the mesh levels)

APPENDIX C

WDC Rainfall Profiles Update 2019

WAIMAKARIRI DISTRICT COUNCIL

MEMO

FILE NO AND TRIM NO:	DRA-16 / 191204170957 [v2]
DATE:	20 March 2020
MEMO TO:	Don Young Senior Engineering Advisor
FROM:	Chris Bacon Network Planning Team Leader
SUBJECT:	WDC Rainfall Profiles Update 2019

Don

The purpose of this memo is document the work undertaken to update the Rainfall Profiles used by the Waimakariri District Council for the purpose of stormwater and flood modelling. These profiles have been adopted and will be used for the 2019 District Flood Model Update being undertaken by DHI.

The profiles have been based on NIWA HIRDS (High Intensity Rainfall Design System) Version 4 together with a newly NIWA developed rainfall profile. The 80 year RCP8.5 emissions scenario has also been adopted for all WDC modelling work in accordance with Ministry for the Environment (MfE) guidelines for strategic infrastructure.

It is recommended that these rainfall figures and the associated profiles are updated when new projections become available.

1. Existing WDC Rainfall Data

The existing WDC rainfall data was derived from HIRDS version 3 together with a WDC developed rainfall profile based on Pearson (*Frequency of High Intensity Rainfalls in Christchurch. CR92.11*, 1992).

A standard climate change allowance of 16% was adopted based on MfE guidelines at the time.

2. Updated 2019 Rainfall Profiles

The rainfall depths for the 2019 Rainfall Profiles have been based on HIRDS version 4. HIRDS4 is available as an online tool on the NIWA website:
https://hirds.niwa.co.nz/

For stormwater and flood modelling WDC uses the RCP8.5 emissions scenario for the period 2081 – 2100 (80 year projection). This is consistent with MfE guidance around long life infrastructure assets. The rainfall projections for RCP8.5 are included in the HIRDS4 output.

To generate temporal rainfall profiles for the urban stormwater models WDC have adopted the NIWA 'East of South Island' profile. This replaces the previous WDC developed profile which itself was based on work undertaken by Pearson in Christchurch in 1992.

The switch from the Pearson profile developed by WDC based on Christchurch data from 1992 to the NIWA East of SI profile was done to reflect the latest available information for the

Waimakariri District. It is noted however that the NIWA East of SI profile is a general representation for the east coast of the South Island and there may be some localised variations within the Waimakariri District that are not being reflected in the adopted profile. However the rainfall data used to generate the NIWA profile is based on recent and up to date information. The Pearson profile was based on rainfall data in a neighbouring district and is now 28 years old. It was considered that the benefits of the using the NIWA profile generally outweighed the benefits of the WDC developed Pearson based profiles.

For a technical explanation of HIRDS4 and the NIWA developed temporal rainfall profiles refer to the online document from NIWA:
https://niwa.co.nz/sites/niwa.co.nz/files/2018022CH_HIRDSv4_Final.pdf

The rainfall has been updated to reflect the latest available rainfall data and climate change factors available from NIWA. The HIRDS4 data represents a more up to date dataset and has superseded HIRDS3 (note that HIRDS3 data is no longer publically available). PDU considers it appropriate to use the latest and most up to date information. For a PDU analysis showing the differences between HIRDS3 and HIRDS4 within the Waimakariri District refer to TRIM report 181203142028.

3. Generation of 2019 Rainfall Profiles

PDU have developed two spreadsheets to generate rainfall profiles across the district for the both urban and district flood modelling. Refer to Table 1 for a description of the two spreadsheets.

Table 1 - Rainfall Profile Spreadsheets

Purpose	File Name and Location	Notes
Urban Stormwater and Wastewater Models	S:\PDU\Modelling\Climate Data\2 - Rainfall Data\40 - Urban Rainfall Events\Rainfall Profiles Urban 2019.xlsm	Used to generate urban stormwater rainfall hyetographs for 2, 5, 10, 50 and 100 year ARI storms with durations of 1, 2, 3, 6, 9, 12, 15, 18, 24, 30 and 36 hours. Generates both .dfs0 files for Catchment Loads in MIKE URBAN Model A and B and Rain on Grid net runoff files for Rain on Grid modelling in MIKE URBAN.
District Flood Models (including urban sub models done with district rain on grid profiles)	S:\PDU\Modelling\Climate Data\2 - Rainfall Data\20 - District Flood Model Events\Rainfall Profiles HIRDS4 Update.xlxs	Used to generate district wide 50, 100, 200 and 500 year 24 hour nested storm profiles based on the alternating block method for both net rainfall (including infiltration and losses) and gross rainfall (excluding infiltration and losses)

It should be noted that the District Flood Models include the North Ashley and South Ashley rain on grid models plus four urban sub models developed for Oxford, Rangiora, Kaiapoi and Woodend-Pegasus that all use the 24 hour nested storm events.

For a detailed explanation on how the rainfall profiles are created it recommended to read the ‘Instructions’ tab on each spreadsheet. This contains detailed instructions for creating the rainfall profiles for use in both MIKE URBAN and MIKE 21.

Figure 1 and Figure 2 illustrates the process used to create the urban and district flood hazard rainfall files. Refer to the Appendix for larger scale view of the process.

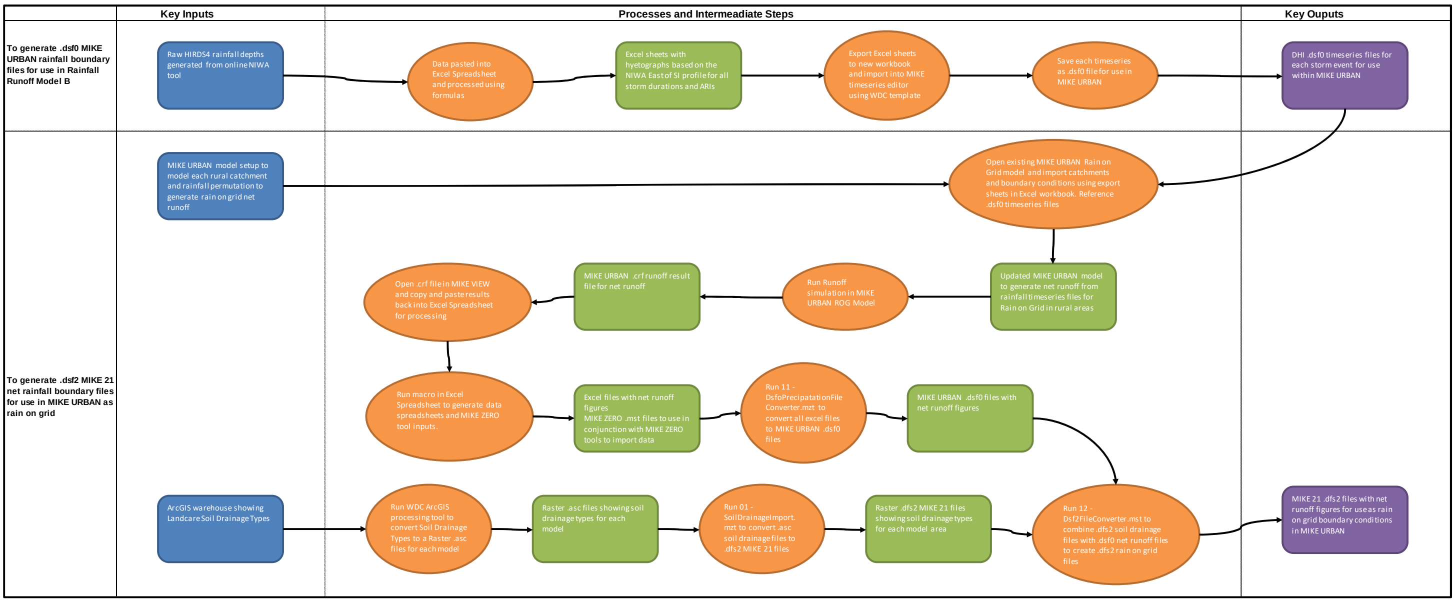


Figure 1 - Process for Creating Urban Rainfall Files

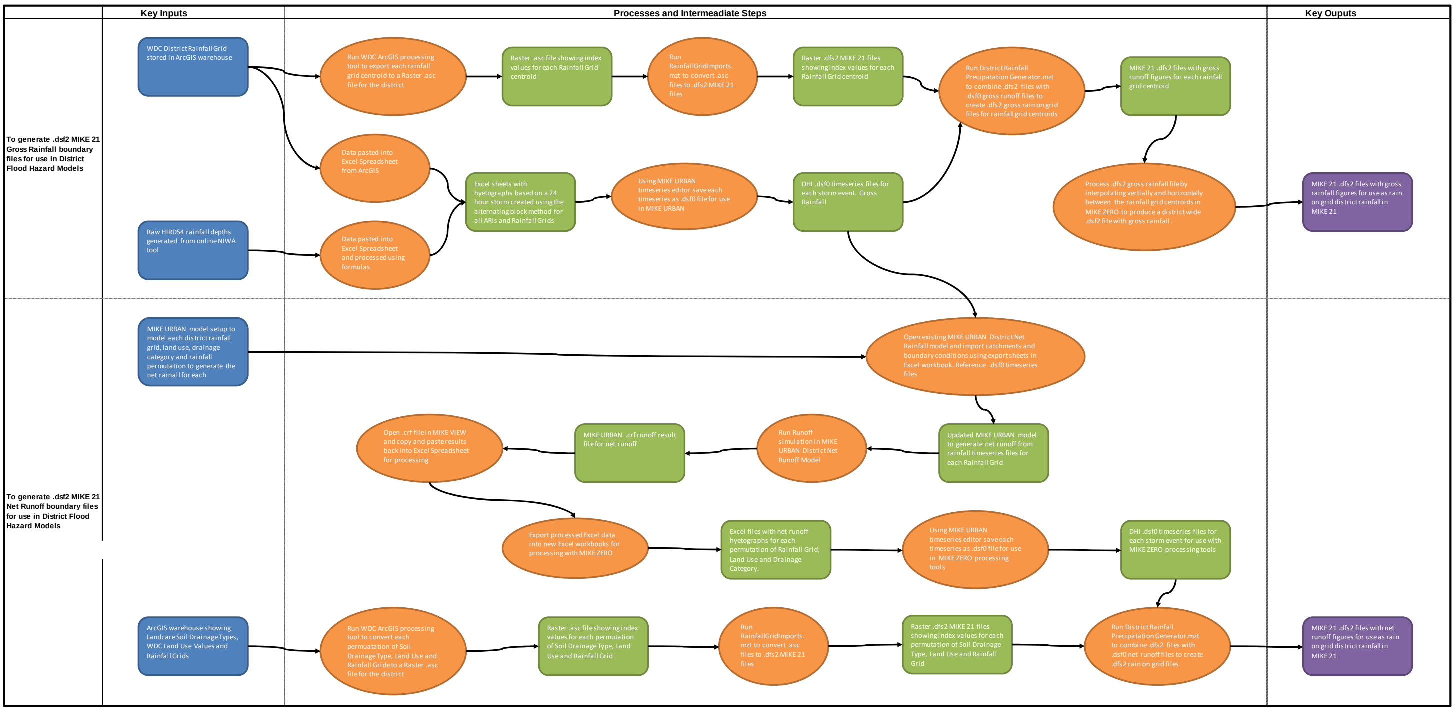


Figure 2 - Process for Creating District Flood Hazard Rainfall Files

4. Key Modelling Principles and Application of the Rainfall Profiles

The rainfall profiles generated using the above processes are used for three different applications:

1. Urban Stormwater and Wastewater Modelling using catchment based rainfall and runoff models.
2. Urban Stormwater Modelling using rain on grid boundary conditions
3. District Flood Hazard Modelling using rain on grid boundary conditions

4.1. Urban Stormwater and Wastewater Models

The Council uses catchment based rainfall and runoff models to model the effect of rainfall within urban catchments for both stormwater and wastewater models in MIKE URBAN. The catchment based approach is used as the urban catchments are normally well formalised and in the case of the wastewater models it enables control of RDII parameters to model inflow and infiltration. The rainfall used in these models is gross rainfall with losses and infiltration accounted for in the catchment runoff model itself.

The Council used MIKE URBAN Model A with RDII for modelling Wastewater Wet Weather Flow and MIKE URBAN Model B with Hortons Infiltration for modelling Stormwater Runoff.

The urban stormwater models also feature the use of rain on grid to model the runoff from rural areas. Rain on grid is used in the rural areas as the drainage systems are not normally well formalised and they rely heavily on overland flow paths. The rain on grid rainfall used in the urban stormwater models is a net rainfall taking into account infiltration and losses. The losses are pre-processed using a MIKE URBAN Model B runoff model designed to simulate typical losses in a rural catchment.

A range of different ARIs and storm durations are used in the urban stormwater and wastewater models to determine the critical storm event for the study area. For each storm event a temporal profile is created based on the NIWA 'East of South Island' profile. The profile features six equally distributed time steps. The same profile is applied to both the catchment based rainfall and the rain on grid rainfall used in the rural areas.

4.2. District Flood Hazard Models

The District Flood Hazard Models rely solely on rain on grid to simulate runoff. Prior to 2019 the District Flood Hazard models used a net runoff rain on grid file to simulate runoff. This file was created in a similar way to the urban rain on grid boundary files for the rural areas but also featured allowance for three different land use types (Residential, Commercial and Rural).

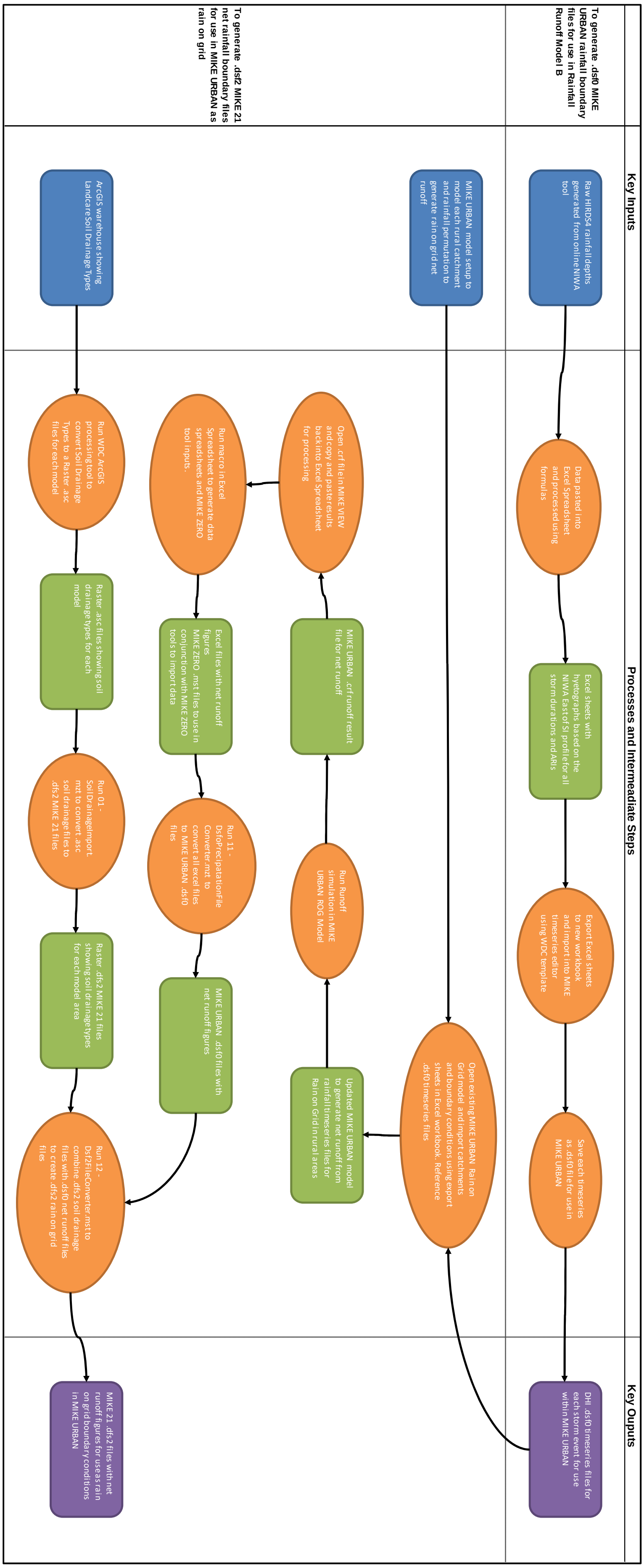
For the 2019 District Flood Hazard Model update being undertaken by DHI a gross rainfall file is being used. The 2019 models will incorporate a new infiltration model to account for infiltration and losses. The gross rainfall files used in the 2019 models are based on calculating gross rainfall at the centroid of a series of grids across the district and then interpolating the values between those points.

The district flood hazard models all employ a 24 hour nested storm event. The nested storm approach is used in the flood hazard models due to the long model run times and the need to manage the number of simulation runs. The nested storm is created using the 'Alternating Block Method' and is constructed using rainfall depths from the 1, 3, 6, 9, 12, 18 and 24 hour storm events. The profile features 24 equally distributed time steps. The 24 hour storm was selected as this is approximately the critical time of concentration for the coastal parts of the district from rainfall originating in the foothills behind Oxford and Okuku.

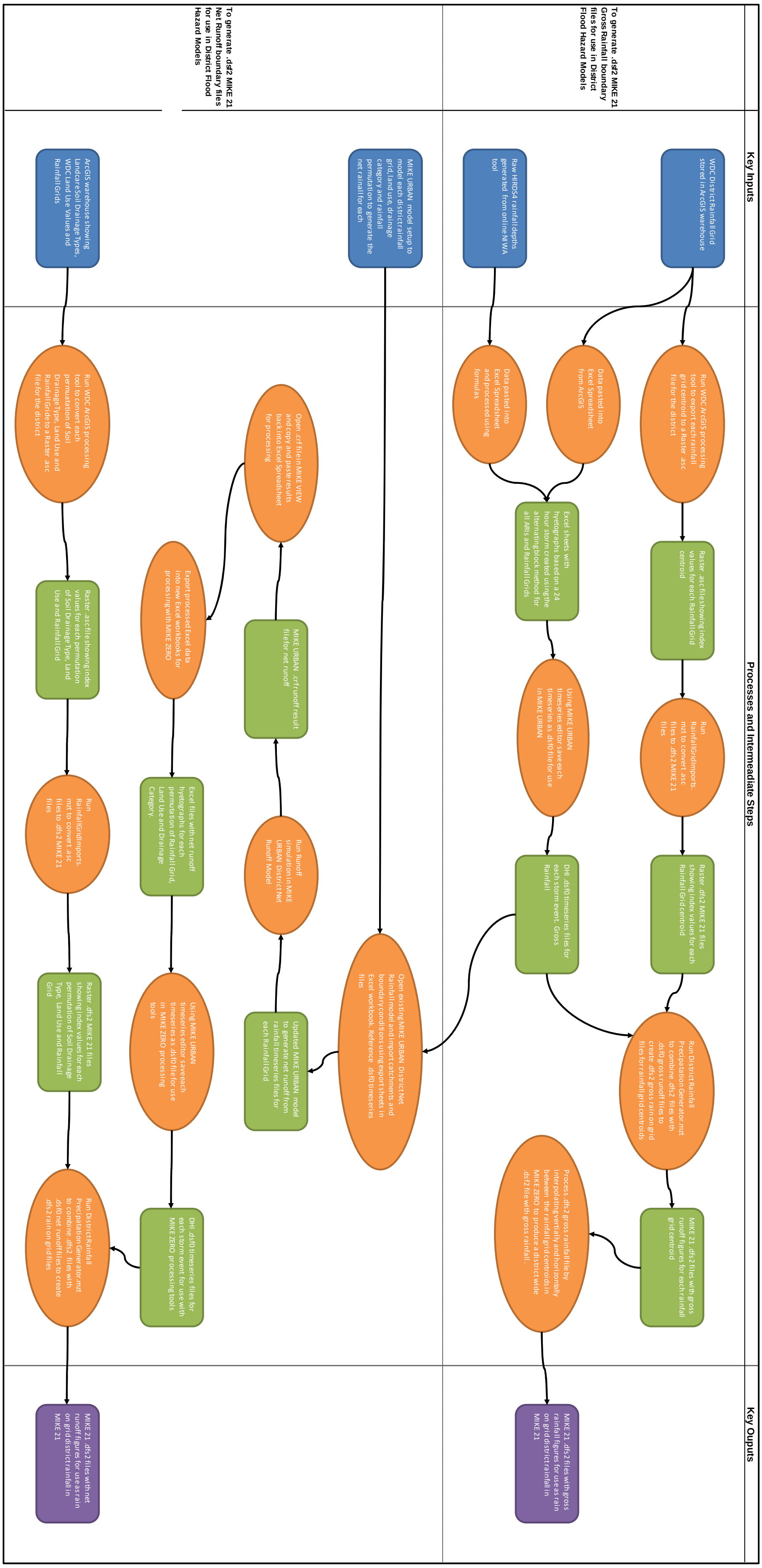
A total of six models are used for the District Flood Hazard work as follows:

- North Ashley Flood Hazard Model (district north of the Ashley River downstream of the Ashley Gorge)
- South Ashley Flood Hazard Model (district south of the Ashley River downstream of the Ashley Gorge)
- Oxford Flood Model (a sub set of the South Ashley model including the Oxford urban area)
- Rangiora Flood Model (a sub set of the South Ashley model including the Rangiora urban area)
- Kaiapoi Flood Model (a sub set of the South Ashley model including the Kaiapoi urban area)
- Woodend-Pegasus Flood Model (a sub set of the South Ashley model including the Woodend and Pegasus urban areas)

APPENDIX – Process for Creating Urban Rainfall Files



APPENDIX – Process for Creating District Flood Hazard Rainfall Files



APPENDIX D

WDC Digital Elevation Model Update 2019

WAIMAKARIRI DISTRICT COUNCIL

MEMO

FILE NO AND TRIM NO:	DRA-16 / 191203169548
DATE:	4 December 2019
MEMO TO:	Don Young Senior Engineering Advisor
FROM:	Chris Bacon Network Planning Team Leader
SUBJECT:	WDC Digital Elevation Model Update 2019

Don

The purpose of this memo is document the work undertaken to update the Waimakariri District Digital Elevation Model (DEM) for the 2019 District Flood Model Update being undertaken by DHI.

Additional elevation data was received from a combination of developers, consultants and Council sourced data. Approximately 435 Ha of the district DEM was updated and is summarised in Table 1.

The 2019 DEM has been supplied to DHI for the purpose of undertaking the 2019 District Flood Model Update. The DEM is available for use by Council staff as either an ArcGIS Raster file or .asc raster file.

1. Existing 2015 DEM

The existing DEM was derived in 2015 following the 2014 LiDAR survey undertaken in the eastern portion of the district. The DEM featured four data sources

1. LiDAR 2014 DEM (Eastern Portion of District)
2. LiDAR 2005 DEM (Western Portion of District)
3. LiDAR 2012 DSM (Foothill Areas not covered by 2005 and 2014 LiDAR)
4. Points Derived from NZ Topographic Contours (All remaining areas)

The 2015 Localised Flood Hazard Modelling Report (TRIM 150410056887) summaries how these data sources were used to create the 2015 DEM. Figure 1 shows the extent of each data source.

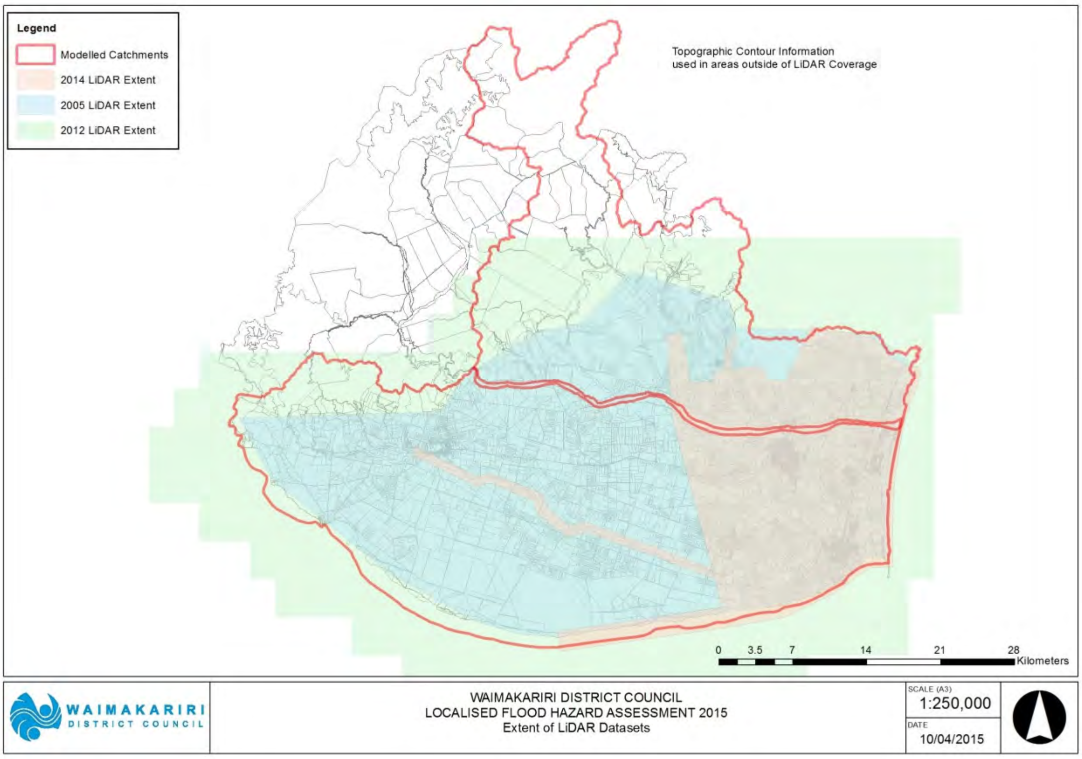


Figure 1 - 2015 DEM Data Sources

2. Updated 2019 DEM

The updated 2019 DEM featured updates from a number of sources. Table 1 summaries the datasources used to update the 2019 DEM.

Table 1 - 2019 DEM Update Areas

Area/Development	Supplier	Data Received	Notes
Copper Beech Subdivision	WDC Contractor (Land Sea River Consultants)	.tiff 0.5m DEM raster file	From drone survey in September 2018 TRIM 181003114538
Silverstream Development	Opus	.mesh MIKE21 modelling file	DEM includes future development areas to the east of the existing development. From modelling work undertaken by DHI and Opus in 2018.
Springbrook Subdivision	Bonish Consultants	.dwg CAD survey file with xyz points	From as-built survey of development TRIM 190916129136
Westpark Subdivision	Aurecon	.dwg CAD survey file with xyz points	From as-built survey of development TRIM 190910126303
Windsor Park Subdivision	Bonish Consultants	.dwg CAD survey file with xyz points	From as-built survey of development TRIM 190913128708
Sovereign Palms Subdivision	Davis Ogilvie	.xml Ground Surface File	Design Surface Used to fill in ground levels in the northern part of the subdivision not captured by 2014 LiDAR TRIM 190806109391
Ravenswood Development	Davis Ogilvie	.xml Ground Surface File	Combination of as-built and design surface information. Includes future development areas.
Alister Cameron Development (Grey View Grove)	Davis Ogilvie	.dwg Civil 3D surface file	Design Surface TRIM 190828120248
East Kaiapoi Stormwater Pond	WDC Regeneration Unit (from E2 supplied design)	.xml Ground Surface File	Design Surface
Townsend Fields Subdivision	Eliot Sinclair	.dwg Civil 3D surface	Combination of as-built and design surface information. Includes future development areas.
Two Roads Subdivision	Site Solutions	.dwg TIN surface file	As-Built ground surface TRIM 190919131282
Amberley LiDAR Survey	ECAN	Raster File	Obtained by DHI and incorporated into WDC derived DEM where model extents exceeded the 2014 LiDAR information in the eastern parts of the district.

It should be noted that the 2019 DEM includes future development areas where development is considered highly likely to occur within the next 3 years at the following sites:

- Ravenswood Subdivision
- Townsend Fields Subdivision
- Silverstream Subdivision (east of Island Road)

Additionally, ground surface information was requested from the following developments but no suitable information was either supplied/or available

- Beach Grove Subdivision (Kaiapoi)
- Hakarau Road Development (Kaiapoi)
- Transport Lane Development (Oxford)

- Weka Street Development (Oxford)
- Enverton Drive Development (Rangiora)
- 50 Parsonage Road Development (Woodend)
- QSB Development Pentecost Road (Rangiora)
- Doncaster Holdings 631 Lineside Road (Rangiora)
- Freeman Homes 73 Kippenberger Ave (Rangiora)
- BA Freeman 70 Parsonage Road (Woodend)
- Ballarat Developments 2 Ballarat Road (Rangiora)
- G & S Stopforth 90 Gladstone Road (Woodend)
- Ryman Heathcare 56 Oxford Road (Rangiora)

Figure 2 shows the areas updated in the District DEM. Refer to the Appendix for larger scale view of the plan.

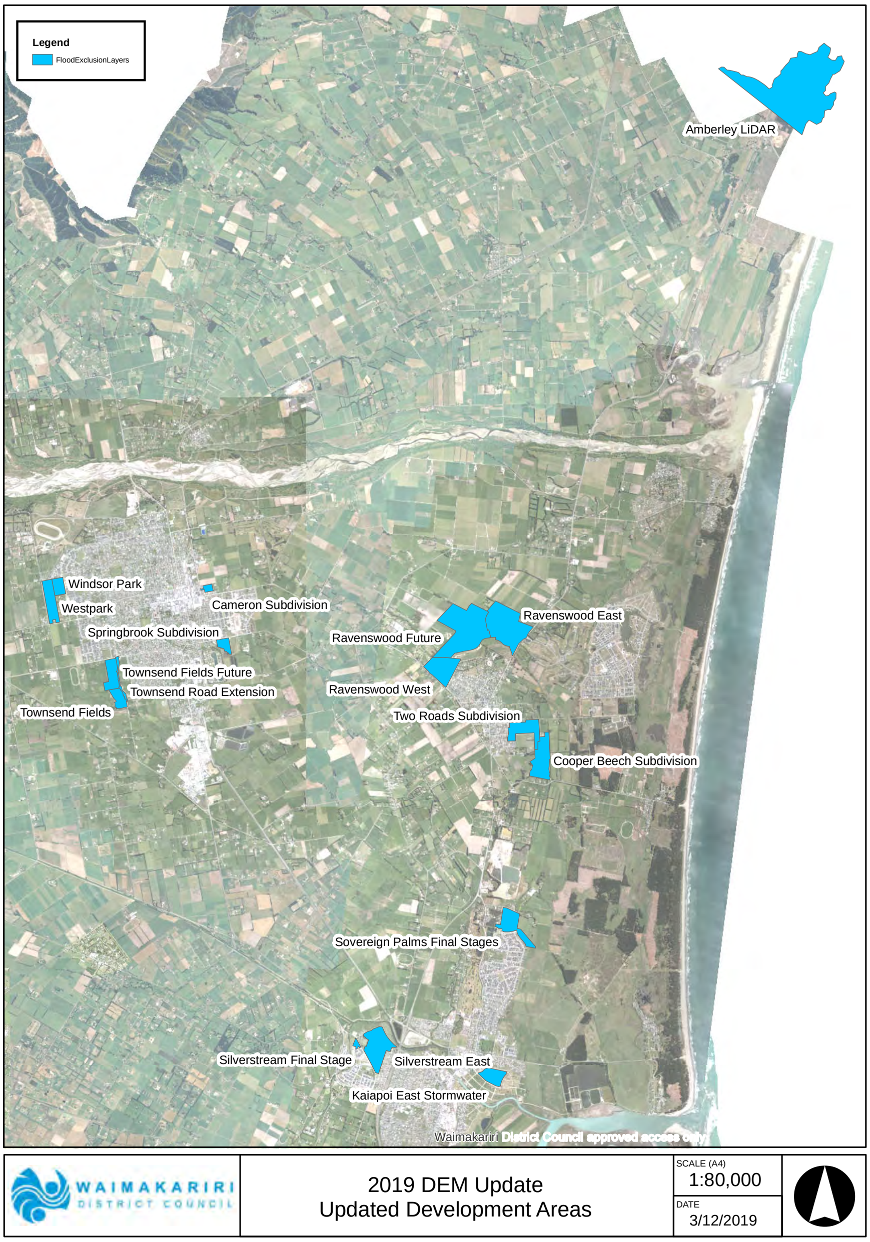


Figure 2 - 2019 DEM Updated Development Areas

3. 2019 DEM Creation

The 2019 DEM was created by taking the best available data from all the datasources in Table 1 and merging these with the datasources used in the existing 2015 DEM.

The starting point was an ArcGIS Terrain dataset used to generate the 2015 DEM. This dataset featured xyz point data from the following sources:

- LiDAR 2014 Points (all)
- LiDAR 2005 Points (where no 2014 LiDAR was available)
- LiDAR 2012 DSM (where no 2005 or 2014 LiDAR was available)
- Points Derived from NZ Topographic Contours (All remaining areas)

The following datatypes were converted in xyz point data and added to this Terrain dataset:

- .dwg CAD survey points
- .mesh MIKE21 modelling file

The .mesh file was converted into nodes with z data in the MIKE ZERO software package before being imported into ArcGIS as point features with z coordinates.

The existing LiDAR 2014 points used in the dataset were clipped out where new xyz point data was available.

The 2019 Terrain Dataset was then converted into a 5m x 5m raster DEM using the tools in ArcGIS.

Files received as .dwg Civil 3D surface files and TIN files were converted into .xml Ground Surface files using AutoCAD Civil 3D. The converted .xml files as well as the received .xml files where then converted into 5m x 5m raster DEM files using the tools in ArcGIS. The DEM files were aligned with the DEM raster file created from the 2019 Terrain dataset.

The remaining raster files were reprocessed into a 5m x 5m raster DEM file using ArcGIS aligning with the DEM raster file created from the 2019 Terrain dataset.

The final step to create the 2019 DEM was to mosaic together all the created raster files ensuring that the new data took precedence over old data where two or more of the created raster files intersected.

Figure 3 illustrates the process used to create the 2019 DEM. Refer to the Appendix for larger scale view of the process.

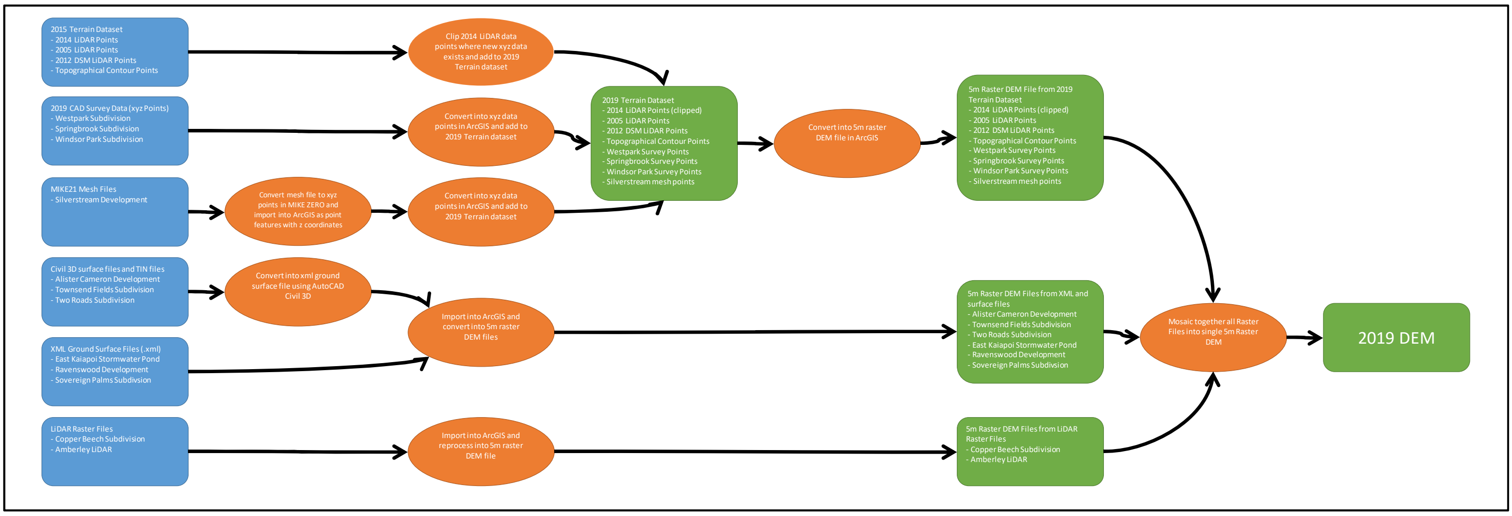


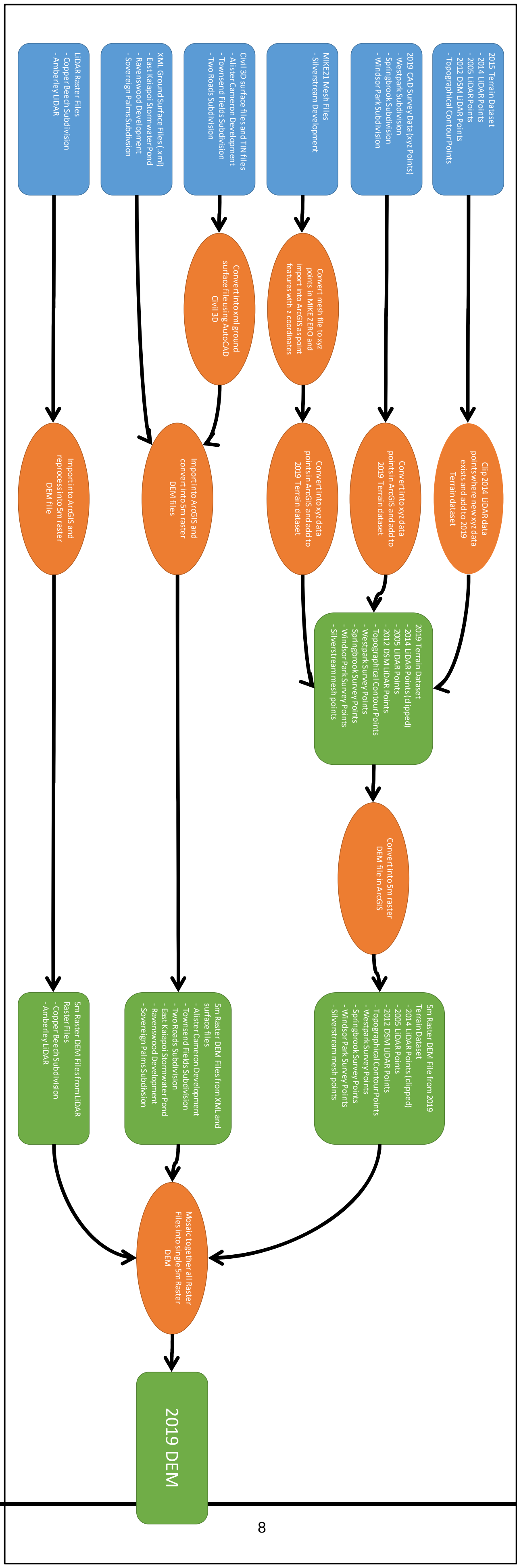
Figure 3 - 2019 DEM Update Process

Note: The work to merge the Amberley LiDAR data into the DEM was completed by DHI in November 2019 as part of the project to build and update the District Flood Hazard Models.

APPENDIX – 2019 DEM Update Development Areas

WAIMAKARIRI DISTRICT COUNCIL	2019 DEM Update Updated Development Areas	SCALE (A4) 1:80,000 DATE 3/12/2019	

APPENDIX – 2019 DEM Update Process



APPENDIX E

High Intensity Rainfall Design System (HIRDS) Memo

WAIMAKARIRI DISTRICT COUNCIL

MEMO

FILE NO AND TRIM NO:	DRA – 12 / 181203142028
DATE:	3rd December 2018
MEMO TO:	Kalley Simpson, 3 Waters Manager
FROM:	Jordan Cathcart, Graduate Engineer
SUBJECT:	Investigation of High Intensity Rainfall Design System (HIRDS V4)

1. Summary

In August 2018 NIWA released an updated version of the High Intensity Rainfall Design System (HIRDS V4). The main purpose of the HIRDS tool is used to provide estimates of high intensity rainfall at ungauged locations (Carey Smith, Henderson, Singh 2018).

In 2017 the Ministry for the Environment (MfE) released a report providing guidance for local authorities to interpret the various climate change scenarios and introduced four relative concentration pathways that could be used.

The Waimakariri District Council (WDC) currently uses HIRDS V3 for rainfall analysis and modelling. HIRDS V2 is also still referenced in the WDC Engineering Code of Practice (ECoP) and can be used for design storm events. The purpose of this memo is to document the difference between each HIRDS version and recommend the most appropriate system to use. This investigation also included consideration of the various climate change scenarios that are introduced in the MfE report and form part of the HIRDS V4 output.

2. Recommendations

That the Waimakariri District Council

2.1. Adopts HIRDS V4 for sewer and stormwater modelling and design

2.2. Incorporates HIRDS V4 as part of the Engineering Code of Practice update

2.3. Adopts the RCP8.5 climate scenario in conjunction with HIRDS V4 data

3. Comparison

The methodology behind HIRDS V4 has largely remained unchanged from HIRDS V3 (released in 2010). The regionalised index-frequency method allows for estimates of high intensity rainfall at any location throughout New Zealand for several return periods and durations. The key difference between each version is the amount of data, with HIRDS V4 updated to include gauged locations and records from the last 8-10 years as well as older records that were found to not be included in older versions.

It is important to consider the impact of climate change on rainfall estimates in the future, especially due to the relatively long life of the infrastructure assets in which rainfall is an input of design. MfE previously recommended a 16% factor be used in Canterbury to account for climate change factors. It is also noted that prior to adopting HIRDS V3 the WDC had applied a 10% climate change factor to HIRDS V2 data which can still be seen in the ECoP.

For HIRDS V4, four different climate change scenarios, called relative concentration pathways (RCPs), are made available. These scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5), represent different rates of increase of climate change and are provided for the mid (2031-2050) and late (2081-2100) 21st century.

MfE provide a report (Bell, Lawrence, Allan, Blackett, Stephens 2017) which provides guidance into how to use these RCPs for planning and design. This document highlights the importance of a risk-based approach and consequentially has moved away from recommending a specific climate change factor. For additional information this report is referenced in Section 6 below.

For the purpose of this investigation the most conservative option available in HIRDS of RCP8.5, (2081-2100) has been used. This is considered to be the most appropriate due to the importance of infrastructure to be able to achieve sufficient design life. Refer to Section 6 for a link to the MfE report. In addition, the time extent aligns well with infrastructure physical life of around 80-100 years.

4. Result Comparison

To make a comparison between each HIRDS version the 5 year and 50 year storm return periods were compared for all durations. A range of sites across the district were considered to highlight spatial differences.

4.1. Raw Data

On average, the raw data produced from HIRDS V4 is less than HIRDS V3 except for the 10, 20 minute and 72 hour durations. The overall trend is similar between the 5 year and 50 year return periods, with the 50 year having slightly larger percentage change.

For the majority of sites and durations HIRDS V2 produced the lowest rainfall depths for the 5 and 50 year return period. For this reason the summary tables below exclude HIRDS V2 and present the percentage change in rainfall depth if a change from HIRDS V3 to HIRDS V4 was to occur.

Table 1 5 Year Storm - Percentage Change from HIRDS V3 to V4

	Duration									
Site	**10m**	**20m**	**30m**	**1hr**	**2hr**	**6hr**	**12hr**	**24hr**	**48hr**	**72hr**
Rangiora	3%	-2%	-3%	-2%	-1%	-1%	-3%	-8%	2%	6%
Kaiapoi	-15%	-18%	-18%	-17%	-13%	-8%	-7%	-10%	0%	3%
Oxford	24%	13%	8%	2%	0%	-3%	-7%	-15%	-11%	-11%
Woodend	1%	-3%	-4%	-5%	-5%	-5%	-8%	-14%	-4%	0%
Cust	19%	12%	1%	-5%	-4%	-1%	-1%	-3%	6%	8%
Sefton	8%	6%	-3%	-6%	-6%	-7%	-10%	-16%	-3%	2%
Average	7%	2%	-3%	-6%	-5%	-4%	-6%	-11%	-2%	1%

Table 2 50 Year Storm - Percentage Change from HIRDS V3 to V4

	Duration									
Site	**10m**	**20m**	**30m**	**1hr**	**2hr**	**6hr**	**12hr**	**24hr**	**48hr**	**72hr**
Rangiora	4%	-1%	-3%	-5%	-4%	-3%	-5%	-10%	-2%	1%
Kaiapoi	-14%	-19%	-20%	-21%	-16%	-9%	-7%	-9%	-1%	2%
Oxford	14%	1%	-4%	-12%	-10%	-9%	-11%	-16%	-13%	-14%
Woodend	5%	-3%	-5%	-8%	-6%	-5%	-8%	-13%	-4%	-1%
Cust	17%	8%	-3%	-10%	-8%	-4%	-3%	-4%	3%	4%
Sefton	12%	8%	-2%	-8%	-8%	-9%	-11%	-17%	-7%	-2%
Average	6%	-1%	-6%	-11%	-9%	-7%	-8%	-12%	-4%	-2%

4.2. Raw Data + Climate Change Factors

HIRDS V4 (RCP8.5) typically returns the largest rainfall depth across the district for storms up to 12 hour duration, and for 72 hours and above. It is evident that HIRDS V3 (+16%) produces the larger rainfall depth for the durations of 24 and 48 hours. HIRDS V2 (+10%) in turn produces rainfall depths that are lower than HIRDS V4 and V3 across most sites. The trends of these results are consistent across the 5 year and 50 year return period.

The most significant difference proportionately is for the storms of 10, 20, 30 minute and 24 hour durations and in particular for the Oxford Township, where the general trend is exaggerated.

Table 3 5 Year Storm - Percentage Change from HIRDS V3 +16% to V4 (RCP8.5)

	Duration									
Site	**10m**	**20m**	**30m**	**1hr**	**2hr**	**6hr**	**12hr**	**24hr**	**48hr**	**72hr**
Rangiora	18%	13%	12%	13%	13%	9%	4%	-5%	3%	5%
Kaiapoi	-3%	-5%	-6%	-5%	-1%	1%	-1%	-7%	1%	3%
Oxford	42%	30%	24%	17%	14%	7%	-1%	-12%	-10%	-11%
Woodend	16%	11%	10%	8%	8%	4%	-2%	-11%	-3%	0%
Cust	26%	22%	14%	9%	9%	8%	5%	0%	6%	8%
Sefton	19%	18%	10%	7%	6%	2%	-4%	-15%	-2%	3%
Average	**20%**	**15%**	**10%**	**8%**	**8%**	**5%**	**0%**	**-8%**	**-1%**	**1%**

Table 4 50 Year Storm - Percentage Change from HIRDS V3 +16% to V4 (RCP8.5)

	Duration									
Site	**10m**	**20m**	**30m**	**1hr**	**2hr**	**6hr**	**12hr**	**24hr**	**48hr**	**72hr**
Rangiora	21%	14%	12%	11%	11%	8%	3%	-6%	1%	2%
Kaiapoi	0%	-5%	-6%	-7%	-2%	2%	1%	-5%	2%	3%
Oxford	31%	17%	11%	4%	4%	2%	-3%	-11%	-10%	-12%
Woodend	22%	13%	11%	7%	8%	6%	0%	-8%	-2%	0%
Cust	36%	26%	12%	4%	6%	7%	5%	1%	5%	6%
Sefton	30%	26%	13%	8%	6%	2%	-4%	-13%	-4%	-1%
Average	**23%**	**15%**	**9%**	**4%**	**5%**	**4%**	**0%**	**-7%**	**-1%**	**0%**

4.3. Result Presentation

Appendix A presents charts for the 5 year and 50 year storm event for each scheme as a comparison between the three HIRDS outputs. These are plotted across each duration and compared to the relative climate change adjusted outputs.

5. Discussion

The methodology behind HIRDS V4 has largely remained unchanged from HIRDS V3 (released in 2010). The key difference between each version is the amount of data, with HIRDS V4 supported by additional monitoring sites combined with an additional 8 years of data.

The method of applying a climate change factor has also changed, with four different scenarios representing different rates of climate change applied to the HIRDS output. This promotes a risk based approach to application of these factors, however it is considered that the most appropriate for long life infrastructure assets is RCP8.5 which is the most conservative option. This is also supported by guidance from MFE (refer Section 6).

It is important to note that the RCP climate adjustment is not a linear increase across the different rainfall durations. This method weights the percentage change more heavily for the smaller durations, ranging from 33% at 10 minutes to 14% at 72 hours. This is reflected by the results above with HIRDS V4 produced higher rainfall depths up to the 12 hour duration.

The changes between the HIRDS tools are reasonably consistent between each scheme, with the exception of Oxford. For this area HIRDS V4 RCP8.5 is higher than average for the lower durations and lower than average for the higher durations. As there haven't been significant changes to the methodology this could be a result of limited data for the surrounding area of Oxford in previous versions of HIRDS.

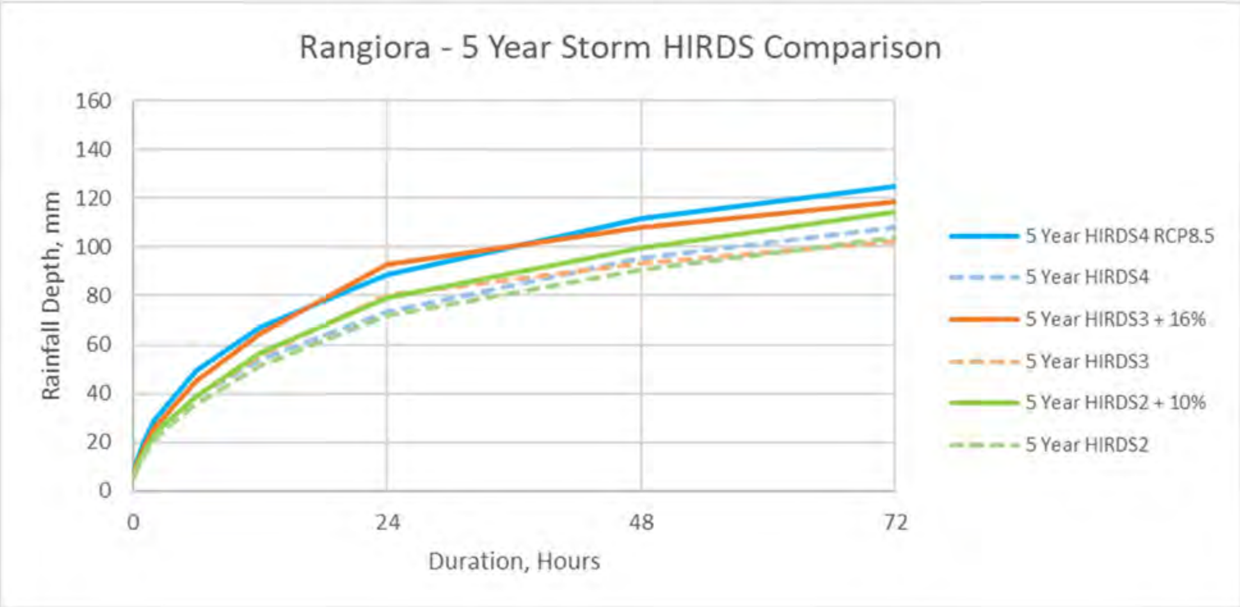
Overall, if a change to HIRDS V4 RCP8.5 was to be adopted the infrastructure design would be more conservative for storm durations up to 12 hours and slightly less conservative for storm durations of 24 hours and above. However it is considered that the most appropriate system to use is HIRDS V4 due to this being the latest rainfall projection tool available and being supported by a more comprehensive database than previous versions.

6. References

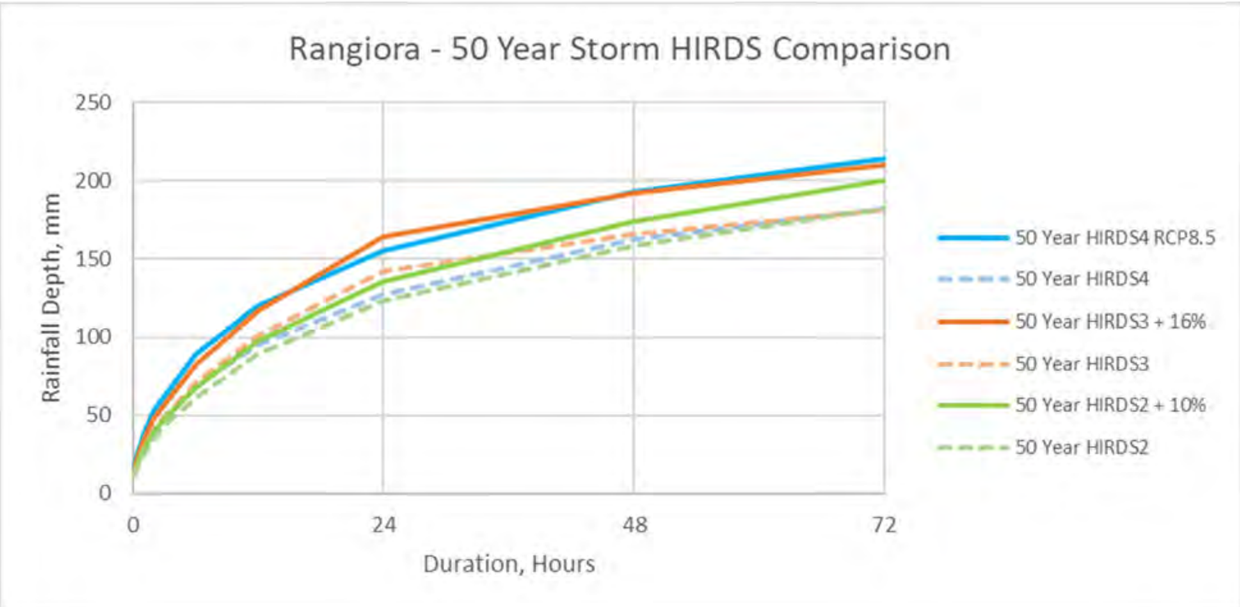
Carey-Smith, T., Henderson, R., Singh, S. (2018), *High Intensity Rainfall Design System, Version 4, Available from https://www.niwa.co.nz/sites/niwa.co.nz/files/2018022CH_HIRDSv4_Final.pdf*

Bell, R., Lawrence, J., Allan, S., Blackett, P., Stephens, S. (2017), *Coastal Hazards and Climate Change: Guidance for Local Government, Available from* http://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-local-government

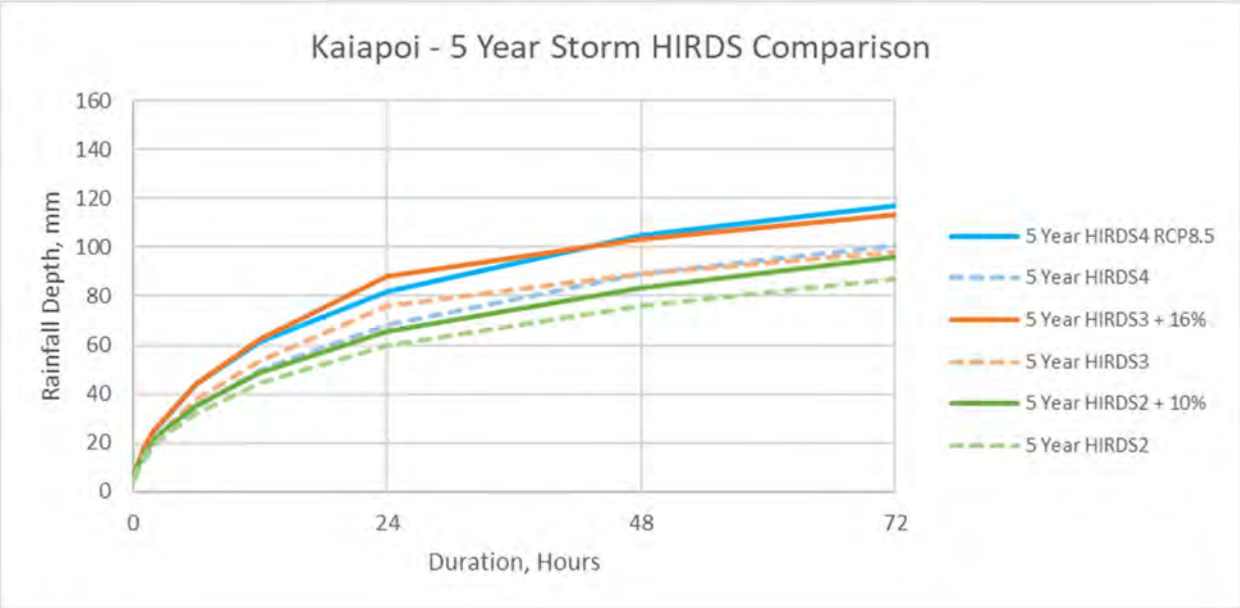
7. Appendix A

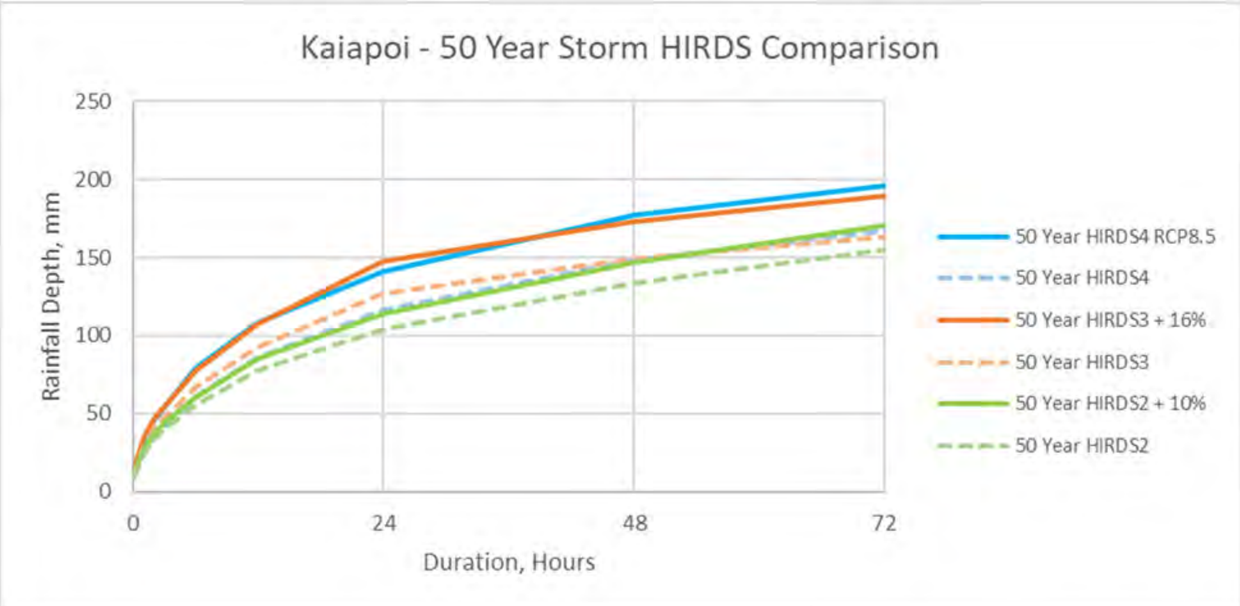


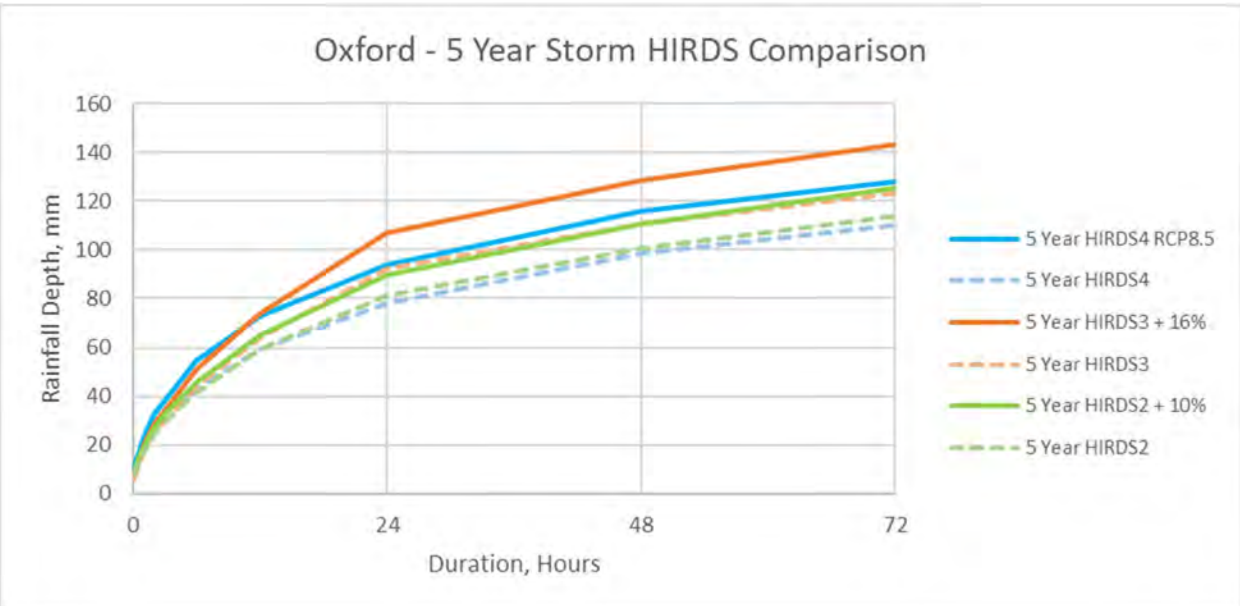
Rangiora - 5 Year Storm HIRDS Comparison
Rainfall Depth, mm
160
140
120
100
80
60
40
20
0
0
24
48
72
Duration, Hours
5 Year HIRDS4 RCP8.5
5 Year HIRDS4
5 Year HIRDS3 + 16%
5 Year HIRDS3
5 Year HIRDS2 + 10%
5 Year HIRDS2

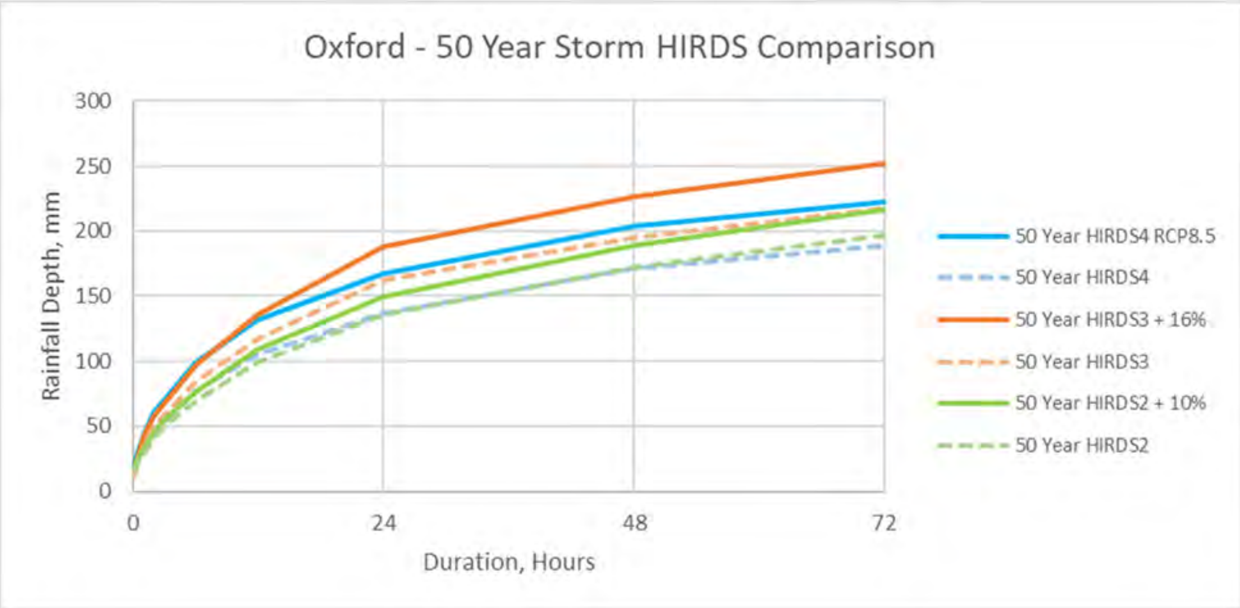


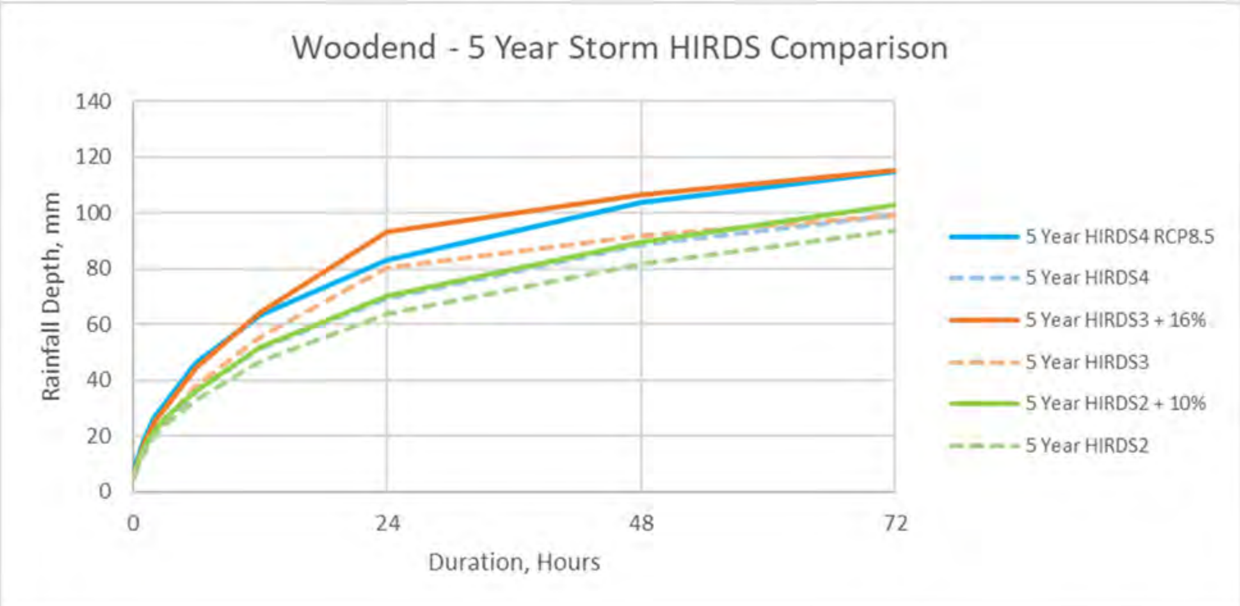
Rangiora - 50 Year Storm HIRDS Comparison
Rainfall Depth, mm
250
200
150
100
50
0
0
24
48
72
Duration, Hours
50 Year HIRDS4 RCP8.5
50 Year HIRDS4
50 Year HIRDS3 + 16%
50 Year HIRDS3
50 Year HIRDS2 + 10%
50 Year HIRDS2


Kaiapoi - 5 Year Storm HIRDS Comparison
160
140
120
100
80
60
40
20
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
5 Year HIRDS4 RCP8.5
5 Year HIRDS4
5 Year HIRDS3 + 16%
5 Year HIRDS3
5 Year HIRDS2 + 10%
5 Year HIRDS2

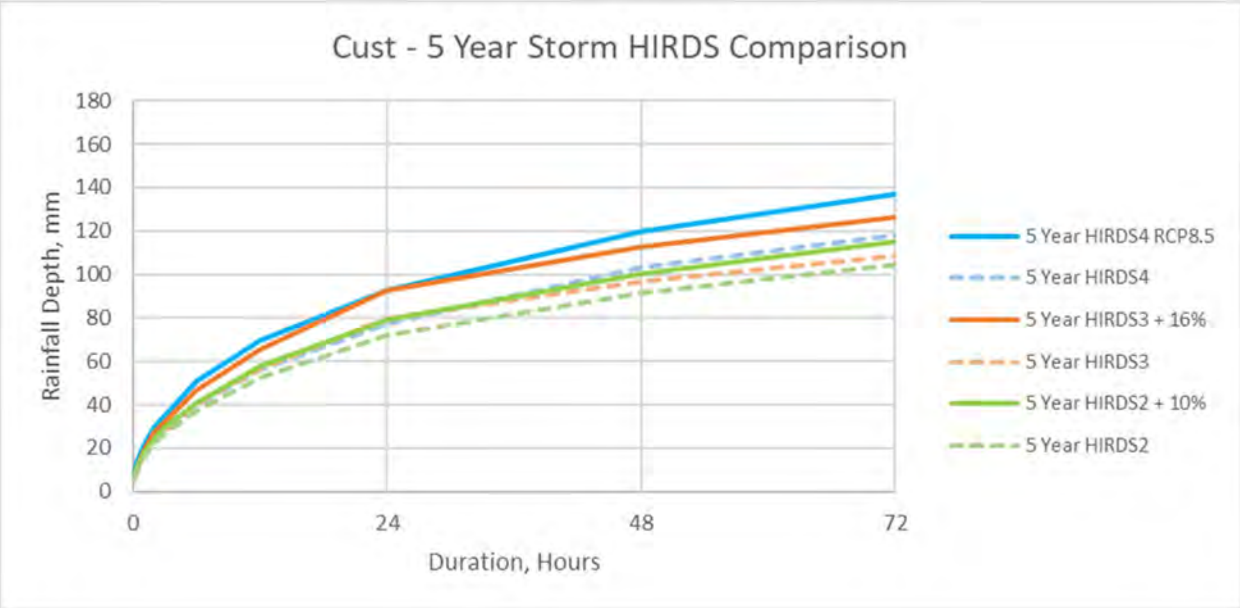

Kaiapoi - 50 Year Storm HIRDS Comparison
250
200
150
100
50
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
50 Year HIRDS4 RCP8.5
50 Year HIRDS4
50 Year HIRDS3 + 16%
50 Year HIRDS3
50 Year HIRDS2 + 10%
50 Year HIRDS2


Oxford - 5 Year Storm HIRDS Comparison
160
140
120
100
80
60
40
20
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
5 Year HIRDS4 RCP8.5
5 Year HIRDS4
5 Year HIRDS3 + 16%
5 Year HIRDS3
5 Year HIRDS2 + 10%
5 Year HIRDS2

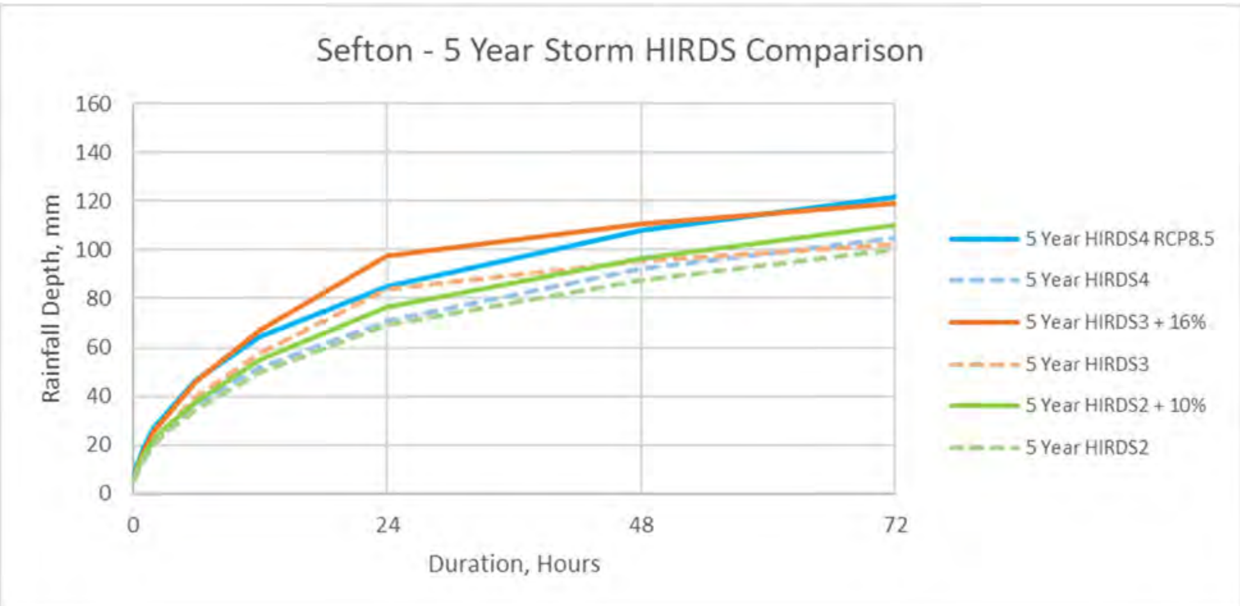

Oxford - 50 Year Storm HIRDS Comparison
300
250
200
150
100
50
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
50 Year HIRDS4 RCP8.5
50 Year HIRDS4
50 Year HIRDS3 + 16%
50 Year HIRDS3
50 Year HIRDS2 + 10%
50 Year HIRDS2

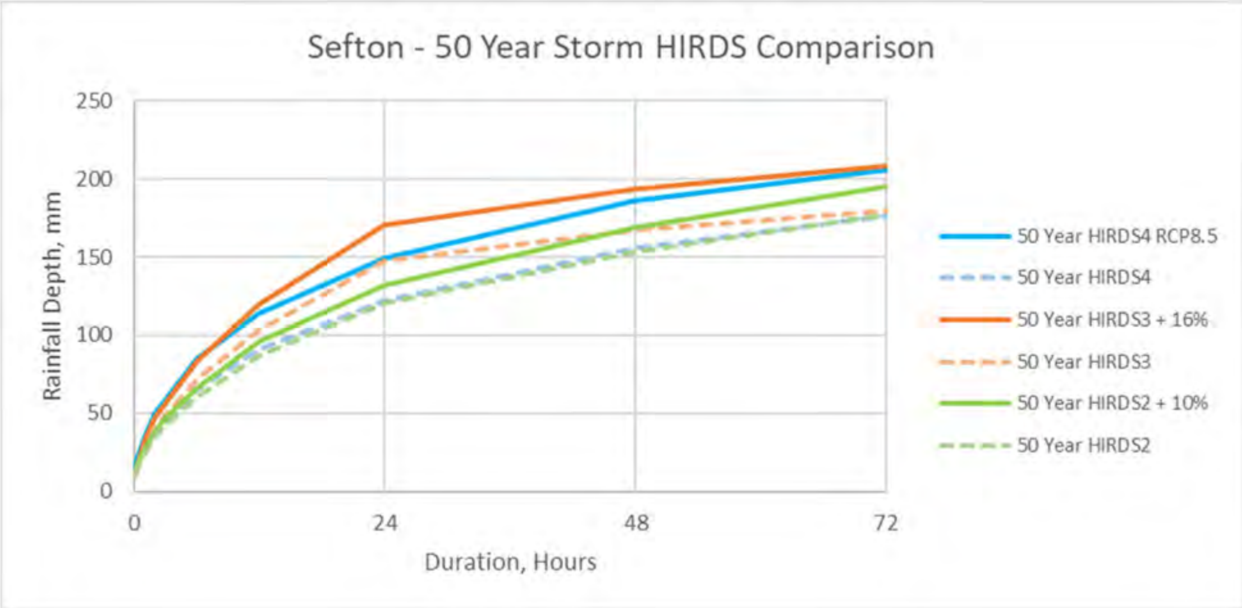

Woodend - 5 Year Storm HIRDS Comparison
140
120
100
80
60
40
20
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
5 Year HIRDS4 RCP8.5
5 Year HIRDS4
5 Year HIRDS3 + 16%
5 Year HIRDS3
5 Year HIRDS2 + 10%
5 Year HIRDS2


Woodend - 50 Year Storm HIRDS Comparison
250
200
150
100
50
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
50 Year HIRDS4 RCP8.5
50 Year HIRDS4
50 Year HIRDS3 + 16%
50 Year HIRDS3
50 Year HIRDS2 + 10%
50 Year HIRDS2


Cust - 5 Year Storm HIRDS Comparison
Rainfall Depth, mm
Duration, Hours
5 Year HIRDS4 RCP8.5
5 Year HIRDS4
5 Year HIRDS3 + 16%
5 Year HIRDS3
5 Year HIRDS2 + 10%
5 Year HIRDS2


Cust - 50 Year Storm HIRDS Comparison
Rainfall Depth, mm
Duration, Hours
50 Year HIRDS4 RCP8.5
50 Year HIRDS4
50 Year HIRDS3 + 16%
50 Year HIRDS3
50 Year HIRDS2 + 10%
50 Year HIRDS2


Sefton - 5 Year Storm HIRDS Comparison
Rainfall Depth, mm
Duration, Hours
5 Year HIRDS4 RCP8.5
5 Year HIRDS4
5 Year HIRDS3 + 16%
5 Year HIRDS3
5 Year HIRDS2 + 10%
5 Year HIRDS2



Sefton - 50 Year Storm HIRDS Comparison
250
200
150
100
50
0
Rainfall Depth, mm
0
24
48
72
Duration, Hours
50 Year HIRDS4 RCP8.5
50 Year HIRDS4
50 Year HIRDS3 + 16%
50 Year HIRDS3
50 Year HIRDS2 + 10%
50 Year HIRDS2